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PALEOGENE STRATIGRAPHY, BIOZONATION AND PALEOECOLOGY OF THE SUB-SURFACE SEDIMENTS IN THE AREA LYING NORTH OF SARASWATI RIVER, GUJARAT[1]

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ABSTRACT

The biostratigraphy and sedimentation of the northern most extremity of Cambay Basin are little studied. In the present paper, an unified attempt of palaeontological, palynological and sedimentological investigations, is thus made to carry out stratigraphic analysis of the subsurface Paleogene sediments of Serau-Sampra-Dasawara area lying in north of Saraswati river Gujarat.

Based on electrolog characteristics, lithologic studies and microfaunal/miofloral evidence, the Paleogene of the are has been divided into six formatiions viz : Olpad, Cambay Shale, Tharad, Kalol, Wara and Tarapur Shale. Of these, the Wara is an informal unit and is newly proposed.

The entire sequence ranging from Early Eocene to Oligocene has been biozoned into four distinct units based on microfaunal/ miofloral assemblages containing diagnostic index taxa. The biozones are : *Triorites-Schizosporis* assemblage zone of Early Eocene; *Octacolpites,—Nummulites acutus* assemblage zone of Middle Eocene; *Pellatispira* spp.—*Palmaepollenites eocenicus* assemblage zone of Late Eocene and *Inaperturata foldexina—Dicolpites* assemblagez one of Ooigoceneage.

Studies on textural analysis of the clastic sequence of Tharad and Kalol formations have been carried out to interpret precisely the depositional environments. The paleoecology of the area and paleoclimatic implications have also been discussed.

INTRODUCTION

The area under study lying between Long. 24°5' : 24°45' and Lat. 71°30' : 72°45' falls in the northern most part of Ahmadabad-Mehsana block of Cambay Tertiary intracratonic basin (Chandra & Choudhary, 1969). The area is flanked on east and north east by the Aravalli mountains, on south west by Saurastra peninsula, on west by the island belt of Kutch and on north by Sanchor depression. The entire area is covered by the alluvium of Banas and Saraswati rivers. Scanty exposures of Tertiary rocks, however, occur in the far eastern and western margins. The area lies essentially in a graben bounded by prominent marginal faults on east and west. The basin trends roughly north-south from Serau to Tharad and assumes a north west-south east direction between Tharad and Dasawara. In the vicinity of Varsada-Deodar, a part of the basin swings westerly towards Kutch. In north and south, it is limited by Serau-Karban ridge and Patan depression respectively.

In the absence of outcrops in the area under study the Paleogene stratigraphy has been worked out on the basis of subsurface data obtained from exploratory drilling. A number of wells drilled in the area have revealed the presence of thick sedimentary rocks of Tertiary-Quaternary age. The important contribution to the stratigraphy and microfauna of Tertiary sequence of Cambay basin were made by Sudhakar & Roy (1959), Chandra & Choudhary (1969), Raju *et al.*, (1970), Roy Choudhury *et al.*, (1972), Sudhakar and Basu (1973) and Pandey and Nath (1974). The detailed lithostratigraphic account of Dasawara—Tharad—Serau area has been given by Varadarajan *et al.*, (1971), and Roy Choudhury et al., (1972). Their observations were however, based mainly on lithological characteristics and electrolog data. No systematic account on microfaunal and miofloral findings of these sediments have been carried out so far. In view of additional data obtained by drilling new locations, an unified approach of palaeontological, palynological and sedimentalogical investigations on cores and cuttings of selected well sections together with their lithological attributes has been made to evolve a precise stratigraphic correlation.

The samples from exploratory wells drilled in Serau East, Tharad, Delvada, Deodar, Wara, Sampra and Dasawara structures are examined for microfaunal and miofloral contents. The lithological studies and electrolog interpretation have been done for lithostratigraphy. The textural analysis of the clastic sequence has been carried out for paleoenvironmental parameters. The

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lithostratigraphy, biostratigraphy and paleoecology are the main topics which form the text of the present paper.

LITHOSTRATIGRAPHY

Roy Chowdhury et al., (1972) have observed that the subsurface Tertiary sequence of Tharad-Serau area is broadly correlatable with the Tertiary sequence encountered in far away wells of Mehsana area. The new wells drilled at Wara, Sampra, Dasawara and Dharnoj between Mehsana and Tharad area have further bridged the gap for precise correlation. The detailed microfaunal, miofloral and lithological studies have helped to establish the continuity of Paleogene formations penetrated in the wells north of Saraswati river. The modified stratigraphic classification is shown in Table 1. The lithostratigraphic correlation of the well section is shown in Figure 1.

A systematic description of the Paleogene formations is given below :

OLPAD FORMATION

The trap conglomerate sequence unconformably overlying Deccan Traps in Serau-Tharad area designated earlier as Balutri Formation by Roy Choudhury *et al.*, (1972) is well correlatable with the Olpad Formation originally described by Chandra & Choudhury (1969) from the Cambay basin. It is encountered in all the wells except in Wara, where the drilling has ended before reaching to this formation. The thickness of the formation varies between 30 m. to 690 m.

The formation consists of trap conglomerates, sandstones, siltstones and clays. Trap conglomerates are composed of rounded to subrounded dark grey to greenish grey, brownish black pebbles and fragments of altered traps and granites embedded in the reddish brown to dark brown and green trap derived matrix.

In Tharad, the formation is represented mostly by ferruginous silty and sandy clays and red siltstone. In Delvada weathered trap derivatives of brownish green colour, fine to medium grained sand and brownish claystones are present. In Deodar the frequency of granitic fragments in conglomerates is more. In Sampra the granules, pebbles and fragments of trap are embedded in dark grey, moderately hard calcareous clay.

The entire sequence is found to be unfossiliferous. Indirect stratigraphic evidences indicate its age between Paleocene to Early Eocene.

Table 1. Paleogene Subsurface Stratigraphy of the area, north of Saraswati River, Gujarat.

AGE \ Formation	SERAU	THARAD	DELVADA	DEODAR	WARA	SAMPRA	DASAWARA
OLIGOCENE	H I A T U S						
EOCENE — LATE	T A R A P U R S H A L E						
EOCENE — MIDDLE	KALOL FORMATION				** WARA LITHO UNIT	KALOL FORMATION	
						UNCONFORMITY	
EOCENE — EARLY	THARAD FORMATION					CAMBAY SHALE	
	?	?	?			?	?
	H I A T U S						
	DISCONFORMITY						
PALEOCENE	O L P A D F O R M * A T I O N						
	NON CONFORMITY						
LATE CRETACEOUS	D E C C A N * T R A P * G R O U P *						

* NOT DRILLED ** NEWLY PROPOSED

CAMBAY SHALE

The formation was proposed by Zubov *et al.*, (1966) and was systematically described by Bhandari and Mathur (1969), Chandra and Chowdhary (1969), Roy Choudhury and Mrs. Kumar (1969) and Sudhakar and Basu (1973). The formation is encountered in Sampra and Dasawara wells overlying the Olpad Formation unconformably and is in turn overlain by Kalol Formation with a distinct unconformity. It varies in thickness from 510 m to 837 metres.

The formation includes mostly an argillaceous sequence comprising of shales and claystones. The shales are grey, soft to moderately hard, and slightly fissile. In Sampra well, the shales are dark grey, carbonaceous, silty occasionally micaceous having nodules of very fine grained sandstone. Towards the base, silty intercalations within shale bands are present. In Dasawara well, which is located towards the eastern basinal margin, marked lithofacies variations are noticed. Here the formation consists of monotonous sequence of variegated claystones in shades of grey, brown, reddish brown and greenish grey. In the lower part, the claystones are generally ferruginous and of dark brown to reddish brown colour.

The formation has yielded a fairly good assemblage of *Triorites*, *Schizosporis*, *Septacolpate*, *Triporites*, *Hystrichosphaerids*, *Monolete*, *Potamogetonaceae*, *Tricolporate*, *Inaperturopollenities*, *Trilete*, *Hexacolpate*,*Polycolpate*, *Pseudonothofagidites* and *Polypodiaceae*. The microfauna is recorded only in the upper part of the formation. The diagnostic taxa include : *Nummulites acutus*, *N. beaumonti* and *Discocyclina* sp., On the basis of these microfaunal/miofloral evidences Early to Middle Eocene age may be assigned to the formation.

