SYSTEMATIC STRATIGRAPHIC STUDY OF CENOZOIC SEDIMENTS OF KERALA WITH SPECIAL REFERENCE TO WARKALLI AND QUILON FORMATIONS

Thesis submitted to the Cochin University of Science and Technology for the degree of

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GEOLOGY

By

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TRIVANDRUM, INDIA

MAY 1987

C E R T I F I C A T E

This is to certify that this thesis submitted to the Cochin University of Science and Technology for the award of the Ph.D. Degree is an authentic record of research carried out by Shri C.P. Rajendran under my supervision and no part of it has previously formed the basis for the award of any other degree in any University.

Trivandrum,
4th May 1987

Dr. K. SOMAN
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I dedicate this thesis to the memory of late ***Dr. N.G.K. Nair****, Head, Geosciences Division, Centre for Earth Science Studies, Trivandrum.*

ABSTRACT

The Kerala region is marked by a sedimentary basin which is the southern most one among the chain of coastal basins along the western margin of India. The marine incursions that occurred in the Mesozoic and Cenozoic periods have a bearing in the depositional facies of the western coastal basins of India. As far as the onshore sedimentary basin of Kerala is concerned, major constraints in understanding the stratigraphy, are the sub-horizontal disposition of the sequences and the paucity of exposures. The present study aims at the stratigraphic studies of these sedimentary sequences, mainly to work out their litho and biostratigraphic classification. It is also aimed at the determination of facies, their inter-relationships, the relative ages of the sediments and the evolution of the basin. The sedimentary sequences consisting of sand-clay intercalations with impersistent lignite seams with occasional calcareous beds form the scattered outcrops. The basin is deepest around Alleppey where the sequence having a thickness of more than 600 metres occur in the subsurface covered by Recent deposits.

Lithologic sections from bore holes and outcrops

were prepared and synthesized to bring out various lithofacies across and along the sedimentary basin so as to understand the lateral and vertical extension of the facies and to establish the lithostratigraphic classification. The sequences found in the outcrops attain greater thickness towards the central part of the basin and their westward extension into the offshore is indicated.

Laterite and occasionally bauxites underlie the sedimentary sequence. Their nature, mode of occurrence, mineralogy and chemistry are discussed. The laterites are overlain by gritty ferruginous sandstones which can be considered as the lowest unit of the sedimentary sequence of Kerala. The occurrence of laterite under the Tertiary sediments suggests a period of widespread lateritization in Kerala during Late Mesozoic period, prior to the deposition of ferruginous sandstone. The stratigraphic significance of the ferruginous sandstones and its relation with other litho units of Kerala have been evaluated.

The sedimentary structures of the Tertiary outcrop sections of Kerala suggest that these were deposited in shallow braided streams as point-bar and channel fill sequences. Petrological studies of the limestones indicate that they were deposited mainly in shallow marine conditions as inner-shelf facies. Biomicritic and sparse biomicritic limestones have been identified. Study of glauconite pellets inside the fossil tests also suggests shallow neritic environment of deposition. The heavy mineral concentrations do not show any significant difference between sediments occurring below and above the limestone beds. They comprise opaques with small proportions of zircon, garnet and sillimanite. Reworked nature of sediments in the sequence lying above the limestone can be discerned from the presence of rounded zircons, silicified fossil casts and lignitic debris. Presence of reworked older sediments in younger sequence in some places is also evident from the palynological studies. Predominance of kaolinite is evident from the study of clay mineralogy of the sub surface sediments. Clay mineralogy andthe geochemistry of the sub-surface samples have been studied in order to bring out their relation to depositional environment.

A new lithostratigraphic classification has been proposed. The lithostratigraphic units of the Cenozoic basin are given definitions as per the code of stratigraphic nomenclature and prominent units were given the status of Formation. The summary of classification is as follows:

Malabar Supergroup

Vembanad Formation

----------------Unconformity----------------

Warkalli Group: Ambalapuzha Formation; Quilon Formation; Mayyanad Formation

----------------Unconformity----------------

Karuchal Formation

----------------Unconformity----------------

Crystalline Rocks

The calcareous Quilon Formation has been observed to be as thick as 130 metres near Alleppey in the western most extremity of the Tertiary basin of Kerala. A number of planktonic foraminifera have been recorded from the sub-surface sections and also from the outcrops. Lower part of the Quilon Formation in the sub-surface section contains Oligocene Zone fossils like *Globigerina binaiensis Globigerina sellii*, *Globigerina* cf *ampliapertura* and *Globigerina opima opima*. Upper most part of the Quilon Formation is characterised by the Early Miocene assemblage of *Globorotalia fohsi peripheroronda*, *Globigerinoides quadrilobatus altiapertura*, *Globigerinoides quadrilobatus triloba* and *Globigerinoides sicanus*. Larger forams like *Miogypsina* sp; *Lepidocyclina sumatrensis* and *Archaias malabarica* also occur in this horizon. At deeper levels, around 454-475 metres Actinosiphon sp., Penoperculoides sp., Assilina sp. have been found indicating Early-Middle Eocene. Palynological studies conducted on the samples also indicated occurrence of sediments ranging from Early Eocene to Early Miocene in the onshore basin of Kerala. Apart from Oligocene and Miocene palynomorphs, Proxapertites, Polycolpites, Meliapollis, Verrutricolporites, Proteacidites, Retitribrevicolporites etc. have been recorded in the deeper parts of the basin indicating Early Eocene. Systematic descriptions of foraminiferal species and palynomorphs are made in the thesis. These data from different wells, boreholes and outcrops have been used for correlation purposes.

Quaternary stratigraphy of the Kerala coast and the genetic aspects of the sediments are discussed. The age of limeshells, and peaty sediments determined by radio carbon dating have been used for reconstruction of sea level changes. Evolution of red sands occurring in some parts of the coastal tract of Kerala is also discussed, based on textural parameters and quartz grain morphology.

The study suggests that the sediments of the onshore basin of Kerala were deposited in fault bound troughs, initiated in Late Mesozoic times. The basin formation is attributed to the main west coast fault, showing evidence of shearing and displacement at several places. The Cenozoic sediments which comprise a thick calcareous sequence sandwiched between two prominent clastic sequences typify sedimentational processes of a passive continental margin. The marine transgression was initiated in Early Eocene in this region. The calcareous sedimentation attained its maximum development during Late Oligocene to Early Miocene. This was arrested in the Late Miocene, marked by break in sedimentation, regression of the sea and widespread lateritisation. During the regressive phase, there was active erosion of already deposited sediments and overlapping sequences were developed. Lateritization marks the Neogene-Quaternary boundary. During Late Quaternary periods, eustatic sea level changes were very pronounced.

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Much of the matter in this thesis have been communicated to various journals as separate research papers. I am thankful to the reviewers for their comments and suggestions, which have been incorporated while preparing this thesis.

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I express my gratitude to the officers of Central Ground Water Board and State Ground Water Department for providing the sediment samples of drill holes.

I take this opportunity to acknowledge my debt to the pioneer workers of the area who have recorded their valuable observations in their publications that helped me in many ways.

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C.P. RAJENDRAN

CONTENTS

FIGURES

PLATES

TABLES

I. INTRODUCTION

The sedimentary basin of the coastal plains of Kerala, India, is known since King (1882) and Foote (1883) reported the occurrence of 'Quilon Beds' and 'Warkalli Beds'. The studies on the Tertiary sediments of Kerala, commenced as early in 1850 when General W. Cullen collected some pieces of limestone from Padappakkara area near Quilon. These samples were analysed for its fossil content by Carter in 1853. Since then many workers have made their significant contributions with regard to the geological history, the distribution and the genetic aspects of these sediments. The study of these sediments became important not only from an academic point of view but also because of its economic potential.

Despite the long history of research on these sediments, many questions remained unanswered. The knowledge about their distribution in space and time was much limited because of lack of stratigraphic records of sub-horizontally disposed sequences. This has restricted a proper assessment of evolution of this sedimentary basin and interrelationship of various facies. With this in view, the present study was formulated to carry out detailed regional stratigraphic studies. Stratigraphic analysis pursued in this work would also be helpful in understanding the regional geological importance of the Kerala sedimentary basin in conjunction with the evolution of the west coast of India.

I.1. Physiography, Drainage and Climate:

Physiographically the area under study falls in the coastal zone of Kerala, south west India, extending over 560 kilometres in length. It has an elevation of 0-5 metres on the western side, bordering the Arabian sea and an elevation ranging from 6 metres to 65 metres towards the eastern side, bordered by Sahyadri (part of Western Ghats) (Fig.1).

The coastal plain has a few scattered hillocks with rocky cliffs. There are thirty four kayals (lagoons and estuaries) in this area. Among the lagoons, the Vembanad is the largest (205 sq.km) followed by Ashtamudi Kayal further south. The coastal plains extend much far towards east in the central part than in the northern and southern parts (Resources Atlas of Kerala, 1984).

There are forty four short swift flowing rivers in Kerala, out of these, forty one rivers flow west. The major rivers are Periyar, Bharathapuzha, Pamba and Chaliyar, which together drain 35% of the State.

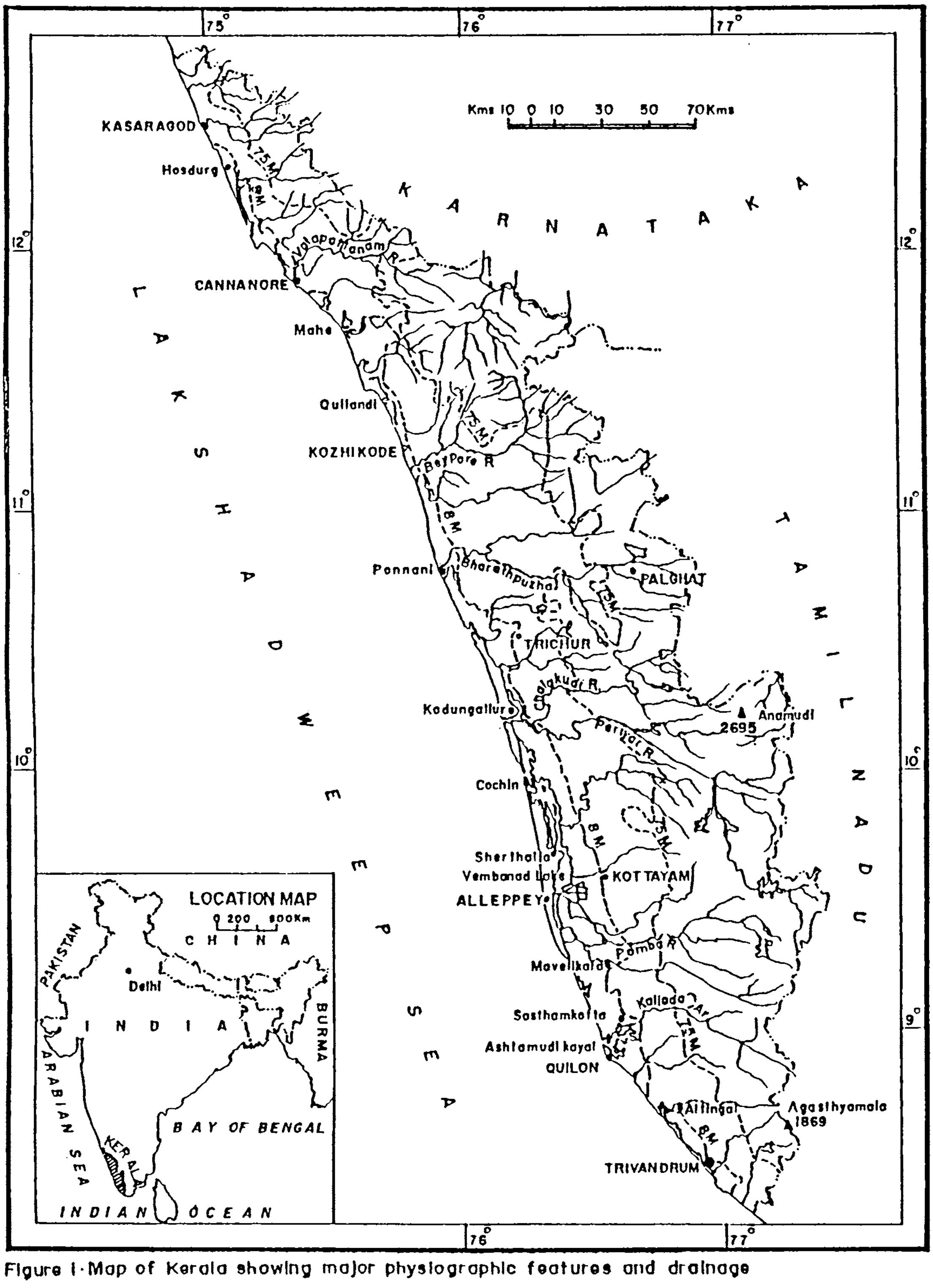


Figure 1 · Map of Kerala showing major physiographic features and drainage

The area falls in the region of tropical climate. The months of March, April and May are the hottest when temperature reaches maximum (32°C - 34°C). From June it comes down due to heavy monsoon. Temperature increases in October and November followed by lower temperature (27°C) in December and January. Along the coast, the temperature is moderate. The State receives its highest rainfall during south west monsoon in the months of June, July, August and September and north-east monsoon in October, November and December.

1.2. Geological Setting

The Cenozoic sedimentary formations of Kerala unconformably overlie the Precambrian crystalline rocks (Fig.2). The crystalline rocks are represented by the gneiss-granulite suite of rocks and the younger igneous complexes (Soman, 1980). These rocks are polyphasedly deformed and metamorphosed through several phases of tectonism and metamorphism which led to the formation of complex tectonites, including several faults, fractures and shear zones (Rao, 1976). These structures have played a significant role in graben subsidence and in the formation of sedimentary basins in the west coast (Eremenko and Gagelganz, 1966).

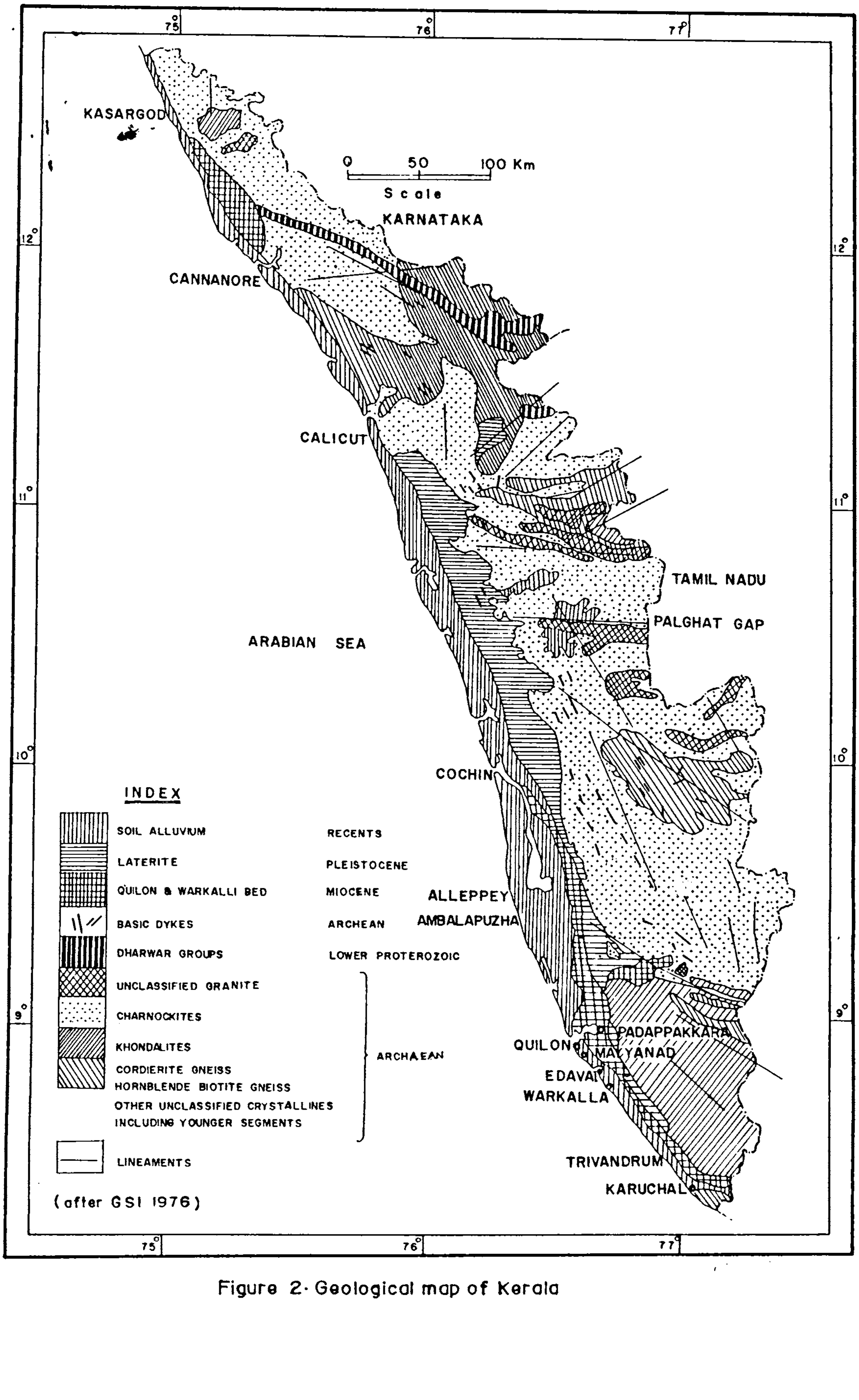


Figure 2· Geological map of Kerala

Paulose and Narayanaswamy (1968) recognised two major basins of deposition in Kerala (i) between Trivandrum and Ponnani in the south and the central Kerala, with a maximum width of 16 km between Quilon and Kundara (Fig.3) and (ii) Cannanore and Kasargod in north Kerala with a maximum width of 10 km at Cheruvathur (Fig.4). They have suggested a general stratigraphic succession of the sedimentary rocks of these basins (Table 1).

Major outcrops of sedimentary formations, consisting of sand and clay intercalations with impersistent lignite seams are exposed at Varkala, Vettur, Kundara, Puliyur, Kottayam, Cannanore and Palayangadi. Outcrops containing ferruginous hard compact gritty sandstones with clay-sandstone intercalations are exposed at Karuchal, south of Trivandrum and Cheruvathur and Nileswar in the north Kerala and some parts of central Kerala as at Kottayam and Thiruvalla. A calcareous sequence is exposed near Padappakkara, Paravur and Edavai in the south Kerala.

Major portion of the Cenozoic sediments in Kerala was deposited around Alleppey in a deep basin bordering the sea and occur under the cover of Recent sediments.

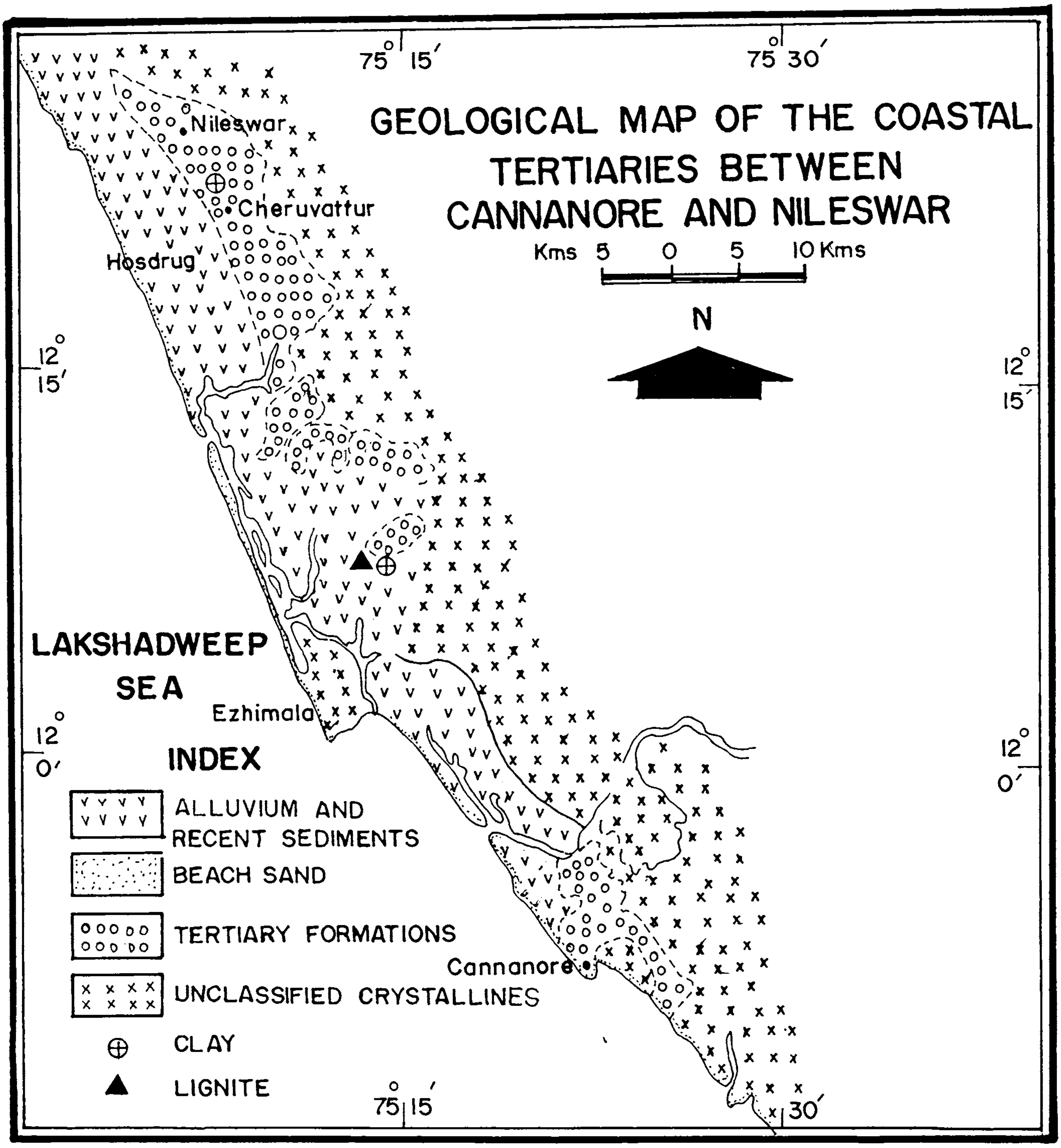

GEOLOGICAL MAP OF THE COASTAL
TERTIARIES BETWEEN
CANNANORE AND NILESWAR
Kms 5 0 5 10 Kms
N
75° 15′
75° 30′
12° 15′
12° 0′
Nileswar
Cheruvattur
Hosdrug
Ezhimala
Cannanore
LAKSHADWEEP
SEA
INDEX
ALLUVIUM AND
RECENT SEDIMENTS
BEACH SAND
TERTIARY FORMATIONS
UNCLASSIFIED CRYSTALLINES
CLAY
LIGNITE

Figure-3

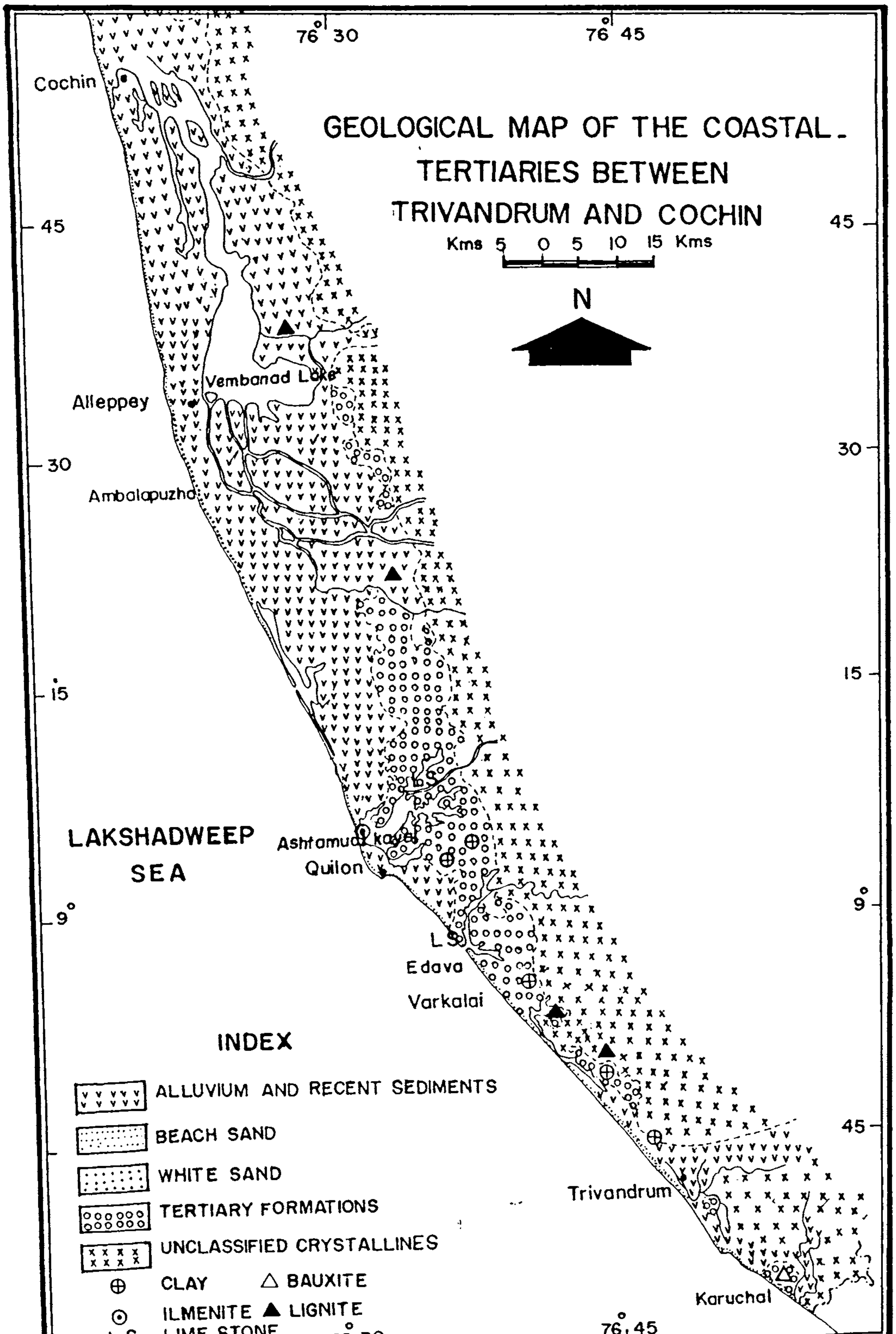

GEOLOGICAL MAP OF THE COASTAL TERTIARIES BETWEEN TRIVANDRUM AND COCHIN
Kms 5 0 5 10 15 Kms
N
76° 30
76° 45
45
30
15
9°
45
Cochin
Vembanad Lake
Alleppey
Ambalapuzha
LAKSHADWEEP SEA
Ashtamudi kayal
Quilon
L S
Edava
Varkalai
Trivandrum
Karuchal
INDEX
ALLUVIUM AND RECENT SEDIMENTS
BEACH SAND
WHITE SAND
TERTIARY FORMATIONS
UNCLASSIFIED CRYSTALLINES
CLAY
BAUXITE
ILMENITE
LIGNITE
L S LIME STONE

Figure-4

I.3. Highlights of Previous Work

The Tertiaries of Kerala coast were initially reported as 'Warkalli' and 'Quilon' Beds from the type localities by King (1882) and Foote (1883). The Tertiary limestone bed was identified by Carter (1854) from the collections of General W. Cullen. The outcrop of the limestone was located in 1883 at Padappakkara about 11 kilometres north east of Quilon by Logan (Meddlicot, 1884). The Tertiary rocks of Varkala were traced upto Kottayam in Central Kerala by Chacko (1921). According to Carter (1853) and Douville (1902), the Quilon fauna represented the Pliocene. Later, Carter (1857) correlated them with the Gaj beds and referred them to the uppermost Aquitanian. Wayland and Davies (1923) equated the Quilon fauna with that of southern Ceylon and referred both to the Vindobonian and placed them in the Middle Miocene. Vaughan (1928) assigned the *Archaias malabaricus* horizon in Travancore and Ceylon to Miocene (Vindobonian and later). Kumar and Pichamuthu (1933), based on the Microfossils observed in two localities, Chattanur and Nedungolam placed Quilon fauna to the Gaj. Furon and Lemoine (1939) have placed these beds in the Tortonian while Henson (1950) has referred *Archaias malabaricus* (Carter) to the genus *Taberina*. Subsequently Eames (1950) and Jacob and Sastri (1951; 1952) assigned

Lower Miocene to these sequences. A comprehensive description of the faunae in Quilon limestone outcropped at Padappakkara was attempted by Dey (1962). Rao and Datta (1976) have indicated a Burdigalian age to the shallow sub-surface samples of Quilon beds from Mynagapalli and from the outcrops of Padappakara and Paravur, based on the study of foraminiferal and ostracod faunae. The foraminifers as well as ostracods in the sediments from bore-holes at Kalarkode, Trikaruva, Pattanakad and Chellanam were studied by Raju (1978) and ascribed an age from Middle Miocene to Recent to the sediments and rich assemblages of Miogypsina droogeri, Austrotrillina howchini were recorded around 104 metres in Pattanakad well and also between 118 and 144 metres in Chellanam well. Rasheed and Ramachandran (1978) have indicated an Early Miocene age to the sediments from the outcrops at Padappakkara, Edavai and the shallow bore-hole samples from Alleppey and Shertallai on the basis of larger foraminifera. They have divided Quilon beds into lower and upper zones. The lower zone is marked by the presence of Miogypsina globulina - Lepidocyclina (Nephrolepidina) sumatrensis and the upper zone is characterised by Miogypsina globulina - Arachaias malabarica. They have also recorded corresponding planktonic foraminiferal zones viz., upper zone containing Globigerinatella insueta-Globigerinoides quadrilobatus trilobus and lower Globigerinoides quadrilobatus trilobus zone.

Occurrence of fish teeth, sphyrna diplana (cartilaginous fish) and Cybium Sp. (Bony fish) were reported from the Quilon Beds (Miocene) exposed near Edavai (Mehrotra, 1982).

Several attempts were made to establish time stratigraphic relations between marine Quilon Beds and the continental Warkalli Beds based on the microfloral investigations. Rao and Vimal (1953) studied the microflorae of the lignite of Warkalli Beds. They have recorded pteridophytic spores referable to polypodiacease and schizaceae. The angiospermous pollen grains recorded by them consist of the following morphophytes, viz. napites, monocolporites, tricolpites, tricolporites, tetracolporites and some of the pollen types were compared with the pollen of Potamogetonaceae, Palmae, Hamamelidaceae, Myrsinaceae, Rubiaceae, Solanaceae etc (Vimal 1953). Potonie and Sah (1958) studied the palynology of the lignite from Cannanore beach on the Malabar coast. The angiospermous pollen recorded from Cannanore lignite consist of Inaperturopollenites, Monoporopollenites, Monosulcites, Cupuliferoipollenites and Polyadopollenites. They have recorded the Permian pollen in the Cannanore lignites. Based on these evidences and the presence of recycled Permian pollens in Katrol (Upper Jurassic) sediments of Kutch and other places, Venkatachala (1969) has inferred that Permian sediments extended as far as Kutch in the west and Cannanore in the south and these have been eroded away and redeposited in later times. Extensive palynological studies have been conducted on outcrops of Tertiary sediments from various localities (Ramanujam and Purnachandra Rao, 1973; Rao and Ramanujam, 1976; Ramanujam and Srisailam, 1978; Ramanujam, 1972, 1982; Ramanujam and Rao, 1977; 1978; Rao and Ramanujam, 1978; 1982; Srisailam and Ramanujam, 1982). The palynological studies conducted by them on the outcrops at Padappakkara, Edavai and Paravur, recorded spores of Peteridophytes and pollen of monocotyledons. They have assigned an Early Miocene age to the Warkalli and Quilon Beds.

Systematic mapping of the Tertiary and associated sediments along the Kerala coast was carried out by Paulose (1965). Menon (1967)reported carbonaceous clays and sandy clays beneath the limestone at Padappakkara and suggested correlation between the sedimentary sequences of Padappakkara, Chattannur, Nedugolam and Kidayangara. Paulose and Narayanaswamy (1968) have suggested a lithostratigraphic classification of these sediments (table 1) Raghava Rao (1975) identified a sedimentary sequence under the Quilon limestone sequence and designated this unit as the 'Vaikom' Beds. Aditya and Sinha (1976) have indicated the possible block faulted nature of the Tertiary sedimentary basin. Varadarajan and Balakrishnan (1976) have suggested that laterites in the coastal areas formed a part of the continental shelf and their occurrences as terraces at different elevations could be due to Neogene and Quaternary uplifts. Desikachar (1976) has discussed the hydrocarbon prospects of the Kerala coastal sedimentary basin and identified four lithologic units within this sedimentary sequences (Table 2). Nair and Rao (1980) have identified five lithological units within the Cenozoic sequence of south Kerala (Table 2).

I.4. Scope of Present Work:

A review of previous literature reveals that a good deal of confusion exists with regard to the litho and biostratigraphy of the sedimentary sequences of Kerala. This ambiguity was mainly because most of the previous works on the Cenozoic sediments were conducted on outcrops and sediments from shallow drill holes. This has constrained the earlier workers from obtaining the true extent and range of these sediments and a comprehensive view of the stratigraphical evolution of the Kerala sedimentary basin.

Previous workers have attributed Early Miocene age to the 'Quilon Beds' whereas the overlying 'Warkalli Beds' have been given a Mio-Pliocene age. But new evidences, like deepening of basin towards the central part, occurrence of sedimentary sequences underlying the calcareous unit etc., necessitated a thorough re-examination of the stratigraphic evolution and age of the Kerala sedimentary basin.

The Kerala coast with the rest of the west coast of India can be categorised as a part of passive continental margin in plate tectonic terms. Thus it also seemed logical that the geological setting and evolution of Kerala sedimentary basin should be linked to the development of similar basins especially on the western margin of India rather than seeing it in isolation.

Considering all these aspects the present study is planned to work out the stratigraphic classification of these sequences involving the determination of litho/

and bio facies, environment of deposition and time-stratigraphic relations of the sediments. This study also seeks to explore the possibility of the presence of Early Tertiary deposits (older than Miocene) which may be probable source beds for hydrocarbons.

The present work attempts a combined approach consisting of sedimentological, mineralogical, micropalaentological and palynological studies on the outcrops and the sediments from deep drill holes.

I.5. Limitations of Present Work:

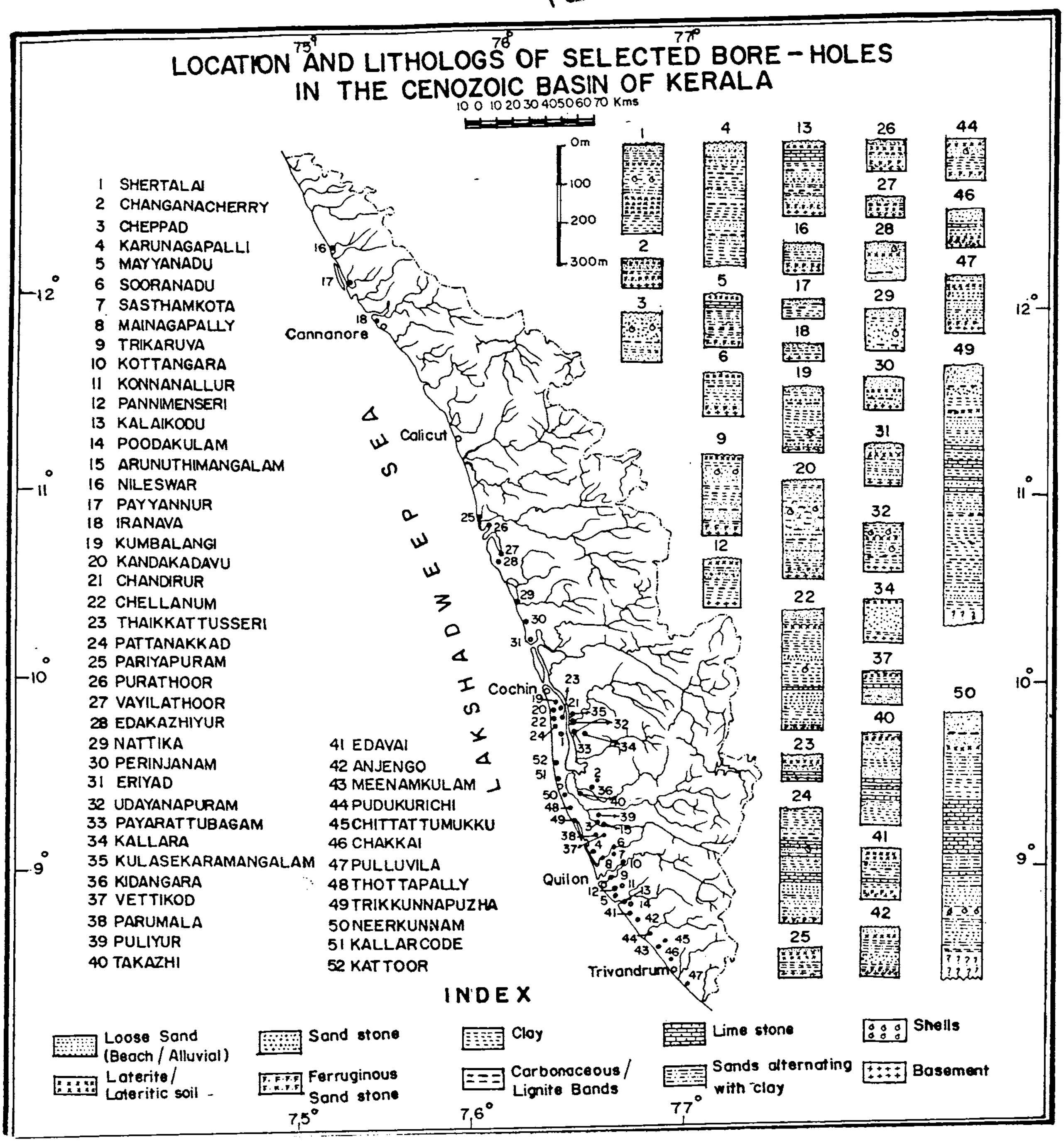
Non-availability of bore-core samples posed great difficulty for the present study. Drill cuttings had to be relied upon and contaminations from upper horizons had to be expected particularly for the palaeontological studies. Care was taken to avoid such situations. However, this remains a major limitation for the study of geochemical and mineralogical aspects. Severe weathering and lateritization, which obliterate and smother original textures and structures of the sedimentary rocks, also offered some hinderances. Though granulometric analysis of such samples can not be fully relied upon, some studies were conducted to supplement and substantiate the main results.