WARA LITHO UNIT

A huge thickness of 1423 m (+) of an arigillaceous sequence underlying Tarapur Shale is developed in Wara Well. The bottom of this sequence is not known as the well has ended before reaching to the underlying formation. The sequence is composed of shales with minor siltstone bands towards base in the lower part and brown to reddish brown monotonous claystones in the upper part. The shales are grey to dark grey, soft to moderately hard, slightly fissile with silty intercalations. The claystone is brown and soft to moderately hard, occasionally with rounded to subrounded trap pebbles and claystone pellets. On electrolog the SP and resistivity curves are almost flat throughout.

The lower shale member of this sequence has yielded Early Eocene polospores, which include : *Triorites*, *Tricolporites reticulatus*, *Triporites*, *Inaperturites reticulatus*. The upper claystone member particularly its top 200 metres of sediment, has yielded typical microfauna of Middle Eocene including *Nummulites acutus*, *N. beaumonti*, *Discocyclina* sp., *Halkyardia* sp., and *Chiloguembelina martini*. Besides, non-diagnostic polospores but younger than Early Eocene assemblage such as *Potamogetonaceae*, *Triletes*, *Monocolpate* and *Biporites* have also been recorded throughout from upper claystone member. Based on these evidences an Early Eocene to entire Middle Eocene age may be assigned to this sequence.

Considering the period which sequence has covered and its uniform argillaceous nature it may be proposed that this sequence may have the status of a new lithounit and may be designated as Wara litho Unit after the locality Wara well.

THARAD FORMATION

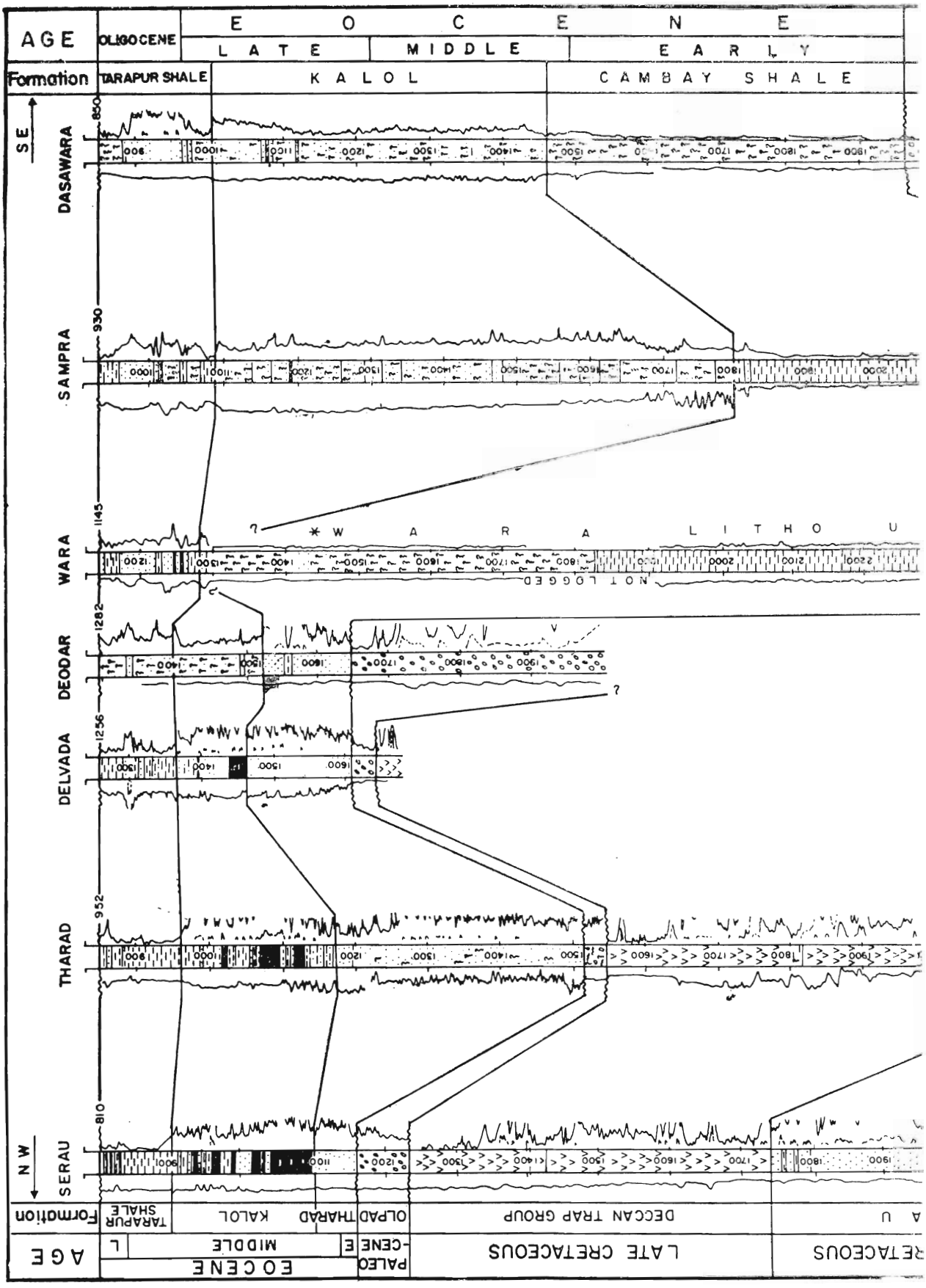
The forrmation was proposed by Roy Chaudhury, *et al.*, (1972) for the sugary sandstones and cyclic sediments comprising of shale-sand-coal in Tharad well which were described as homotaxial to Kalol and partly to Cambay Shale formations. The present authors have made detailed investigations and reached to the conclusion that Tharad Formation is restricted to the sandstone facies homotaxial to Cambay Shale. The overlying sequence of coal-shale-sand included earlier in Tharad Formation belongs to Kalol Formation.

The formation unconformably overlies the Olpad Formation and conformably underlies Kalol Formation. A marked change in lithology prevails in Wara and southwards. The sandstone sequence is best developed in Tharad well and has attained the thickness of 343 metres. It is poorly represented in Serau well and is only 60 metres thick. The formation consists of monotonous sugary sandstones with highly resistive hard siltstone intercalations. The sandstone is generally pinkish to buff and grey in colour, medium to fine grained and well sorted.

The formation has yielded rich assemblage of polospores particularly in Delvada and Serau wells which include : *Schizosporis*, *Palmaepollenites eocenicus*, *Polycolpate* 8 & 9, *Monocolpate*, *Monolete*, *Tricolporate*, *Hexacolpate*, *Diadites* and spinous *Inaperturite* indicative of Early to Middle Eocene age. The formation is thus assigned Early to Middle Eocene age.

KALOL FORMATION

Proposed originally by Zubov *et al.*, (1969), it was subsequently described by Bhandari and Mathur (1969), Roy Choudhary and Mrs. Kumar (1969) and Chandra and Chowdhary (1969). The last mentioned authors have traced this fonmation throughout the Cambay basin except in west of Mehsana structure and in the area south of Dhadhar river. In the area studied, the formation unconformably overlies Cambay Shale in the Southern part and with gradational contact to Tharad Forma-


AGE
OLIGOCENE
EOCENE
LATE
MIDDLE
EARLY
Formation
TARAPUR SHALE
KALOL
CAMBAY SHALE
SE
DASAWARA
SAMPRA
WARA
DEODAR
DELVADA
THARAD
SERAU
NW
WARA LITHOLOGY
NOT LOGGED
Formation
TARAPUR SHALE
KALOL
THARAD
OLPAD
DECCAN TRAP GROUP
AGE
EOCENE
L
MIDDLE
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PALEOCENE
LATE CRETACEOUS
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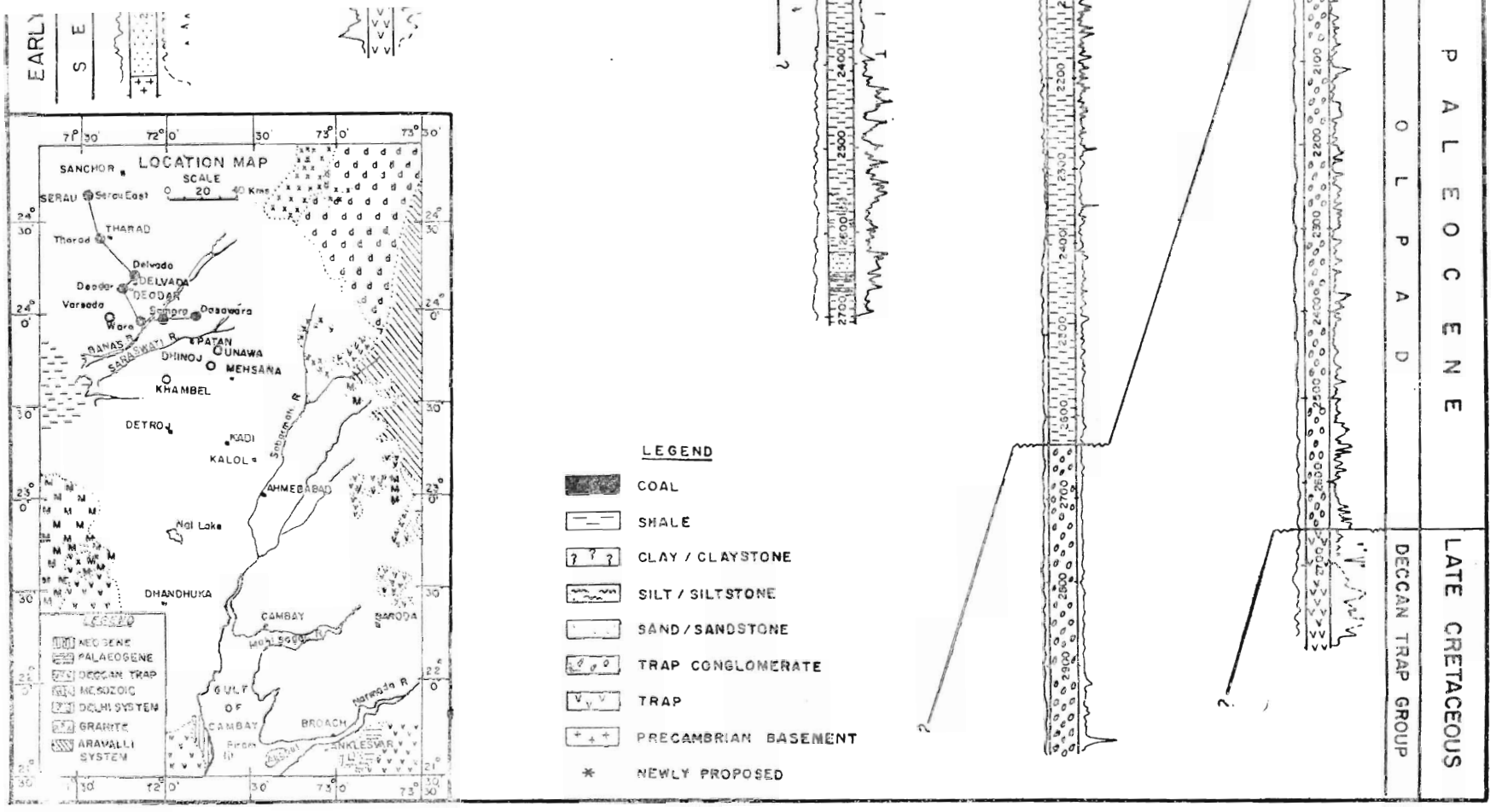
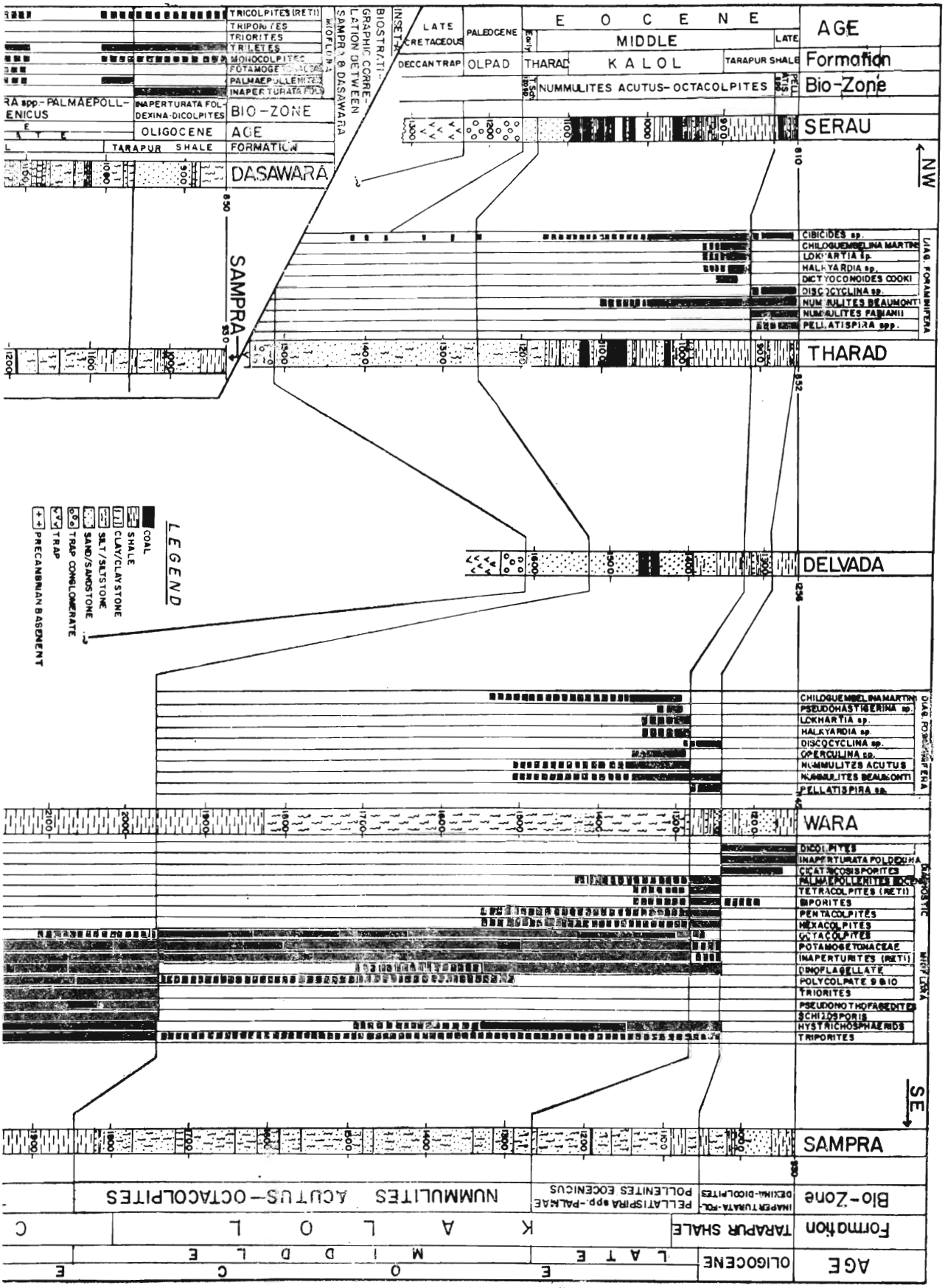


Fig. 1. Lithostratigraphic Correlation of Paleogene Sediments in the Wells along Serau-Deodar-Dasawara Section.