II.1. Sub-horizontal Sections

The Cenozoic sedimentary basin of Kerala that occurs under the coastal plains extends into the shelf zone of the offshore region and in all probability further westward across the Lakshadweep Sea. An understanding of disposition of the sedimentary sequences under the coastal sediments of Kerala, is important in comprehending the superposition of the sequences and the stratigraphy of the basins. Lithology of some of the selected bore-holes drilled by Central Ground Water Board is diagramatically represented in the Figure 5.

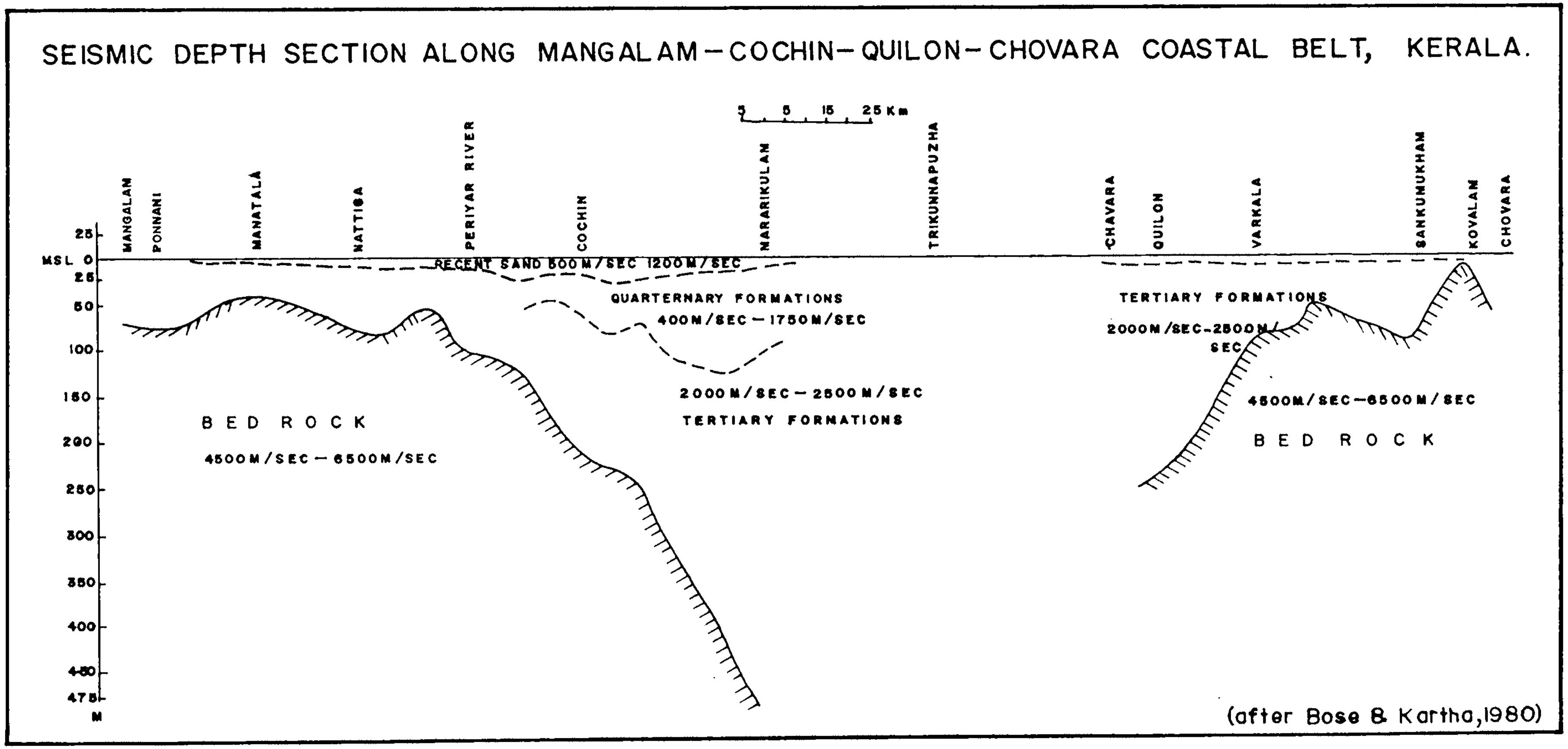
A study of the geological map (Fig.2) of this area shows the spatial distribution of these elements of which the Holocene covers a wide tract especially between Quilon and Cochin covering the Tertiary deposits. Geophysical explorations (Bose and Kartha, 1977; 1980) and the drilling by the Central Ground Water Board indicate that the Cenozoic basin of the coastal plain of Kerala is thickest near Alleppey, midway between Cochin and Quilon (Fig.6). A thicker blanket of Quaternary deposits in this area has also been noticed, 60 metres thick Quaternary deposits have a prominent zone of peaty horizon (6 metres) at a depth of 38 metres in the central

12-9



LOCATION AND LITHOLOGS OF SELECTED BORE-HOLES IN THE CENOZOIC BASIN OF KERALA
10 0 10 20 30 40 50 60 70 Kms
1 SHERTALAI
2 CHANGANACHERRY
3 CHEPPAD
4 KARUNAGAPALLI
5 MAYYANADU
6 SOORANADU
7 SASTHAMKOTA
8 MAINAGAPALLY
9 TRIKARUVA
10 KOTTANGARA
11 KONNANALLUR
12 PANNIMENSERI
13 KALAIKODU
14 POODAKULAM
15 ARUNUTHIMANGALAM
16 NILESWAR
17 PAYYANNUR
18 IRANAVA
19 KUMBALANGI
20 KANDAKADAVU
21 CHANDIRUR
22 CHELLANUM
23 THAIKKATTUSSERI
24 PATTANAKKAD
25 PARIYAPURAM
26 PURATHOOR
27 VAYILATHOOR
28 EDAKAZHIYUR
29 NATTIKA
30 PERINJANAM
31 ERIYAD
32 UDAYANAPURAM
33 PAYARATTUBAGAM
34 KALLARA
35 KULASEKARAMANGALAM
36 KIDANGARA
37 VETTIKOD
38 PARUMALA
39 PULIYUR
40 TAKAZHI
41 EDAVAI
42 ANJENGO
43 MEENAMKULAM
44 PUDUKURICHI
45 CHITTATTUMUKKU
46 CHAKKAI
47 PULLUVILA
48 THOTTAPALLY
49 TRIKKUNNAPUZHA
50 NEERKUNNAM
51 KALLARCODE
52 KATTOOR
Cannanore
Calicut
Cochin
Quilon
Trivandrum
LAKSHADWEEP SEA
0m
100
200
300m
INDEX
Loose Sand (Beach / Alluvial)
Laterite / Lateritic soil
Sand stone
Ferruginous Sand stone
Clay
Carbonaceous / Lignite Bands
Lime stone
Sands alternating with clay
Shells
Basement

Figure-5



SEISMIC DEPTH SECTION ALONG MANGALAM–COCHIN–QUILON–CHOVARA COASTAL BELT, KERALA.
5 5 15 25 Km
MANGALAM
PONNANI
MANATALA
NATTIKA
PERIYAR RIVER
COCHIN
NARARIKULAM
TRIKUNNAPUZHA
CHAVARA
QUILON
VARKALA
SANKUMUKHAM
KOVALAM
CHOVARA
25
MSL 0
25
50
100
150
200
250
300
350
400
450
475
M
RECENT SAND 500 M/SEC 1200 M/SEC
QUARTERNARY FORMATIONS
400 M/SEC – 1750 M/SEC
2000 M/SEC – 2500 M/SEC
TERTIARY FORMATIONS
BED ROCK
4500 M/SEC – 6500 M/SEC
TERTIARY FORMATIONS
2000 M/SEC-2500 M/SEC
4500 M/SEC – 6500 M/SEC
BED ROCK
(after Bose & Kartha,1980)

Figure - 6

part of the basin. The lateritic zone of the Tertiary sediments at 60 metres depth is also a very prominent marker horizon (Fig.7). The top of the Tertiary is marked by a sandstone-clay bed alternations followed by a thick zone of clay beds. The clay beds are underlain by a thick zone of coarse pebbly sandstone and followed downward at a depth of 210 metres. Fossiliferous calcareous and carbonaceous clays with intercalations of sandy horizons continue down to a depth of 350 metres. This is followed downward by coarse pebbly sandstones. The coarse pebbly sands are followed downward by the carbonaceous clays. Lenses of limestones and microfossils have been recovered around 470 metres. Below a depth of 560 metres the sediments consist of mainly black shales and clays. Maximum depth to which the drilling continued was 600 metres while the geophysical data indicate that the basement is around 628 metres deep in this region. The sedimentary sequences become gradually thin towards the margins of the basin and the limestone sequence totally disappears towards the eastern pheriphery of the basin. Ferruginous sandstones and laterite pieces have been recorded at the base of the sedimentary sections towards the eastern margins.

13-a

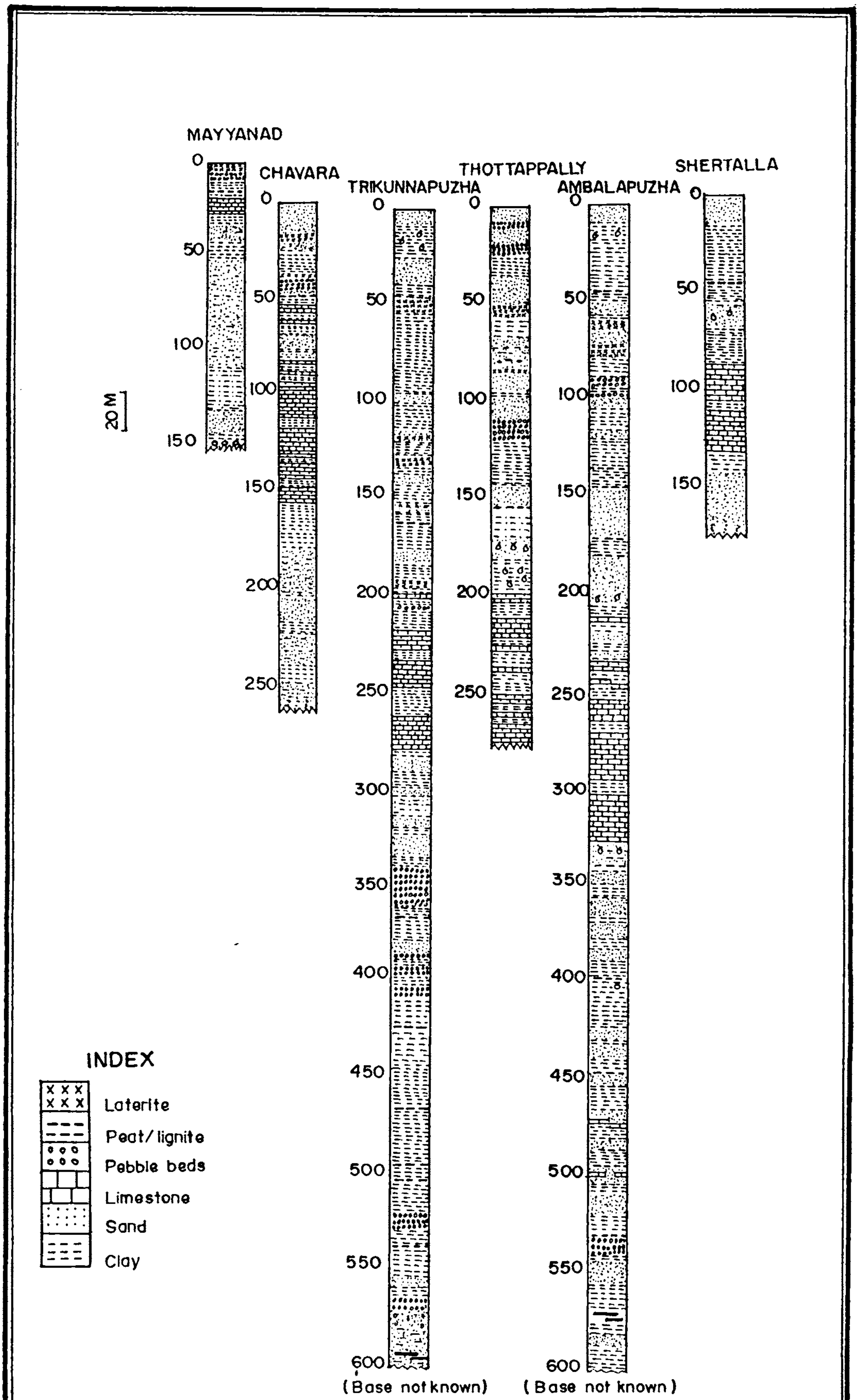


Figure-7 Lithology of deeper boreholes, Quilon Alleppey-coast

II.2. Major Sedimentary Outcrops of Kerala

Scattered sedimentary sections are exposed at a number of places along the coastal tract of Kerala. Major outcrops are described below:

i) Karuchal cliff:

On the sea coast near Karuchal in Trivandrum district, running parallel to the coast for about 2 kilometres, exposes a good section of the sedimentary clays and sandstone (Fig.8). It attains a height of 20-30 metres composed of cross-bedded and variegated sandstones, clays and grits. Sandstones and clays show lenticular distribution along the section with lateral intertouguing of clay and sand facies. The most interesting feature of the sequence is that the sediments overlie bauxitised/ lateritized khondalitic basement. The top of the sedimentary sequence is also lateritized with ferruginous lateritic gravel occurring on the top of the cliff. Large scale cross bedding has been noticed in the sandstone layers in the steep cliff at the upper part. The basal sandstone horizons comprise the hard and compact ferruginous sandstones. Carbonaceous clays and remains of plant fossils are not recorded in this section.

ii) Varkala cliff

This is a type area of the Tertiary sediments known as 'Warkalli Beds' (Fig.9). There are vertical cliffs with intervening valleys running parallel to the coast, striking NE-SW. The sequence first recorded by King (1882) is as follows:

Lithology	Thickness (in metres)
Laterite with sandstone	9-1.2
Sands and sandy clays	17
Kaolinitic clays	25
Lignite beds	2-4

Besides various horizons of sands, clays, sandy clays, clayey sands, a prominent horizon of dark carbonaceous clay has been noticed. This carbonaceous clay band thins out northerly. However, in the northern part of the cliff section, north of a stream, there are two carbonaceous clay horizons. The lower horizon shows leaching of sulphide and deposition of sulphur through percolating waters. The lowest exposed sands on the southern flank is gritty and shows graded bedding in different layers.

Figure 8. Photograph showing Karuchal cliff section. Note the contact between sandstone and the underlying clay.

Figure 9. Photograph showing Varkala cliff section.

Fig · 8

Fig · 9

iii) Thonnakal section

A clay mine near Thonnakal contains sedimentary clay and sandstone alternations. White clay layer with lateritic zone on the top is underlain by a sandstone layer followed downward by another band of the white clay. The base of the mine exposes gray carbonaceous clay with plant remains and impressions of dicotyledon leaves. Bedding laminations have been noted in the clay indicating their sedimentary nature. Cross bedding is very common. Graded bedding is a common feature in the sandstone horizons.

iv) Kundara section

In Kundara section, overlying the weathered crystalline rocks is a thick sequence of kaolinitic clay (Fig. 10). Over this sequence is the lignitic bands. Lignitic impressions of monocotyledon, dicotyledon stems and *in situ* lignitisation of trees are observed here. There is a sequence of ball clay above the lignite. A prominent band of conglomerate separates the overlying cross laminated sandstones and underlying ball clay. These sandstones are mostly covered by the laterite in the upper part.

v) Padappakkara section

The cliff section on the banks of Asthamudi *kayal* at Padappakkara in Quilon district is the type area for Quilon Beds. Menon (1967a) has given following sequence at the type locality.

Lithology	Thickness (in metres)
Detrital laterite	2.00
Laterite	11.00
Limestone	0.65
Sandy clay 1	0.15
Carbonaceous clay	0.50
Carbonaceous shale	0.50
Sandy clay II	1.00

During the present field investigations all the units mentioned above could not be located, most of them being covered by debris fallen from the cliff face (Fig.11). However, a patch of weathered calcareous sand and fossiliferous limestone is exposed in one part. This sequence grades laterally into 1 m thick sandy clay and clayey sand. The limestone band is overlain by a dark carbonaceous clay capped by a thin band of red ferruginous clay and laterite.

17-a

Figure 10. Photograph showing Kundara section

Figure 11. Photograph showing Padappakkara section.

Fig·10

Fig·11

vi) Edavai section

The cliff section near Edavai exposes light gray calcareous clay underlain by a dark carbonaceous clay under the lateritic cliff. The light gray calcareous clay has yielded a number of microfossils. In the dark carbonaceous clay there are some pyritized shells of gastropoda and foraminifera.

vii) Paravur section

Paravur about 3 km north of Edavai, the sea cliff exposes reefal limestone with corals, echinoids, lamellibranchs, gastropoda and foraminifera (Fig.12). This horizon is overlain by a lignitic horizon intercalated with carbonaceous clay. The base of the limestone horizon is concealed under the beach sand.

viii) Sections around Kottayam .

Several sedimentary sections are seen around Chengannur, Thiruvalla and Kottayam. Conglomerates are seen at several places at the contact zone of crystalline rocks and sedimentary rocks. The exposures of Tertiary rocks are confined to Puliyoor, Cheriyanad, Vazhapally, Kurichi, Puvanthuruthu, Olassa, Paravanthuruthi, Kallara and Nindur. Small boulders, gravels, grit and sandstone are seen within the lateritic soil further east which indicate erosion. The general sequence of Tertiary sediments starting from the top are bluish clay, carbonaceous clay, peat/lignite and coarse sandstone intercalated with clay. The maximum thickness of the Tertiary sequence is around 15 metres. Cross bedding and graded bedding are the prominent sedimentary structures seen in the sections.

Typical section resembling type area at Varkala occurs at Puliyoor having a maximum thickness of 14 metres. The vermicular laterite occurs at the top, underlain by fine to coarse grained sand followed by limonitic clay. Carbonaceous clay underlies the limonitic clay followed by carbonaceous shale. This shale is encrusted with sulphur and gives a sulphurous colour.

The carbonaceous shale is exposed also at Kurichi. Two or three inches of reddish clay which gives a prominent red mark on the finger is seen above the carbonaceous shale. Sandy portions are poorly developed in the sequence.

ix) Cannanore cliff

The cliff section at Cannanore (Fig.13) is sampled at Meenkunnu, 6 km north of the Cannanore Guest House in the Cannanore-Azhikode road. This section lithologically resembling Varkalla cliff section, has thick band of sandstone intercalated with clays, underlain by carbonaceous clay. The base is not exposed. The top of the section is covered by laterite. In some parts of the section, a sequence of ball clay with carbonaceous clay is developed in between sandstone and lignite. The sequence is as follows:

Laterite pebble bed	0-1 m
Lateritic grit	1-4 m
Pebble bed with iron encrustation	4-7 m
Carbonaceous clay with peaty and silty beds with sulphur encrustations	7-12 m

x) Palayangadi section

Palayangadi section (Fig.14) which is around 45 km north of Cannanore exposes well developed lignitic and carbonaceous clay bands, indicating a rhythmic sedimentation. The bottom sequence comprises coarse sand and weathered zone. Kaolinitic clay overlies this sequence of coarse sand. Over the band of china clay, sedimentary units comprising lignite and ball clay have been deposited which are successively alternated with each other till these are covered by aluminous clay and hard laterite at the top. The lithology of the section is given below:

Lithology	Thickness (in metres)
Hard laterite	0-6
Ball clay	6-9
Lignite	9-10
Ball clay	10-11
Lignite	11-12
Ball clay	12-13
Lignite	13-14
Ball clay	14-16
Lignite	16-16.5
Ball clay	16.5-17
Lignite	17-18
Ball clay	18-19.5
Lignite	19.5-20
Ball clay	20-21
Lignite	21-21.5
Ball clay	21.5-22.5
Lignite Kaolinitic clay	22.5-23

The sections at Cheruvathur and Nileswar are discussed in the Chapter II.6.

Figure 12. Photograph showing Paravur section.
Note the underlying lignite beds.

Figure 13. Photograph showing Cannanore cliff section.

Figure 14. Photograph showing Palayangadi section. Note the rhythmic bedding.

Fig · 12

Fig · 14

Fig · 13

II.3. Salient Sedimentary Structures

The sedimentary features developed on the outcrops of the Tertiary sediments of Kerala are helpful to bring out probable environments of deposition. Majority of the structures fall in the category of primary sedimentary structures of Pettijohn (1975) and syndepositional of Selly (1976) and these are formed during transportation and deposition of sediments. These are potentially valuable indicators of palaeohydrodynamics. Sedimentary structures have been often related to flow conditions in laboratory experiments (Mc Kee, 1957; 1965; Simons et al, 1965). Although it is not possible to obtain exact measurements of flow velocities it is possible to relate structures to flow conditions by observing modes of occurrence.

i) Horizontal bedding

The most commonly occurring sedimentary feature in the outcropped sections of the sedimentary sequences of Kerala is the horizontal bedding (Fig.15). The thickness of single bed varies from 0.3 m to 7.0 m. This consists of thin strata almost parallel with the others and the entire set approximately horizontal. Parting lineation is found to be always associated with this type of bedding. This bedding is often superposed and interbedded by thin clay beds and cross bedded strata. The planar beds are associated with high velocity water flow. It may be inferred that the horizontal beds were formed during floods when currents were vigorous and capable of producing upper-flow regime bed forms. As the flood waters recede, corresponding lower flow regime bed forms would be produced.

ii) Graded bedding

Another common sedimentary feature recorded in the sedimentary outcrops of Kerala is graded bedding. This is characterised by an upward decrease in size, whereas the sediments of the lower part of the unit are coarser than the above, the gradation ranging from medium sand at the base to the silt at the top.

Graded bedding in streams results from a decrease in transport velocity. Initially deposited sediments are laid by vigorous currents and are relatively coarse. As the velocity decreases, the size of the bed load becomes smaller until silt and clay settle. Fining upward cycles are common in fluvial rocks and are mostly characteristic of point bar deposits (Visher, 1965; Allen, 1965; 1970, Mc Cormick and Picard, 1969).

iii) Cross-stratification

Medium scale cross-stratifications as well as micro cross stratifications such as tabular, wedge (Fig.16) and trough shaped (Fig.17) cross-stratifications are common in the outcrops. They are consisted of laminae inclined to the principal bedding.

The cross-stratifications are generally produced due to migration of bed forms such as ripples. Micro cross-stratifications are formed by moderate velocity currents in the lower-flow regime (Harms and Fahnestock, 1965). Micro and festoon cross-stratifications (medium scale) are common in the fluvial rocks. In the fluvial rocks, these types are most common in the braided streams (Williams and Rust, 1969; Smith, 1970).

iv) Significance of the structures

The Karuchal and the Varkala sections in the south and the Cheruvathur section in the north resemble point bar sequences of braided streams. These are distinguished by a fining upward cycle of low angle cross-stratification, micro cross-stratification and horizontal parallel stratification (Picard and High, 1973). Some places these are not fully represented possibly due to poor separation of micro-cross stratifications and ripple stratified units, lack of horizontality in

Figure 15. Photograph showing horizontal bedding, Cheruvathur.

Figure 16. Photograph showing wedge shaped cross stratification, Karuchal section.

Figure 17. Photograph showing trough shaped cross stratification, Varkala section.

Fig · 15

Fig · 16

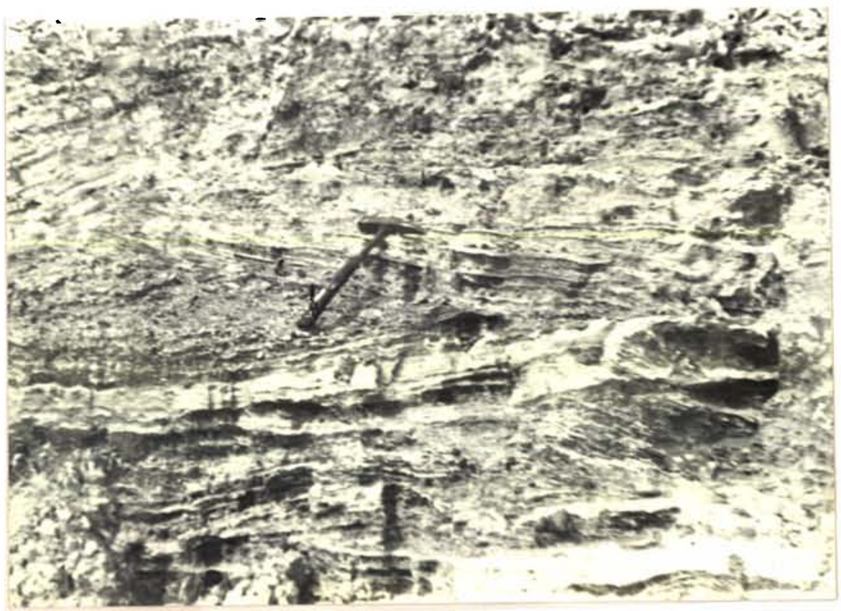


Fig · 17

the stratification and partial erosion of upper units.

The point bar sequence is deposited on a unit during the receeding stages of floods. With the onset of deposition at sometime after passing of the flood crest, low angle cross strata are deposited while flow in the channel is still vigorous. Vertical and lateral variations of facies is very common in the outcrops. This is possibly due to shifting of depositional centres. This occurs within single regime as in the case of bar to channel and back again. This kind of shifting is usually prevalent in braided streams.

The sandy units found in Karuchal, Cheruvathur, Nileswar are formed as a part of channel fill sequences. From the base upwards, the cycle consists of basal erosion, lag deposits (gravels) horizontal stratification and large and micro cross-stratifications. This progression is commonly terminated at a point by erosion surface. Inclined or horizontal strata is first deposited during upper flow conditions and micro cross-stratification develops with the decrease in water velocity.

II.4. Basal Ferruginous Sandstone

i) Distribution

The ferruginous dark coloured hard compact gritty sandstones which have been traced in various parts of the sedimentary basin of Kerala (Fig.18) are well endurated in contrast to other Tertiary sandstones of the basin. The sandstones are coarse to gritty with bands of pebbly conglomerates with angular to sub-rounded grains (Fig.19). These are exposed around Karuchal and Kottayam in the south and Cheruvathur and Nileswar in the north. These basal sandstones were traced through the eastern periphery of the Cenozoic basin extending northward upto Mangalore and Udupi. A weathered mantle, consisting of laterite or bauxite with lenses of impure kaolinite with coarse quartz grains capping the Precambrian crystalline rocks, is found to underlie these sandstones. These ferruginous sandstones are overlain by a sequence of coarse gritty arkoses and clays.

ii) Petrography

The sandstone comprises angular to sub-angular grains of quartz which commonly form about 45 to 50 per cent of the rock. The quartz grains of the size of coarse sand to granules and pebbles occur

26-a

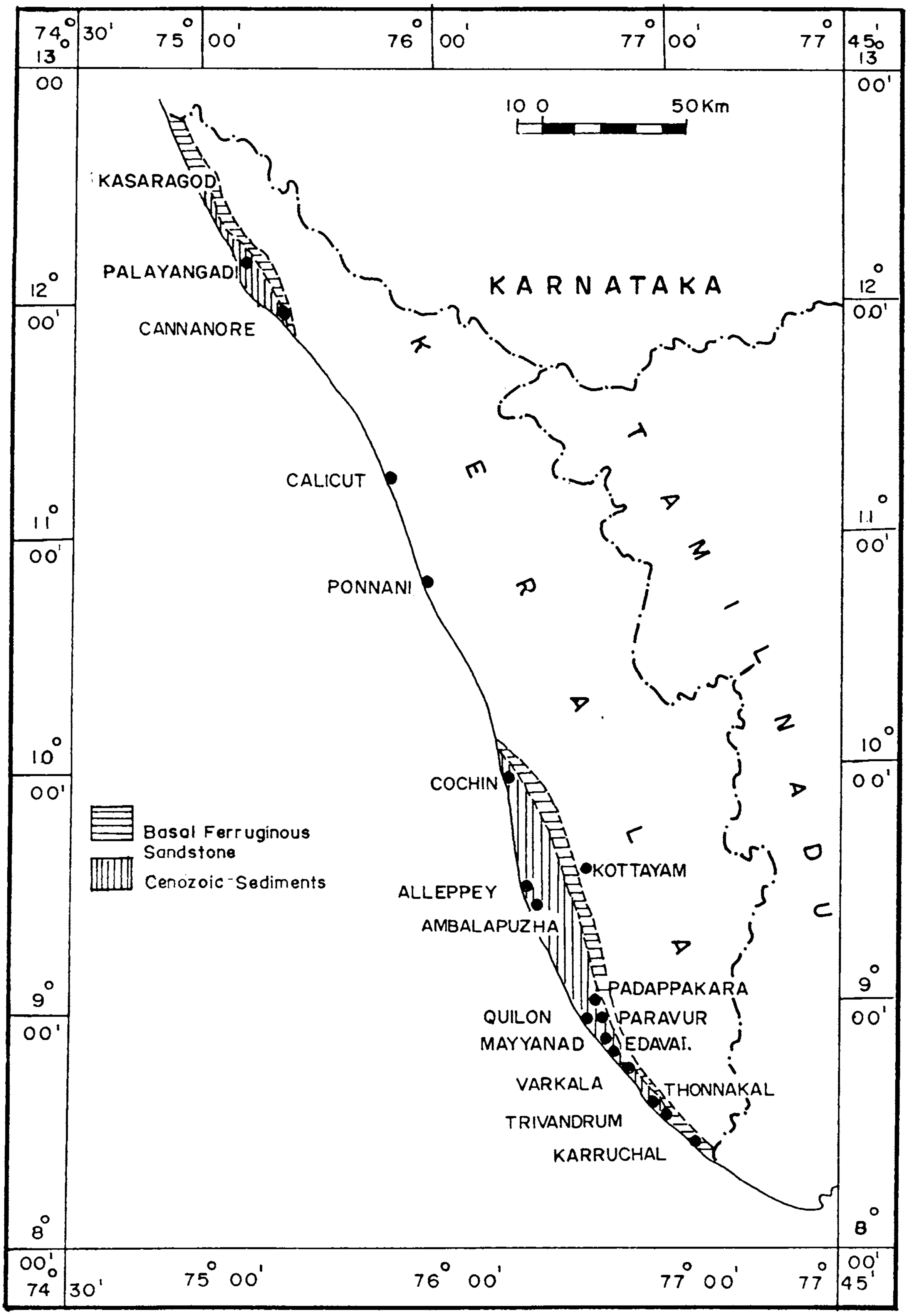


Figure 18. Location map of Ferruginous Sandstone

in a matrix, cement of haematite forming 45 to 50 per cent of the rock (Fig.20 a). Quartz grains show fragmented nature because of the haematite in-filling of the cracks from the solutions in the pore spaces (Fig. 20 b). Infrequent grains of feldspar, often sericitized and/or kaolinised, are also observed along with rock fragments and detrital mica/biotite flakes (Fig. 20 c) which constitute about 1-2 per cent of the rock. Infrequent grains of garnet, monazite and sillimanite are also observed. Abundance of iron-oxide minerals is the most characteristic feature of the sandstones. These are cryptocrystalline pigmenting oxides and hydroxides of iron, eg., haematite, goethite, etc., (fig. 20 d). The coarser opaque grains are mostly haematite. The predominance of iron oxide is also evident from the chemical analysis (Table 3).

iii) Heavy mineral assemblages

Similar assemblages of heavy minerals such as ilmenite (1% to 2.5%), leucoxene (4% to 7.2%), zircon (0.5% to 1%), sillimanite (3% to 5%) and traces of rutile, monazite/etc. are present in these sandstones. The heavy mineral assemblage points to metamorphic rocks as the major source.

Figure 19. Photograph showing polished section of ferruginous sandstone.

Figure 20. Photomicrographs of ferruginous sandstone - a: angular to subangular grains of quartz in a hematitic matrix/cement; b: hematite infilling of the cracks in quartz grains; c: biotite flake in the sandstone; d: discrete grains of monazite with a rim of hematite; e: hematite specks and needles in quartz grain; f: a grain of sillimanite with quartz and hematite; g: secondary hematite and goethite forming alternate layers in the matrix/cement.

27-b

Fig · 19

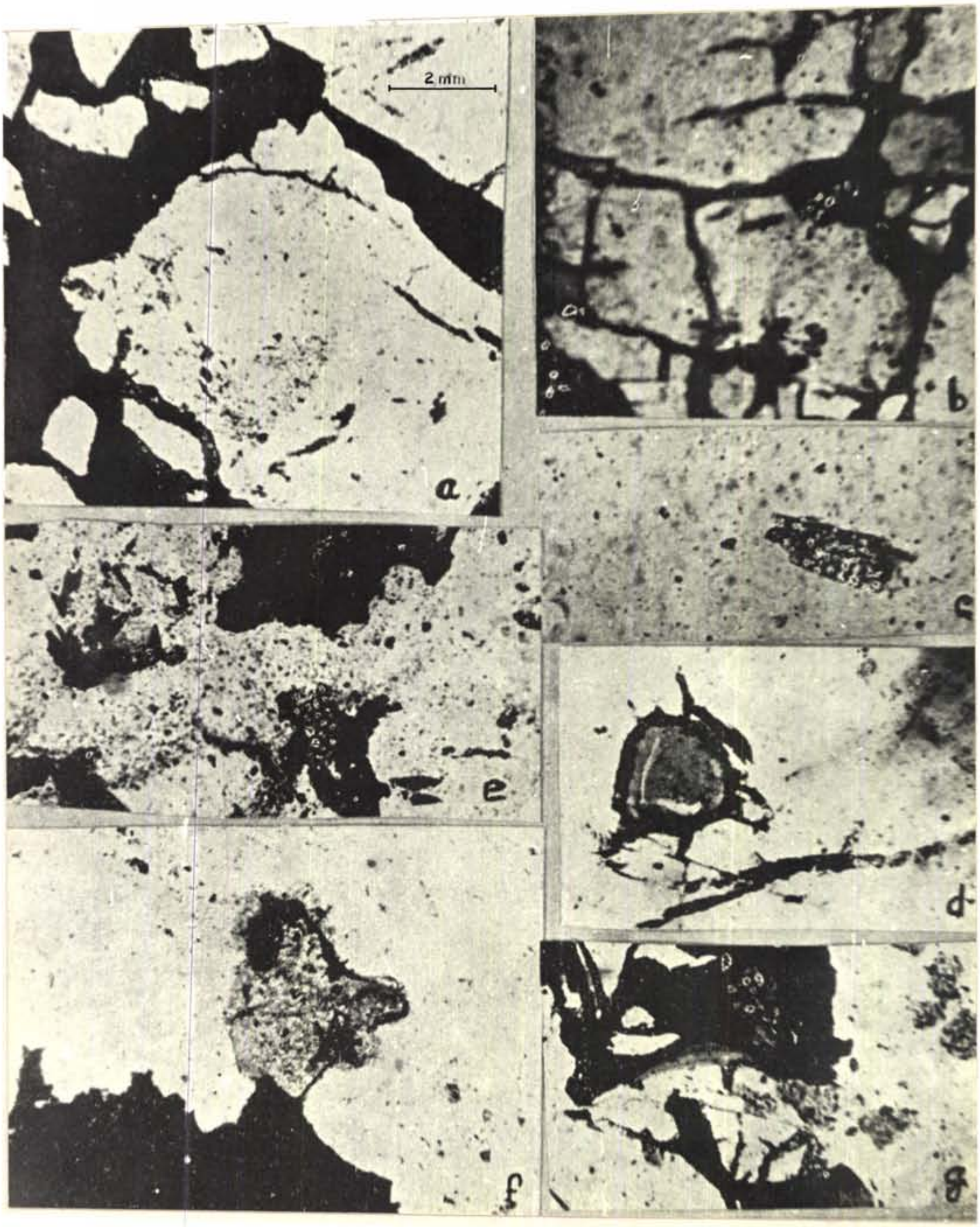


Fig · 20

iv) Stratigraphic significance

The outcrop and subcrop data indicate that these sandstones form the basal unit of the sedimentary sequences of this region. It is to be noted that the lower most strata of the offshore well drilled at Cochin by the Oil and Natural Gas Commission also contained coarse grained sandstones having angular to sub-angular grains of gritty and pebbly quartz with magnetite as the dominant heavy mineral constituent (Mitra et al., 1983). The ferruginous sandstones occurring in the on-shore deposits, essentially contain haematite and very little magnetite compared to magnetite bearing sandstones found in the offshore well.

Though these ferruginous sandstones attracted the notice of previous workers as revealed by some passing remarks (Paulose & Narayanaswamy, 1968), these were considered to be a mere inconsistent unit of the Warkalli Beds. They occur as a distinct litho-unit all along the basin margin from Karuchal in the south through Chengannur, Changanacherry, Kottayam into Cheruvattur, Karyankote and Nileswar in the north.

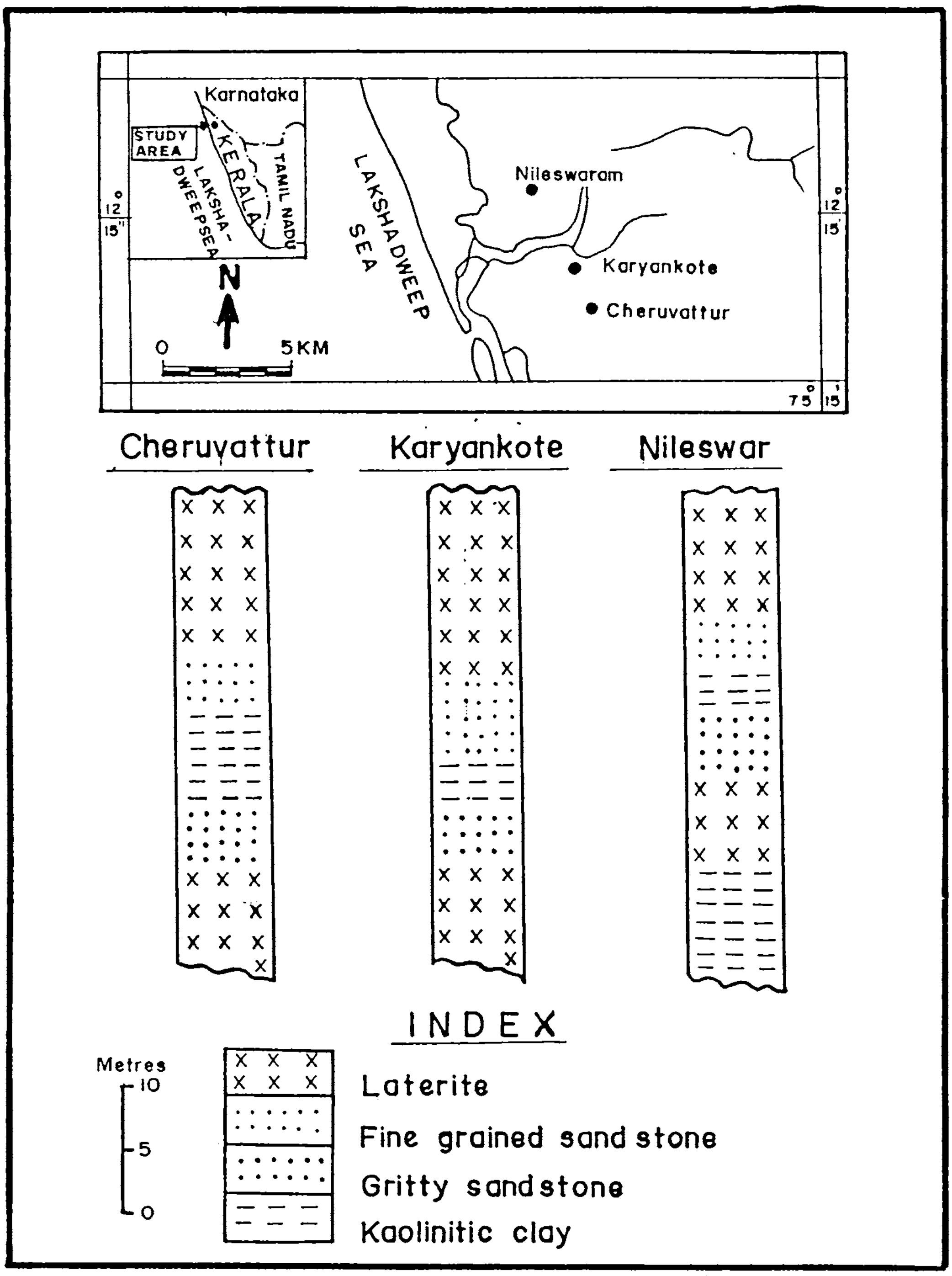
The basal ferruginous sandstones from these areas and reported from other parts of the west coast of India (Krishnan, 1960) are suggestive of a warm oxidising sedimentary environment, depositing iron bearing sandstones in the Cretaceous - Early Tertiary periods. However, age data is needed to confirm this conjunction.

II.5. Cycles of Lateritization

Occurrences of laterite and bauxite have been reported from several localities in Kerala (Paulose, 1967; Subramanian and Mani, 1978; Mallikarjuna et al., 1981). Presence of these laterites and bauxites is explained as due to faulting of older planation surfaces (Subramanian and Mani, op. cit). Mallikarjuna et al., (1981) suggest three spells of lateritization in Kerala, the first spell of lateritization underlying the Tertiary sediments, the second spell overlying the Tertiary sediments and the third one overlying the Quaternary sediments.

Recent find of lateritic zones under the three exposed Tertiary sections around Cheruvathur and Nileswar in the north Kerala (Fig.21) and their field relations, mineralogy and geochemistry are discussed here.

22



Figure·21·Location map and lithology of the localities showing two cycles of lateritizati(

i) Field relations

Sedimentary sections around Cheruvathur, Karyankote and Nileswar are given in the figure 21. The sections exposed in these areas reveal that the sedimentary units are sandwiched between two lateritic surfaces, laterite-I at the base and laterite-II at the top (Fig. 22 and Table 4). Field observations of the laterite profiles indicate a detrital component at the top and a residual component at the base. The laterite at the bottom has relict textures of the parent rock which are retained at Cheruvathur, Karyankote and Nileswar and at Puvalankai, Nileswar in a fresh excavation for clays (not represented in the Figure 21) charnockitic boulders are seen at the base. A gradual transformation of charnockite to weathered zone (Kaolinised bed) and in situ laterite development are clearly visible The boundary between the laterite at the bottom and the overlying sediments is sharp in contrast to the gradational contact of the top most laterite and the sediments. This gradational contact is probably due to in situ lateritization of the upper part of the sediments, which is further substantiated by the relict sedimentary features like cross bedding which occur in the overlying laterite. The laterite underlying

Figure 22. Photograph showing section at Karyankote, Kasaragod district showing development of laterites under sedimentaries.

30-b

Fig. 22

the sedimentaries is hard and compact and fine grained as compared to the laterite exposed at the top of the profiles.

ii) Chemistry and Mineralogy

Chemically the laterites below the Tertiaries (laterite-I) have more SiO_2, Al_2O_3 and less Fe_2O_3 than the laterites (laterite-II) over the Tertiaries (Table 5). Ternary diagram of SiO_2, Fe_2O_3 and Al_2O_3 (Fig.23) are used here (Schellman 1981) to characterise the laterite indicates that laterites below the Tertiaries are weakly lateritized compared to the laterites occurring above. Mineralogical study reveals significant increase of coarse quartz grains which are mostly angular to subangular and minerals like goethite and haematite in the laterite at the top as compared to the laterite at the base. Study of the results of X-ray analyses of laterite samples (laterite I) and laterite (II) indicate characteristic mineralogical constituents (Fig.24) in both types of the laterites such as kaolinite, gibbsite, goethite, quartz and hematite. There is a high incidence of gibbsite in the laterites below the sedimentaries (laterite-I in Fig.24). The low incidence of gibbsite (free alumina) and high incidence of kaolinite and quartz in the laterites overlying the

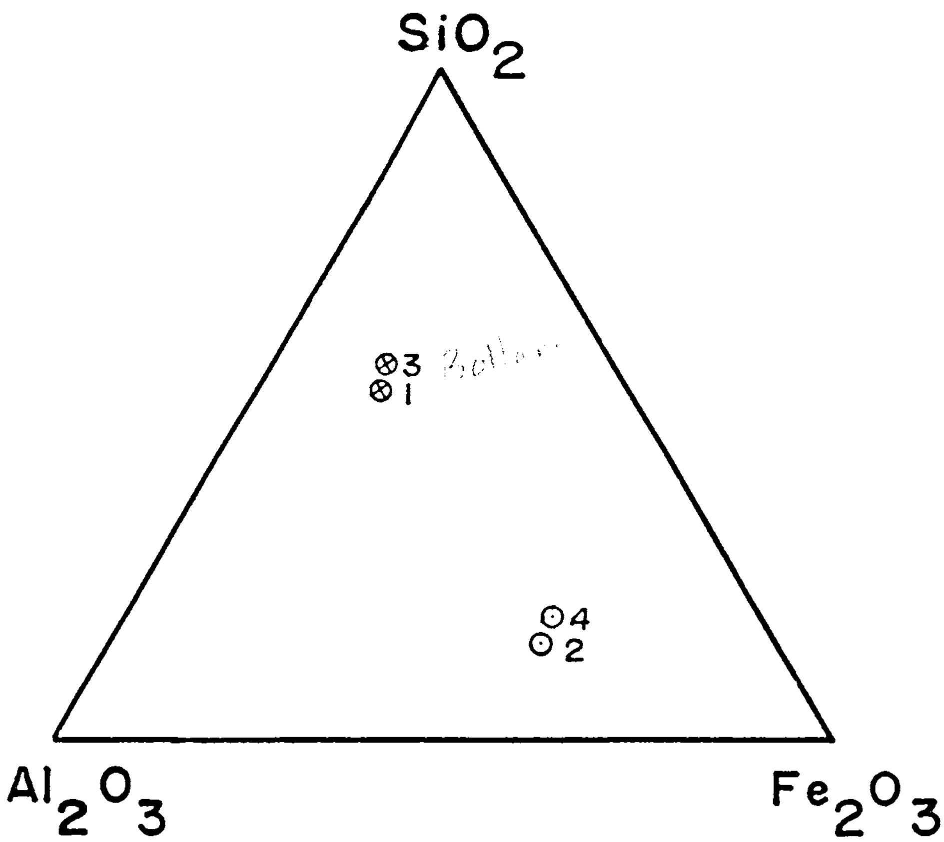


Figure - 23 · Ternary diagram of laterites·

1 – Laterite from the bottom, Cheruvathur

2 – Laterite from the top Cheruvathur

3 – Laterite from the bottom, Nileswar

4 – Laterite from the top, Nileswar

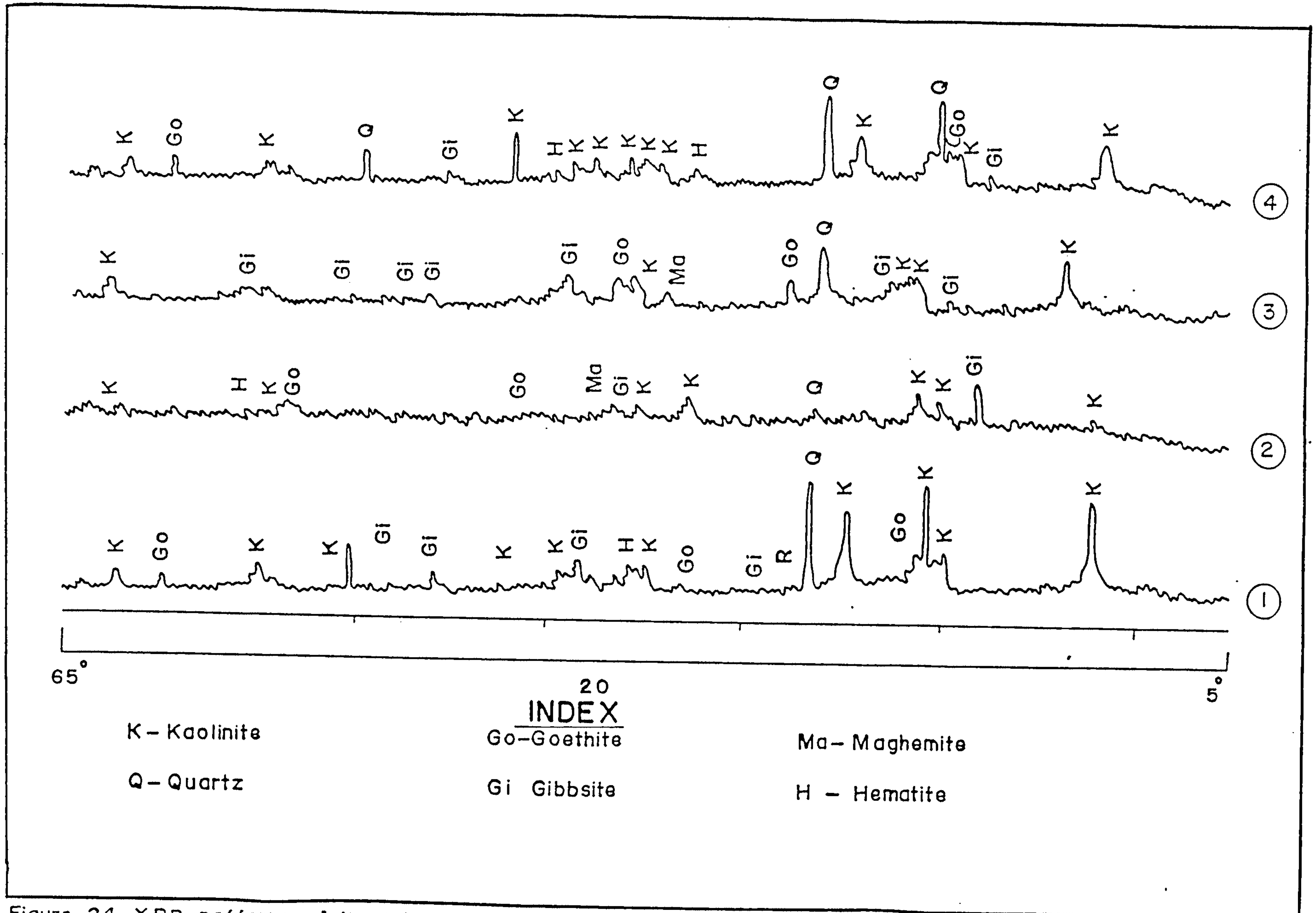


Figure-24 XRD patterns of the laterites

sediments (laterite II) suggest that the process of breaking up and leaching of silica and resultant concentration of alumina has not taken place in the laterite at the top. This also suggests that the intensity of chemical weathering was very high during the formation of the older laterite which now occur under the sedimentaries. (Rajendran and Narayanaswami, 1987)

Heavy mineral studies suggest that the parent material for laterite below the sedimentaries must have originated from charnockitic rocks. The heavy mineral assemblage of the top laterite does not compare with that of the laterite at the base which is suggestive of different source for the laterite at the base.

iii) Discussion

Gradual downward passage of laterite into kaolinitic clay and weathered crystalline rocks and the heavy mineral assemblage point to the *in situ* nature of the laterite underlying the sedimentaries. The predominance of gibbsite in this laterite suggests initiation of desilication or bauxitisation due to some favourable conditions. At a later stage this desilication process was stopped and lateritization process was started (Rao, 1981). Apparently these weathering processes began before the basin for sediment deposition was formed. The sedimentary sections of these areas indicate that the laterite at the bottom is overlain by gritty ferruginous sandstones. This sequence of ferruginous sandstones was identified elsewhere in Kerala as the oldest Tertiary sequence (Raha and Rajendran, 1984). The occurrence of laterite under the Tertiary sediments suggest that there was a period of widespread lateritization in Kerala, prior to Late Cretaceous - Early Tertiary period (Valenton, 1972, Mallikarjuna et al., 1981). This must have happened before the deposition of ferruginous sandstone underlying the Tertiary sediments.

The laterite overlying the Tertiary sequence point to another spell of lateritization during Late Tertiary period. Paleomagnetic investigations of the laterites over the Tertiary sediments in south Kerala also indicate Mid/Tertiary to Late Tertiary in age (Schmidt et al. 1983).. Thus it can surmised that the area under study was effected by two lateritization cycles.

II.6. Facies Relations

A proper understanding of the sedimentary facies is essential to build the lithostratigraphy and to suggest a classification. For this purpose, the law of correlation of facies, enumerated first by Johannes Walther may be considered. The law states that, "the various deposits of the same facies areas and similarly the sum of the rocks of different facies areas are formed beside each other in space though in cross-section we see them lying on top of each other "(Middleton, 1973). This simple and logical interpretation of the sedimentary sequences in their spatial setting is significant to understand their stratigraphic relations.

The oldest sedimentary formation of Kerala as discussed in the previous chapter, comprises coarse gritty sandstones, conglomeritic at places, intercalated and overlain by arkoses and clay beds. These were deposited over older lateritic or bauxitic surfaces (i e, first spell of lateritization). These facies observed in the eastern part of the basin as the outcrops extend to the deep basinal parts in the west. Lateritic pieces and ferruginous sandstones have been recovered from the bottom of the bore holes from various localities (Fig. 5). The sedimentary formations attained its greatest development in the basinal part especially around Thottappally, Trikunnapuzha and Ambalapuzha areas near Alleppey. The terrigenous sediments, comprising sandstone, carbonaceous clay and lignite are the dominant litho units occurring above the ferruginous sandstone at the bottom of the bore holes. Above these terrigenous sediments, carbonate sediments were deposited. Though this is a prominent sequence in the western part of the basin, it pinches out towards the east. An attempt has been made here to bring out prominent features of the interrelationship of different facies.

In order to obtain a picture of the distribution of the Cenozoic sedimentary facies in Kerala, a north-south cross section correlating the various sedimentary facies along the western margin of the Tertiary basin (Fig.25) and east-west sections across various parts of the basin (Fig.26) have been prepared from borehole data and from field observations at cliff-facies and shallow wells distributed around Quilon, Padappakkara, Edavai and Varkala. The vertical scale has been exaggerated in these cross-sections to bring out the relationship of different sedimentary facies.

A major stratigraphic marker unit within the sequences of the western part of the basin, from the top, is the laterite horizon (i.e., second spell of lateritization) which covers the Tertiary sediments and occurs beneath the Quaternary sand-peat associa-

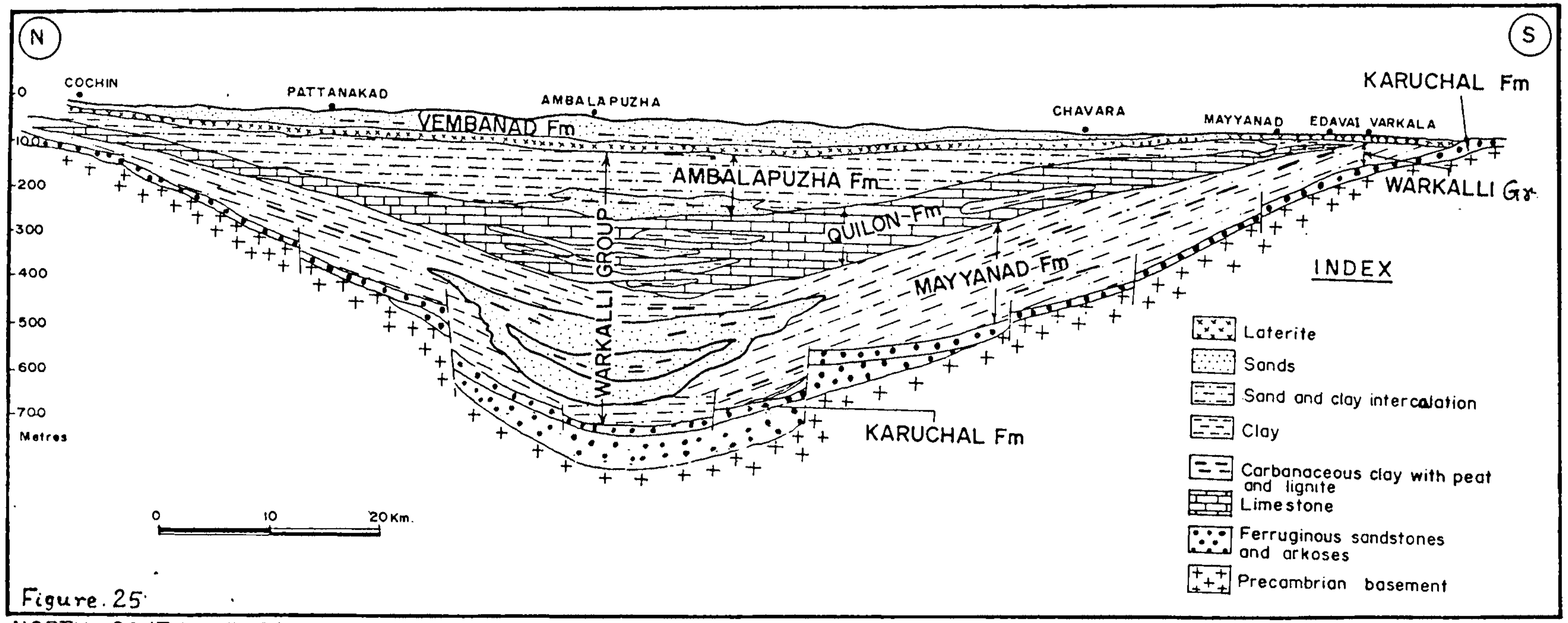


Figure. 25

NORTH-SOUTH CROSS SECTION OF THE CENOZOIC BASIN BETWEEN COCHIN - VARKALA.

25-a

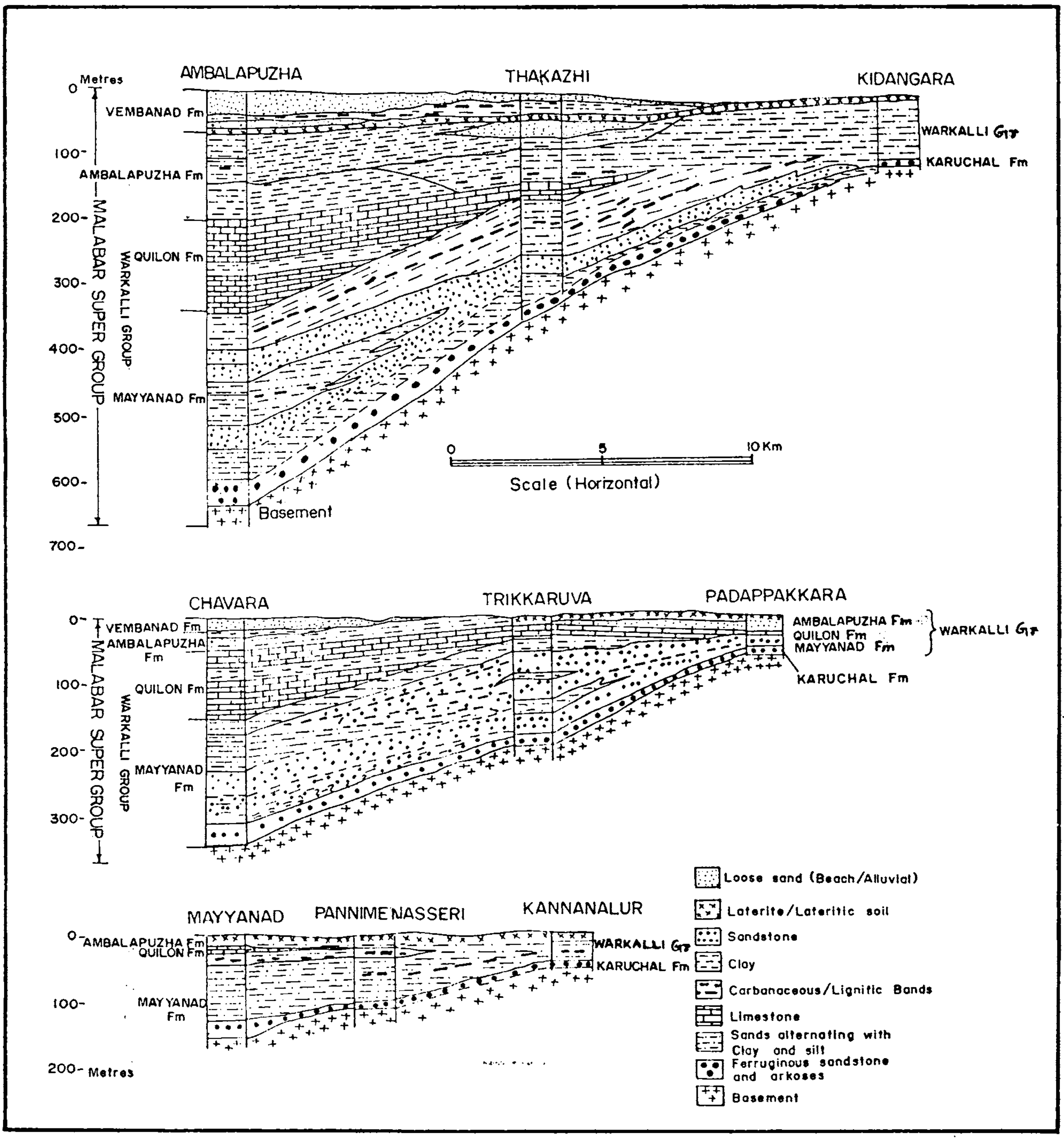


Figure-26.- EAST-WEST CROSS SECTIONS ACROSS THE CENOZOIC BASIN tion around Ambalapuzha and Alleppey. The block diagram (Fig.27) of the area lying to the north of Ambalapuzha brings out the distribution of the various facies within this basin along the E-W Ambalapuzha-Thakazhi line and in areas lying to the north of Ambalapuzha.

The laterite horizon is underlain by a zone of coarse to medium grained sands, interbedded with variegated clays, lignitic and carbonaceous clay beds. The upper part is rich in clays which is underlain by coarse pebbly sandstone.

The limestones with calcareous clays and sandstones form a prominent horizon with a maximum thickness of about 130 metres at Ambalapuzha and around 100 metres at Chavara. This carbonate facies pinches out around Paravur cliff section, north of Varkala, where fossiliferous calcareous clay is exposed as a thin band (0.5 m) nearly 1.5 m above the sea level. This carbonate facies also gradually thins out eastward being represented at Padappakkara and Pannimenseri (Fig.26) by very thin bands as the eastern most extension of the shelf facies.

The thinning out feature of the carbonate facies (Quilon Formation) is prominent around Thakazhi, Trikaruva and Mayyanad (Fig.26). The marine shelf facies

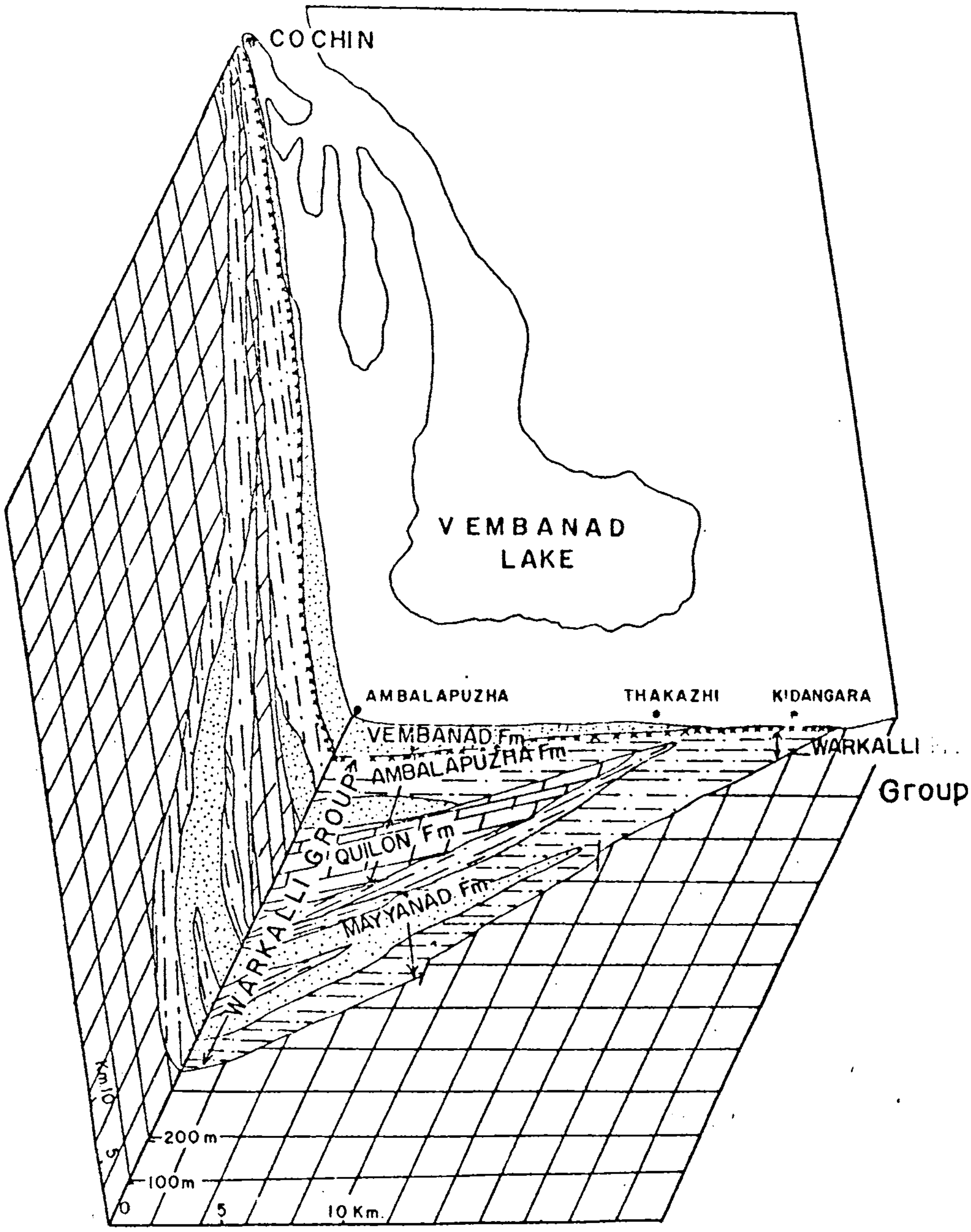


Figure-27 BLOCK DIAGRAM SHOWING THE DISTRIBUTION PATTERN OF LITHO-UNITS intertongues with and grades into a continental facies of sandstones interbedded with white and gray clays and lignite bands to the south of Edava. This continental facies developed in the Warkalli (Varkalla) type-section continues to the south along the eastern margin of the sedimentary basin.

The important exposures in the extreme south are located at the cliff sections at Karuchal, near Trivandrum, where the basal sandstone horizons of the section are characteristically dark gray to reddish brown sand which are quite hard and compact. This formation was traced along the eastern margin of the basin around Kottayam and also in the northern Kerala through Cannanore and Kasaragod districts.

The present facies analyses indicate that the calcareous platform facies (Quilon Formation) forms a wedge within a predominantly terrigenous sequence. It appears that the entire Tertiary sedimentary sequence with varied facies in the western part of the Kerala basin is compressed in the eastern part with the total disappearance of limestone sequence.

The sediments underlying the calcareous Quilon Formation are mostly sandstones, clays and lignitic beds, typical of the continental facies with the exemption of thin bands of limestone around 470-480 metres depth level around Ambalapuzha. The granulometric analysis of the sandstones overlying and underlying the Quilon Formation and of the sediments of the Varkala type section and the Karuchal section was carried out for a comparison of the sedimentologic parameters and to ascertain the depositional environments.

The sediments overlying the limestone generally have large grain size with mean size varying between -1 and -2 phi in contrast to a small mean size (-0.7 to 0.1 phi) for the sediments lying below the Quilon Formation (Table 6). The standard deviation (sorting) for the sediments beneath the calcareous horizon is moderate (0.8-1.3), but that for the sediments above this horizon varies widely and is inversely proportional to the mean size of the sediments (Table 6). However, the grain size of the sandstone of Warkalli type section is very fine (mean size 1 to 3 phi). The grain size frequency curves for the Warkalli sediments are mostly polymodal and are both skewed positively and negatively. The fine grained size of these sandstones may be attributed to post-depositional weathering. The grain size of sandstones of Karuchal and that of sediments under the Quilon Formation around Quilon and Alleppey are comparable with each other, with size modes at-0.75, -0.25 and 0.5 phi (Fig.28) and the values are suggestive of fluvial regime.