AGE
Formation
Bio-Zone
OLIGOCENE
TARAPUR SHALE
PELLATISPIRA spp.-PALMAE POLLENITES EOCENICUS
INAPERTURATA FOL-DEXINA-DICOLPITES
NUMMULITES ACUTUS-OCTACOLPITES
SERAU
THARAD
DELVADA
WARA
SAMPRA
DASAWARA
NW
SE
LEGEND
COAL
SHALE
CLAY/CLAYSTONE
SILT/SILTSTONE
SAND/SANDSTONE
TRAP CONGLOMERATE
TRAP
PRECAMBRIAN BASEMENT
DIAGNOSTIC MICROFLORA
DIAG. FORAMINIFERA
CIBICIDES sp.
CHILOGUEMBELINA MARTINI
LOKHARTIA sp.
HALKYARDIA sp.
DICTYOCONOIDES COOKI
DISCOCYCLINA sp.
NUMMULITES BEAUMONTI
NUMMULITES FABIANI
PELLATISPIRA spp.
PSEUDOHASTIGERINA sp.
OPERCULINA sp.
NUMMULITES ACUTUS
DICOLPITES
INAPERTURATA POLYGONHA
CICATRICOSISPORITES
PALMAEPOLLENITES KUTCHENSIS
TETRACOLPITES (RETI)
TRIPORITES
PENTACOLPITES
HEXACOLPITES
OCTACOLPITES
POTAMOGETONACEAE
INAPERTURITES (RETI)
DINOFLAGELLATE
POLYCOLPATE 9 & 10
TRIORITES
PSEUDONOTHOFAGIDITES
SCHIZOSPORIS
HYSTRICHOSPHAERIDS
TRIPORITES
TRICOLPITES (RETI)
TRIPORITES
TRIORITES
TRILETES
MONOCOLPITES
POTAMOGE
PALMAEPOLLENITES
INAPERTURATA FOL-
DEXINA-DICOLPITES
BIO-ZONE
AGE
FORMATION
TARAPUR SHALE
BIOSTRATIGRAPHIC CORRELATION BETWEEN SAMPRA & DASAWARA
INSET
LATE CRETACEOUS
PALEOCENE
DECCAN TRAP
OLPAD
EOCENE
MIDDLE
LATE
THARAD
KALOL
TARAPUR SHALE
NUMMULITES ACUTUS-OCTACOLPITES
SERAU
DASAWARA
SAMPRA
THARAD
DELVADA
WARA
SAMPRA
NW
SE

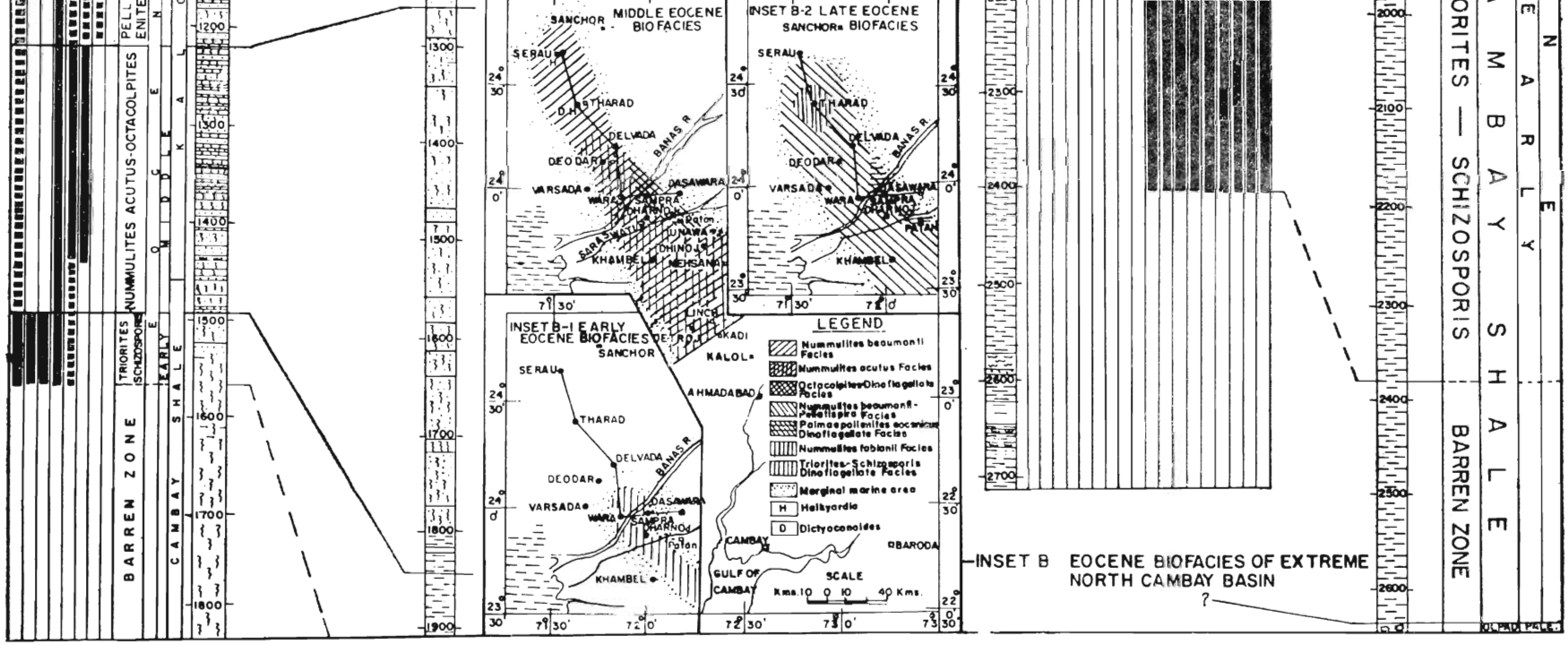


Fig. 2. Biostratigrafic Correlation of Paleogene Sediments in the Wells along Serau-Delvada-Sampra Section

tion in the northern part. It is conformably overlain throughout by Tarapur Shale. The thickness varies between 102 metres to 708 metres.

The formation is represented dominantly by coal, shale, claystone and subsidiarily by sandstone in the northern part of the area between Serau and Deodar, but is dominantly sandstone and claystone with minor coal bands in the southern part of the area between Sampra and Dasawara. In Serau-Deodar section the shales are grey to dark grey, silty, carbonaceous and moderately fissile. The coals are black, lignitic, brittle and resinous. The claystones are generally ash grey in colour. Sandstones are medium to fine grained subangular and fairly sorted. In southern part of the area, i.e. in Dasawara-Sampra Section, the upper most part is dominated by colourless to light green, occasionally light yellow, fine to coarse grained sandstone with dirty grey to grey carbonaceous claystone streaks and lower part comprises claystone and sandstone alternations with brownish black, soft coal bands. The claystones are silty grey to grey occasionally greenish grey, silty and moderately hard. Sands are colourless to pale yellow subangular to subrounded mostly fine grained. In Daswara the coal bands are rare.

The formation has yielded foraminifera which include *Pellatispira* sp., *Discocyclina* sp. *Nummulites acutus, Halkyardia* sp. *Lokhartia* sp., *Chiloguembelina martini, Pseudohastigerina micra.* Besides, the miofloral assemblage including *Palmaepollenites, Pentacolpate, Inaperturopollenites, Polycolpate, Reti Tricolpate* and *Diadites* is also recorded from the formation. Both the above assemblages suggest Middle to Late Eocene age to the formation. It may be pointed out here that the lower part of the formation is relatively rich in miofloral assemblage and consists of no diagnostic microfauna.

TARAPUR SHALE

The formation was initially proposed by Zubov *et al.*, (1966). Later Chandra and Chowdhary (1969) designated a type section in a Cambay well and described it systematically. Varying in thickness between 81 to 157 metres the formation is present throughout the studied area and conformably overlies the Kalol Formation encountered throughout in the area except in Wara well section where it overlies Wara lithounit. The formations is overlain unconformably by Neogene formations, which have not been included in the present study.

The formation is composed of grey to dark grey laminated, fissile shales and claystones with medium to coarse grained sandstone intercalations. The sandstones are light grey to colourless, mostly coarse grained and poorly sorted. Claystones are dark grey to grey, moderately hard. In Serau and Wara coal streaks are noticed.

The formation has yielded the following fossils ; *Pellatispira* sp. *Nummulites fabianii, Discocyclina* sp., *Palmaepollenitcs eocenis, Tetracolporate, Inaperturata foldexina, Dicolpites, Oudhkusumites, Dinoflogellate, Tricolporate,* and *Nonocolpate* which indicate its age ranging from Late Eocene to Early Oligocene. The presence of luxurient Oligocene flora in Wara, Sampra and Dasawara is being reported for the first time, thus extending the age of this formation to definite early Oligocene times.