The intertonguing relation between the marine and the continental facies is prominent in the Padappakkara section where a thin cover of sandstone underlain by carbonaceous clay occurs above the fossiliferous

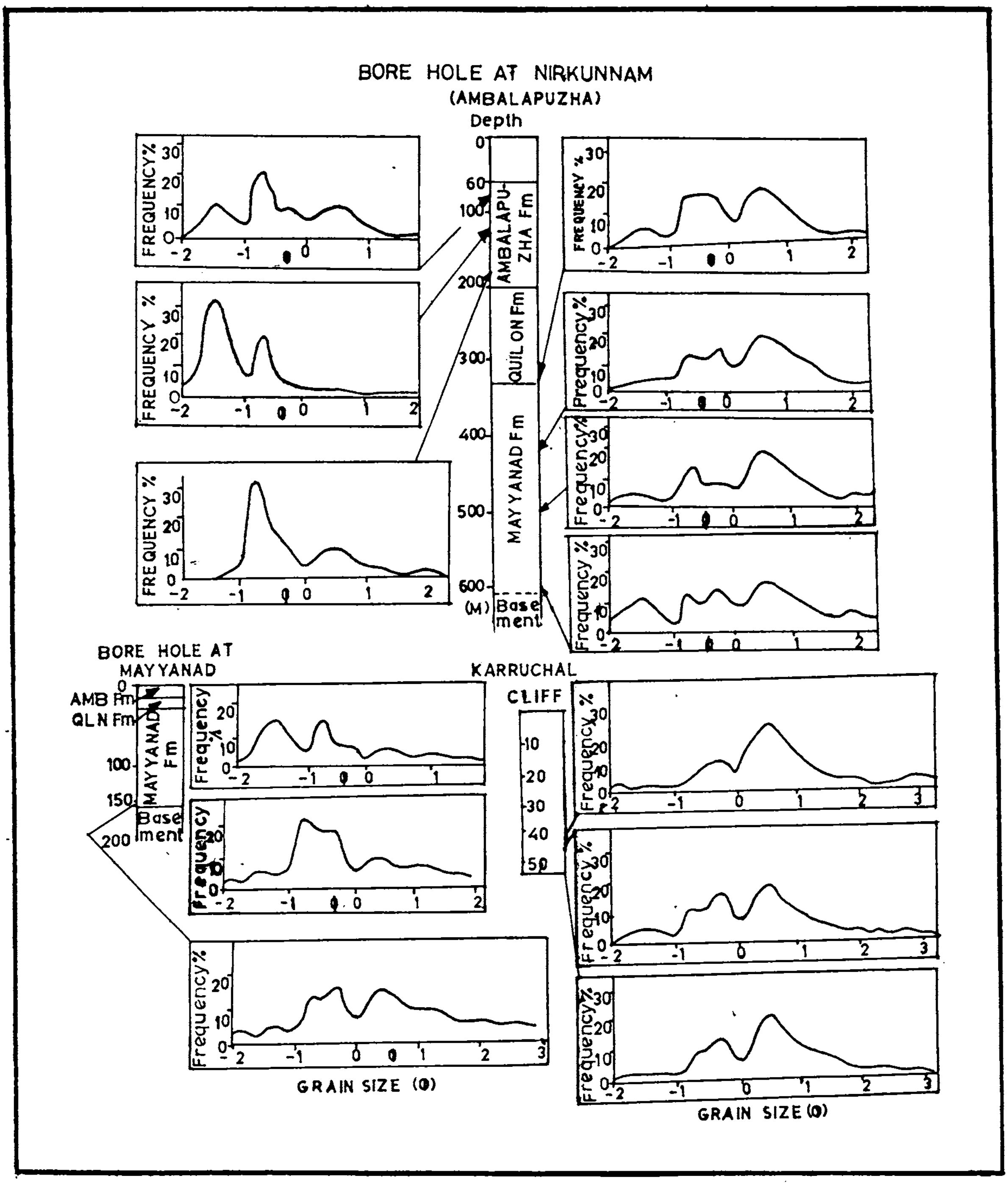


Figure-28· Grain size parameters of sediments from Ambalapuzha, Mayyanad and Karuchal

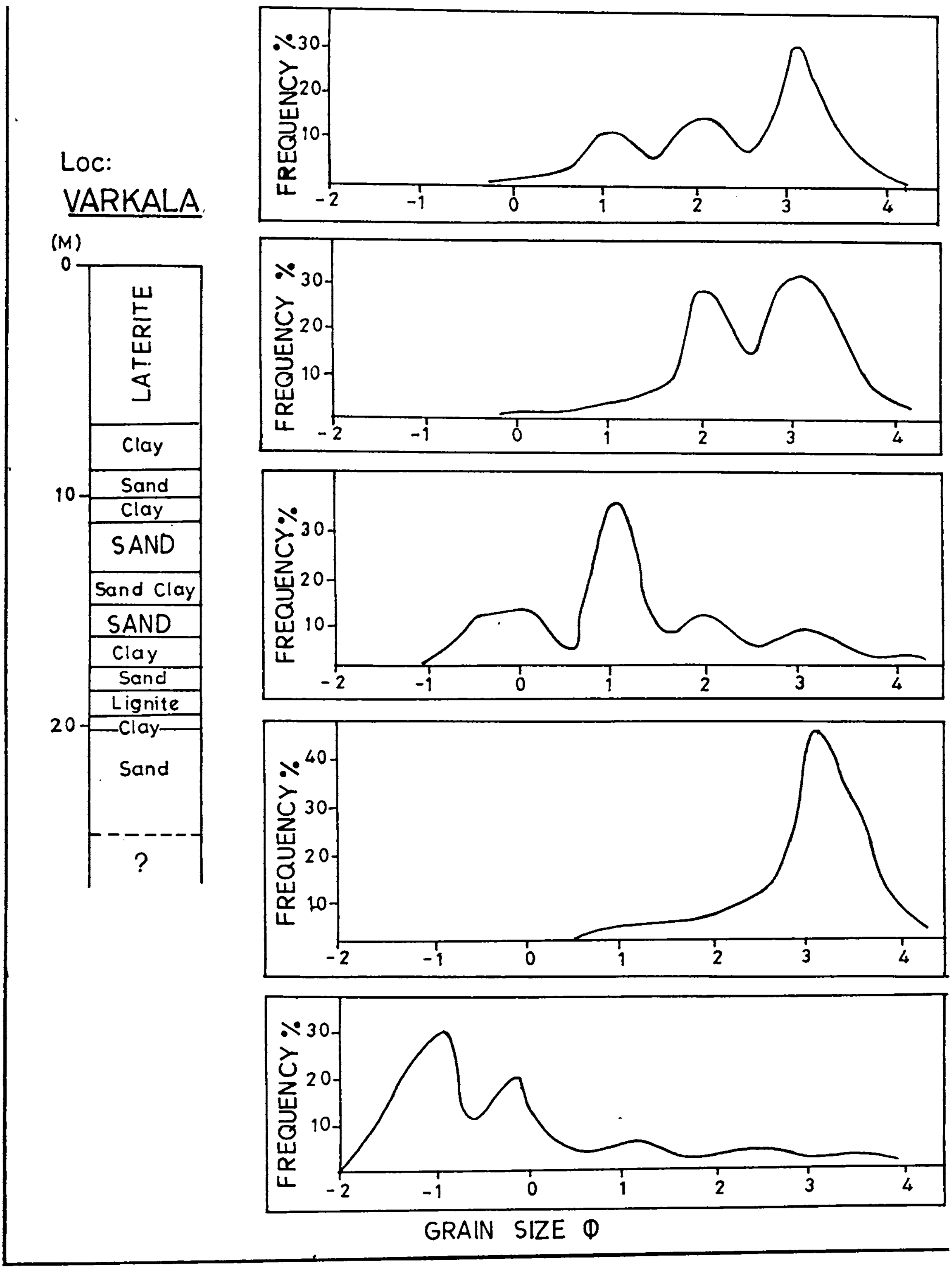


Figure-29 Grain size parameters of sediments from Varkala limestones, the carbonates at Padappakkara being the easternmost occurrence of the platform facies. The fluvial and deltaic nature of the continental deposits are indicated by the grain size parameters (Table 6) showing positively skewed frequency distributions for the sandstones (Figs. 28 & 29) and by the association of lignitic beds.

II.7. Stratigraphic Classification

The classification of lithostratigraphic units as given by Krumbein and Sloss (1963) define the Formations as the fundamental units of lithostratigraphy. These are distinguished in terms of definite lithologic composition, observable lithologic separation from adjacent units above and below and traceability. The Formations may be subdivided into smaller groupings called Members. The formations combine to form "Group" (Krumbein and Sloss, op. cit). It is clear from the foregoing discussions that the existing stratigraphic classifications of the sedimentary sequence of Kerala (Table 2) need a modification. As per the Code of Stratigraphic Nomenclature of India (Anon, 1971) these lithostratigraphic units need a formal definition for identification in the outcrop and the subcrop sections. Based on the observations made in the study, a new lithostratigraphic classification of the Cenozoic sediments of Kerala is proposed (Table 7).

II.8. Definition of Lithounits

The lithounits defined in the proposed classification are the following:

i) Karuchal Formation: This formation is the lowermost unit which underlies the Warkalli Group with an unconformity (see Table 7). It is consisted of dark coloured hard, compact gritty sandstones, traced in the peripheral parts of the Tertiary basin and the bottom most part of the basinal areas in the west. These are exposed over the laterite/bauxite cappings. The Formation is named after the type locality, Karuchal, south of Trivandrum, where it is developed extensively (see the Chapter on basal ferruginous sandstone).

ii) Mayyanad Formation: This Formation occurs above the Karuchal Formation. It comprises coarse grained sandstones with intercalations of clay and lignite with occasional lenses of limestone. This can be considered as a marginal fluvial and deltaic facies that migrated towards basin margin before the transgression of the sea resulting in the deposition of the overlying Quilon Formation. Thick beds of black steaky carbonaceous clays are developed in the deeper part of the basin. This unit is designated as Mayyanad Formation (Desikachar, 1976), as it attains a thickness of over 100 metres at Mayyanad. The subcrop section from Mayyanad, Chavara, Thottappally, Trikunnapuzha and Ambalapuzha can be considered as typical sections of the Formation.

iii) Quilon Formation: This unit overlies the Mayyanad Formation and is characterised by fossiliferous limestones, calcareous clays, marls and calcareous sandstones. It outcrops at Padappakkara and Paravur. It is best developed in the subcrop sections at Ambalapuzha and Chavara. Bioclastic calcarenites with corals, bryozoan and echinoid fragments in association with gastropods and foraminifera are developed in the Padappakkara section and in the upper part of the Formation in the Ambalapuzha, indicating reefal character. The miliolids and operculinids which are abundant in the major part of the Formation indicate shallow inner-shelf facies and at depths not exceeding 30 metres. The hard compact bio-micrite are characterised by abundance of rotaliidae. Planktonic foraminifera though occur in low frequency indicate connection with the open sea.

This unit was originally designated as the Quilon "Beds" (see previous work) based on the occurrence of outcrops around Quilon at Padappakkara, Edavai and Paravur. Considering its thickness varying from 150 metres to 50 metres in most of the western part of the basin and on the basis of distinctive lithology, it is necessary to elevate this to the rank of a Formation. This is named after Quilon, because typical outcrops occur only around this area (Raha et al., 1983)

iv) Ambalapuzha Formation: This Formation comprises the terrigenous sediments consisting of pebbly and coarse sandstones, gray clays, lignite and peat and overlies the Quilon Formation. This has been designated as the Ambalapuzha Formation as it is observed to be best developed in the subcrop section at Ambalapuzha region attaining a maximum thickness of about 140 metres. A coarse pebbly sandstone has been recorded in the basal part of the section. It is different from the typical Mayyanad Formation in having a relatively coarser grain size (Fig. 28). On the basis of geographic location of the best developed section at Ambalapuzha, this Formation is designated after this locality. The name 'Ambalapuzha

Formation' was also used by Desikachar (1976) for this upper unit.

v) Vembanad Formation: The lagoonal deltaic and beach sand facies are developed over the laterite capping of the Ambalapuzha Formation with an unconformity. This is best developed around Vembanad Lake and is well recorded in the borehole near Ambalapuzha. These Quaternary deposits are named as Vembanad Formation after the Vembanad Lake of Alleppey district. It comprises shell-limestone, red sands, peat beds, sands and clays. In the outcrops at marginal areas of the basin this Formation is represented at places by a gravel bed and alluvium.

vi) Discussion

The carbonate facies (Quilon Formation) pinches out in the eastern part of the basin and consequently the distinction between the constituent arenaceous Formations, which is well marked in the west, disappears in the east (Fig.30). With the thickening of the sedimentary section from less than 30 metres in east to over 600 metres in the west, it splits into three distinct and mappable units in subcrop level (Fig. 30). as Ambalapuzha, Quilon and Mayyanad Formations.

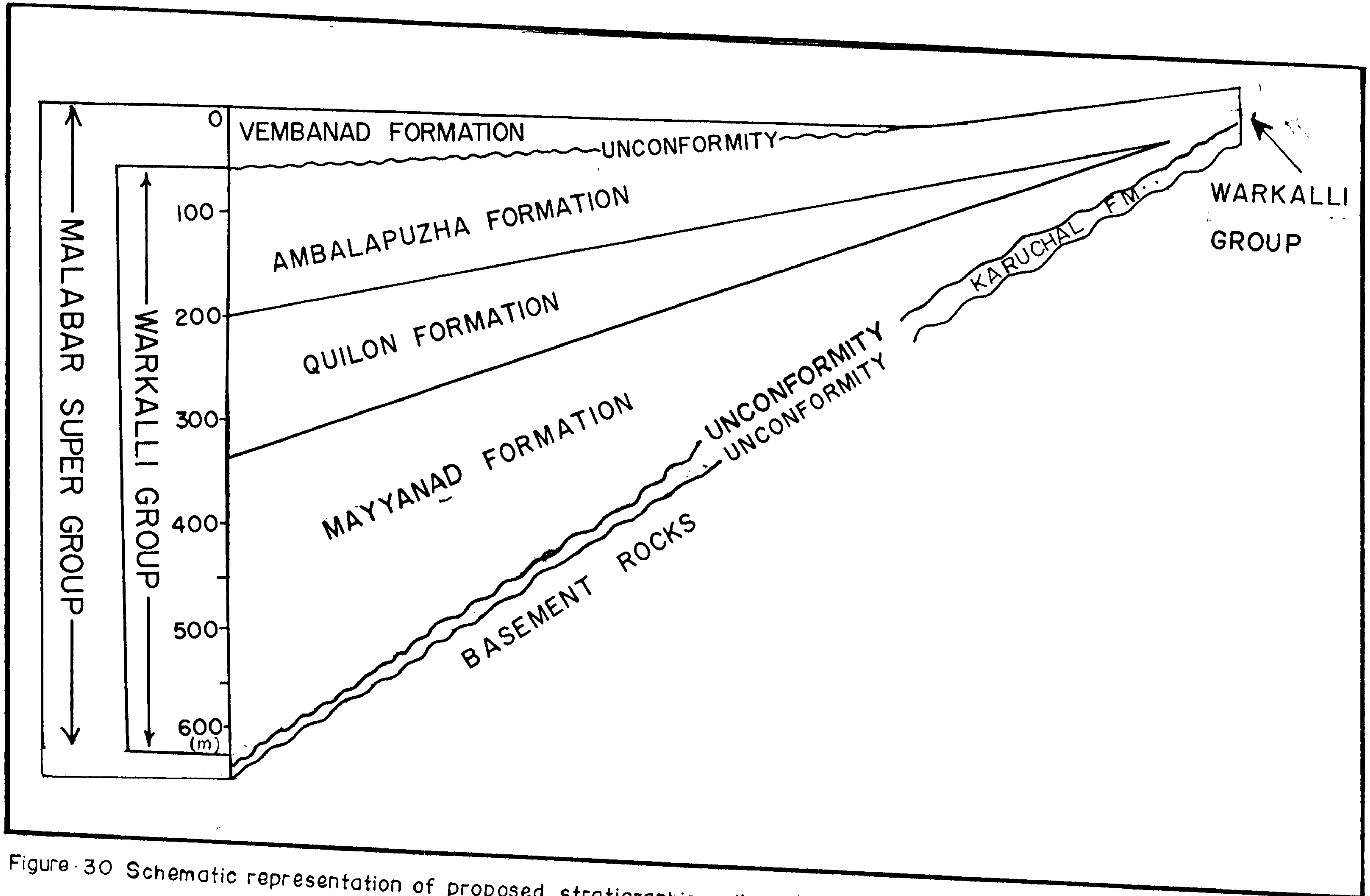


Figure · 30 Schematic representation of proposed stratigraphic units of Kerala

As per the Code of Stratigraphic Nomenclature of India (Anon, 1971) and as illustrated in Fig.30, the three Formations mentioned above are designated as the Warkalli Group (Table 7). The entire Cenozoic sequence of the coastal Kerala, comprising the Vembanad Formation, the Warkalli Group and Karuchal Formation, is designated as the Malabar Super group (Table 7), after the Malabar coast, by which the southern part of the western coast is popularly known.

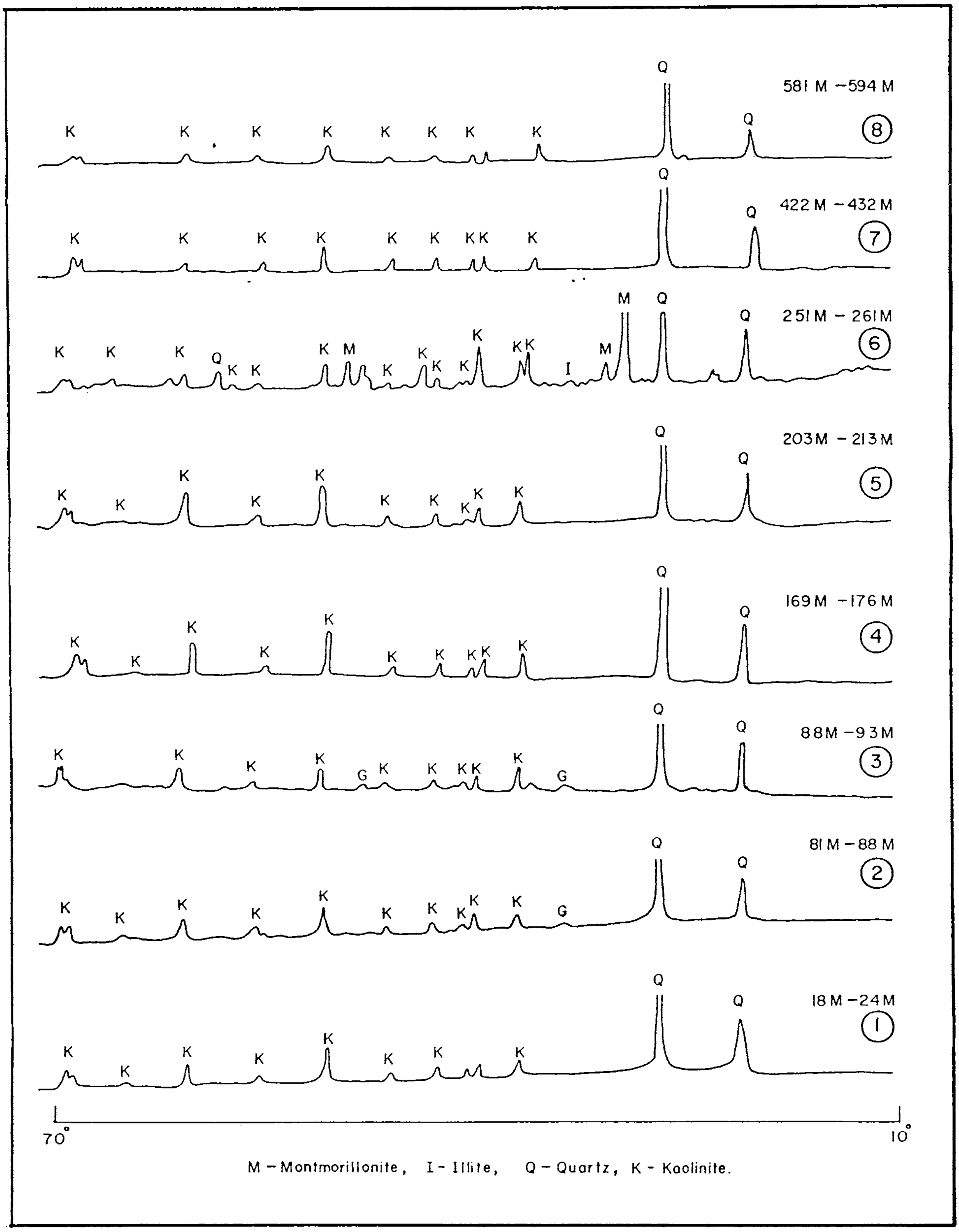
III. MINERALOGICAL AND GEOCHEMICAL ASPECTS OF SUBSURFACE SEDIMENTS

III.1. Clay Mineralogy

The clay mineral assemblage of the sediments from the Ambalapuzha subsurface section includes Kaolinite, montmorillonite, goethite, gibbsite and illite (Fig.31). Identification of various clay minerals was done with the help of tables of Grim (1969) and selected powder diffraction data (1974).

Kaolinite is the most abundant clay mineral in these sequences. Montmorillonite together with illite occur only in one sample, from the depth of 251 metres to 261 metres. Goethite and gibbsite are found in the samples from 81 metres to 93 metres.

Presence of kaolinite is noticeable through out the subsurface section. It appears to be stable even in the sediments deposited in marine conditions (depth around 251 metres to 261 metres) where it occurs along with montmorillonite and illite. Montmorillonite must have been formed in marine conditions due to enrichment of Mg. The presence of goethite and gibbsite around 81 metres to 93 metres can be explained as due to the effects of lateritization.



Figure·31·XRD patterns of subsurface clay samples from Ambalapuza

i) Discussion

The character of a clay assemblage is controlled by the long term climatic influences on pedogenesis (Lange, 1982). The clay mineral assemblage with the predominance of kaolinite, indicates tropical weathering processes (Millot, 1970) during the entire Cenozoic period with almost complete disintegration of primary mineral assemblages. The basic processes involved in kaolinite formation are intense rainfall, moderate to high temperature, and dense vegetation, (Grim, 1968)

Predominance of kaolinite in the basinal areas of Kerala must have been due to heavy influx of kaolinite from the continental sources. In the outcrops also, kaolinite is the most abundant clay mineral (Ghosh, 1986). This may be one of the major reasons for the low content of feldspar in the arenaceous rocks of Kerala, as feldspars are prone to decomposition and conversion to kaolinite.

III.2. Heavy Minerals

The heavy minerals constitute less than 3.40% of the subsurface sediments around Alleppey. A total of eight minerals have been identified. Opaques are most abundant in all the sediments, in addition to zircon, sillimanite, monazite, garnet, epidote, rutile and vermiculite.

Opaques: Mostly the opaques are subrounded to subangular. Ilmenite is very common.

Garnet: Mostly colourless occasionally pink coloured and in some cases with inclusions. Occasionally irregular and fractured.

Epidote: Green or yellowish green, colourless, yellow (Pleochroic), subangular to subrounded, occasionally altered.

Zircon: Mostly subangular with pyramidal termination and some cases rounded.

Biotite: Mostly subangular, pale brown, typical pleochroism is noted.

Rutile: Mostly reddish brown or blood red in colour, mostly prismatic with rounded terminations. Strongly pleochroic from reddish brown to intense brown.

Monazite: The mineral is pale yellow in colour with high relief and rounded grains with no cleavages.

Sillimanite: It is found in the form of long slender colourless prisms with pronounced cross fracture. Some grains are slightly altered.

i) Discussion

Distinct demarcation between different formation viz., Ambalapuzha Fm, Quilon Fm and Mayyanad Fm, on the basis of heavy minerals is difficult. However, these studies are useful in making some observations about the sedimentary history. The absence of heavy minerals in the Quilon Formation for example is indicative of a break or slowing down of continental sedimentation. Similarly, the presence of diopside and epidote in the Ambalapuzha Fm on the top indicate near source for these sediments. Terminally rounded zircons probably derived from pre/existing sedimentary rocks are also found to be admixed with these sediments. The persistence of the same heavy mineral assemblages without appreciable change in the mineral content points out that all the sediments have been derived from the same type of source rock. The presence of garnet, sillimanite, epidote, diopside etc. suggests that the source rock may be of high rank metamorphic type. Presence of rutile, monazite etc., indicates admixture of pegmatitic granites in the source area.

The sudden increase of opaques in the top most Vembanad Fm is another interesting observation (Fig. 32). This might have been derived from the abundant clastic sediments rich in opaques generated in a major tectonic event during Late Tertiary - Early Quaternary period.

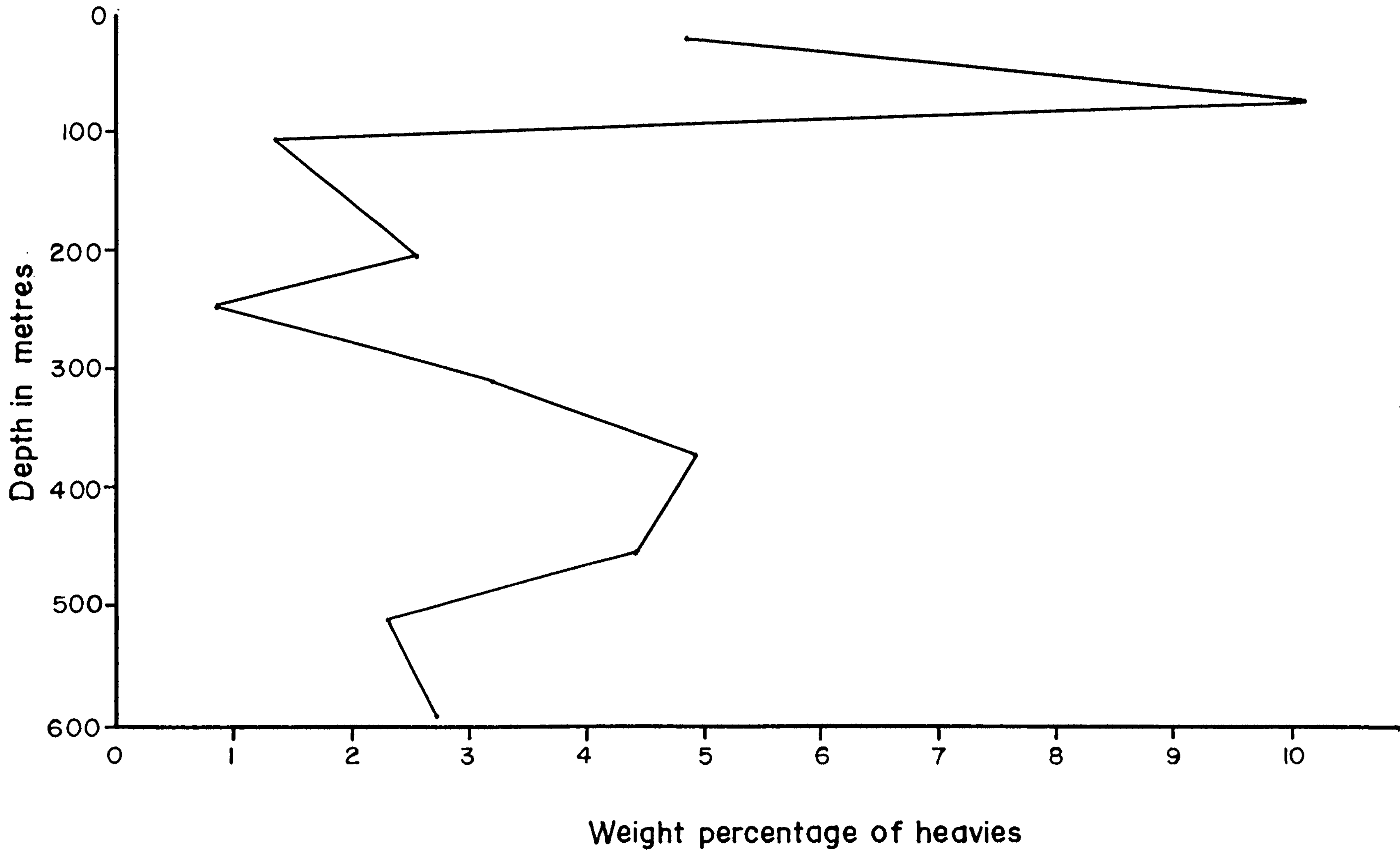


Figure 32·Plot of weight percentage of heavy minerals and depth

III.3. Geochemistry

The results of chemical analysis for major, minor and trace elements in the clay samples from different depth levels of Ambalapuzha borehole are presented in the Table 8. There is a definite trend for SiO_2 and Al_2O_3. These elements are generally high on the sequence overlying the calcareous unit (44 metres to 139 metres) and gets depleted towards calcareous unit. Likewise SiO_2 and Al_2O_3 increase towards the sequence underlying the calcareous unit (440 metres to 594 metres). Fe_2O_3 is enriched more in the sediments close to the surface and maximum near the zone of lateritized sediments (85 metres to 88 metres). CaO and MgO and trace elements like Bi, Sr and B are enriched in the calcareous sediments (241 metres to 263 metres). Organic matter is very high towards the bottom of the sequence (503 metres to 594 metres) indicating euxinic conditions.

The major, minor and trace elements of the calcareous sediments from Thottappally borehole are presented in the Table 9. Correlation between SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO is noticeable from the table and whenever there is an increase in SiO_2

Al_2O_3 and, Fe_2O_3 there is a decrease in CaO and MgO. The correlation of Ba and Mn which are environmentally sensitive, is established in the figure 33.

i) Discussion

The tendencies in the distribution of particular elements can be linked to geological evolution of the basin such as transgressions, regressions, climatic development, changes in the supply of sediments, tectonic disturbances, diagenetic influences etc. (Ernst, 1970). It may be seen that in the present study, for example, the concentration of SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO can be linked to the magnitude of marine influences on the sediments. This is illustrated by the decrease of SiO_2, Al_2O_3, Fe_2O_3 and corresponding increase in CaO and MgO in calcareous sediments from Thottappally (Table 9). Fluctuations of the marine influences must be the reason for the corresponding variation in the respective elements. From the table 8, it can be seen that SiO_2 and Al_2O_3 tend to be more concentrated when the clastic sedimentation was more pronounced. Distribution of elements can be related to facies variation.

Trace elements are now recognised as environmental indicators of carbonate sediments, a conclusion reached based mostly on the studies of modern sediments (Friedman, 1969). The plot of Barium and Manganese, after Friedman (1969) has been tried for the Thottappally carbonates (Fig.33). This clearly demarcates the brackish and marine environmental conditions for these carbonates.

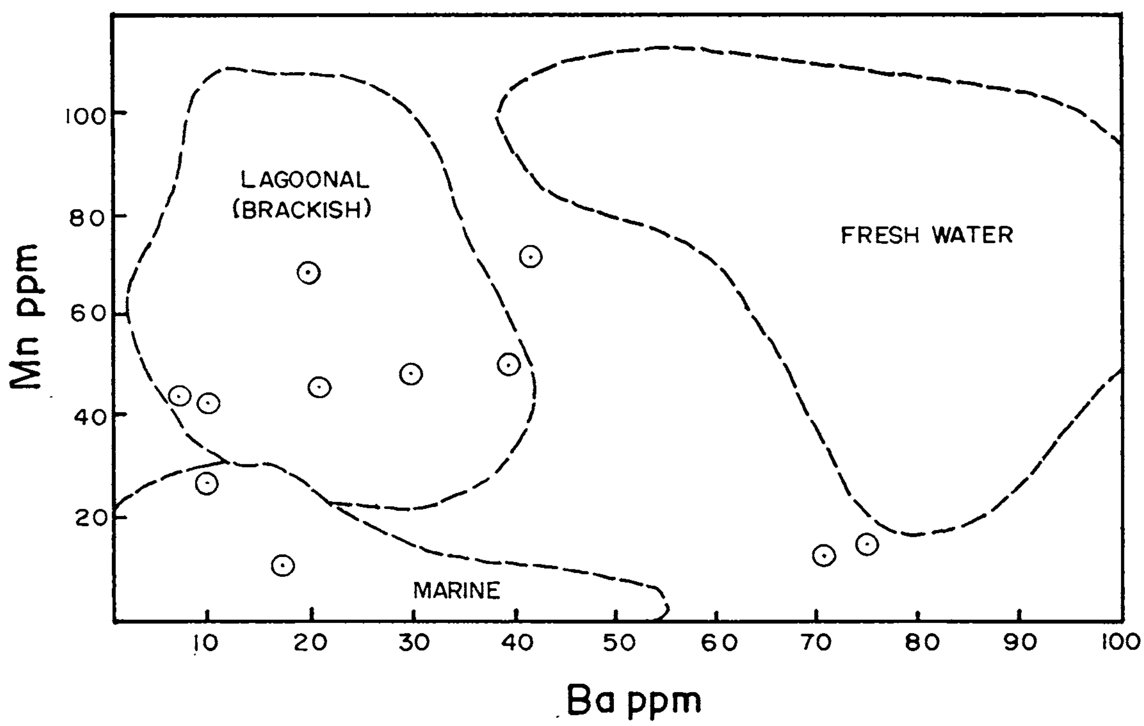


Figure-33 · Plot of barium and manganese for the calcareous sediments from Thottappally

IV. PETROLOGY OF CARBONATES (QUILON FORMATION)

A critical evaluation of the observed and relevant petrographic features of the carbonates belonging to Quilon Formation of the Kerala onshore basin is presented here. Work of Folk (1959, 1962), Dunham (1962) and others have pointed out that all carbonate rocks could be considered as a mixture of sand sized grains of calcium carbonate and carbonate mud. Detrital reworked carbonates, invertebrate fossils and their fragments constitute the coarser fraction while precipitates and faecal pellets comprise the finer part of the rocks (Blatt et al., 1980).

The limestones are bluish gray to ash gray in colour, massive, quite hard and compact (Figs. 34 and 35). These comprise megascopically, very fine grained calcareous material, fossils, quartz and glauconite. The detrital quartz grains are coarser towards the east. The fossils include bryozoans, lamellibranchs, gastropods, ostracods and foraminifers. Pyrite grains, including framboidal forms are common in thin sections (Menon, 1967). Lignite pieces are found to be embedded in the limestone from Padappakara and Paravur (Figs. 34 and 35).

The thin section study of the limestone samples revealed that the carbonates are characterized by two typical grain components - the coarser ones comprising biogenic particles (allochems) like the tests of foraminifers, ostracodes, lamellibranchs, corals and bryozoans and the finer ones consisting of micrites or carbonate ooze (orthochems).

Fossil shells of foraminifers, ostracods, gastropods, lamellibranchs, bryozoans are the major constituents of allochems. Shells which range in size from 50 microns to more than 2 mm, mostly show internal structure. Quartz grains are seen to be abundant in the limestone (10% to 50%) which are on the increase towards Padappakkara and Mayyanad and clayey towards Alleppey (i e west). Glauconite is also present in the limestones in appreciable quantity which occur as internal casts of fossil shells (discussed in the Chapter V).

The most commonly occurring orthochems in these limestones are light to dark brown cryptocrystalline to microcrystalline (1 to 4 microns) calcite. Allochems occur in this micritic matrix.

Besides allochems and orthochems, there are also some evidences of recrystallisation. These are uniform in size and are termed 'microspar' (Folk, 1959). Generally these recrystallized products occur in the periphery of fossil shells.

The proportion of the coarse and fine particles vary in these rocks, offering grounds for classification, after Folk (1962) and Dunham (1962) which are discussed below:

IV.1. Biomicrite:

It is hard and compact limestone (Fig.36). It contains chiefly the fossils comprising the tests of foraminifera, ostracods, gastropods and lamellibranchs in a micritic matrix. The gastropods and lamellibranchs, constitute the large coarser (2 mm) fraction of the sediment. Foraminifera are usually less than 2 mm in size and majority of them are of fine to medium sand size. The bioclasts make up 50 to 70 per cent of the rock. The micritic cement at places show neo-crystallisation and development of sparritic grains (Folk, 1962). The development of sparry carbonate grains is very small and localised. The biomicrites of Padappakkara with MgO content (18-20%) indicate dolomitic nature of the rock. Those of Mayyanad and Ambalapuzha are calcitic (Table 10). Occasional presence of pyrites and glauconite infilling, encrusting or replacing the microfossils of foraminifera and gastropods has also been observed. Limonitic matters also fill in and encrust some of the shells, especially of the Austrotrillina and Quinqueloculina.

IV.2. Sparse biomicrite.

It is composed of micritic carbonate mud and clay enclosing mainly miliolid foraminifera. It is chiefly admixture of soft muddy clay and carbonate mud with small proportion of microfossils. It is argillaceous sparse biomicrite after Folk (1962). The calcareous ooze and clay constitute 80 to 90 per cent of the rock mass. It is chiefly characterised by miliolids like Quinqueloculina, Triloculina and Operculina.

IV.3. Biocalcarenite

This is poorly cemented to loose fossiliferous rock (Fig.37). The fossils comprise more than 70% of the mass with some quartz and clay in micritic matrix. Chemically it also shows high magnesia content. The fossils show characteristic assemblage of foraminifers, gastropods, corals, bryozoans and fragments of echinoid

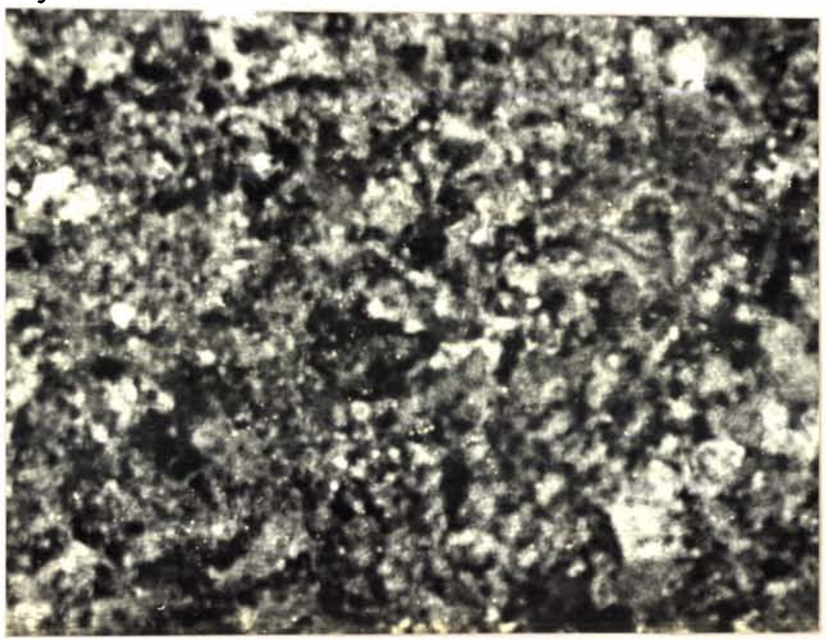
Figure 34. Photograph of limestone from Padappakkara outcrop. Note the lignite pieces embedded in the limestone.

Figure 35. Photograph of limestone from Paravur outcrop. Note the lignite pieces in the limestone.

Figure 36. Photomicrograph of biomicrite. Bar scale 2 mm

Figure 37. Photomicrograph of biocalcarenite. Bar scale 2 mm.

Fig · 34



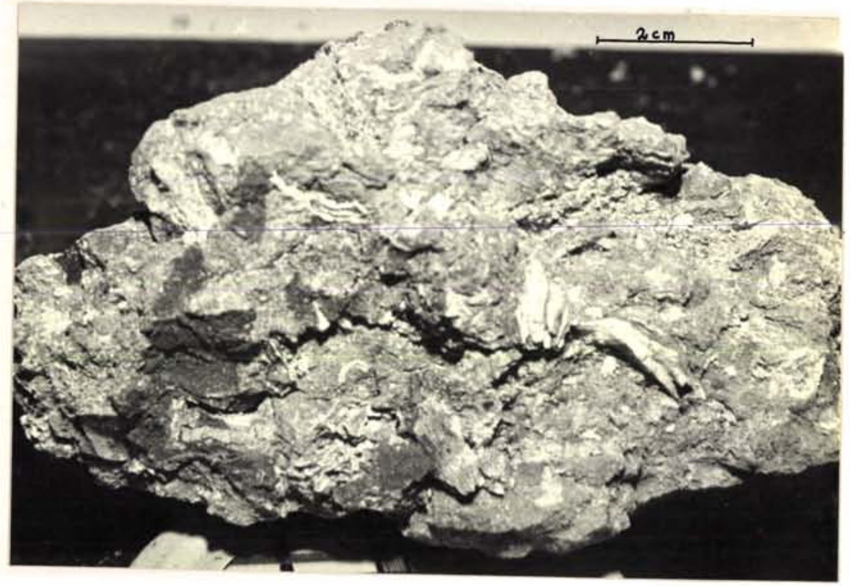
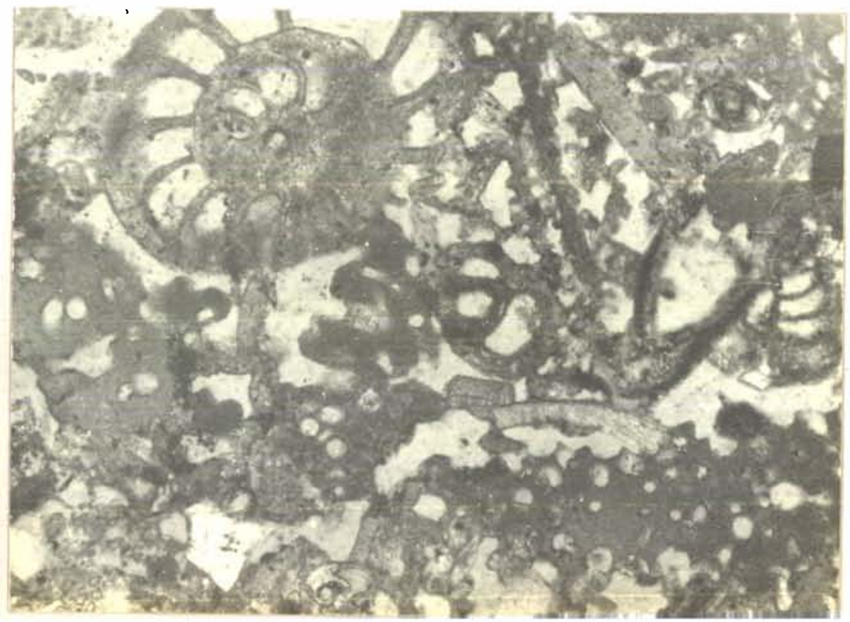


Fig · 35



shells and spines. This can be classed as poorly washed unsorted biopelsparite after Folk (1959, 1962). The mega and micro-fossils constitute 75 to 80 per cent of the rock mass while fine silt and clay occur in the matrix along with some micritic carbonate mud. Fine sand to silt sized quartz grains, both angular and subrounded feldspar (Plagioclase), and detrital grains of sillimanite and some muscovite and phlogopite are seen to be associated. Glauconite occurs as small pellets and blebs in the matrix and as infillings in chambers of the foraminifera and micro-gastropods. Pyrite also occurs in a similar way.

IV.4. Environment of Deposition of Carbonates

Carbonates mainly occur in (1) eulittoral and supralittoral environments (principally in tropical and subtropical environments), (2) sublittoral environments (in water depths approx. between 20 and 200 m (shelf margin) and (3) in the deep sea, down to calcium compensation depth between 4000 and 5000 m (Flugel, 1978). Most of the ancient carbonates are observed to occur in the intertidal (eulittoral) and supratidal (supralittoral) environments. This is because the shallow water of bank will soon fill up to the sea-level if sedimentation is rapid and subsidence is relatively low. On carbonate platform, supratidal carbonate sedimentation may be followed by continental sedimentation prograding across earlier tidal flats. If the carbonate platform rises from the seabeds, supratidal sedimentation may be followed by a break or diasterm or by a carbonaceous continental plant bearing deposits, preceeding the subsequent regression.

The petrographic characters of the biomicrite indicate that the deposition was in a quiet, protected shelf environment free from much winnowing action of the waves. The major limestone horizons encountered in the boreholes near Mayyanad, Ambalapuzha and Thottappally revealed a number of bands of limestone intercalated with clay beds. Besides, a few planktonic foraminifera, Archaias, Operculina, Miogypsina, Rotalia, Elphidium, Quinqueloculina, Triloculina are common foraminifera. Other invertebrate fossils include ostracodes, bryozoans, corals, lamellibranchs and gastropods. The petrographic character and the fossil assemblages are thus indicative of a shallow protected shelf, probably an embayment of the sea in the coastal part. This is also present at Padappakkara as a very thin band (0.5 metres or less).

The bio-calcarenite comprises an assemblage of foraminifera, corals, gastropods, bryozoans and lamellibranchs with some fine silt sized quartz sand and clay as matrix. This indicates reefal condition exposed with winnowing action of sea waves which removed most of the micritic carbonate mud and clay. This horizon, 0.5 metres - 1.0 metres thick, is exposed on the Padappakkara cliff-section. The gray miliolid-bearing marl with Quinqueloculina and Triloculina in abundance encountered at the Edava cliff section indicate shallow stable shelf environment. It overlies a black carbonaceous clay indicating a peneplanation in the source area and a transitional phase of marine transgression. Thus the carbonate facies in the Tertiary sequence of Kerala was in all probability deposited in a shallow protected basin. Increase in grain size and association with arenaceous sediments towards eastern periphery of basin, suggest reworking of older sediments during initial transgression (Hardas et al., 1982). These limestones might have been a product of erosional transgression which Curray (1964) described as a destructive phase of deltaic environment.

The dolomitic nature of the carbonates with eastward increase in the MgO content (Table 10) has been observed between the sections of Mayyanad and Padappakkara. At Padappakkara, the carbonates contain 12 to 20.5% MgO. In the seaward section near Ambalapuzha the MgO content in the carbonate rocks is between 1 and 3 per cent. This indicates dolomitization was intensive in the landward part, especially in the estuarine block. The Dorag Dolomitization has been experimentally shown by Land (1973) that admixture of a small amount of sea water with fresh water results in a solution that is supersaturated with respect to dolomite, and yet has a very low ionic strength. Badiozamani (1973) assumed the mixing of groundwater with sea water in different proportions and found that solutions with 5 to 30% sea water were not only supersaturated with respect to dolomite but were undersaturated with respect to calcite. Accordingly it is advocated that dolomitization is favoured where there is a zone of mixing of fresh and marine waters. This observation suggests that the carbonates were forming on a platform forming embayments with barrier reef near Padappakkara, the eastern most extent of the fossiliferous carbonate facies. This reef might have been formed in a shallow embayment of a relatively stable shelf while the areas away from the reef were possibly subsiding.

V. GLAUCONITE IN QUILON LIMESTONE

Glauconite occurs in the limestone as blebs in the matrix of limestone and as infillings in the chambers of the microfossils (see Fig.38A) of foraminifera and gastropods. Glauconite was encountered at Padappakkara, Edavai and in sub surface sections, at depths of 18-20 m at Mayyanad, at depths of 200-300 m at Ambalapuzha, Trikunnapuzha and Thottappally. A study of size, shape and other properties of glauconite was carried out to understand the mode of its formation.

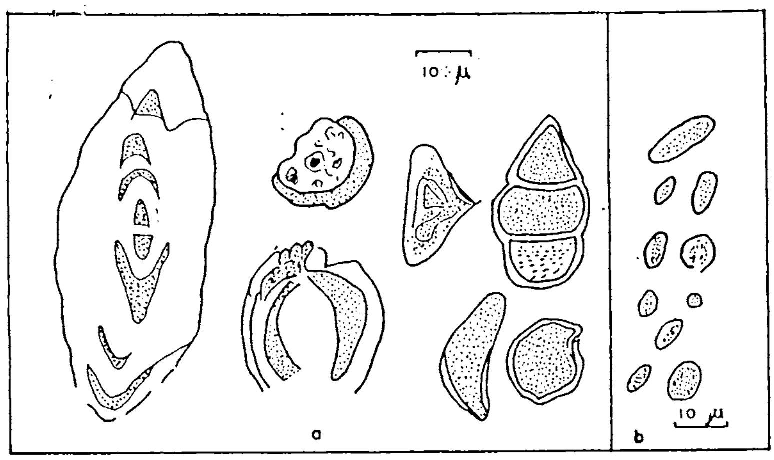
Petrographically the carbonate containing glauconite is a biomicrite comprising fossil shells of various forms and sizes embedded in a micritic matrix. Occasional detrital grains of silt-sized quartz, and rare specks of heavy minerals like garnet and sillimanite have been observed in samples from Padappakkara. Pyrite occasionally developed within the fossils (Fig.39) and sometimes filled up the entire fossil tests forming a mould of the organism, especially seen in some of the drill cuttings of Mayyanad and Ambalapuzha. Characteristics and mode of formation of glauconites are discussed below:

V.1. Microscopic Characteristics

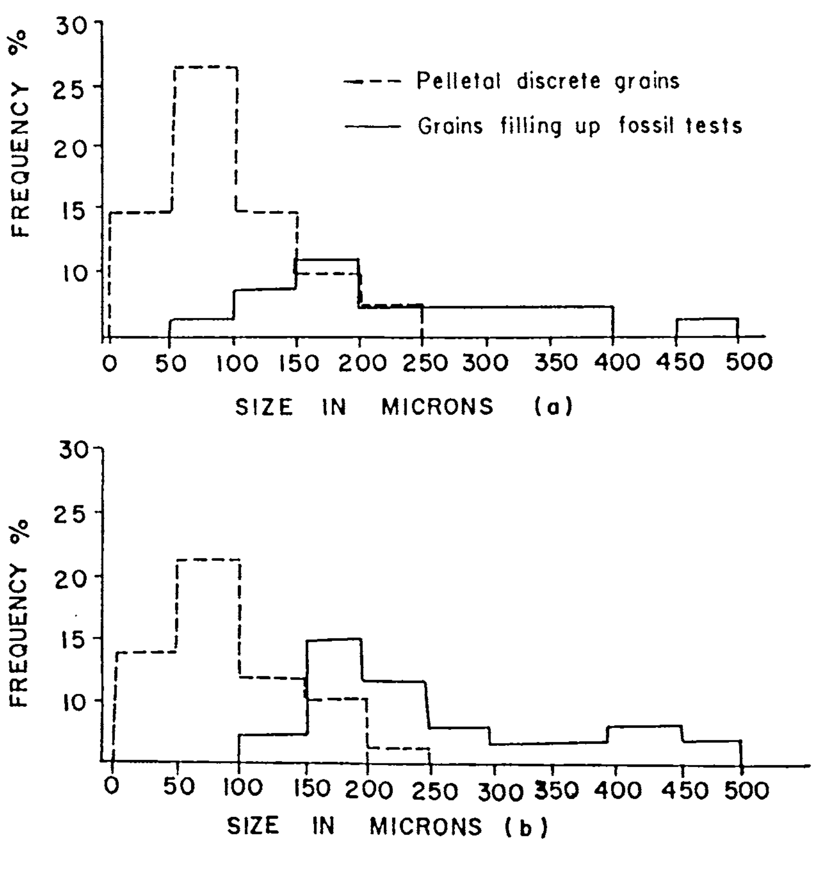
i) Colour: Glauconite occurs as light green and dark grass green varieties. Both of these varieties are intimately associated in the form of fillings in the chambers of fossils as well as pellets and blebs occurring in the matrix. Sometimes a gradation from light green to dark grass green colour is seen within the same grain.

ii) Shape: The shape of most of the glauconite pellets are usually rounded or oval and elongated or bulbous. Those occurring as infillings in the chambers of fossils usually take the various shapes of the chambers of the organisms. Besides there are some elongated capsule shaped grains occurring as discrete bodies in the washed material of drill cuttings from the fossiliferous carbonate horizons.

iii) Size: Granulometric analysis in thin sections shown in the histograms (Fig. 38 B) clearly indicates that the size ranges of the glauconite are quite different for those occurring as fossil-fillings from those occurring in the matrix. The size range of the former is 50 to 500 microns with a mode between 150 and 200 microns, while that of the latter is restricted between 0 to 250 microns with the mode between 50 and 100 microns. Volumetrically the fraction infilling the fossil shells constitute more than 70% of the



A . Glauconite (a) as fossil test fillings, (b) as pellets.



B . Grain size distribution of glauconite in the early Miocene carbonate rocks of coastal Kerala; (a) & (b) are samples from Padappakkara and Mayyanad respectively.

Figure 38 · Glauconite – shape and grain size total glauconite content of the rock. The glauconite content in these carbonates varies from 2% to 10%.

V.2. Mode of formation of glauconite

Glauconite is supposed to have formed mainly by alteration of infillings in the empty foram tests (McRae, 1972). In the present case both the varieties of glauconite, light green and dark grass green occur as fillings in fossil tests as well as discrete bodies in the matrix. This clearly indicates a biochemical control on the genesis of the glauconite. Sarma and Basumallick (1969) described yellow green and grass green varieties of glauconite from the Eocene carbonates of Mikir hills, Assam. They ascribed an allochthonous origin to the dark grass green variety occurring in the matrix and an authigenic nature to yellow green variety that filled up from tests. This is likely because even in an oxidising environment a reducing microenvironment can prevail within the test of the organisms (Burst, 1958 a, b). Glauconite, though requiring reducing conditions for its development, occurs in well oxigenated environments where there is rich supply of organic matter. Thus it is found on open sea floors today, but inside the tests of foraminiferids where the microenvironment that had at one time a negative redox potential (Bathurst, 1975). This reducing environment might have originate through decayed soft parts of the organisms (Thrivikramji and Ghosh, 1983). Similarly the glauconite pellets in the matrix have mainly formed after faecal pellets as indicated by the size and shape of the pellets and presence of larger gastropods and lammellibranchs in the rock. Like the fossil chambers, the decaying faecal pellets probably produced the reducing environment facilitating the formation of glauconite in them. The smoothness of the grains and their well rounded circular, oval and elongated shapes strongly support such origin. However, in a number of thin sections studied no secondary transformation of glauconite from other mafic minerals like biotite could be observed. The form, the shape and the size of glauconite grains with circular or oval sections characteristically indicate that they are mostly formed after faecal pellets in the matrix.

Presence of glauconites suggests that the carbonates were formed in continental shelves in neritic environment at depths not exceeding 400 fathoms (Cloud, 1955). These conditions have also been indicated by the fossil assemblages and petrography of the biocalcarenite associated with these glauconitic infillings.

VI BIOSTRATIGRAPHY

VI.1. Foraminiferal Studies

The Quilon Formation (see Table 7) comprises limestones, marls, calcareous clays, calcareous sandstones biocalcarenites and massive compact biomicrites which are well developed in the various subsurface sections at Mayyanad, Chavara and around Alleppey. The biocalcarenites with reefal fossil assemblage containing corals, bryozoans, and echinoids with shallow water foraminifera like miliolids and operculinids in abundance have been recorded at Padappakkara and in the upper part of the Quilon Formation in the subsurface sections. Planktonic foraminifera have been recorded at various depths in these boreholes. Though their frequency is very low compared to the benthonic forms, it is well established that such planktonic foraminifera are of great use in deciphering stratigraphic position of the containing formations (Berggren, 1969; Blow, 1969; Posthuma, 1971; Stainforth et al., 1975).

Sub-surface explorations in connection with ground water investigations in the coastal tract of central

Kerala have revealed that the calcareous Quilon Formation has a thickness of 100-130 metres on the western margin of the coastal plains with a prolonged sedimentation history of chiefly inner shelf carbonate facies. In the bore holes near Ambalapuzha, Trikunnapuzha and Thottappally, around Alleppey, the Quilon Formation extends between 200 metres to 356 metres. The calcareous Quilon Formation contains at its base a 25 metres thick zone of black carbonaceous clay with foraminifera and ostracodes. Below this, the sequence contains predominantly sandstones with clays and lignites. An analysis of the foraminifera of the samples from these bore-holes revealed the presence of Oligocene Zone fossils viz, Globigerina sellii, Globorotalia opima opima, Globigerina cf. ampliapertura in the depth zones from 290 metres to 356 metres. Globigerina binaiensis has been noted at a depth of 258 metres (Plate 1).

The upper part of the Quilon Formation (200 metres to 270 metres) is characterised by Globorotalia fohsi peripheroronda, Globigerinoides quadrilobatus altiapertura, Globigerinoides quadrilobatus triloba and Globigerinoides sicanus Assemblage Zone (Plate 2) which marks the Lower Miocene (N.6 - N.9

planktonic foraminiferal zones after Blow, (1969). At the depth of 290 metres to 310 metres, occurs Globigerina binaiensis (P. 22, zone after Blow, 1969), which marks the Late Oligocene. Globorotalia opima opima and Globigerina of. ampliapertura which marks the middle Oligocene (P.19-P.20), occurs between 330 metres and 356 metres. The characteristic Early Miocene larger forams so far referred to from the Quilon Formation like Archaias malabarica, Miogypsina sp. and Lepidocyclina sumatrensis are restricted to the upper part of the Quilon Formation, which occur up to 90 metres in the bore holes.

Larger foraminifers like Actinosiphon sp., Penopercu-loides sp. and Assilina sp. were recorded indicating Early - Middle Eocene age, from the subcrop section at Ambalapuzha of 454-494 metres.

VI.2. Systematic Description of Foraminifers

Archaias malabarica Carter, 1853

Figure: 40

Super family	: Miliolicea Ehrenberg, 1839
Family	: Soritidae Ehrenberg, 1839
Sub Family	: Archaiasinae Cushman, 1927
Genus	: Archaias De Montfert, 1808 (syn. Orbiculina Lamarck, 1816)

Orbitolites malabarica Carter, 1853, P. 425
pl. 16-b, figs. 1-4.

Orbiculina malabarica (Carter), Douville, 1902
pp. 299-301, 305

Archaias malabarica (Carter), Vaughan, 1928, p. 302

Taberina malabarica (Carter), Henson, 1950,
p. 50, Pl. 3, figs. 7, 11-12.

Test typically lenticular, chambers planispirally arranged, subdivided into chamberlets by radial secondary septa. Wall usually not preserved, when partially preserved it is finely ornamented by spiral and radial lines probably corresponding to spiral and radial septa, which form ridges on the surface. This is characteristically noted on larger forms which leave only impressions of their external faces on the rock surfaces. The shells are thin and flat. Aperture as small pores in the peripheral wall.

Occurrence : Loose calcareous sand and gray limestone of Padappakkara section and upper part of Ambalapuzha region.

Distribution : Lower to Middle Miocene

Miogypsina Sp. Sacco, 1893

Figure: 41

Super family : Rotaliacea Ehrenberg, 1839

Family : Miogypsinidae Vaughan, 1928

Genus : Miogypsina Sacco, 1893

Test large lenticular, triangular to fan shaped and subcircular in outline; juvenarium peripheral; chambers planispirally arranged; surface with tuberous ornamentations.

Occurrence : Occur in abundance in the calcareous sandstone of Padappakkara.

Distribution : Upper Oligocene to Lower Miocene

Lepidocyclina (Nephrolepidina) sumatrensis Brady, 1885

Figure: 42

Super family : Orbitoidacea Schwager, 1876

Family : Lepidocyclinidae Scheffen, 1932

Sub family : Lepidocyclininae Scheffen, 1932

Genus : Lepidocyclina Gumbel, 1870

<u>Orbitoides sumatrensis</u> Brady, 1875, p. 536 pl. 14, fig. 3a-b

<u>Lepidocyclina sumatrensis</u> (Brady) Caudri, 1939, pp. 185-187 243, 247, 250-257, pl. 7, figs. 36-41, 44

<u>Lepidocyclina (Nephrolepidina) sumatrensis</u> (Brady, 1885) Cole, 1957, p. 343, pl. 104, figs. 1-9 pl. 106, figs. 5; pl. 109, fig. 1-3.

Axial section presented here brings out the embryonic apparatus consisting of a smaller protoconch embraced to about half of its diameter by a larger deuteroconch, followed by two primary auxiliary chambers; two adauxiliary chambers; median chambers arcuate to spathulate with annular stolons; lateral chambers rectangular.

Occurrence: Outcrops of Padappakkara and bore holes at Ambalapuzha, Trikunnapuzha and Chavara.

Distribution: Middle Eocene to Middle Miocene

Super family: Globigerinacea Carpenter, Parker and Jones, 1862

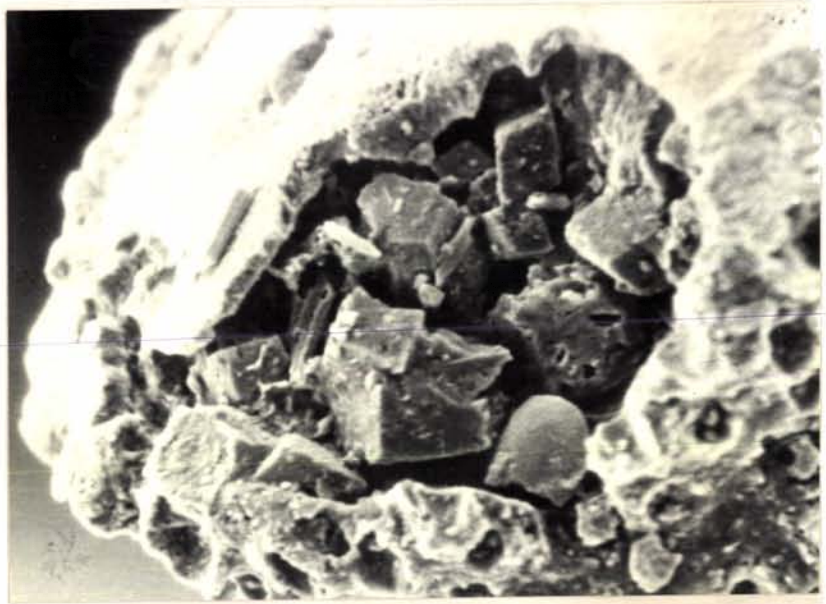
Family : Globigerinidae Carpenter, Parker & Jones, 1882.

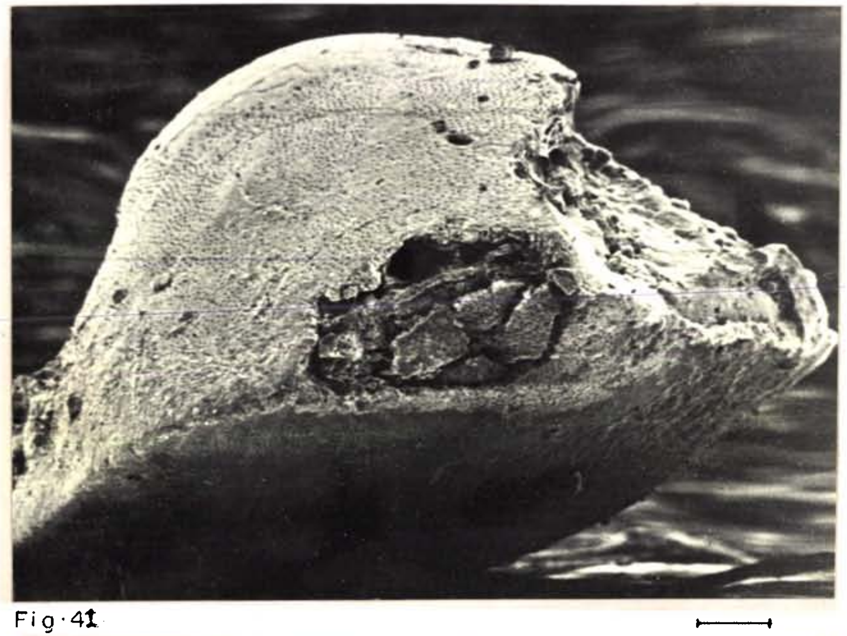
Figure 39. SEM - micrograph of pyrite crystals in foraminiferal test (x 1000)

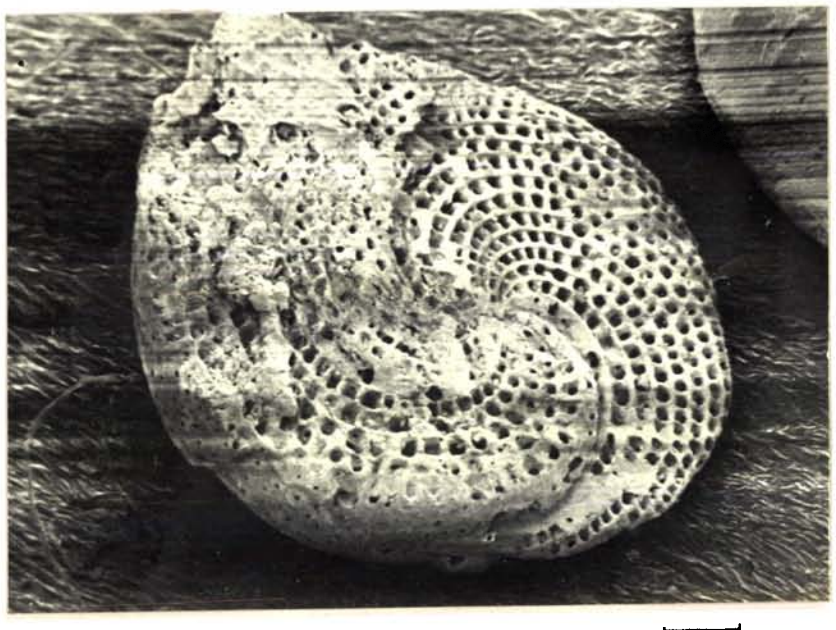
Figure 40. SEM - micrograph of *Archaias malabaricus*. Bar scale 200 μ

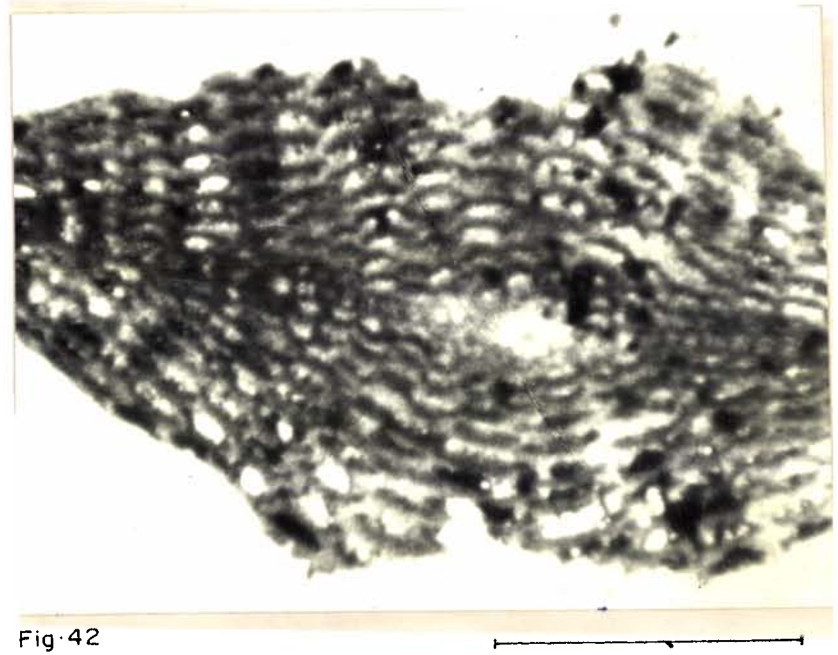
Figure 41. SEM - micrograph of *Miogypsina* sp Bar scale 200 μ

Figure 42. Photomicrograph of *Lepidocyclina (Nephrolepidina) sumatrensis* Bar scale 2 mm.


Fig·39


Fig·41


Fig·40


Fig·42

Sub family : Globigerininae Carpenter, Parker & Jones, 1862

Genus : Globigerina d' Orbigny, 1826

Globigerina binaiensis

Plate 1, Fig. 1

Globigerina? aspera Koch, 1926, p. 737, 746, fig. 22-23
Globigerina binaiensis, Koch, 1935, p. 558 - Blow, 1969 p. 216, 222, 316, pl. 13, fig. 1-2, Postuma, 1971, p. 262-263.

Test a trochospire of closely appressed chambers which increase rapidly in both size and axial prolongation so that final whorl contains only 3 chambers. Spiral profile characterised by acute angle between periphery and apertural face of final chamber; side view dominated by flat, roughly semicircular apertural face occupying more than half of visible area. Adult sutures distinct, incised. Aperture a low arch-embracing 2 penultimate chambers. Surface is finely cancellate. Diameter 0.4 to 0.5 mm.

Distribution: This species is a useful zonal marker but appears to be confined to the tropical portion of the Indo-Pacific province (Stainforth et al., 1975). It is found mainly in late Oligocene beds (Globigerina ciperoensis ciperoensis Zone)

Occurrence: Bore holes at Ambalapuzha and Trikunnapuzha.

Globorotalia opima nana Bolli

Plate : 1 .; Fig. 2

Globigerina wilsoni Cole (?) Stainforth, 1948b, p.117, pl. 26, fig. 1-3.

Globorotalia opima nana Bolli, 1957b, p. 118, pl. 28, fig. 3 Bolli, 1957c, p. 169 - Pessagno, 1963 p. 53, pl. 2, fig. 1-2.

Turborotlia increbescens (Bandy), Bermudez, 1960 p. 1322.

Globorotalia (Turborotalia) opima nana Bolli. Blow & Banner, 1962, p. 119 - Blow, 1969, p. 215-219, 352-353, pl. 39, fig. 1

Globigerina opima nana (Bolli). Hofker, 1963a, p. 199-200 fig. 1-3. - Hofker, 1968, p. 15, pl. 6, fig. 5

Globorotalia (Turborotalia) nana nana Bolli Jenkins, 1971, p. 123, pl. 11, fig. 303-308

Test a small, tightly coiled, almost planispiral trochospire; 4 chambers in final whorl. Spiral outline almost a square with rounded corners. Sutures clear that only slightly depressed, typically forming a right-angled cross on umbilical side. Aperture a curved slit around periphery on umbilical side, commonly carrying a slight rim or lip, surface smooth. Diameter 0.3 mm.

Distribution: Globorotalia opima nana ranges through the Late Eocene and most of the Oligocene and has a wide geographic distribution (Stainforth et al., 1975).

Occurrence: Bore holes at Ambalapuzha and Trikunnapuzha.

Globorotalia opima opima

Plate : 1 Fig. 5

Globorotalia opima opima Bolli, 1957b, p. 117, pl. 28 fig. 1-2, Blow, 1959, p. 92-95 Pessagno, 1963, p. 53, pl. 1, fig.4-6.

Globorotalia (Turborotalia) opima opima Bolli, Blow & Banner, 1962, p. 119 - Blow, 1969, p. 215-219,352-353, pl. 39, fig. 2-3.

Globorotalia increbescens opima Bolli, Bandy, 1964b p. 7-8, 13, fig. 5

Globorotalia opima Bolli, Jenkins & Orr, 1972, p. 1101-1102, pl. 28, fig. 10-12

Test a depressed trochospire of bulbous chambers, initial portion almost planispiral, spiral surface flat to concave; 4 chambers in last whorl. Spiral profile subcircular with indentations at sutures; side profile ovate. Early sutures obscure, later ones distinct, approximately radial, slightly incise. Aperture a low arched slit extending from spiral suture to umbilical axis, occassionally with slight rim or tip. Diameter 0.5 mm.

Distribution: Globorotalia opima opima is a valuable zonal index, being recorded only from the Oligocene within the interval between extinction of Pseudohastigerina and first appearance of Globorotalia kugleri (Stainforth et al., 1975).

Occurrence: Bore holes at Ambalapuzha and Trikunnapuzha.

Globigerina sellii (Borsetti, 1959)

Plate: 1, Fig. 2

Globigerina conglomerata (part)Beckmann, 1953
p. 391, pl. 25, fig. 8-9

Globoquadrina sellii Borsetti, 1959, p. 209,
pl. 1, fig. 3

Globigerina oligocaenica Blow & Banner, 1962,
p. 88-89, pl. 10, fig. G, L-N
Bandy, 1964b, p. 7

Globigerina sellii (Borsetti). Blow & Banner, 1962, p. 146 - Berggren, 1963, p. 471-472 - Reiss & Gvirtzman, 1966, p. 314 fig. 84 - Saunders & Cordey, 1968, p. 179, 181 - Blow, 1969, p. 213-222, 322, pl. 19, fig. 4-6 Fuenmayor, 1969 p. 356-367, pl.1, fig. 1-5 Soediona, 1969, p. 343, pl.2, fig. 1 - Postuma, 1971, p. 272-273 Duque - caro, 1971, p. 366

Test medium size to large, a globose trigonal coil. Bulk of test formed by 3 chambers of last whorl, more than doubling in size as added so that final chamber forms fully one-half test. Spiral and side profiles both subcircular to ovate with indentations at sutures; if slightly tilted, flattening of apertural face breaks smooth curve of profile. Sutures distinct, variably depressed. Umbilicus small to non existent. Aperture a slit or low arch, bordered by delicate flange at base of last chamber; apertural face appreciably flattened and, in immediate area of aperture, recessed.

Distribution: This species is a reliable guide to Oligocene age; first reported from northern Italy (Stainforth et al., 1975).

Occurrence: Bore holes at Ambalapuzha and Trikunnapuzha.

Globigerina cf ampliapertura

Plate: 1, Fig. 5

Globigerina apertura Cushman - Bronnimann, 1950a, p.80

Globigerina ampliapertura Bolli, 1957b, p. 108, pl.22 fig. 4-7 Bermudez, 1960, p. 1155, pl.3, fig. 8 - Hofker, 1968, p. 17, pl.7, fig.2 - Blow, 1969

Glogigerina (Globigerina) ampliapertura Bolli, Jenkins, 1971, p. 137, pl. 15, fig. 423-425

Test a regular trochospire of inflated chambers which maintain their shape while increasing rapidly in size. Consistently 4 chambers in last whorl. Spiral outline subquadrate to sub circular; overall shape globose, spiral side flattened. Sutures distinct, depressed to incised ; on umbilical side radial, on spiral side tangential to spire and giving it a rectangular aspect. Aperture a smooth-rimmed arch aligned obliquely across umbilical region, usually conspicuous through somewhat concealed by projecting inferior margin of last chamber, embracing three penultimate chambers. Essentially nonumbilicate, as chambers reach axis of coiling on umbilical side. Surface finely cancellate to granulose Diameter 0.6 mm.

Distribution: *Globigerina ampliapertura* is a valuable index fossil, widely distributed and limited in range to the late Eocene and early Oligocene (Stainforth et al, 1975).

Occurrence: Bore holes at Ambalapuzha and Trikunnapuzha.

Globigerinoides quadrilobatus altiapertura

Plate : 2 : Fig. 3

Globigerinoides triloba altiapertura Bolli, 1957 b, p. 113, pl. 25, fig. 7-8 - Blow, 1959 p. 1?7, pl. 10, fig. 61

Globigerinoides trilobus (Reuss) var. *altiaperturus* Bolli. Bermudez, 1960, p. 1246

Globigerinoides quadrilobatus altiaperturus Bolli Banner & Blow, 1965 a, p. 111, fig.9 - Cordey, 1967, p. 651-653, fig.2, - Blow, 1969, p. 325.

Globigerinoides altiaperturus Bolli. Jenkins, 1971 p. 174-175, pl.20, fig. 604-606

Test ovoid with gaping apertures, a low - spiral quadrate coil of appressed globular chambers, each approximately, double size of preceeding chamber. Periphery in both vertical and side aspects ovate, sutures initially faint, later depressed. Primary aperture a large circular arch facing outward along prolongation of spire, completely embracing umbilical part of penultimate chamber. Final chamber also carries large lunate aperture contiguous with spiral suture on spiral side. Surface coarsely cancellate, hispid. Diameter 0.50 mm.

Distribution *Globigerinoides quadrilobatus altiapertura* is a useful index of Early Miocene age (mainly the *Catapsydrax stainforthi* Zones). It was first recorded from the Lower Miocene (*Catapsydrax dissimilis* zone) in the Cipero Formation of Trinidad (Stainforth et al., 1975).

Occurrence: Bore holes at Ambalapuzha, Trikunnapuzha and Thottappally.

Globigerinoides quadrilobatus trilobus

Plate: 2, Fig. 1

Globigerinoides triloba (Reuss). Coryell & Rivero, 1940, p. 340 - Coryell & Mossman, 1942, p. 238, pl. 36, fig. 29-30 Cushman, 1946, p.20, pl.3, fig. 8, pl.4, fig. 16-18.

Globigerinoides trilobus (Reuss). Grimsdale, 1951, p.446- Drooger, 1953, p. 142 - Bermudez, 1960, p.1244, pl. 12, fig. 6 - Lipps, 1964, p. 120, pl.2, fig.3

Globigerinoides triloba triloba (Reuss), Bolli, 1957b, p. 112, pl. 25, fig. 2 - Blow, 1959, p. 187, pl. 11 fig. 60

Globigerinoides quadrilobatus trilobus (Reuss) Blow & Banner, 1962, p. 137, Banner & Blow, 1965a, p. 105-112, pl. 16, fig. 4 - Blow, 1969, p. 326

Test consists of two unequal subspherical portions separated by a conspicuous incised suture. One portion is initial quadrate coil of appressed chambers, other is final chamber. On umbilical side only 3 chambers visible. Periphery with incised median line. Primary aperture a simple arch turned inward to embrace earlier portion of test.

Distribution: *Globigerinoides quadrilobatus trilobus* developed explosively in Early Miocene time. The *Globigerinoides* Datum is highly important for the separation of Neogene from Paleogene (Stainforth et al., 1975).

Occurrence: Bore holes at Ambalapuzha, Trikunnapuzha and Thottappally.

Globigerinoides sicanus de Stefani, 1952

Plate: 2, Fig. 2.