MICROFAUNA AND MIOFLORA

In the subsurface of the Cambay basin Paleogene foraminiferal assemblages have been recorded throughout from south to north, i.e. from Dumas to Serau. The larger foraminifers constitute the major portion of the total microfaunal assemblage, which is dominated by *Nummulites.* As such the genus forms the basis for the biozonation of the Paleogene sequence. However, in the studied area the entire Paleogene section has not yielded microfauna, as a result the mioflora has also been taken into account for biozoning the Paleogene sediments. The important species of larger foraminifers and polospores are given in Table 2.

BIOZONATION

Based on characteristic fossil assemblages the entire Paleogene sequence has been divided into four biozones. The boundary of each zone is placed at the appearance/ disappearance level of diagnostic faunal/floral assemblage. It has been observed that the boundaries of the biozones and lithostratigraphic units generally lie at different stratigraphic levels. Nevertheless, at some places, they coincide. The following four biozones have been recognised in ascending order and are described briefly below. The biostratigraphic correlation with the ranges of diagnostic taxa of foraminifera and polospores is shown in Figure 2.

4. *Inaperturata foldexina—Dicolpites* Assemblage Zone.
3. *Pellatispira* spp.—*Palmaepollenites* Assemblage Zone.
2. *Nummulites acutus—Octacolpites* Assmblage Zone.
1. *Triorites—Schizosporis* Assemblage Zone.

1. *Triorites-Schizosporis* Assemblage Zone : The zone is defined by the range of Triorites and is characterised by abundant *Triporites, Triorites, Schizosporis* and *Pseudonothofagidites.* The zone occurs in all the well sections but is not typically developed in Serau, Tharad and Deodar Wells. Its thickness varies between 20 metres and 450 metres. Stratigraphically the zone overlies the basal barren zone encountered in Cambay Shale and Wara litho unit in the southern part of the area and in Tharad Formation in the northern part of the area between Deodar and Serau. However in Delvada and Serau well sections it overlies directly Olpad Formation.

Table 2. Diagnostic Paleogene foraminifera and mioflora in subsurface of the area in north of Saraswati river, Gujarat.

Age	Foraminifera	Mioflora
Oligocene	Barren zone	*Dicolpites, Inaperturata foldexina, Oudh kusumites, Inaperturite* (Reti), *Tricolporate, Dinoflagellate, Monocolpate,* Striated *trilete, Polypodiaceae.*
Late Eocene	*Nummulites fabianii* (Prever), *Pellatispira, madraszi* Hankten, *Pellatispira inflata* Umgrove, *Discocyclina* sp., *Baculogypsinoides* sp., *Chiloguembelina* sp., *Calcarina* sp.	*Palmaepollenites eocenicus, Tetracolpate, Pentacolpate, Hystrichosphaerids, Tricolporate, Biporate, Diadites* and Potamogetonaceae.
Middle Eocene	*Nummulites acutus* (Sowerby), *N. beaumonti* d'Archiac and Haime, *Lokhartia* sp., *Halkyardia* sp., *Dictyoconoides cooki* (Carter), *Discocyclina* sp, *Pseudohastigerina micra* Cole, *Globigerina yeguaensis* Weinz and Applin, *Chiloguembelina martini* (Pijpers), *Operculina* sp., *Epistomaria* sp.	*Polycolpate , Inaperturopollenites reticulatus, Tricolporite* (Reti), *Monocolpate* (Reti), *Trilete, Hexacolpate* (Reti), *Triporite, Monolete, Palmaepollenites, Dinoflagellate Inaperturite, Diadites,* Polypodiaecae, Potamogetonaceae and Nymphaecae.
Early Eocene	Non-diagnostic microfauna including *Rotalia* sp., *Cibicides* sp., *Bolivina* sp., and rare ostracods.	*Schizosporis, Triorites, Septacolpate Triporites, Hystrichosphaerids Monolete, Pseudonothofagidites* Potamogetonaceae and Polypodiaceae.

The sediments of this zone have not yielded any microfauna except in Tharad well in which some non-diagnostic Rotalids have been recorded in side wall cores up to 1475 metres. The mioflora is being reported for the first time from this area.

AGE : Early Eocene.

2. *Nummulites acutus—Octacolpites* Assemblage Zone: This zone occurs between the disappearance level of *Triorites* and near first appearance of *Palmaepollenites eocenicus* and *Pellatispira* spp. Defined by the common occurrence of the zonal taxa it is widely present in all the well sections of the studied area. The zone overlies *Triorites—Schizosporis* biozone in all the well sections ranging in thickness between 100 m? to 670 metres, it shows gradual thickening in the southern part of the area. Stratigraphically the zone encompasses uppermost Cambay Shale and Tharad Formations, upper claystone member of Wara Litho Unit, Kalol Formation and basal portion of Tarapur Shale in Serau, Tharad, Delvada and Deodar wells.

AGE : Middle Eocene.

3. *Pellatispira* sp.—*Palmaepollenites eocenicus* Assemblage Zone : The zone is confined between the stratigraphic disappearance of *Nummulites acutus* and *Pellatispira* sp., *Palmaepollenites eocenicus* and it is widely present in the area. It is usually thin and varies between 20 and 55 m. in northwestern subcrops. However, it gradually increases in thickness reaching up to 250 m. in Dasawara. In Serau East, Tharad, Delvada and Deodar it is restricted to the lower part of Tarapur Shale, Whereas in Wara, Sampra and Dasawara it includes a part of Kalol and a part of Tarapur Shale.

AGE : Late Eocene.

4. *Inaperturata foldexina—Dicolpites* Assemblage Zone: Defined by the range of the index species, this zone is present in Wara, Sampra and Dasawara only. The presence of Oligocene sediments in this part of the basin is a characteristic feature and is being reported here for the first time based on miofloral evidences. The microfaunal yield is extremely poor except some arenaceous forms and dimunitive rotalids in Sampra and Dasawara. Varying between 100 and 120 metres in thickness, the zone is underlain by *Pellatispira* sp. *Palmaepollenites eoceniens* zone and is overlain by Neogene strata. It occupies upper part of Tarapur Shale.

AGE : Oligocene.

CORRELATION

As mentioned earlier Varadarajan et al., (1971, IPE unpub. rep.) and Roy Choudhury et al., (1972) carried out first study of this area and attempted correlation mainly on the basis of electrolog and lithological characteristics. The lithostratigraphic and biostratigraphic correlation of the sediments encountered in the wells drilled in north of Saraswati river is thus attempted and is given in figures 1 and 2 respectively.

The lowermost Paleogene formations of the studied area is considered to belong to Olpad Formation. The formation is represented mostly by trap conglomerates. However, varying lithologies like ferruginous silty clay and red siltstone in Tharad well and brown to reddish brown moderately hard claystone bands in Deodar and Dasawara wells have also been noticed. The formation is found to be entirely devoid of microfauna and mioflora, thus no definite age can be assigned to it. However, its

stratigraphic position (i.e. underlying Cambay Shale/ Tharad Formation) and lithological characters support the view to call it Olpad Formation. It is extending throughout the area except in Wara, where it has not been penetrated through and varies in thickness from 60 to 620 metres. This erratic behaviour of thickness is controlled by the tectonics of the area. The thick sedimentation is generally confined to the areas facing fault scarp in the Deccan Trap country.

The extension of Cambay Shale is established in north of Saraswati river up to Wara. Its deposition seems to be restricted in the southern part of the area as its extension in Deodar, Delvada, Tharad and Serau has not been observed. It appears that the general basement upgradient as evident in the refraction survey profile (Ramanathan ; 1971), in north of Wara and onwards, has delimited the deposition of this formation. There seems to be a major change in facies of this formation between Wara and Deodar. Besides, some minor lateral lithological variations of this formation have also been noticed in Dasawara well. The sediments between 1460 to 1970 metres of this well classified earlier under Olpad Formation by Varadrajan *et al.*, (1971, IPE Unpub. rep.) have yielded in its upper part polospores consisting *Triorites* and *Tricolpate* (Reti) indicative of Early Eocene age. This suggests that the claystone sequence in Dasawara well is nothing but lithofacies variant of the Cambay Shale. The reddish brown to chocolate brown claystone is deposited in shallow water oxidising environment nearer to the margin of the basin.