Globigerinoides conglobata Cushman & Stainforth, 1945 p. 68, pl. 13, fig. 16 Stainforth, 1948 b. p. 121, pl. 26, fig. 4 - Weiss, 1955, p.311, pl.3, fig. 17

Globigerinoides sicana de Stefani, 1982, pl 9, note.4 (Type figure designated as Cushman & Stainforth, 1945, pl. 13, fig. 6)

Globigerinoides sicanus de Stefani, Bermudez, 1960, p. 1240, pl. 11, fig. 12; pl.12, fig. 1, Blow, 1969 p. 326-327, pl.3, fig. 10-11 Postuma, 1971 p. 304-305.

Test ovoid to spherical, divided unequally by circumferential depression, smaller portion being initial coil of rapidly enlarging and appressed chambers, larger portion hemisperhical final chamber. Main aperture a crescentric slit, on umbilical side; supplementary apertures one or more triangular to slit openings on spiral side. Surface is finely cancellate. Diameter 0.4-0.6 mm.

Distribution: Globigerinoides sicanus is intermediate between Globigerinoides quadrilobatus triloba and the genus Praeorbulina, evolution marked by increasing sphericity of test and diminution of apertures. (Stainforth et al., 1975) G. sicanus generally show much variation in the amount of test occupied by the final chamber and in the width of apertural slits (Op. cit). G. sicanus appeared near the end of Early Miocene and an important index fossil (Bolli, 1957; Blow, 1969; Jenkins, 1971).
Occurrence: Bore holes at Ambalapuzha, Thottappally and Trikunnapuzha

Globorotalia fohsi peripheroronda Blow & Banner, 1966

Plate: 2, Fig. 4

Globorotalia (Turborotalia) fohsi barisanensis (Leroy). Banner & Blow, 1959, p. 22, pl. 1 fig. 1

Globorotalia (Turborotalia) peripheroronda Blow & Banner, 1966, p. 294, pl. 1, fig. 1;

pl. 2, fig. 1-3 Blow, 1969, P. 230-233, 354.

Turborotalia peripheroronda Blow & Banner. Lipps, 1967, p. 996 Lipps, 1969, p. 1805, fig. 4

Globorotalia fohsi peripheroronda Blow & Banner, Bolli, 1967; p. 505-508, fig. 2 - Beckmann - et al., 1969, p. 101

Globigerina barisanensis Leroy (sic). Hofker, 1968 p. 49-50, pl. 24, fig. 4-5.

Globorotalia peripheroronda Pujol, 1970, p. 201-219.

Turborotalia foshi peripheroronda (Blow & Banner) Soediono, 1970, p. 217, pl.1. fig. 1.

Globorotalia (Turborotalia) mayeri barisanensis Leroy, Jenkins, 1971, p. 119, pl. 11, fig. 288-293.

Turborotalia (Turborotalia) peripheroronda Blow & Banner, Biely & Salaj, 1971, p. 76-89.

Test a discoidal trochospire, umbilical side more convex than spiral, 5 to 6 chambers in final whorl. Spiral profile subcircular, tending to become slightly lobulate. In umbilical aspect sutures distinct, lightly incised, initially radial but becoming curved; in spiral aspect sutures indistinct on initial portion, later distinct and commonly incised, recurved, defining coma shaped to crescentic chambers. Aperture a slit from umbilicus to periphery, bordered by a thin, flauge-like lip.

PLATE 1

1. *Globigerina binaiensis*

2. *Globigerina sellii*

3. *Globorotalia opima nana*

4. *Globigerina* cf *ampliapertura*

5. *Globorotalia opima opima*

Plate ·I

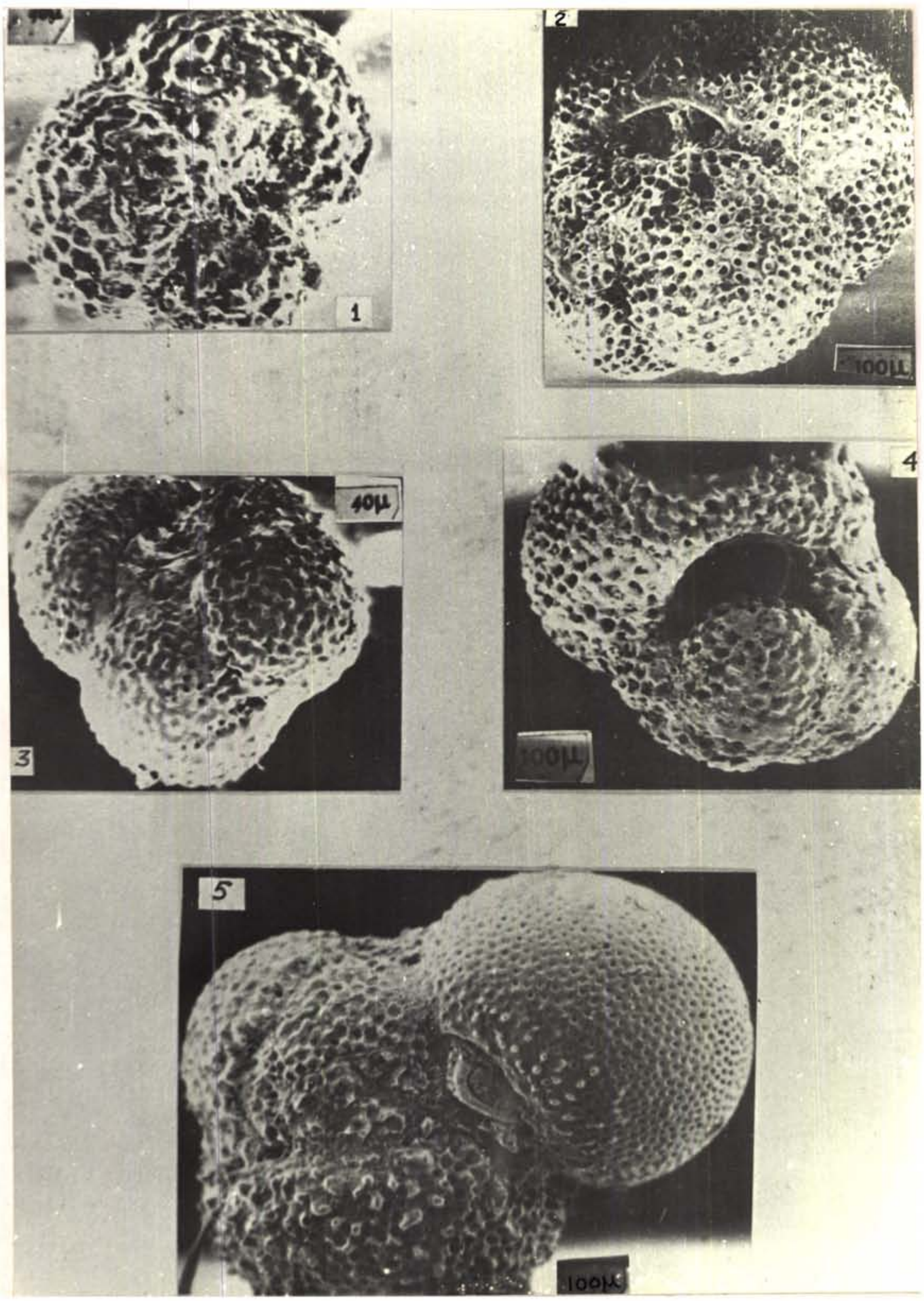


PLATE 2

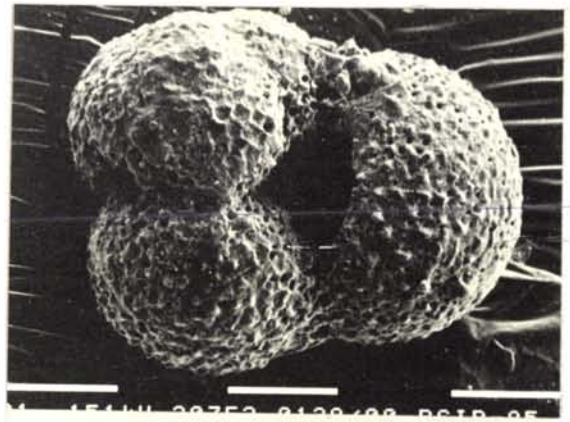
1. Globigerinoides quadrilobatus trilobus

2. Globigerina sicanus

3. Globigerinoides quadrilobatus altiapertura

4. Globorotalia fohsi peripheroronda

Plate·2



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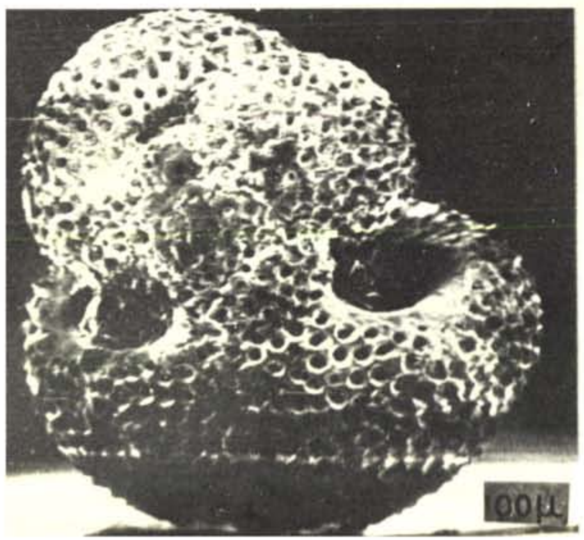


4

Distribution Early to Middle Miocene - approximately *Catapsydrax dissimilis* Zone to within *Globorotalia foshi lobata/robusta* (Stainforth et al., 1985)

Occurrence: Bore holes at Ambalapuzha, Trikunnapuzha and Thottappally.

Actinosiphon sp

Fig. 43

Family Orbitoididae, Schwager, 1876

Type species : *Actinosiphon semmesi* Vaughan, 1929

The test is lenticular with bilocular embryonic chamber completely surrounded by a ring of about 8 to 9 periembryonic apparatus and well develeped lateral chambers. The embryonic apparatus consists of a larger subspherical initial chamber followed by a smaller chamber.

Remarks: According to Vaughan (1929) these genus has a strong resemblance to *Pseudoorbitoides*, but it is different from that genus by its single layer of equatorial chambers and the stoloniferous passages through the walls of chambers and further there are no radial markings as in the *Pseudoorbitoides*. Loeblich and Tappen (1964) are of the opinion that although *Lepidoorbitoides* and *Actinosiphon* resemble the *Lepidocyclina* in form and structure, they cannot be related to them.

A similar one has been reported from the Ranikot Beds of Punjab Salt Range, N.W. India by David and Pinfold (1937) calling it Polylepidina punjabensis and later Narayana Rao (1940) included this genus under Orbitosiphon. Actinosiphon has been assigned to the Orbitoides and the Actinosiphon is the final representative of the dominantly Upper Cretaceous family.

Distribution : Early Eocene

Occurrence : Ambalapuzha and Trikunnapuzha

Penoperculoides sp.
Figure : 44

Family : Rotallidae Ehrenberg, 1839

Sub family : Cuvillierininae Ehrenberg, 1839

Genus : Penoperculoides Cole and Gravell, 1952.

Remarks: Identification of this species has been made on the basis of the description given by Loeblich and Tappan (1964). The axial section obtained from the thin section which is presented here agrees with the details given by them.

Distribution : Middle Eocene

Occurrence : Ambalapuzha

Assilina Sp

Figure 45

Family Nummulitidae de Blainville, 1825

Sub family Nummulitinae de Blainville, 1825

Genus Assilina d' Orbigny, 1839

Remarks Axial section presented here resembles the section given by Loeblich and Tappan (1964)

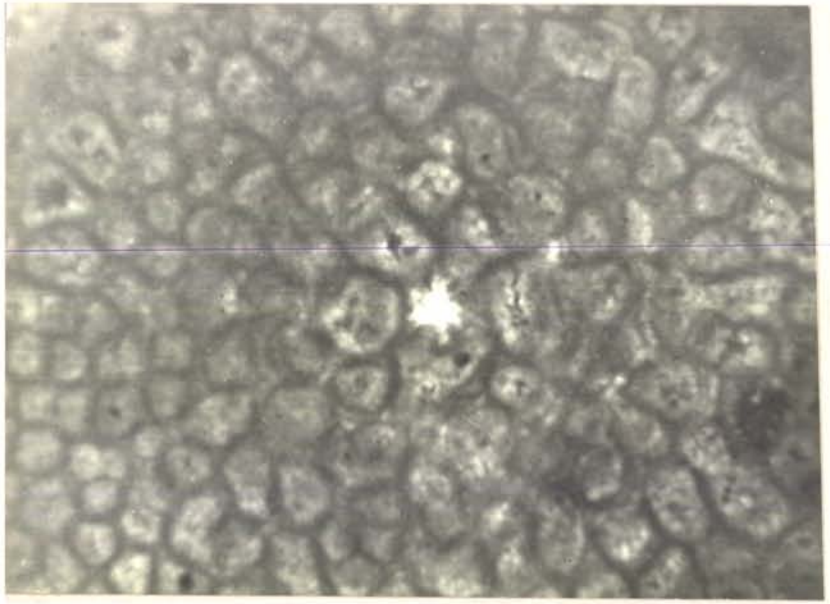
Distribution Middle Eocene

Occurrence Ambalapuzha

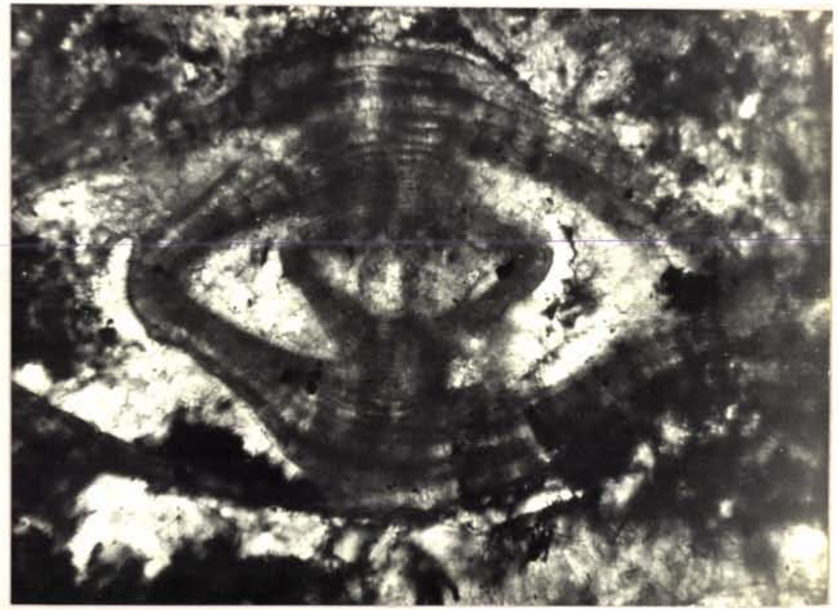
Figure 43. Photomicrograph of _Actinosiphon_ sp. (x 63)

Figure 44. Photomicrograph of _Penoperculoides_ sp. (x 63)

Figure 45. Photomicrograph of _Assilina_ sp. (x 63)



Fig·43



Fig·44

Fig·45

VI.3. Palynological Studies

Palynostratigraphy involves the study of fossil spores and pollen and its application to stratigraphic studies. The pollen and spores are distinguished on the basis of morphology such as size, shape, apertures, surface sculpture and wall structure (Faegri and Iversen, 1975; Kapp, 1969). The taxonomy of spores and pollen is mostly based on morphology. The relatively indestructible nature of palynomorphs, their relative abundance etc make them very useful for stratigraphic studies (Tschudy and Scott, 1969). They are also good indicators of the ecological habitat.

The study of palynomorphs in the Tertiary sediments was undertaken mainly to obtain stratigraphic correlation and relative age of the sediments. It is found that this is an useful and reliable way to understand the relative age and correlation of the sediments, as there are very few outcrops containing faunal assemblages whereas peat/lignite/carbonaceous sediments have a widespread occurrence in Kerala.

The samples from depths of 506 metres to 509 metres and 461 metres to 464 metres from the Ambalapuzha and Trikunnapuzha bore holes were found to contain Palmaepollenites, Couperipollis, Proxapertites, Polycolpites, Meliapollis, Verrutricolporites, Retitribrevicolporites, Paleosantalaceaepites, Striatocolporites and Proteacidites in appreciable numbers.

It is a well known phenomenon in India that palm pollen generally represented by Palmaepollenites, Palmidites, Couperipollis and Spinozonocolpites, are mostly restricted to Paleocene-Eocene. Of the four genera, Spinozonocolpites stands for the Nypa type of pollen which being a mangrove has a special environmental requirement and is not found in all the other Lower Tertiary formations of India (Kar, personal communication). So presence of Palmaepollenites and Couperipollis in these sediments generally points towards a Paleocene-Eocene age. However, typical Paleocene index species like Dandotiaspora dilata, Dandotiaspora telonata, Dandotiaspora auriculata and Dandotiaspora densicorpa which are invariably found in all the Paleocene sediments of India, have not been recorded in this area. Moreover, the presence of Proxapertites, Polycolpites, Meliapollis, Verrutricolporites, Proteacidites, Retitribrevicolporites, Paleosantalaceaepites and Striatocolporites together with palm pollen indicate Eocene age.

From 446 metres to 443 metres and 288 metres to 276 metres Crassoretitriletes, Trisyncolpites and Bombacacidites together with Deltoidospora, Cyathidites, Lygodiumsporites, Cheilenthoidspora, Polypodiaceaesporites, Tricolpites, Margocolporites, Ctenolophonidites Paleosantalaceaeapites, Meliapollis and some microplanktons are found.

The commencement of Crassoretitriletes in these sediments is significant. Germeraad, et al., (1966) studied in detail the occurrence and behaviour of this genus in pantropical areas. They noted that this genus generally occurs in Lower Oligocene and continues into the Miocene. Trisyncolpites is an important palynological taxon in Oligocene of Kachchh, western India and a cenozone Trisyncolpites ramanujamii has been designated after it. Bombacacidites generally makes an appearance in India in Oligocene and is also found in Miocene. So the presence of Crassoretitriletes, Trisyncolpites and Bombacacidites demarcate Oligocene in this section.

Occurrence of Malvacearumpollis, Hibisceaepollenites, Psiloschizosporis and Quilonipollenites mostly delineate Lower Miocene in the bore hole from the depth of 278-279 metres. It may be mentioned here that in Khari Nadi Formation (Lower Miocene) in Kachchh, western India, Kar (1985) also recovered Malvacearumpollis, Hibisceaepollenites and Psiloschizosporis and considered them as marker fossils for Lower Miocene. This genus is rather poorly represented in Kerala though in Oligocene-Miocene sediments of Kachchh, Meghalaya and Assam, it is found as one of the most dominant elements. Striatriletes - the dispersed spores of Ceratopteris (family-Parkeriaceae) favours fresh water coastal plain and perhaps in Kerala during Oligocene-Miocene, it was not prevalent. Miocene palynological assemblage is richest in the bore-core and the following genera are frequently found: Cyathidites, Lygodiumsporites, Tricolpites, Retitrescolpites, Lakiapollis, Ctenolophonidites, Triporopollenites, Polyporites, Phragmothyrites, Parmathyrites, Notothyrites and microplanktons.

To sum up, of the total thickness of 600 metres analysed in these deep bore holes, Eocene is represented between depths 443 metres down to 509 metres. Possibly Early Eocene is marked by the sediments ranging in depth from 509 metres, part of which and underlying sediments may represent Paleocene, though typical Paleocene zone fossils were not found in them. Based on palynological evidences the Oligocene base appears to be at around 443 metres depth with an upward vertical extent upto 279 metres. Oligocene planktonic foraminifera are noticed between depths of 290 metres and 356 metres.

The Miocene-Oligocene boundary may lie between 256 metres and 278 metres.

Lignitic and carbonaceous clay samples for palynological studies were collected from the outcrops at Thonnakal, Kundara, Padappakkara, Varkala, Edava Paravur, Cannanore and Palayangadi.

Thonnakkal

Common palynological fossils

Phragmothyrites, Notothyrites, Parmathyrites, Kutchiathyrites, Inapertisporites, Dicellaesporites, Multicellaesporites, Pluricellaesporites, Lygodiumsporites, Todisporites, Polypodiaceaesporites, Retipilonapites, Quilonipollenites, Monoporopollenites, Polyporites and Triporopollenites.

Kundara

Common palynological fossils

Phragmothyrites, Parmathyrites, Inapertisporites, Dicellaesporites, Lygodiumsporites, Crassoretitriletes, Striatriletes, Polypodiaceaesporites, Polypodiisporites, Retipilonapites, Tricolpites, Retitrescolpites, Ctenolophonidites, Quilonipollenites, Monoporopollenites, Polyporites and Triporopollenites.

Padappakkara

Common palynological fossils

Phragmothyrites, Notothyrites, Parmathyrites, Kutchiathyrites, Inapertisporites, Monoporosporites, Dicellaesporites, Pluricellaesporites, Lygodiumsporites Todisporites, Polypodiaceaesporites, Tricolpites, Retitrescolpites, Ctenolophonidites and Polyporites

Varkala

Common palynological fossils

Phragmothyrites, Inapertisporites, Multicellaesporites, Pluricellaesporites, Diporisporites, Lygodiumsporites, Todisporites, Crassoretitriletes, Polypodiaceaesporites, Quilonipollenites, Tricolpites, Retitrescolpites, Ctenolophonidites, Monoporopollenites and Triporopollenites

Edaval

Common palynological fossils

Phragmothrites, Parmathyrites, Multicellaesporites Pluricellaesporites, Notothyrites, Kutchiathyrites Inapertisporites, Dicellaesporites, Diporicellaesporites, Lygodiumsporites, Todisporites, Crassoretitriletes, Quilonipollenites, Tricolpites, Retitrescolpites, Ctenolophonidites and Polyporites.

Paravur

Common palynological fossils

Phragmothyrites, Parmathyrites, Dicellaesporites, Multicellaesporites, Pluricellaesporites, Inapertisporites Lygodiumsporites, Todisporites, Crassoretitriletes, Striatriletes, Polypodiaceaesporites, Quilonipollenites, Tricolpites, Retitrescolpites, Ctenolophonidites and Triporopollenites

Cannanore

Common palynological fossils

Inapertisporites, Phragmothyrites, Notothyrites, Parmathyrites, Dicellaesporites, Multicellaesporites, Pluricellaesporites, Lygodiumsporites, Polypodiaceaesporites, Tricolpites, Retitrescolpites and Ctenolophonidites.

Palayangadi

Common palynological fossils

Phragmothyrites, Notothyrites, Parmathyrites, Inapertisporites, Lygodiumsporites, Polypodiaceaesporites, Polypodisporites, Crassoretitriletes, Quilonipollenites, Tricolpites, Retitrescolpites, Ctenolophonidites, Monoporopollenites and Triporopollenites.

Bore hole at Ambalapuzha

Common palynological fossils

Phragmothyrites, Notothyrites, Parmathyrites, Kutchiathyrites, Inapertisporites, Dicellaesporites Multicellaesporites, Pluricellaesporites, Malvacearumpollis, Hibisceaepollenites, Psiloschizosporis and Quilonipollenites.

Common reworked pollen genera found in the outcrops

Couperipollis, Lakiapollis, Retitribrevicolporites Meliapollis, Retistephanocolpites, Triangulorites and Pseudonothofagidites.

Sections studied here show more or less homogenous representation of spore-pollen genera with some minor variations perhaps due to local factors. In some of the sections at Thonnakal, Varkala and Paravur, the fungal elements are dominant whereas in Palayangadi and Kundara the angiosperm pollen are well represented. Polyporites is very common particularly in the middle part of the Kundara section whereas in others it is not very frequently encountered. Striatriletes is only occasionally found in the sections but it has been given importance because it is very common in Oligocene-Miocene palynological assemblages in the sections. Correlation of the sections are presented in the figure 46.

The occurrence of older Tertiary pollen genera viz. Couperipollis, Lakiapollis, Retitribrevicolporites, Triangulorites, Pseudonothofagidites etc. points out that during Miocene, the Eocene rocks were eroded and redeposited in the coast of Kerala (Rajendran et al, 1986). The samples studied from the depths of 506 metres to 509 metres and 461 metres to 464 metres from the bore holes of Alleppey coast were found to contain most of the above mentioned genera. Striatriletes, Crassoretitriletes, Quilonipollenites, Bombacacidites, Trisyncolpites, Palaeomalvacearumpollis, Hibisceae-pollenites and Psiloschizosporis which are markers of Oligocene and Miocene sequences were however, absent in those depths at Ambalapuzha and Trikunnapuzha.

VI .4. Systematic Description

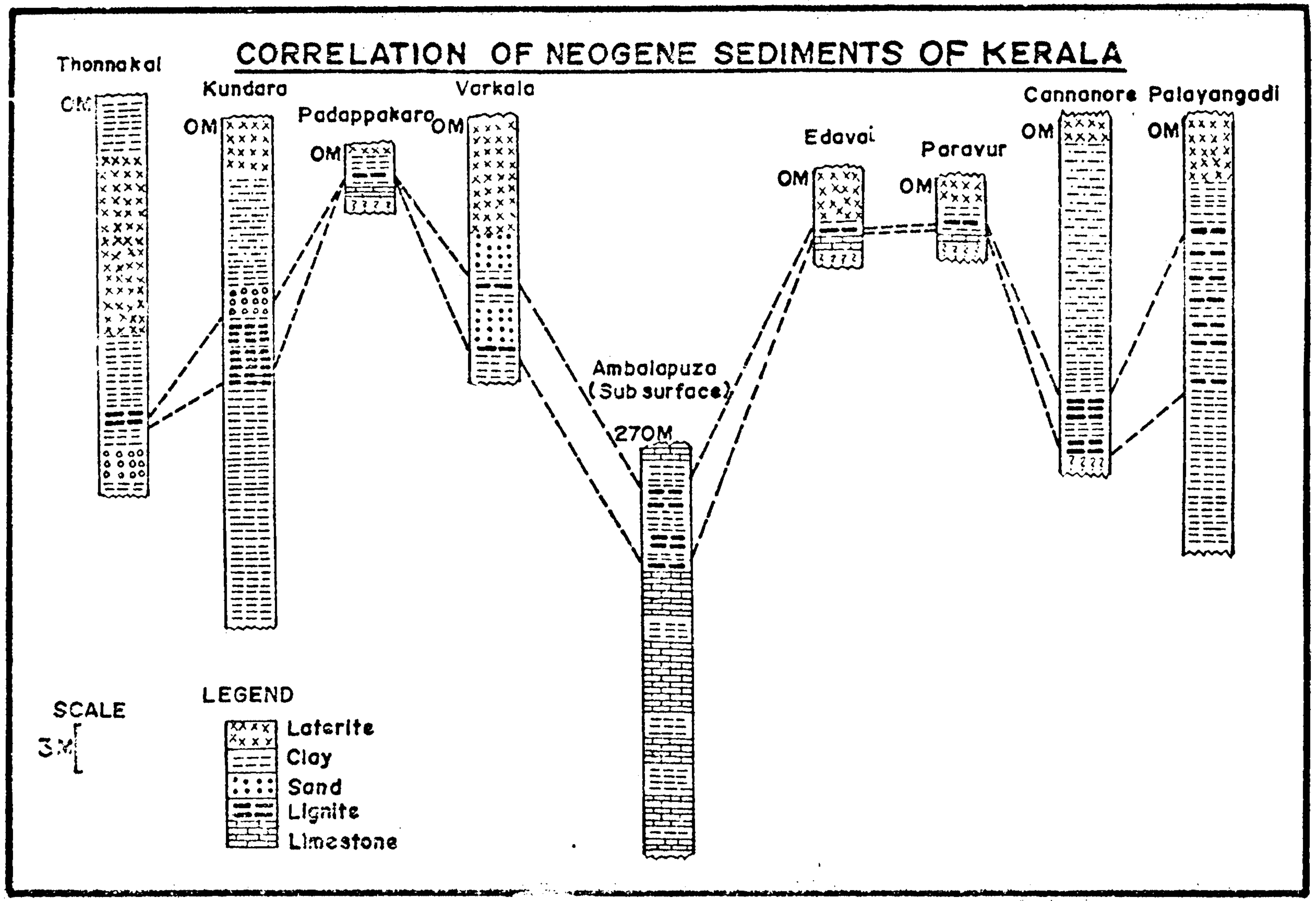
Genus - Cyathidites Couper, 1953

Type Species - Cyathidites australis Couper, 1953

Cyathidites australis Couper, 1953

Plate : 5, Figure 33

Holotype - Couper, 1953, pl.2, fig. 11



Figure·46· Correlation of Neogene sediments of Kerala based on palynomorphs

Description - Spores triangular - subtriangular, apices rounded, interapical margin generally straight to concave. Trilete well developed, rays extending upto three-fourths radius. Exine 2-3 μm thick, laevigate.

Genus - Lygodiumsporites Potonie', Thomson & Thiergart emend. Potonie', 1956

Type Species Lygodiumsporites adriensis (Potonie' & Gelletich) Potonie', Thomson & Thiergart, 1950

Lygodiumsporites lakiensis Sah & Kar, 1969, pl.5,

Pl.5,fig. 15; pl. 6, fig. 4

Holotype Sah & Kar, 1969, pl. 1, fig.16

Description Spores triangular - subtriangular, apices rounded, interapical margin straight to slightly convex. Trilete distinct, rays equal in length, extending upto three-fourths radius. Exine upto 2 μm thick, laevigate.

Genus - Alsophilidites (Cookson) ex Potonie', 1956

Type Species - Alsophilidites kerguelensis Cookson, 1947

Alsophilidites kerguelensis Cookson, 1947

Pl.5, figs. 16, 25; pl. 7, fig. 19

Holotype Cookson, 1947, pl.3, fig. 69

Description Spores triangular - subtriangular, apices rounded, interapical margin straight to slightly convex. Trilete well recognizable, rays extending upto two-thirds radius. Exine upto 2 μm thick laevigate.

Genus - Intrapunctisporis Krutzsch, 1959

Type Species - Intrapunctisporis intrapunctis Krutzsch, 1959

Intrapunctisporis intrapunctis Krutzsch, 1959
Pl. 5, fig.11; pl. 6, fig. 8

Holotype - Krutzsch, 1959, pl. 5, fig. 30

Description - Spores triangular - subtriangular, apices rounded, interapical margin straight - convex. Trilete distinct, rays extending upto three fourths radius. Exine upto 2μm thick, laevigate and intrapunctate.

Intrapunctisporis sp.
Pl. 5, fig. 6

Description - Spore triangular, apices blunt, interapical margin more or less straight. Trilete well developed, rays extending upto three-fourths radius. Exine upto 2μm thick, laevigate and intrapunctate.

Genus - Dandotiaspora Sah, Kar & Singh, 1971

Type Species - Dandotiaspora dilata (Mathur) Sah, Kar & Singh, 1971.

Dandotiaspora telonata Sah, Kar & Singh, 1971

Pl. 4, fig. 14

Holotype - Sah, Kar & Singh, 1971, pl. 2, fig. 8

Description - Spores triangular - subtriangular in polar view, 55-81 μm. Trilete well developed, rays more or less equal, extending upto three-fourths of radius. Exine 2-3 μm thick, mostly laevigate, sometimes intrapunctate at interradial areas, exine distally thickened opposite to trilete rays, may be bifurcating or producing globular beads at ray ends.

Dandotiaspora plicata (Sah & Kar) Sah, Kar & Singh, 1971.

Pl. 4, fig.5; pl. 7, fig. 43

Holotype - Sah & Kar, 1969, pl. 1, fig. 11

Description - Spores triangular - subtriangular, apices rounded, interapical margin slightly convex. Trilete well developed, rays extending upto two-thirds radius, exine 2 μm thick, laevigate, folded distally at ray ends in semilunar fashion.

Genus - Lycopodiumsporites Thiergart ex Delcourt & Sprumont, 1955

Lectotype - Lycopodiumsporites agathoecus (Potonie') Thiergart, 1938

Lycopodiumsporites sp.

Pl.5, fig. 14, pl. 7, fig. 48

Description - Spore triangular apices rounded, inter-apical margin straight. Trilete distinct, rays extending upto three-fourths radius. Exine about 2μm thick, reticulate, reticulation on proximal side ill-developed than distal side.

Genus - *Cheilanthoidspora* Sah & Kar, 1974

Type Species - *Cheilanthoidspora enigmata* Sah & Kar, 1974

Cheilanthoidspora monoleta Sah & Kar, 1974

Pl.3, fig. 20

Holotype - Sah & Kar, 1974, pl. 1, fig. 11

Description - Spores subcircular - subtriangular, 38-61 x 35-59 μm. Monolete, ray distinct in most specimens, extending three-fourths along longitudinal axis. Exoexine well developed, forming broad reticulation on both surfaces.

Genus - *Laevigatosporites* Ibrahim, 1933

Type Species - *Laevigatosporites vulgaris* (Ibrahim) Ibrahim, 1933

Laevigatosporites cognatus Sah & Kar, 1969

Pl. 3, fig. 6

Holotype Sah & Kar, 1969, pl. 2, fig. 20

Description - Spores oval with more or less equally broad lateral ends, 34-56 μm, monolete mark extending upto three-fourths along the longer axis, exine upto 2 µm thick, laevigate.

Laevigatosporites lakiensis Sah & Kar, 1969

Pl. 3, fig. 9

Holotype - Sah & Kar, 1969, pl. 2, fig. 13

Description - Spores oval with equally broad lateral ends, 51-67 µm. Monolete distinct, closed or open, extending not more than half of longer axis. Exine upto 2 µm thick, laevigate.

Laevigatosporites sp.

Pl. 5, fig. 22

Description - Spore oval, monolete distinct, extending upto two-thirds radius. Exine upto 2 µm thick, laevigate.

Genus - Polypodiaceaesporites Thiergart, 1940

Type Species - Polypodiaceaesporites haardti Thiergart, 1940

Polypodiaceaesporites chatterjii Kar, 1979

Pl. 5, figs. 28-29; pl.7, fig.40

Holotype - Kar, 1979, pl. 28, fig. 18

Description - Spores mostly beam shaped, 60-81 µm. Monolete mark indistinct, extending generally upto two-thirds radius along longer axis. Exine about 2 µm thick, laevigate.

Genus - Polypodiisporites Potonie', 1934

Type Species - Polypodiisporites favus (Potonie') Potonie', 1934

Polypodiisporites rependus Takahashi, 1964

Pl. 5, figs. 4, 13; Pl. 7, fig. 28

Holotype - Takahashi, 1964, Pl. 30, fig. 5

Description - Spores bean shaped, 36-51 μm, monolete mark distinct, extending upto two-thirds along longer axis. Exine sculptured with verrucae/warts, generally upto 2 μm high, closely placed forming negative reticulum on surface view.

Genus - Schizaeoisporites Potonie', 1951

Type Species - Schizaeoisporites dorogensis Potonie', 1934

Schizaeoisporites palanaensis Sah & Kar, 1974

Pl. 7, fig. 32

Holotype Sah & Kar, 1974, Pl. 1, fig. 4

Description Spore bean shaped, monolete distinct extending half along longer axis. Exine - 1-2 μm thick, costate, costae upto 2 μm high, closely placed, parallel to each other.

Genus - *Retipilonapites* Ramanujam, 1966

Type Species - *Retipilonapites arcotense* Ramanujam, 1966

Retipilonapites arcotense Ramanujam, 1966

Pl. 7, fig. 25

Holotype - Ramanujam, 1966, Pl. 1, fig. 2

Description - Pollen grains subcircular - circular, 42-54 x 39-52 μm, nonaperturate. Exine 1-2 μm thick, pilate - baculate forming negative reticulum on surface view.

Genus - *Palmaepollenites* Potonie', 1951

Type Species - *Palmaepollenites tranquillus* (Potonie') Potonie', 1951

Palmaepollenites kutchensis Venkatachala & Kar, 1969

Pl. 3, figs. 1-2, Pl. 4, fig. 9; Pl. 5, figs. 9, 26

Holotype Venkatachala & Kar, 1969, pl. 1, fig. 9

Description - Pollen grains generally oval with equally broad lateral ends, 26-32 x 12-18 μm. Monocolpate, colpus well defined, extending from one end to other. Exine more or less laevigate.

Genus - *Couperipollis* Venkatachala & Kar, 1969

Type Species - *Couperipollis perspinosus* (Couper) Venkatachala & Kar, 1969

Couperipollis brevispinosus (Biswas) Venkatachala & Kar, 1969

Pl. 3, fig. 16; pl. 4, fig. 15

Holotype Baksi, 1962, pl. 2, fig. 22

Description Pollen grain oval - elliptical with equally rounded lateral ends. Monocolpate, colpus distinct, extending one end to other. Exine 2-3 µm thick, spinose, spines 3-6 µm long with bulbous base and pointed tip, interspinal exine laevigate.

Genus - Proxapertites van der Hammen, 1956

Type Species - Pyroxapertites operculatus van der Hammen, 1956

Proxapertites microreticulatus Jain, Kar & Sah, 1973

Pl. 4, figs. 12-13

Holotype - Jain, Kar & Sah, pl. 1, fig. 19

Description - Pollen grain subcircular-circular, 42-62 µm, zonisulcate, sulcus generally well defined, pollen mostly split into two equal halves. Exine upto 2 µm thick, intramicroreticulate.

Genus - *Psiloschizosporis* Jain, 1968

Type Species - *Psiloschizosporis cacheutensis* Jain, 1968

Psiloschizosporis psilata Kar & Saxena, 1981

Pl. 6, fig. 11

Holotype - Kar & Saxena, 1981, pl. 3, fig. 48

Description Pollen grains mostly oval with equally broad laternal ends, 60-96 x 38-56 μm. Exine 1-2 μm thick, laevigate. Furrow traceable often splitting pollen in two equal halves.

Psiloschizosporis punctata Kar & Saxena, 1981

Pl. 6, fig. 18

Holotype Kar & Saxena, 1981, pl. 3, fig. 48

Description : Pollen grain oval with more or less equally broad lateral ends. Exine 2 μm thick, punctate, Furrow distinct, sometimes breaking pollen into two equal halves

Dicolpate pollen type - 1

Pl. 5, fig. 24

Description: Pollen grain more or less oval, dicolpate. colpi recognizable. Exine about 1.5 μm thick, laevigate to intrastructured.

Genus - *Tricolpites* (Erdtman) Potonie', 1960 .

Lectoholotype - *Tricolpites reticulatus* Cookson, 1947

Tricolpites reticulatus Cookson, 1947

Pl. 7, figs. 36, 41, 46

Holotype - Cookson, 1947, pl. 15, fig. 45

Description - Pollen grains subcircular-circular with notches due to apertures. Tricolpate, colpi distinct, funnel shaped. Exine about 2 μm thick, reticulate.

Tricolpites crassireticulatus Dutta & Sah, 1970

Pl. 3, figs. 7-8

Holotype Dutta & Sah, 1970, pl. 6, fig. 9

Description: Pollen grains roundly triangular - subcircular, tricolpate, colpi distinct, funnel shaped, with bulging mesocolpia, exine 2-4 μm thick, sexine as thick as nexine, pilate, tegillate, coarsely reticulate, meshes squarish - rectangular, lumina shallow.

Genus - Retitrescolpites Sah, 1967

Type Species - Retitrescolpites Sah, 1967

Retitrescolpites sp.

Pl.3, fig. 15; pl. 5, fig. 3

Description: Pollen grain subtriangular in polar with three notches due to apertures. Colpi well developed, funnel shaped. Exine 2-3 μm thick, retibaculate, sculptural elements forming pseudoreticulate pattern on surface view.

Genus - *Sastriipollenites* Venkatachala & Kar, 1969

Type Species - *Sastriipollenites trilobatus* Venkatachala & Kar, 1969

Sastriipollenites trilobatus Venkatachala & Kar, 1969

Pl. 5, fig. 19; Pl. 7, fig. 30

Holotype - Venkatachala & Kar, 1969, pl. 3, fig. 69

Description - Pollen grains in polar view, subcircular with three notches due to apertures. Tricolporate, colpi long, funnel shaped, margin thickened. Exine 2-3 μm thick, sexine thicker than nexine, granulose - conied.

Genus - *Cupuliferoipollenites* Potonie', 1951

Type Species - *Cupuliferoipollenites pusillus* (Potonie Potonie', 1951

Cupuliferoipollenites ovatus Venkatachala & Kar, 1969

Pl. 5, fig. 7

Holotype - Venkatachala & Kar, 1969, pl. 2, fig. 44

Description - Pollen grains generally found in equatorial condition, oval, 16-26 x 19-15 μm. Tricolporate colpi long, narrow, extending upto three-fourths radius Pores distinct, exine upto 2 μm thick, laevigate and more or less intrapunctate.

Genus - Palaeocoprosmadites Ramanujam, 1966

Type Species - Palaeocoprosmadites arcotense

Pl. 5, Fig. 8 Ramanujam, 1966

Holotype - Ramanujam, 1966, pl. 3, fig. 61

Description - Pollen grains isopolar, oblate, subtriangular in shape, tricolpate, brevicolpate. Exine upto 2 µm thick, columellae indistinct, surface smooth.

Genus - Meliapollis Sah & Kar, 1970

Type Species - Meliapollis ramanujamii, Sah & Kar, 1970

Meliapollis ramanujamii Sah & Kar, 1970

Pl. 3, fig. 21; Pl. 4, fig. 16;

Pl. 6, fig. 13; Pl. 7, figs. 47, 50

Holotype - Sah & Kar, 1970, pl. 2, fig. 62

Description - Pollen grains subcircular - circular, 48-63 x 45-60 µm. Tetracolpate, colpi medium in size, pore circular - lalongate, pore margin thickened. Exine upto 3 µm thick, laevigate.

Meliapollis quadrangularis (Ramanujam) Sah & Kar, 1970

Pl. 4, fig. 17

Holotype - Ramanujam, 1966, Pl. 5, fig. 82

Description - Pollen grain prolate-subprolate, tetrazonicolporate, 44-56 x 31-36 µm, more or less quadrangular, colpi tenuimarginate, long, narrow at ends, ora distinct with thickened margin. Exine 2-3 μm thick, mostly psilate.

Genus - Lakiapollis Venkatachala & Kar, 1969

Type Species - Lakiapollis ovatus Venkatachala & Kar, 1969

Pl. 3, figs. 17-19; Pl. 4, figs. 7-8; Pl. 5, fig. 12

Holotype - Venkatachala & Kar, 1969, pl. 3, fig. 77

Description Pollen grain subcircular - circular, 42-53 x 32-47 μm. Tribrevicolporate, colpi small, sometimes not traceable, pores well developed, almost of same length of colpi, aperture subequatorially placed. Exine upto 2 μm thick laevigate, sometimes weakly intrastructured.

Genus - Margocolporites Ramanujam, 1966

Type Species - Margocolporites tsukadai Ramanujam, 1966

Margocolporites sitholeyi Ramanujam, 1966

Pl. 5, figs. 23, 31; Pl. 7, fig. 23

Holotype - Ramanujam, 1966, pl. 4, fig. 68

Description - Pollen grain subcircular, trizonimargocolporate, 32-41 x 30-39 μm. Tricolpate, colpi funnel shaped, long extending upto three-fourths in equatorial view. Margocolpate condition discernible in most specimens; exine 2-3 µm thick, sexine thicker than nexine, distinctly reticulate, homobrochate, muri simplibaculate, lumina smooth or with free bacula.

Genus - Paleosantalaceaepites Biswas emend Dutta & Sah, 1970

Type Species - Paleosantalaceaepites dinoflagellatus Biswas emend. Dutta & Sah, 1979

Paleosantalaceaepites ellipticus Sah & Kar, 1970

Pl. 3, fig. 3

Holotype Sah & Kar, 1970, pl. 2, fig. 55

Description Pollen grains generally in equatorial view, 45-56 x 26-42 µm. Tricolporate, colpi long, distinct, extending three-fourths along longitudinal axis, pore well recognizable, lalongate. Exine upto 2 µm thick, laevigate, finely intrastructured.

Genus - Tribrevicolporites Kar, 1985

Type Species - Tribrevicolporites eocenicus Kar, 1985

Tribrevicolporites eocenicus Kar, 1985

Pl. 3, figs, 10-11

Holotype - Kar, 1985, pl. 13, fig. 9

Description - Pollen grains subtriangular in polar view, tribrevicolporate, colpi 15-25 µm long, pores distinct, 4-6 µm in diameter, margin not much thickened. Exine 2-3 µm thick, sexine as thick as nexine finely reticulate.

Genus - Dermatobrevicolporites Kar, 1985

Type Species - Dermatobrevicolporites dermatus (Sah & Kar) Kar, 1985

Dermatobrevicolporites dermatus (Sah & Kar) Kar, 1985

Pl. 3, figs. 12-18

Holotype Sah & Kar, 1970, pl. 2, fig. 49

Description Pollen grains generally subtriangular, 32-41 x 29-36 µm, tricolporate, colpi short, 10-17 µm in length, pore well marked, 6-11 µm in diameter. Exine 2-4 µm thick, sexine thicker than nexine, mostly psilate, sometimes weakly intrastructured.

Dermatobrevicolporites triangulus (Saxena) Kar, 1985

Pl. 4, fig. 18

Holotype Saxena, 1979, pl. 3, fig. 50

Description Pollen grains triangular - subtriangular in polar view, 38-56 µm. Tricolporate, brevicolpate, pores distinct, margin thickened. Exine 2-3.5 µm thick, generally laevigate, sometimes weakly intrastructured.

Genus - Striacolporites Sah & Kar, 1970

Type Species - Striacolporites striatus Sah & Kar, 1970

Striacolporites cephalus Sah & Kar, 1970

Pl. 4, figs. 10-11

Holotype Sah & Kar, 1970, pl. 2, fig. 68

Description Pollen grains subcircular in polar view, 68-73 x 56-66 µm. Tricolporate colpi membrane faintly granular, funnel shaped, pore distinct - indistinct, margin slightly thickened. Sexine thicker than nexine, striato-reticulate.

Genus - Tricolporopilites Kar, 1985

Type Species - Tricolporopilites robustus (Kar & Saxena) Kar, 1985

Tricolporopilites pseudoreticulatus Kar, 1985

Pl. 4, figs. 1-6; Pl.7, figs. 21,35, 44

Description Pollen grain subtriangular in polar and subcircular in equatorial views, 78 - 95 x 77 - 88 µm Tricolporate, colpi long, pore mostly distinct, margin appreciably thickened. Exine 2-3 µm thick, sexine thicker than nexine, pilate, pila 5 - 7 µm long, thicker at base, interpilar space granulose, sculptural elements closely placed, providing negative reticulum on surface view.

Genus - *Tribrevicolporites* Kar, 1985

Type Species - *Tribrevicolporites eocenicus* Kar, 1985 Pl. 7, fig. 42

Holotype - Kar, 1985, pl. 13, fig. 9

Description Pollen grains subtriangular - triangular in polar view, 30-39 x 28-36 µm. Tribrevicolporate, colpi short, sometimes inconspicuous, pore distinct, margin thickened. Exine 2-3 µm thick, sexine as thick as nexine, finely reticulate.

Genus - *Ratariacolporites* Kar, 1985

Type Species - *Ratariacolporites plicatus* Kar, 1985 Pl. 4, fig. 19

Holotype - Kar & Saxena, 1981, pl. 4, fig. 73

Description Pollen grains subtriangular - triangular in polar view, 48-57 x 43-55 µm. Tricolporate, brevicolpate, colpi indistinct. Pore circular, mostly traceable. Exine upto 2 µm thick, laevigate - slightly granulose. Exine folded regularly in interapertural region.

Genus - *Retistephanocolpites* Leidelmeyer emend. Saxena, 1982

Type Species - *Retistephancolpites angeli* Leidelmeyer, 1966

<u>Retistephanocolpites</u> <u>kutchensis</u> Saxena, 1979

Pl. 3, figs. 4-5

<u>Holotype</u> - Saxena, 1979, pl. 2, fig. 33

<u>Description</u> - Pollen grains generally subcircular in polar view, 22 - 34 µm. Pentacolpate, colpi long, mesocolpia broad. Exine 2-3 µm thick, foveoreticulate, muri very thin.

Genus - <u>Polybrevicolporites</u> Venkatachala & Kar, 1969

Type Species - <u>Polybrevicolporites cephalus</u> Venkatachala & Kar, 1969

Pl.5, figs. 2, 18

<u>Holotype</u> - Venkatachala & Kar, 1969, pl. 2, fig. 55

<u>Description</u> Pollen grains circular - subcircular, mostly found in equatorial view, 18-36 x 16-30 µm. Polycolporate, usually pentacolporate, brevicolpate, pore traceable, margin thickened. Exine 3-5 µm thick, intrabaculate.

Genus - <u>Proteacidites</u> Cookson, 1950

Type Species - <u>Proteacidites</u> <u>adenanthoides</u> Cookson, 1950

<u>Proteacidites</u> <u>triangulus</u> Kar & Jain, 1981

Pl. 4, fig. 20; Pl. 7, fig. 34

<u>Holotype</u> Kar & Jain, 1981, pl. 4, fig. 121

Description Pollen grain triangular in polar view, 32-45 x 30-43 µm. Triorate, anguloperturate. Exine 2-3 µm thick, pilate, pila forming negative reticulum on surface view.

Proteacidites protrudus Sah & Kar, 1970
Pl. 7, fig. 45

Holotype Sah & Kar, 1970, pl. 2, fig. 61

Description - Pollen grains triangular, 48-58 x 44-53 µm. Triporate, pore distinct. Exine upto 2 µm thick, scrobiculate.

Genus - Triangulorites Kar, 1985

Type Species - Triangulorites bellus (Sah & Kar) Kar, 1985

Triangulorites bellus (Sah & Kar) Kar, 1985

Pl.3 fig. 14

Holotype Sah & Kar, 1970, pl. 2, fig. 70

Description Pollen grains mostly triangular in polar view, 62-77 x 59-71 µm, margin convex. Generally triorate, sometimes tetraorate with one rudimentary ora in one. Exine upto 2 µm thick, granulose - conied, sculpture about 1 µm high, more or less closely placed at apertural region.

Triangulorites triradiatus (Saxena) Kar, 1985

Pl. 7, fig. 27

Holotype - Saxena, 1979, pl. 3, fig. 54

Description Pollen grain triangular in polar view with marked protuberances, 45-55 µm. Triorate, ora well developed. Exine about 2.5 µm thick, sexine thinner than nexine, finely scrobiculate to granulose.

Genus - Striatriletes van der Hammen emend. Kar, 1979

Type Species - Striatriletes susannae van der Hammen emend. Kar, 1979
Pl. 5, figs. 10, 27

Holotype - van der Hammen, 1956, pl. 2, fig. 5

Description - Spores subtriangular, anisopolar, with rounded apices and straight to convex interapical margin, 70-112 µm. Trilete, rays extending upto three-fourths radius. Exine costate, costae 4-7, a few arising at inter radial area and continue on distal side forming continuous, parallel, concentric rings. Costae of one inter radial area never coalesce with other on proximal as well as on distal side. Costae ribbon-like, sometimes branched, intercostal exine laevigate.

Genus - Crassoretitriletes Germeraad, Hopping & Muller, 1968

Type Species - <u>Crassoretitriletes vanraadshooveni</u> Germeraad, Hopping & Muller, 1968

<u>Crassoretitriletes vanraadshooveni</u> Germeraad, Hopping & Muller, 1968

Pl. 5, fig. 32; Pl. 6, fig. 9

<u>Holotype</u> - Germeraad, Hopping & Muller, 1968 pl. 4, fig. 10

<u>Description</u> - Spores triangular - subtriangular, apices rounded, interapical margin straight to markedly convex. Trilete distinct, rays extending upto two-thirds radius. Exine 2-4 µm thick, crassireticulate, reticulation more developed on distal side.

Genus - <u>Quilonipollenites</u> Rao & Ramanujam 1978

Type Species - <u>Quilonipollenites sahnii</u> Rao & Ramanujam, 1978

<u>Quilonipollenites sahnii</u> Rao & Ramanujam

Pl.5 : Fig. 17 pl. 7, fig. 20

<u>Holotype</u> - Rao & Ramanujam, 1978, pl. 5, fig. 59

<u>Description</u> Pollen grain oval with more or less equally broad lateral ends. Monocolpate, colpus generally open, wide, extending from one end to other. Exine upto 2 µm thick, microreticulate.

Genus - _Ctenolophonidites_ van Hoeken-Klinkenberg, 1966

Type Species - _Ctenolophonidites_ _costatus_ (van Hoeken-Klinkenberg) van Hoeken - Klinkeberg, 1966

Ctenolophonidites _costatus_ (van Hoeken-Klinkenberg) van Hoeken-Klinkenberg, 1966

Pl. 5, figs. 1, 20, 30; Pl.7, figs.26, 31

Holotype - van Hoeken - Klinkenberg, 1964, photo nos. 10a, b

Description - Pollen grains circular - subcircular in polar view, 31-39 x 28-36 µm. Hexacolpate, may be colporate in some specimens, colpi long, well recognizable. Ecto-exine thickened to form long, sinuous ridges on both sides. Exine about 2 µm thick, generally laevigate, sometimes weakly intrastructured.

Ctenolophonidites _palaeoparvifolius_ Kar & Jain, 1981

Pl. 5, fig. 5

Holotype Kar & Jain 1981, pl. 4, fig. 109

Description Pollen grains subcircular-circular, 34-46 x 32-42 µm. Penta - septacolpate, colpi distinct, colporate condition also observed in some specimens. Ectoexine well developed forming a blanket like disposition. Exine upto 2 µm thick, laevigate.

Genus - Hibisceaepollenites Kar, 1985

Type Species - Hibisceaepollenites splendus Kar, 1985

Hibisceaepollenites splendus Kar, 1985
Pl. 5, fig. 35

Holotype - Kar, 1985, pl. 36, fig. 11

Description - Pollen grains subcircular - circular, sometimes folded in irregular fashion, 82-115 x 80-112 µm Panporate, pores uniformly distributed on both sides. Exine upto 2 µm thick, spinose, spines 8-15 µm long with broad base and blunt tip, interspinal space pilate.

Genus - Palaeomalvaceaepollis Kar, 1985

Type Species - Palaeomalvaceaepollis rudis Kar, 1985
Pl. 5, fig. 34

Holotype - Kar, 1979, pl. 2, fig. 46

Description - Pollen grain subcircular, 50-70 x 48-68 µm. Panporate, pore margin thickened. Exine upto 2 µm thick, spinose, basal part of spines columellate, base bulbous with sharply pointed tip. Spines on surface appear as mammilate processes. Sexine columellate, interspinal space microreticulate granulate.

Genus - Polyporina (Naumova) Potonie', 1960

Type Species - Polyporina multistigmosa (Potonie') Potonie', 1960

Polyporina multiporosa Kar, 1985
Pl. 5, fig. 21

Holotype Kar, 1985 pl. 30, fig. 13

Description Pollen grain radially symmetrical, subcircular - circular, 26-35 x 24-33 μm, polyporate, pores subcircular, uniformly distributed on both sides, 20-30 in number. Exine upto 2 μm thick, sexine as thick as nexine, interporal space more or less microreticulate.

Genus - Inapertisporites Elsik, 1968

Type Species - Inapertisporites kedvesii Elsik, 1968

Inapertisporites kedvesii Elsik, 1968
Pl. 6, fig. 14

Holotype - Elsik, 1968, pl. 2, fig. 8

Description - Spores subcircular-circular, irregularly folded, inaperturate, spore coat about 1 μm thick, laevigate.

Genus - Phragmothyrites Edwards emend. Kar & Saxena, 1981

Type Species - Phragmothyrites eocenica Edwards emend.
Kar & Saxena, 1981
Pl. 6, fig. 6

Lectotype - Edwards, 1922, pl. 8, fig. 3

Description - Ascostromata subcircular - circular, dimidiate, nonostiolate. Hyphae anastomosing to form pseudoreticulate pattern, central region few celled thick, outer cells setose, mature cells having pores in some specimens.

Genus - Parmathyrites Jain & Gupta, 1970

Type Species - Parmathyrites indicus Jain & Gupta, 1970
Pl. 6, figs. 7, 16

Holotype - Jain & Gupta, 1970, pl. 1, fig. 1

Description Ascostromata subcircular-circular with radially placed spine like processes outside, nonostiolate hyphae anastomose to form pseudoparenchymatous pattern, marginal hyphae radially placed with pointed end.

Parmathyrites robustus Jain & Kar, 1979
Pl. 6, fig. 1

Holotype - Jain & Kar, 1979, pl. 1, fig. 14

Description - Ascostromata dimidiate, nonostiolate, hyphae in middle region anastomose to form pseudoparenchymatous cells, marginal hyphae strongly built, radially placed with pointed end.

Genus - Notothyrites Cookson, 1947

Type Species - Notothyrites amorphus Kar & Saxena, 1981

Pl. 6, fig. 15

Holotype - Kar & Saxena, 1981, pl. 4, fig.14

Description - Ascostromata subcircular - circular, dimidiate ostiolate, ostiole well marked, hyphae anastomosing to form pseudoparenchymatous cells; marginal cells slightly thickened, setiferous.

Genus - Lirasporis

Type Species - Lirasporis intergranifer Potonie' & Sah, 1961

Pl. 6, figs. 5, 12

Holotype - Potonie' & Sah, 1961, pl. 4, fig.4

Description - Ascostromata oval - elliptical in shape with equally broad lateral ends. Hyphae parallel and transversely placed to form pseudoparenchymatous pattern.

Genus - Kutchiathyrites Kar, 1979

Type Species - Kutchiathyrites eccentricus Kar, 1979

Kutchiathyrites eccentricus Kar, 1979

Pl. 6, fig. 17

Holotype Kar, 1979, pl. 3, fig. 49

Description Ascostromata dimidiate, nonostiolate, hyphae develop in one direction, anastomose to form pseudoreticulate pattern, marginal cells as thick as middle cells.

Genus - *Cleistosphaeridium* Davey, Downie, Sarjeant & Williams, 1966

Type Species - *Cleistosphaeridium diversispinosum* Downie, Sarjeant & Williams, 1966

Cleistosphaeridium sp.

Pl. 4, fig. 21

Description - Cyst spherical, double walled, endophragm smooth, periphragm reticulate bedecked with numerous processes, processes distally bifid or recurved, closed, stem fibrous, striated with fenestration. Archaeopyle while observed apical, margin zigzag.

Plate - 3

(All photomicrographs are enlarged *ca.* x 500)

1- 2. *Palmaepollenites kutchensis* Venkatachala & Kar

3. *Paleosantalaceaepites ellipticus* Sah & Kar

4 - 5. *Retistephanocolpites kutchensis* Saxena

6. *Laevigatosporites lakiensis* Sah & Kar

10-11 *Tribrevicolporites eocenicus* Kar

12-18 *Dermatobrevicolporites dermatus* (Sah & Kar) Kar

13. *Cyathidites minor* Couper

14. *Triangulorites bellus* (Sah & Kar) Kar

15. *Retitrescolpites* sp.

16. *Couperipollis brevispinosus* (Biswas) Venkatachala & Kar

17-19 *Labiapollis ovatus* Venkatachala & Kar

20. *Cheilanthoidspora monoleta* Sah & Kar

21. *Meliapollis ramanujamii* Sah & Kar

Plate 3

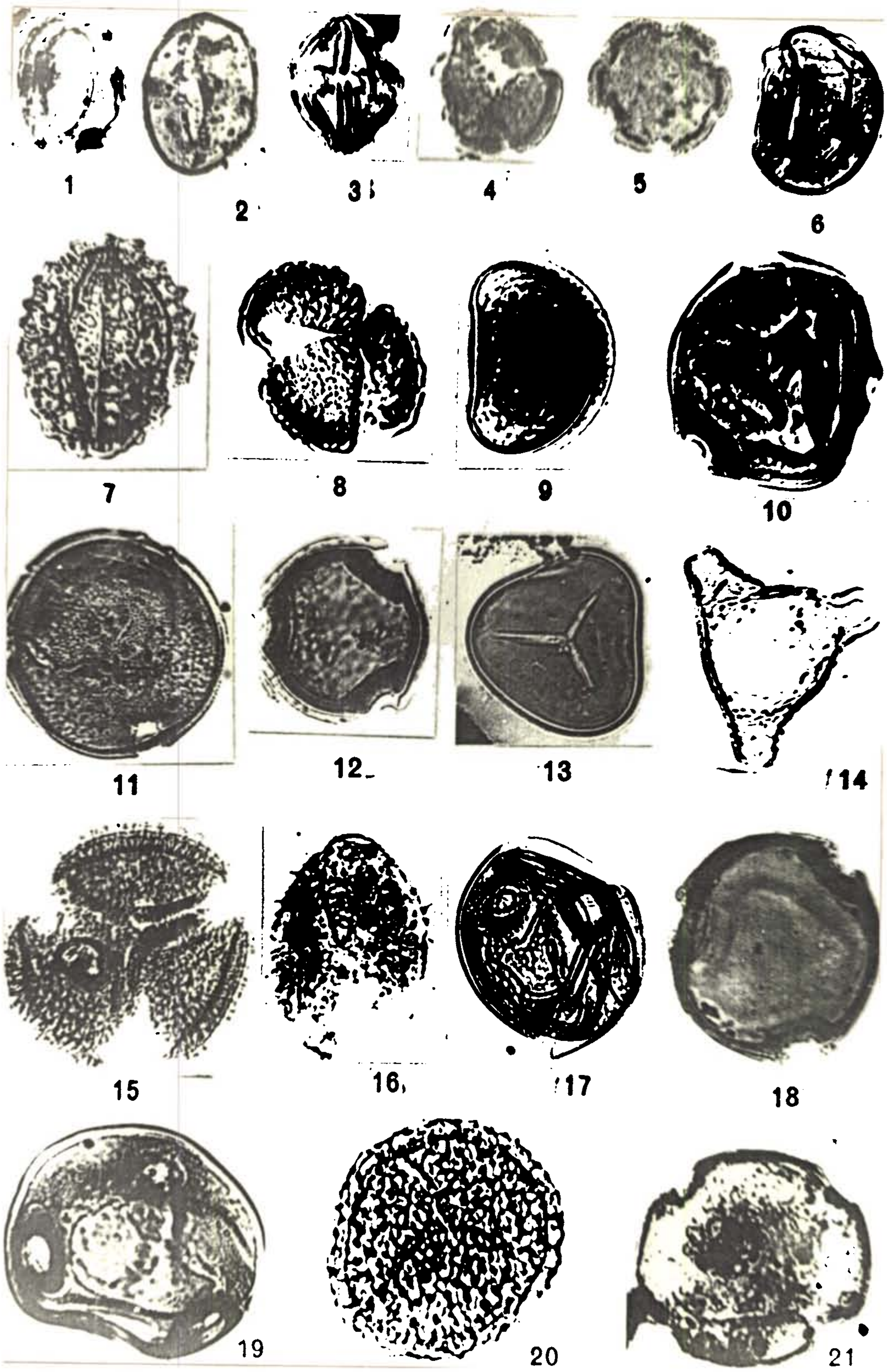


Plate - 4

(All photomicrographs are enlarged *ca* x 500)

1-6 *Tricolporopilites pseudoreticulatus* Kar

7-8 *Lakiapollis ovatus* Venkatachala & Kar

9. *Palmaepollenites kutchensis* Venkatachala & Kar

10-11 *Striacolporites cephalus* Sah & Kar

12-13 *Proxapertites microreticulatus* Jain, Kar & Sah

14 *Dandotiaspora telonata* Sah, Kar & Singh

15 *Couperipollis brevispinosus* (Biswas) Venkatachala & Kar

16 *Meliapollis ramanujamii* Sah & Kar

17 *Meliapollis quadrangularis* (Ramanujam) Sah & Kar

18 *Dermatobrevicolporites triangulus* (Saxena) Kar

19 *Rotariacolporites plicatus* Kar

20 *Proteacidites triangulus*

21 *Cleistosphaeridium* Sp.

Plate 4

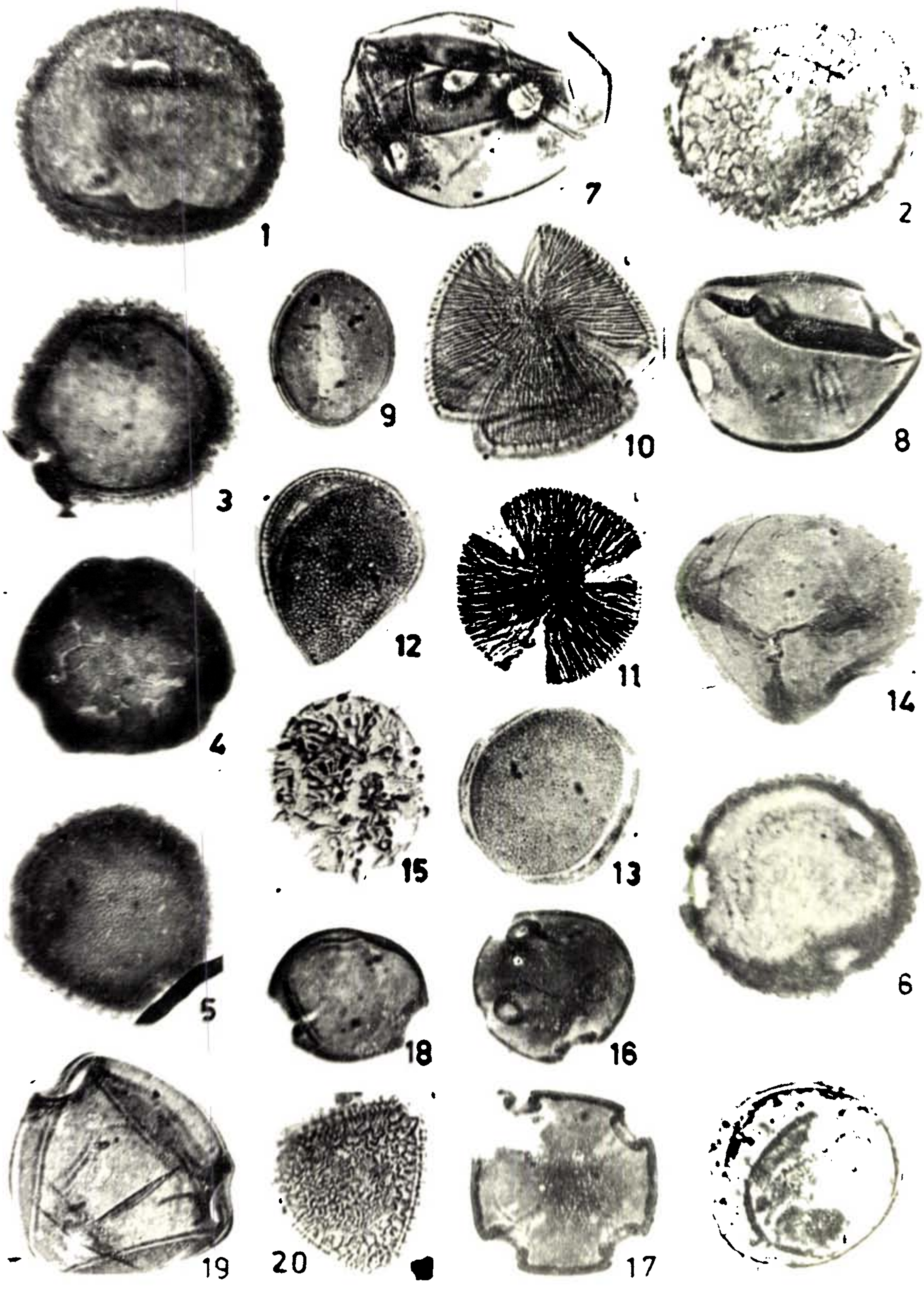


Plate 5

(All photomicrographs are enlarged ca x 500)

1,20,30	Ctenolophonidites costatus van Hocken - Klinkenberg
2, 18	Polybrevicolporites cephalus Venkatachala & Kar
3	Retitrescolpites sp.
4, 13	Polypodiisporites repandus Takahashi
5	Ctenolophonidites palaeopervifolius Kar & Jain
6	Intrapunctispories sp.
7	Cupuliferoipollenites ovatus Venkatachala & Kar
8	Palaeocoprosmadites arcotense Ramanujam
9,26	Palmaepollenites kutchensis Venkatachala & Kar
10,27	Striatriletes susannae (van der Hammen) Kar
11	Intrapunctisporis intrapunctis Krutzsch
12	Lakiapollis ovatus Venkatachala & Kar
14	Lycopodiumsporites sp.
15	Lygodiumsporites lakiensis Sah & Kar
25	Alsophilidites kerguelensis Cookson
17	Quilonipollenites Sahnii Rao & Ramanujam
19	Sastriipollenites trilobatus Venkatachala & Kar
21	Polyporina multiporosa Kar
22	Laevigatosporites sp.
23,31	Margocoloporites sitholeyi Ramanujam
24	Dicolpate pollen type - 1
28,29	Polypodiaceaesporites Chatterjii
32	Crassoretitriletes vanraadshooveni Germeraad, Hopping & Muller
33	Cyathidites australis Couper
34	Palaeomalvaceaepollis rudis Kar
35	Hibisceaepollenites splendus Kar

Plate · 5

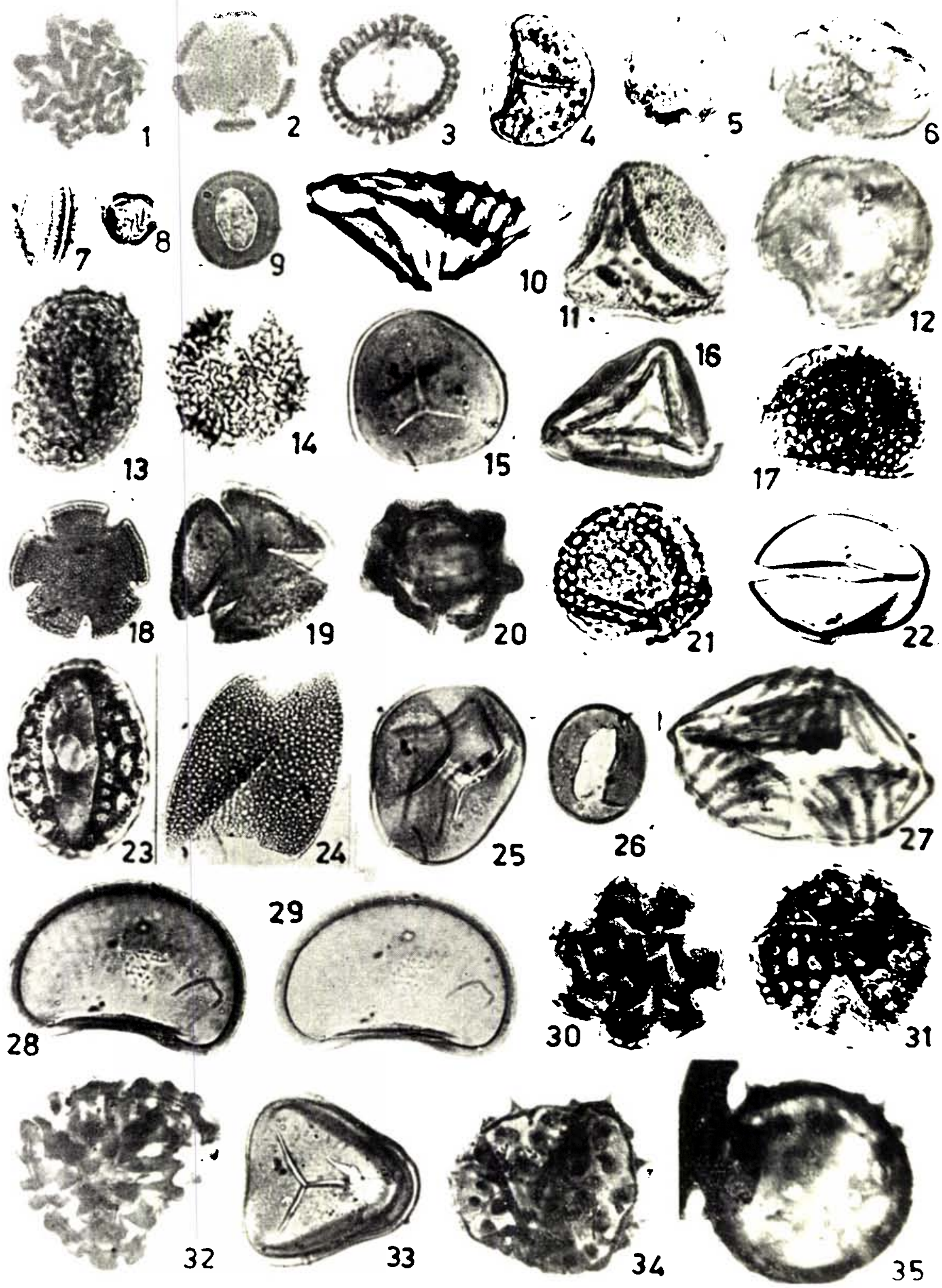

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Plate 6

(All photomicrographs are enlarged ca.x 500)

1 Parmathyrites robustus Jain & Kar

2,10 Retitrescolpites sp.