A thick argillaceous sequence comprising shales in the lower part and claystone in the upper part is encountered in Wara well. This has covered the period from Early Eocene to entire Middle Eocene encompassing the time and space of Cambay Shale and Kalol Formation. Moreover this sequence on the whole is not correlatable with rock formations encountered in the adjoining areas in the north and south. In view of these facts, the sequence is proposed to be a new litho-unit, i.e. Wara Litho Unit. The possibility that it may be considered as Cambay Shale having two members lowerone shale and upperone red claystone because the presence of reddish brown claystone within the Cambay shale's upper part is noticed in one of the Mehsana wells, is untenable, because such sequences are sporadic and have developed in different times indicating appreciable change in depositional environment. In Wara well particularly, the deposition of Wara Litho-Unit is continued in different depositional environment than adjoining areas up to the close of Middle Eocene epoch. It is therefore more apt to call it as a new Litho-Unit (i.e. Wara Litho Unit) than to put it under Cambay Shale. This shows almost parallel status as of Hazira shales in southern Cambay basin (Sudhakar and Basu, 1973).

Tharad Formation covers the northern area of investigation. Its extension further in south beyond Deodar could not be traced as speculated by Roy Choudhury et al., (1972). The formation has yielded a rich assemblage of polospores of Early Eocene age in Delvada well. Though such good miofloral control could not be extended for other wells like Tharad and Deodar, due to paucity of mioflora, however, the presence of meagre mioflora and rare microfauna (only in Tharad Well) has helped in correlation of these sediments. The formation is by and large correlatable in all the wells from Deodar to Serau and may be taken as homotaxial to Cambay Shale and partly of Wara Litho-Unit.

Kalol Formation is extending in whole of the area except in Wara area where the claystone sequence is developed at the expense of Kalol Formation. In Deodar-Serau area the formation is represented by coal, shale and sandstone sequence. The typical Middle Eocene microfauna is recorded from this formation. The *Nummulites acutus* biozone is identified and correlated in all the wells. The alternating marine and non-marine conditions seem to have developed during the deposition of this formtion.

In Sampra-Dasawara area an essentially arenaceous sequence with intercalations of claystone and coal and siltstone (thin bands) has developed. An appreciable thickness of 708 metres is recorded from Sampra well. It is underlain and overlain by Cambay Shale and Tarapur Shale respectively. This sequence too is considered to be Kalol Formation. However, it is quite likely that its increase in thickness may be due to coalescing of Kadi Formation with the Kalol. The typical lithology of the formation is not recorded owing to lateral facies variations. Lower part of the formation has yielded rich assemblage of polospores including *Polycolpate*, *Inaperturopollenite*, *Diadites*, *Reti-tricolpate* indicating Middle Eocene age, whereas the upper part is enriched with the polospores such as *Palmaepollenites eocenicus*, *Tetracolpate*, *Pentacolpate* indicative of Late Eocene age. The formation is thus dated Middle to Late Eocene in age. Broadly speaking the formation in Serau-Deodar and Sampra-Dasawara sections is mostly confined chronologically to Middle Eocene, though in Sampra-Dasawara Section the formation has partly transgressed in Late Eocene to lusba without any lithological change.

The sequence of mainly shales and claystones with sandstone intercalations overlying Tharad Formation in Delvada-Tharad-Serau area designated as Vav Formation by Roy Chaudhury et al., (1972) has excellent correlation with Tarapur Shale. The formation is dated Late Middle Eocene to Late Eocene but in southern wells of the studied area (i.e. in Wara, Sampra and Dasawara) the presence of Oligocene sediments is also evidenced on the basis of miofloral assemblage and hence

the formation is correlatable lithologically and chronologically with Tarapur Shale.

DEPOSITIONAL ENVIRONMENT OF THARAD AND KALOL FORMATIONS

The granulometric analysis of Tharad sands from Serau East, Tharad, Delvada and Deodar wells and Kalol sands from Deodar and Dasawara wells has been carried out. In the present study the samples from abovementioned wells have been analysed for determining four statistical parameters, graphic mean, standard deviation, skewness and Kurtosis proposed by Folk and Ward (1957).

The results of size analyses are shown in Table 3.

The sands of Tharad Formation are medium to fine grained, poorly sorted, positively skewed (near symmetrical samples are both positively and negatively skewed), meso- to leptokurtic. Larger cluster of kurtosis values is between 0.90 to 1.11, which indicates that sorting in the central portion and average of tails (coarse and fine) is equal.

The overlying sands, i.e. of Kalol Formation are dominantly find grained, poorly sorted, positively and negatively skewed and platy-(biomodel) to leptokurtic (unimodel).

ENVIRONMENTAL INTERPRETATION

Friedman (1967) has shown that there are three modes of transportation and deposition namely sliding or rolling, saltation and suspension, which influence textural parameters of sands. Sliding or rolling affects the grains in the size interval between 0.250 and 0.500 mm (+1.00 ϕ to 2.00 ϕ), and especially grain sizes that are larger than 0.500 mm (<+1.00 ϕ), saltation, which is effective between 0.250 mm and 0.500 mm (+1.00 ϕ to 2.00 ϕ) at the coarser end and about 0.140 mm (about 2.80 ϕ) to 0.062 mm (4.00 ϕ) at the finer end, and suspension which effects grains less than 0.140 mm (about 2.80 ϕ) and especially those in <62 micron range (> 4.00 ϕ). The beach sands are deposited most commonly by saltation mechanism whereas river sands most commonly subject to deposition from both saltation and suspension. According to Friedman (1962), most beach and marine sands show standard deviation between 0.35 ϕ and 0.50 ϕ. The upper limit for beach sands is 0.80 ϕ and range of river sands is 0.50 ϕ to 1.40 ϕ.

The skewness measure shows that beach sands are negatively or slightly positively skewed and a larger percentage of river sands are more positively skewed than those of positively skewed beach sands (Firedman, 1967).

In the light of above findings, an attempt has been made to bring out the mechanism of transportation and environment of deposition of sandstone from Tharad and Kalol Formations.

The range of mean size (1.41 ϕ to 3.70 ϕ) for sands of Tharad Formation suggests that sediments were transported dominantly by saltation and suspension mechanisms. A few sand samples from Serau East well indicate transportation by rolling or sliding mechanism. Tharad sands are poorly sorted, positively skewed and mainly

Table 3. Range of size parameters of Tharad and Kalol sands.

Textural Parameters / Wells		KALOL SANDSTONES	
		Deodar	Dasawara
ϕ MZ	Rng.	1.65— 2.37	2.13— 3.96
ϕ δ1	Rng.	1.36— 1.58	0.92— 1.99
SKI	Rng.	—0.32—+0.35	—0.05—+0.39
KG	Rng.	0.85— 0.98	0.99— 1.11

Textural Parameters / Wells		THARAD SANDSTONES			
		Serau	Tharad	Delvada	Deodar
ϕ MZ	Rng.	1.41— 2.96	2.20— 3.70	2.16— 2.56	1.18— 2.31
ϕ δ1	Rng.	1.12— 1.72	1.14— 1.98	1.05— 1.35	1.21— 1.41
SKI	Rng.	—0.03—+0.39	—0.02—+0.39	+0.14—+0.33	+0.07—+0.40
KG	Rng.	0.83— 1.11	0.91— 1.08	0.92— 1.09	0.85— 1.11

mesokurtic, thus suggesting an abundance of finer fraction. Based on the proportion of three transporting processes and abundance of fines, it appears that Tharad sands might have been deposited in a deltaic environ ment-probably of lower deltaic complex.

The sands of Kalol Formation are fine to very fine (2.13 ϕ to 3.96 ϕ) suggesting saltation and suspension transport mechanisms. These sands are moderately to poorly sorted positively to negatively skewed and platy- to mesokurtic. These three measures indicate either abundance of fines or winnowing of the same depending upon the availability of wave energy.

Considering the sedimentary processes, natur of deposition of finer fraction and other ilthological association (occurrence of coal, shale etc.), Kalol sands seem to have been deposited in a paralic environment.

PALEOECOLOGY AND GEOLOGICAL HISTORY

The Cambay Tertiary Basin came into existence with down faulting along its margins, which started during Upper Cretaceous (Chandra & Chowdhary, 1969). The major Tertiary event of Cambay basin started with the Early Eocene subsidence and transgression in the areas north of Saraswati river up to Wara. It, however, was not only confined in the areas south of Saraswati river as concluded by Pandey and Nath (1974). In such areas of subsidence, the thick sedimentary sequence of continental deposits consisting of volcanic conglomerates, sandstones, siltstones and claystones derived exclusively from Deccan Trap basalts were laid down during Late Cretaceous to Paleocene times (Olpad Formation). During Early Eocene first marine transgression as evidenced by miofloral assemblage, occurred leading to the deposition of grey to dark grey shales (Cambay shale & partly Wara Litho Unit) in Sampra and Wara Wells. D.T.A. studies carried out for a few samples of the shale member of Wara Litho Unit indicated the presence of illite along with kaolinite suggesting the marine origin of the shale. In Dasawara however the marginal marine conditions prevailed.

While the Cambay Shales were being deposited in Early Eocene sea, which formed a gulf in the axial part of the basin, the contemporaneous deposition of poorly sorted thick sandstone sequence of Tharad Formation in Serau, Tharad, Delvada and Deodar areas took place in deltaic conditions as suggested by the textural analysis of the sands. The miofloral assemblage including mainly *Triorites* and *Schizosporis* recorded from this clastic sequence indicate subtropical to humid climatic conditions. The recovery of dimunitive Rotaliids and Ostracods from Tharad Sands corroborate the sedimentological inference. The lateral facies sequence from marine shale to deltaic sandstone during this period record the coeval existence of these two major depositional environments.

The succeeding Kalol Formation comprising sandstone, coals, silty and carbonaceous shales in Serau, Tharad, Delvada and Deodar during Middle Eocene times represents incomplete cyclothems (Roy Choudhary, et al. (1973), indicating its deposition in alternate transgressive and regressive phases, the former leading to the deposition of marine shales and the latter to the deposition of coarse clastics, coal seams and carbonaceous shales. The sediments of this formation in Sampra and Dasawara are dominated by coarser clastics without any appreciable coal seams.

Following an early Middle Eocene regressive phase, the Middle Eocene transgression was quite widespread. It extended further in north of Banas river and submerged the areas from Varsada-Deodar to Serau. However the fluctuations of sea to the extent of short lived regressions can not be ignored as evident with the lithological association as well as the intervening thin barren zones. The paralic environment suggested by textural analysis of kalol sands supports the view. The sequence has yielded *Nummulites acutus, N. beaumonti, Dictyoconoides cooki, Lokhartia* sp. and *Halkyardia* sp. The presence of *Nummulites acutus, N. beaumonti* assemblage indicate inner shelf condition of deposition. The large, discoidal imperforate calcareous foraminifera with simple, or pillared interior are identified within the bathymetric range of fifty metres with almost stable salinities (Bandy 1964), Presence of sporadic planktonics such as *Truncorotaloides rohri?* and *Globigerina yeguaensis* indicate change in bathymetry.

However, absence of microfauna during Middle Eocene and Late Eocene in Sampra and Dasawara wells is noteworthy. It appears that more supply of clastics with decreasing shale and fall of salanities have adversely affected for thriving of microfauna. The marginal marine conditions during Middle Eocene as indicated by miofloral assemblage including Microthyriaceae Potamogetonaceae and Dicolpites further confirm the views. This phase, however was followed by shallow marine conditions during Early late Eocene time in Sampra as evidenced with the recovery of *Palmaepollenites eocenicus* and *Hystrichosphaerids.*

The deposition of the cyclic sediments of Kalol Formation was followed by marine transgression in Late Middle and Late Eocene times when relatively thin sequences of Tarapur Shales were deposited. *Nummulites beaumonti* biofacies of Middle Eocene with added element of *Pellatispira* sp. with an exception of *Nummulites fabiani* in Tharad well section continues in Late Eocene. The microfaunal assemblage indicates its deposition in near shore to infralittoral environments. Rapid regression started at the close of Late Eocene and complete regression occurred during Oligocene. The succeeding sediments in Wara, Sampra and Dasawara have yielded polospore assemblage consisting of *Inaperturata foldexina, Dicolpi'es* and *Tricolporates* (*Reti.*) in regressive phase. The presence

of Striated *triletes* of Schizaeceae and Parkeriaceae alongwith Polypodiaceae in the Oligocene assemblage is indicative of damp and humid climate with marshy vegetation. The thick sequence of coarse clastics (sands) in this part is of typical regressive sediments.

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REFERENCES

BANDY, O. L. 1964. *General correlation of foraminiferal struture with environmental Approaches to Paleoecology;* John Willey and Sons, Inc. : 75-90.

BHANDARI, L. L. AND MATHUR, R. B. 1969. Strand line sands—Eocene prospects in northern Cambay Basin. *Second Indian Petroleum Conference*, Baroda.

CHANDRA, P. K. AND CHOWDHARY, L. R. 1969. Stratigraphy of the Camby Basin, *Bull. ONGC.* **6** (2) : 37-50.

FOLK, R. L. AND WARD, W. C. 1957. Brazos River Bar; A study in the significance of grain size parameters. *Jour. Sed. Pet.* **27** : 3-26.

FRIEDMAN, G. M. 1967. Dynamic processes and statistical parameters, compared for size frequency distribution of beach and river sands. *Jour. Sed. Pet.* **37** : 327-354

PANDEY, J. AND NATH, D. 1974. Larger Foraminiferal zonation and Biofacies in the Paleogene of Cambay Basin. *Proc. 4 colloq. Indian Micropal. Strat.*: 46-54.

RAJU, D. S. N., GUHA, D. K., BEDI, T. S., KUMAR, P. AND BHATT, D. K. 1970. Microfauna, biostratigraphy and paleoecology of the Middle Eocene to Oligocene sediments in Western India. *Pub. Centre. Adv. study. Geol. Punj. Univ.* Chandigarh. **7** : 155-178.

ROY CHOUDHURY, S. C., AND MRS. KUMAR, S. 1969. Geological assessment of Kathana structure. ONGC, Rep. (Unpub.)

RAMANATHAN, P. 1971. Report on Seismic refraction Survey in Patan-Delvada area, Mehsana-Banaskantha district, North Gujarat. ONGC, Rep. (Unpub.)

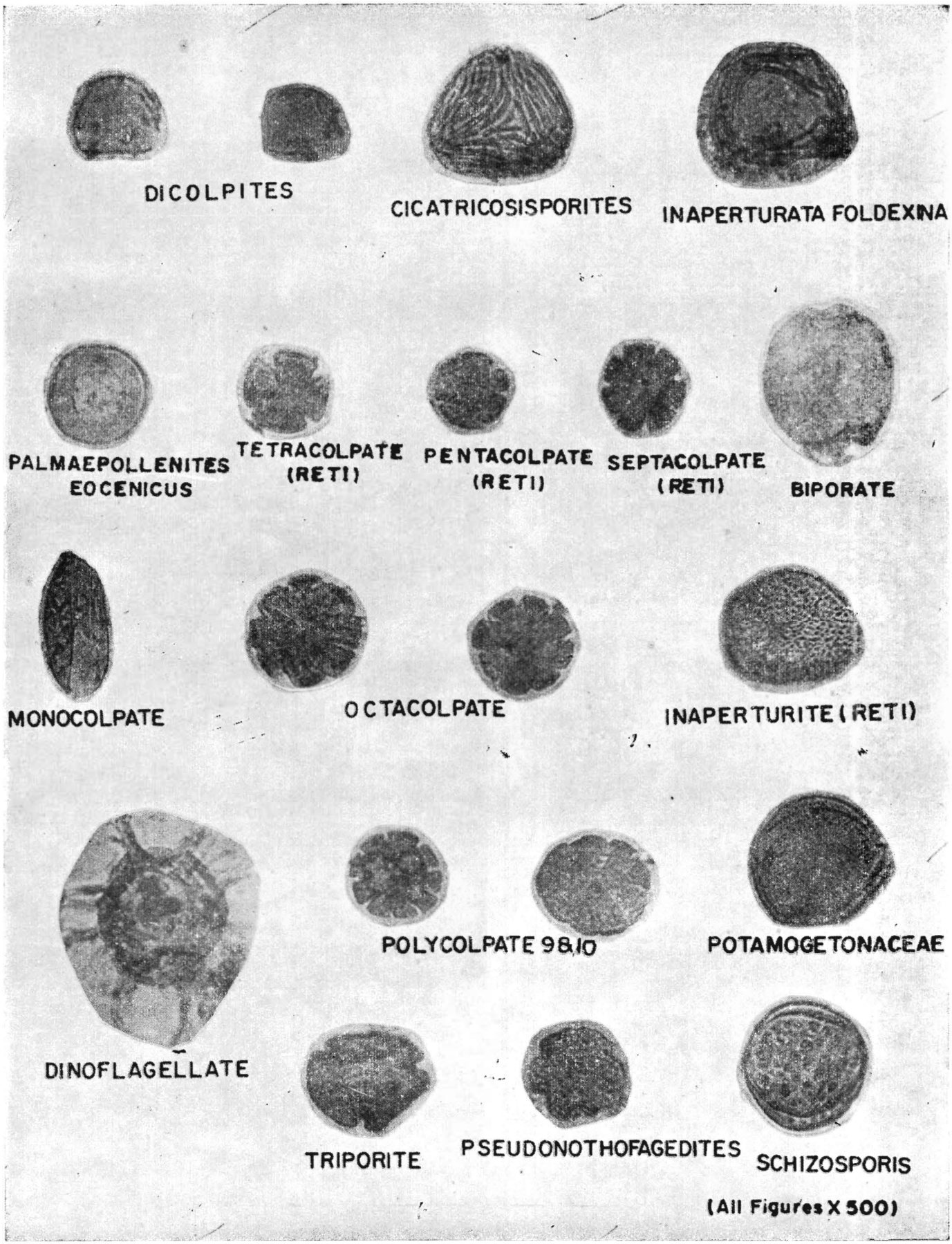
ROY CHOUDHURY, S. C., MATHUR, R. B. AND MISRA, G. S. 1972. Subsurface stratigraphy of Tharad-Serau area, Gujarat. *Bull. ONGC.* **9** (2) : 57-74.

SUDHAKAR, R. AND ROY, T. K. 1959. Progress report on the Geology of Tertiary formations of Broach and Surat districts, Bombay state. ONGC, Rep. (Unpub.)

SUDHAKAR, R. AND BASU, D. N. 1973. A reappraisal of the Paleogene stratigraphy of southern Cambay Basin. *Bull. ONGC.* **10** (1 & 2) : 55-76.

VARADARAJAN, S., CHOWDHURY, L. R., BEHL, G. N., AND PATIL, M. 1971. Petroleum prospects of Cambay Basin lying between Mehsana horst and Tharad ridge. ONGC, rep. (Unpub.)

ZUBOV, I. P., NAUGOLNY, I. K., ZAPILOVE, N. P. AND CHANDRA, P. K. 1966. Problem of correlation and distribution of hydrocarbon. bearing horizons in the Eocene of Cambay Basin. *Bull. ONGC* **3** (2).


DICOLPITES
CICATRICOSISPORITES
INAPERTURATA FOLDEXINA
PALMAEPOLLENITES EOCENICUS
TETRACOLPATE (RETI)
PENTACOLPATE (RETI)
SEPTACOLPATE (RETI)
BIPORATE
MONOCOLPATE
OCTACOLPATE
INAPERTURITE (RETI)
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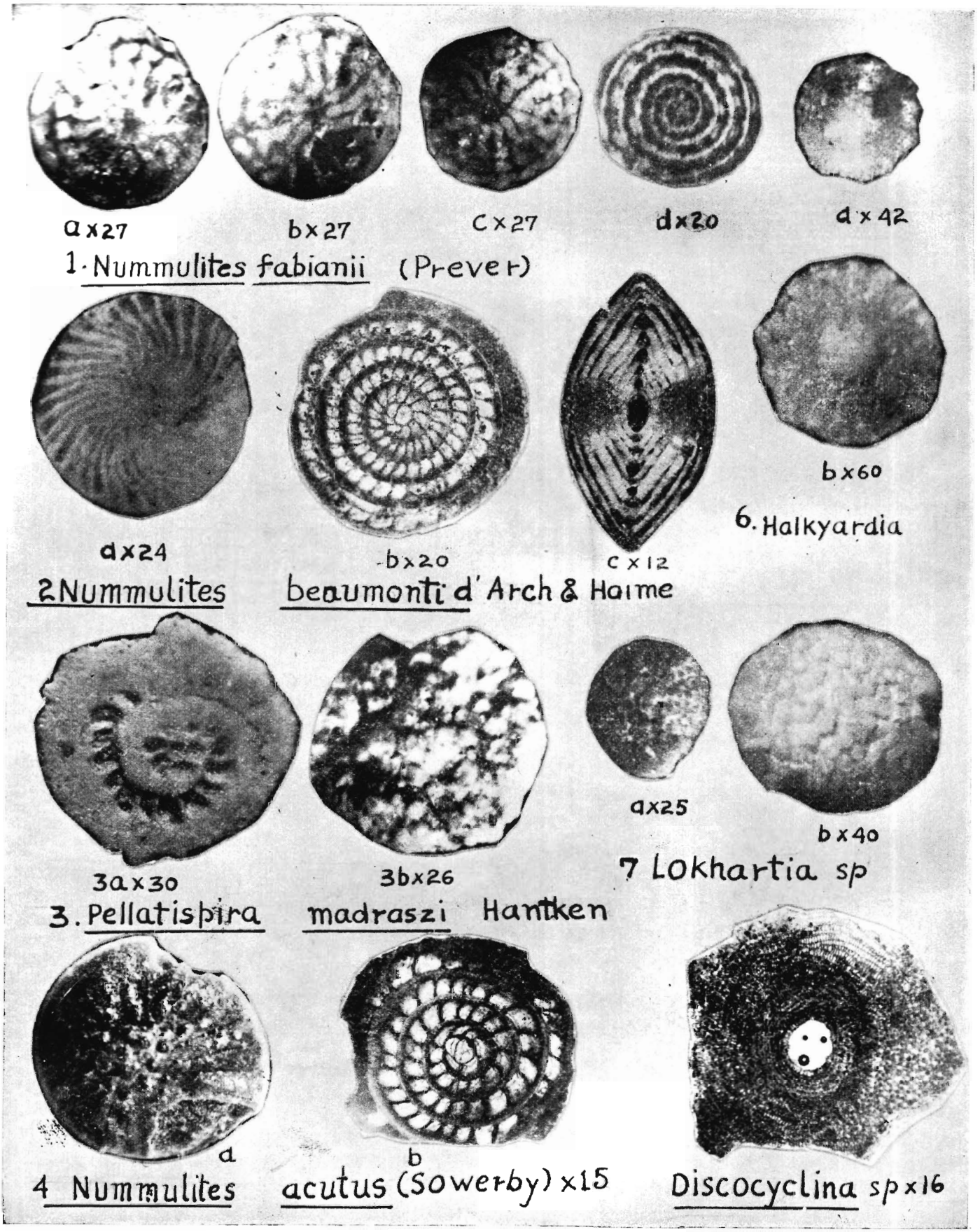
a x27
b x27
C x27
d x20
d x 42
1. Nummulites fabianii (Prever)
d x24
b x20
c x 12
b x60
6. Halkyardia
2 Nummulites beaumonti d' Arch & Haime
3a x30
3b x26
a x25
b x40
7 Lokhartia sp
3. Pellatispira madraszi Hantken
a
b
4 Nummulites acutus (Sowerby) x15
Discocyclina sp x16