3 Dandotiaspora plicata (Sah & Kar) Sah, Kar & Singh

4 Lygodiumsporites lakiensis Sah & Kar

5,12 Lirasporis intergranifer Potonie & Sah

6 Phragmothyrites eocenica Edwards emend. Kar & Saxena

7,16 Parmathyrites indicus Jain & Gupta

8 Intrapunctisporis intrapunctis Krutzsch

9 Crassoretitriletes vanraadshooveni Germeraad, Hopping Muller

11 Psiloschizosporis psilata Kar & Saxena

13 Meliapollis ramanujamii Sah & Kar

14 Inapertisporites kedvesii Elsik

15 Notothyrites amorphus Kar & Saxena

17 Kutchiathyrites eccentricus Kar

18 Psiloschizosporis punctata Kar & Saxena

Plate · 6

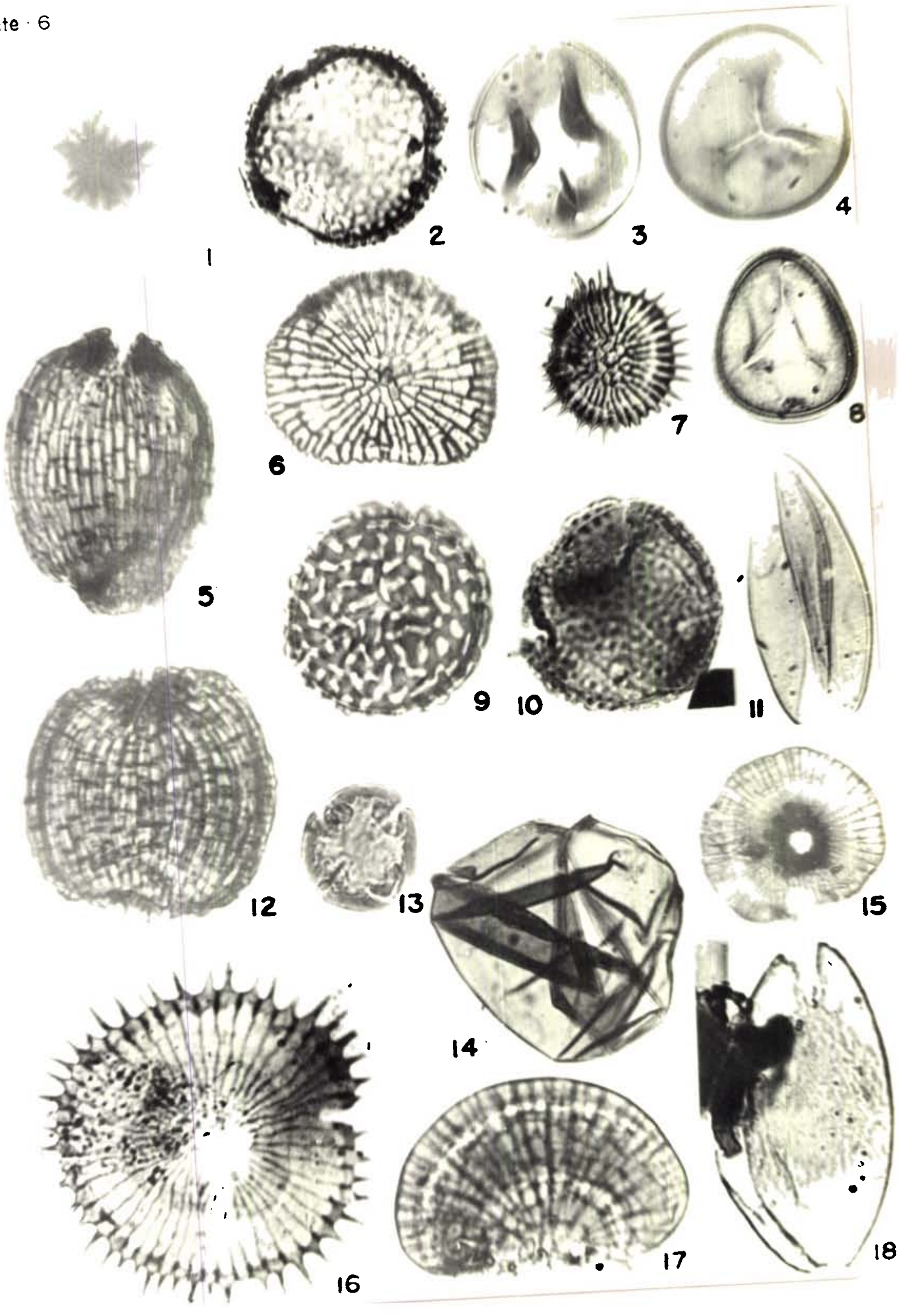


Plate - 7

(All photomicrographs are enlarged *ca.* x 500)

19 *Alsophilidites kerguelensis* Cookson

20 *Quilonipollenites sahnii* Rao & Ramanujam

21,33, 44 *Tricolporopilites pseudoreticulatus* Kar

22 *Parmathyrites robustus* Jain & Kar

23 *Margocolporites sitholeyi* Ramanujam

24,37 *Lygodiumsporites lakiensis* Sah & Kar

25 *Retipilonapites arcotense* Ramanujam

27 *Triangulorites triradiatus* (Saxena) Kar

26,31 *Ctenolophonidites costatus* van Hoeken-Klinkenberg

28 *Polypodiisporites repandus* Takahashi

29 *Pellicieroipollis langenheimmii* Sah & Kar

30 *Sastriipollenites trilobatus* Venkatachala & Kar

32 *Schizaeoisporites trilobatus* Venkatachala & Kar

34 *Proteacidites triangulus* Kar & Jain

36,41,46 *Tricolpites reticulatus* Cookson

39 *Phragmothyrites eocenica* Edwards emend. Kar & Saxena

40 *Polypodiaceaesporites chatterjii* Kar

42 *Tribrevicolporites eocenicus* Kar

43 *Dandotiaspora plicata* (Sah & Kar) Sah, Kar & Singh

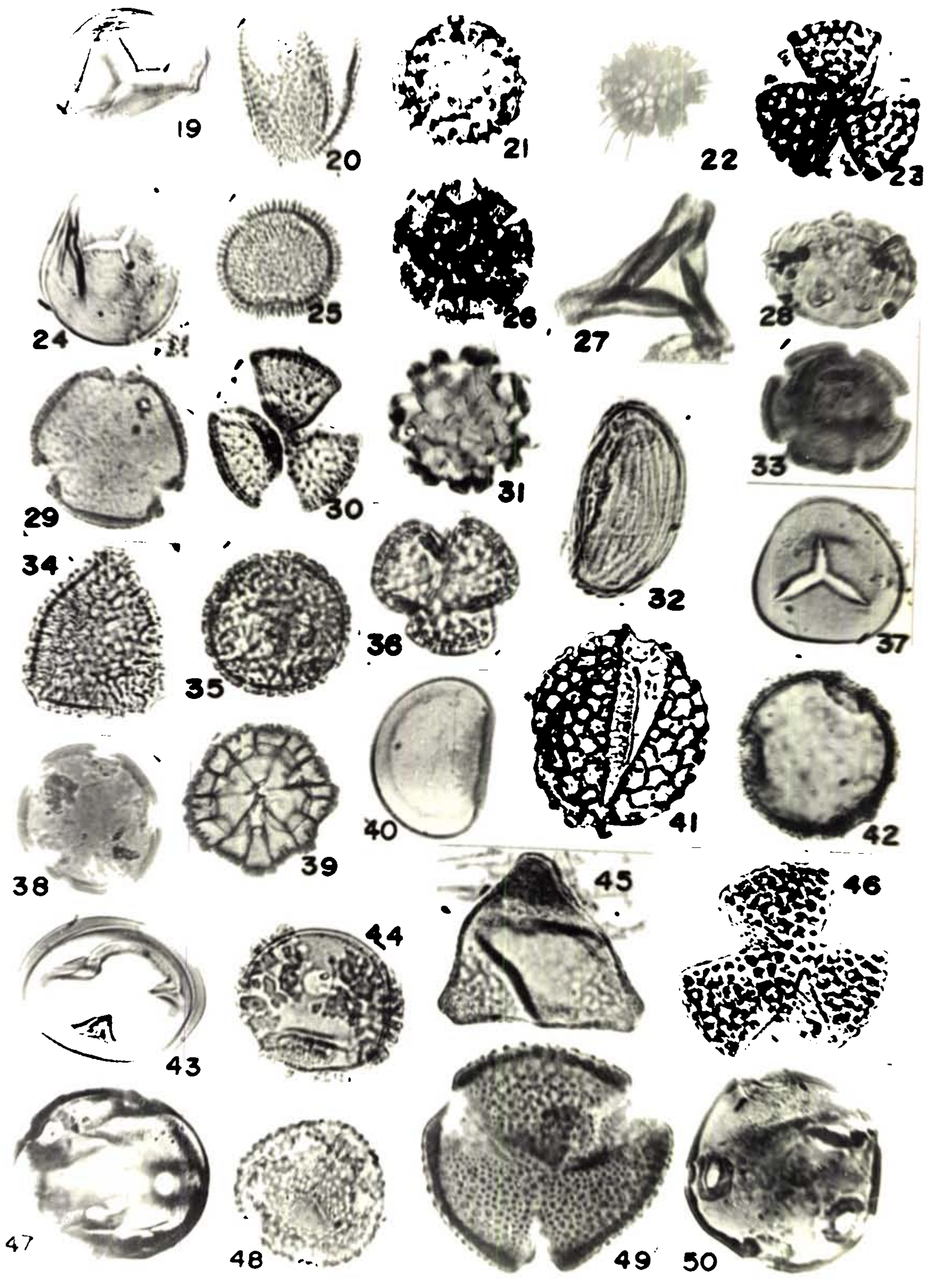
45 *Proteacidites protrudus* Sah & Kar

47,50 *Meliapollis ramanujamii* Sah & Kar

48 *Lycopodiumsporites* sp.

49 *Retitrescolpites* sp.

Plate 7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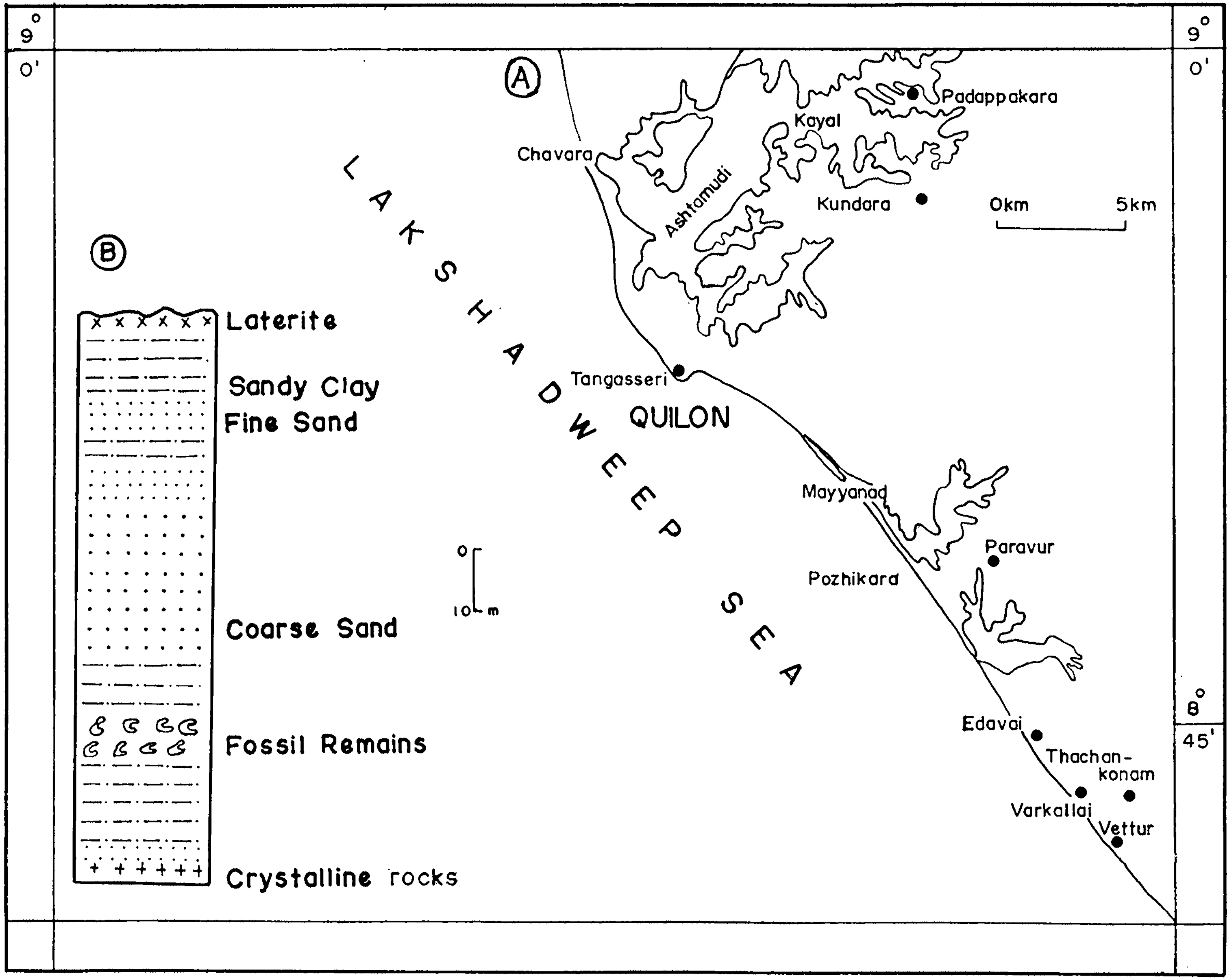
VII. FOSSIL REMAINS IN WARKALLI SEDIMENTS (TYPE AREA)

The sedimentary section at Varkala (Warkallai) located to the south of Quilon (Fig. 47A) has been recorded as the type area of Tertiary sediments (King, 1882). This section consisting of sandstones, variegated clays with lignitic bands, is considered to be a littoral facies partially overlapping the underlying Quilon limestones (Paulose and Narayanaswamy, 1968). Palynological studies conducted on the carbonaceous sediments at the base of Warkalli sediments in the type area indicated an Early Miocene age for these carbonaceous sediments (Ramanujam and Rao, 1977; Rajendran et al., 1986). An Early Miocene age has been assigned to the Quilon limestone (Rasheed and Ramachandran, 1978), located at Padappakkara (Fig. 47A) on the basis of foraminiferal studies. This obviously brings out that the deposition of limestone and lignite are more or less coeval which occurred in two different types of environments. A slightly younger age (Mio-Pliocene) has been assigned (Paulose and Narayanaswamy, op. cit) to the top most Warkalli sediments, tentatively, as these sediments are barren of plant and animal fossils.

VII.1. Silicified Fossil Remains

During the course of palaeontological studies



Figure·47·A Location map, B·Lithology of Thachankonam bore hole of the Tertiary sediments of the area, milky white grains resembling fossil tests (Fig. 48) have been observed in a bore hole at Thachankonam, behind the Varkala cliffs (Figs. 47A & B). Similar silicified fossil fragments have been observed in the Varkala cliff sediments also (Fig. 48). The silicified fossil remains recorded at Thachankonam, have a vertical distribution ranging from 60 metres to 70 metres (Fig. 47B). The mode of occurrence of these fossil remains with indications of transportation and rolling of their fragmented nature, recorded in this area indicate that these could be drift assemblage, initially deposited in areas where marine conditions were prevailing such as areas around Padappakkara, Paravur, Edavai etc. (Rajendran, 1987) where the environment was conducive to the growth of these organisms. Later these fossils were transported and redeposited in the Varkala area. Subsequently the silica present in the sediments was dissolved due to high pH conditions and was reprecipitated in the form of opal inside the fossils tests controlled by factors like pH, presence of reactive oxides, hydrological conditions, temperature etc. (Ghosh and Raha, 1983).

Figure 48. SEM - micrograph of silicified fossil casts.

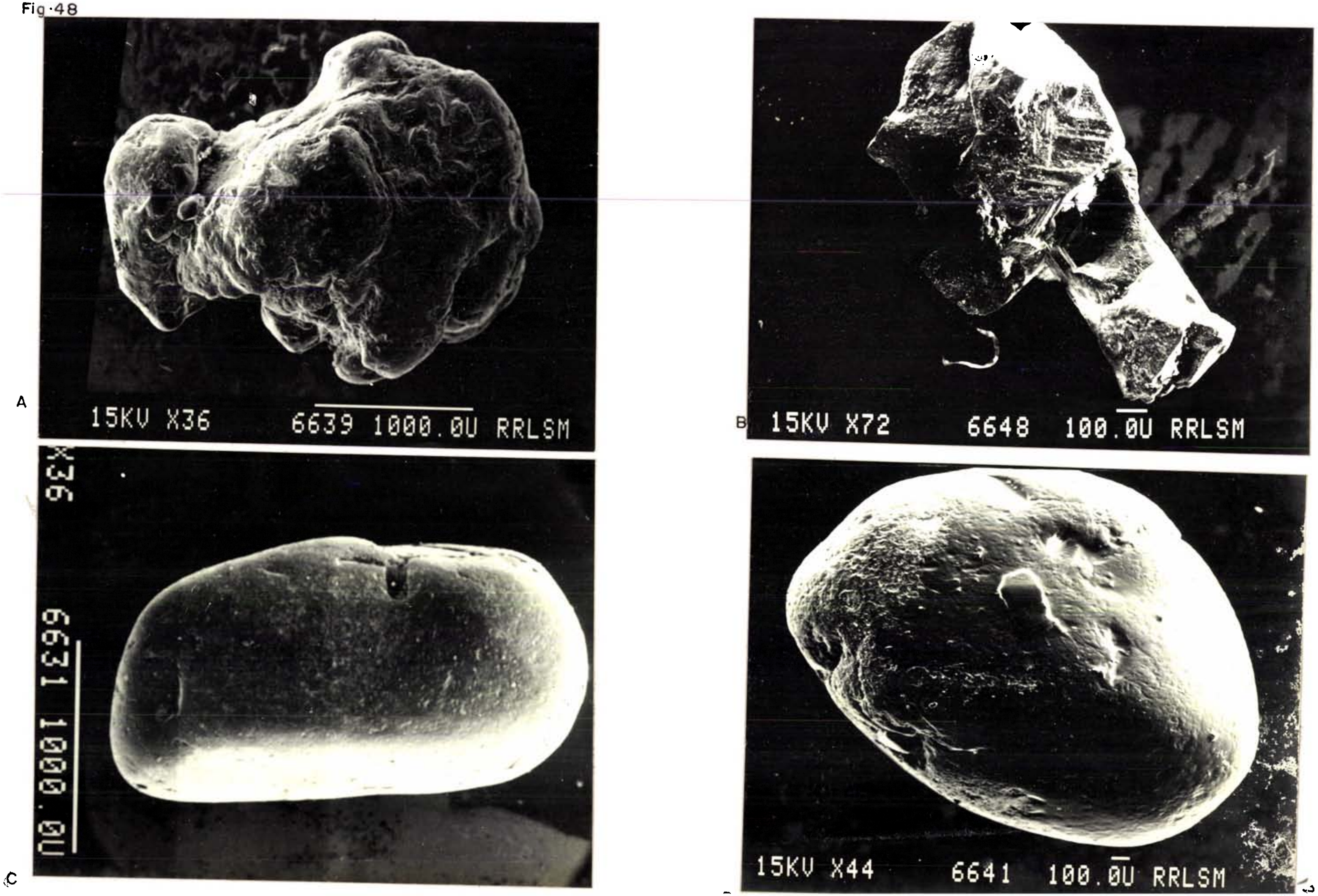
A. Fossil cast from Varkala

B. Fossil cast from Varkala

C. Fossil cast from Thachankonam

D. Fossil cast from Thachankonam

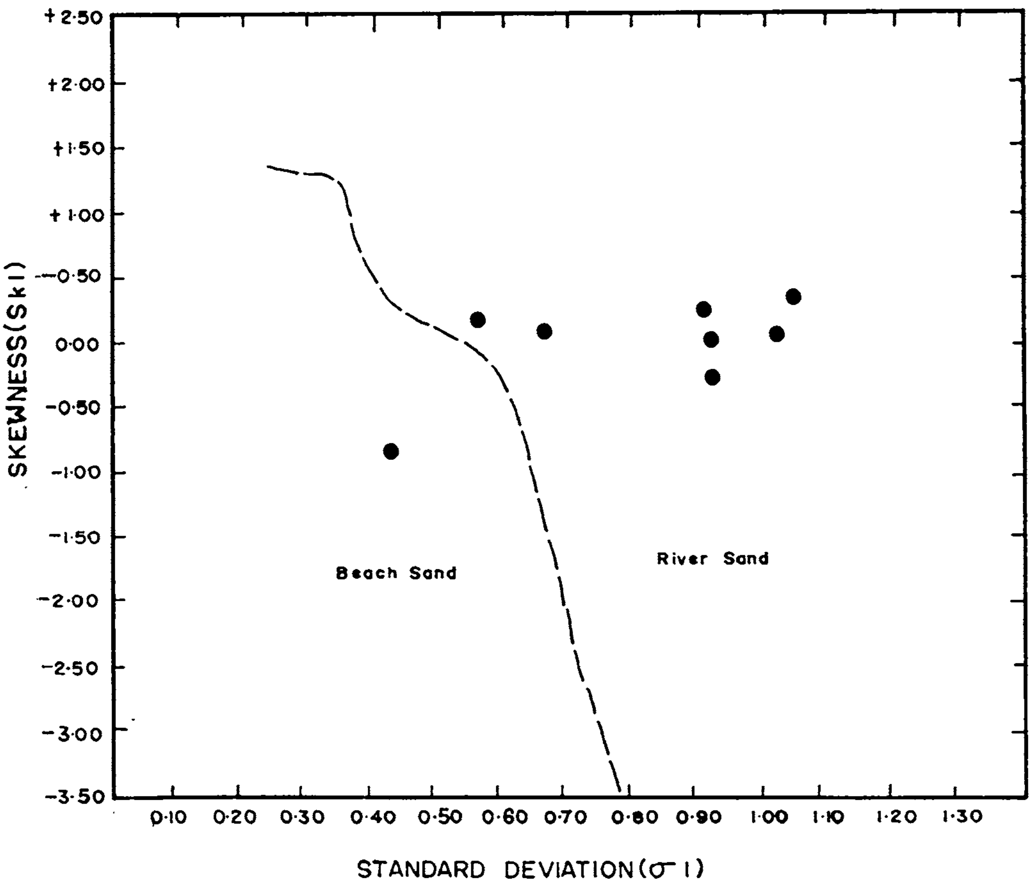
Fig·48


A
15KV X36
6639 1000.0U RRLSM
B
15KV X72
6648 100.0U RRLSM
C
X36
6631 1000.0U
D
15KV X44
6641 100.0U RRLSM

VI 2. Discussion

In situ lignitisation of trees can be observed at Kundara in the eastern periphery of the basin whereas lignites at the Varkala cliff are observed to be of drifted origin (Rajendran et al., 1986). This is further substantiated by the occurrence of lignitic pieces embedded in the limestones outcropped at Padappakkara and Paravur (Figs. 34 & 35). The size analysis of the cliff sediments at Varkala indicates that these were mostly deposited by streams (Fig. 49).

On the basis of the occurrence of drift assemblage of silicified fossil tests in the Warkalli sediments (type area) it is surmised that during a regressive phase of the sea, possibly in the Late Miocene the sediments including lignitic pieces and fossils were eroded and redeposited in the littoral area. This further suggests that the overlap sequence at Varkala type area should necessarily be younger (Late Miocene-Pliocene) than the sediments occurring around Kundara, Padappakkara, Paravur and Edavai.



Figure·49· Plot of skewness and standard deviation for Varkala sediments

VIII COMPARISON WITH OFFSHORE GEOLOGY

The nature and distribution of sediments in the offshore part of the southwest India are summarised and its possible relation to the onshore basin of Kerala is discussed in this chapter.

VIII 1. DSDP Site 219

DSDP bore hole at site 219 on the Chagos-Lakshadweep ridge (Fig. 50) as reported by Whitmarsh et al., (1974) penetrated through a sediment thickness of 411 metres in a water depth of 1764 metres. The sediments have been classed into five major units (Table 11). Apart from the predominant pelagic deposition from Pleistocene to Middle Eocene (Table 11 and Fig. 51) the important feature to be noted is the shallow water origin of the lowest (Paleocene) unit as indicated by the nature of its detrital sediments (Vallier and Kidd, 1977) and the limestone beds deposited during Late Paleocene to Early Eocene.

*Based on the fossil evidence the entire sedimentary column at site 219 has been demarcated from Pleistocene to Paleocene. The base of the Pleistocene

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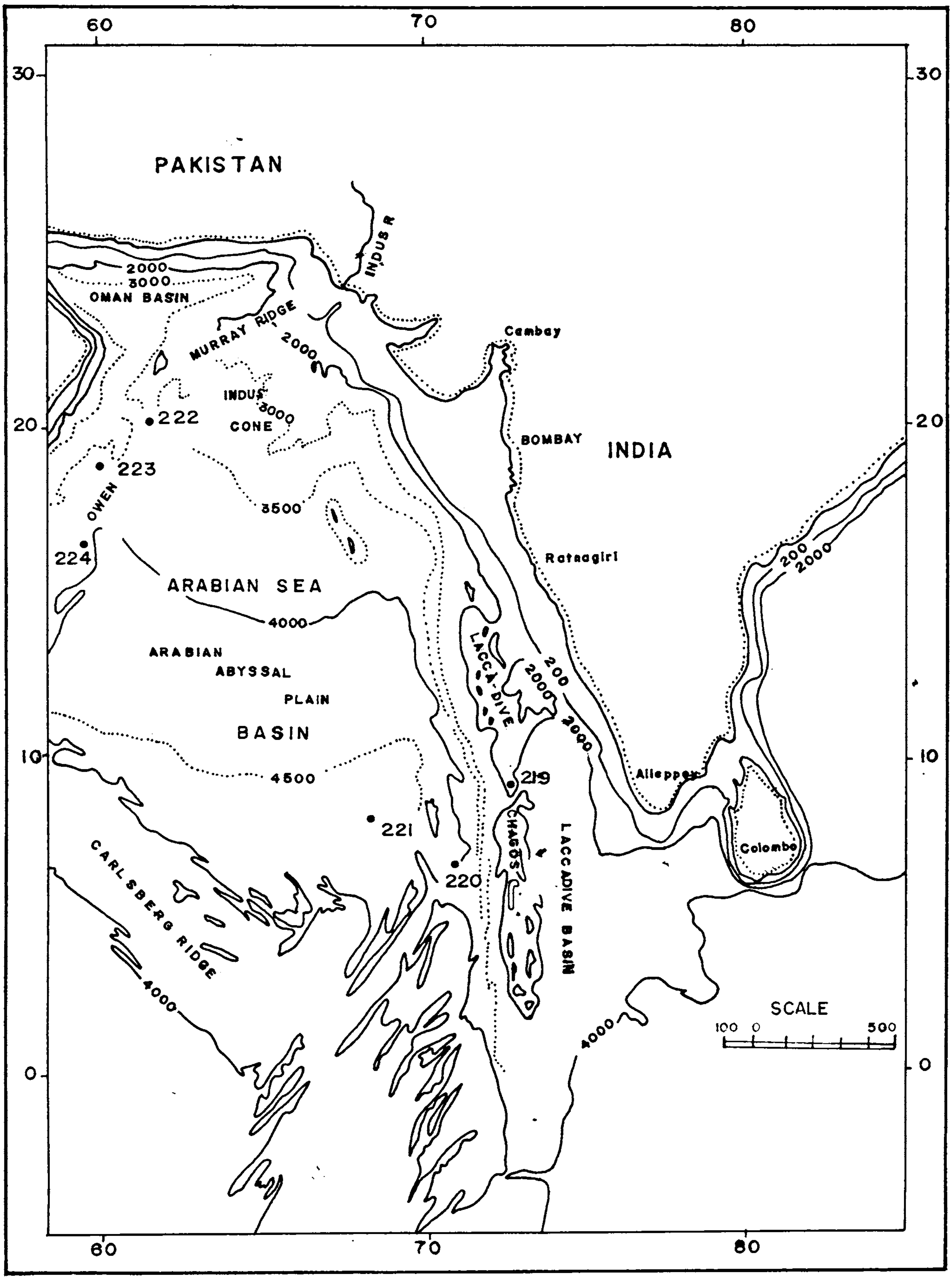
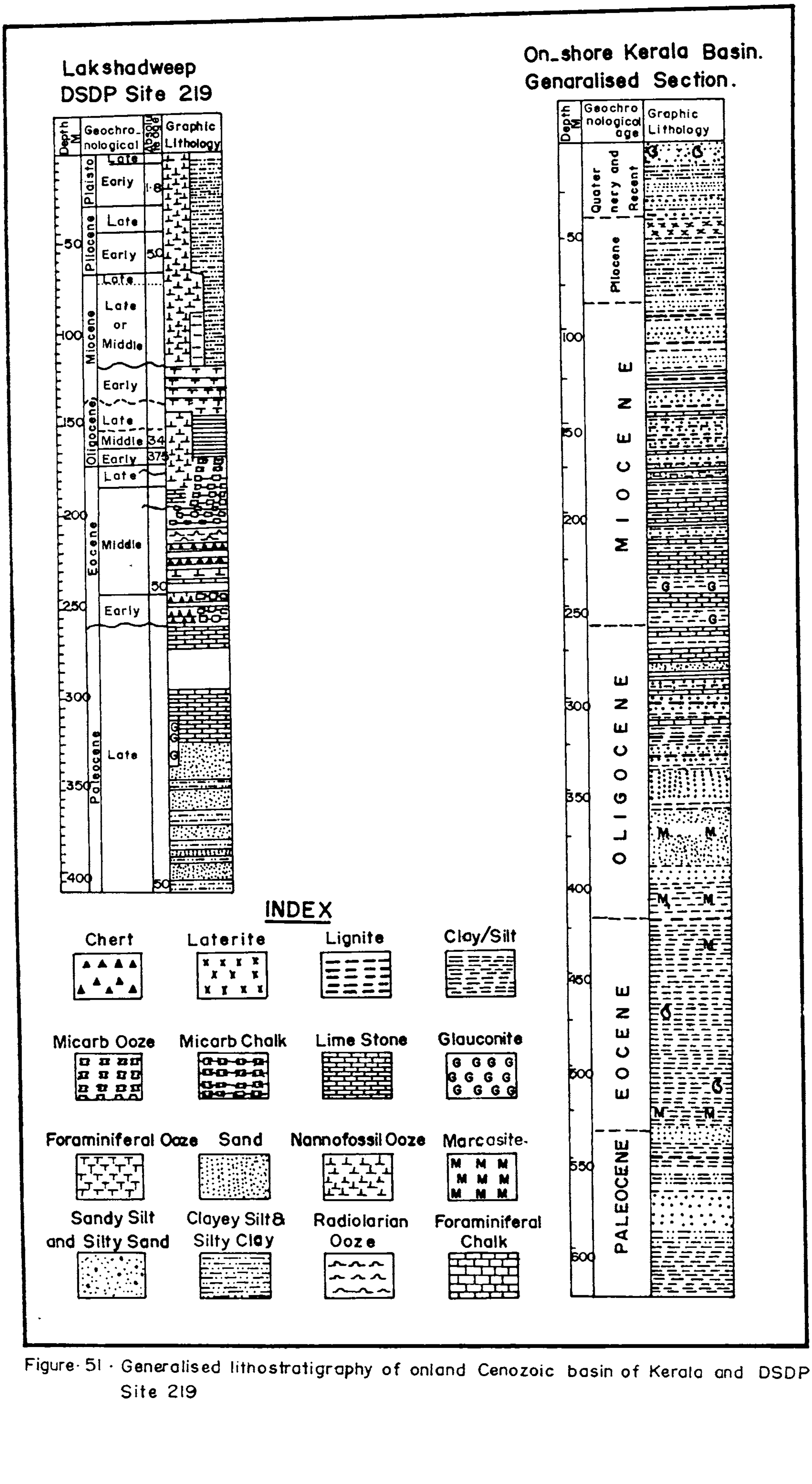
*Initial Reports of the Deep Sea Drilling Project, Volume XXII Washington, 1974.



FIGURE·50· POSITION OF LEG 23 (DSDP) SITES IN THE ARABIAN SEA·



Figure· 51 · Generalised lithostratigraphy of onland Cenozoic basin of Kerala and DSDP Site 219 is marked by the presence of Globorotalia truncatulinoides. The Miocene-Pliocene boundary is marked by the occurrence of Globorotalia tumida while the Late Miocene is indicated by the presence of Turborotalia accostaensis. Early Miocene faunae are mainly Globorotalia archaeomenardii and Globigerinoides sicanus. Faunae are relatively less abundant during Oligocene sequence possibly destroyed due to selective solution. Middle Eocene is marked by Truncorotaloides pseudodubius. Below this zone Hantkenina mexicana aragonensis was recorded indicating Middle Eocene. Important larger foraminifera reported are Discocyclina ramaraoi and Operculina sp.

VIII.2. Offshore Well

An exploratory well to assess hydrocarbon potential was drilled by ONGC in the Kerala offshore (10°20'36": 75°50'40") off the Cochin coast located in the shelf and was drilled to 1,760 metres (Mitra et al., 1983).

The section drilled was essentially terrigenous clastics with coarse grained sandstones, clay stones with lignite streaks and minor limestones in Mio-Pliocene section (Table 12). Two basaltic flows of 104 metres and 11 metres thick at 828 metres and 1133 metres respectively with intervening reddish brown clays occur in the bottom part (Table 12). The nature of the sediments suggests basal clastic nature of the sequence at the bottom (Mitra et al., op cit). The Miocene section has been marked on the basis of occurrence of *Miogypsina* sp and *Lepidosemicyclina sumatrensis* (Madanmohan and Kumar, 1980).

VIII 3. Relation with Onshore Basin of Kerala

The study of sub surface and outcrop sections of the Tertiary sequence of onshore basin of Kerala showed sediments ranging from Paleocene/Eocene to Early Miocene and upwards (Fig. 51) which has a more or less continuous extension into the offshore upto Lakshadweep ridge, with possible greater development of marine facies, in the central part of the offshore basin.

The sedimentary sequences in the onshore and offshore exhibit clastic nature of the sediments in the lowest units. This goes to prove that atleast from Late Mesozoic to Early Tertiary terrigenous processes of deposition were predominant in most of the parts of Kerala-Lakshadweep basin. But from Late Paleocene to Early Eocene onwards, marine influences were gradually becoming prevalent, as evidenced by the sedimentary units in the offshore and Lakshadweep ridge sequence. Late Eocene upwards, the ridge sequence is marked by pelagic sedimentation whereas transitional environmental processes were predominant in the onshore part of the basin.

The sequence at the Cochin well (Table 12) is essentially comprised of clastic sediments. This is suggestive of pronounced terrigenous sedimentation in the region of upwarps as in the case of Cochin offshore region. The marine depositional conditions were relatively more evident in the basinal parts as in the areas around Alleppey (onshore and offshore) and Lakshadweep ridge. Similar basins and upwarps (paleo-highs) have been reported elsewhere in the western coast of India (Desikachar, 1976).

The limit of paleobasins in the western India is confined to Chagos, Maldive and Lakshadweep islands which is suggested to be a zone of uplift (Pustilnikov et al., 1982). The uplift must have caused by thermal expansion owing to heat generated along the contact of rifting (Bolt, 1971). The block uplift of the area comprising Chagos Lakshadweep Ridge, western continental shelf and west coast must have occurred concommittant to the rifting of Indian plate in Late Mesozoic times (McKenzie and Sclater, 1971). The thick accumulation of terrigenous sediments in this area during this period is indicative of tectonic uplift and erosion of land areas, A correlation is suggested between mechanical load and mean continental elevation (Garrels and Mackenzie, 1971). The dyke swarms in the western India, basaltic flows in the offshore and the massive Deccan Trap eruptions were precursors to the rifting (Sinha Roy, 1982). Thus, it is surmised that the thick accumulation of terrigenous sediments in the major part of offshore and onshore basins of Kerala during Late Mesozoic - Early Tertiary times are related to the block uplift in the neighbouring land areas associated with rifting.

Subsequent to the rifting, Kerala - Lakshadweep basin was close to the sea level and the basin started subsiding with the transgression of sea during Late Paleocene which was conducive for the development of limestone beds in the ridge area. The ridge area was affected by a major subsidence in Early Eocene (Whitmarsh et al., 1974) and the effects could be seen even in the onshore area around Alleppey during this period. The transgressive and regressive phases of the sea in the marginal part of the basin must have been the reasons for the reworking of older sediments in the onshore area.

IX. SOURCE ROCK CHARACTERISTICS OF SUBSURFACE SEDIMENTS

The results of maturation studies on five selected bore hole samples from Ambalapuzha, from a depth of 500 metres to 594 metres (Paleocene - Eocene strata) are discussed in this chapter. In order to understand the source rock potential, vitrinite reflectance, maximum temperature of hydrocarbon generation (T max), total organic carbon (TOC), and HC/TOC (mg.hc/g. org.c) were found out for the samples.

The values for total organic carbon content is moderate. The values range from 0.39% to 20.59% with the maximum around depth of 509 metres to 513 metres. The petroleum source rocks generally contain 1% to 10% organic carbon (Bostick, 1979) and values less than 0.5 wt.% are considered below average (Claypool and Reed, 1976). Under favourable conditions, a lower limit of about 0.4 wt.% organic carbon may still yield significant amounts of recoverable hydrocarbons (Dow, 1977).

Optical examination of organic constituents shows that the samples are dominated by Type III Kerogen, probably derived from continental plants and in the diagenesis stage (Tissot, 1977). Vitrinite reflectance data (Table 13) shows that the sediments at this particular range of depth have not reached a level of thermal maturity conducive for hydrocarbon generation as the values range from 0.20 to 0.29%. But evaluation of thermal maturity values are not always easy because they are dependent upon temperature (a function of burial depth and geothermal gradient), duration of burial and the types of organic constituents present (Tissot et al., 1974).

As shown in Table 13 the percentages of total organic carbon (% TOC) are all greater than the minimum requirement (0.5%) for petroleum source rock (Underwood, 1985) - and the ratios of hydrocarbon to total organic carbon (HC/TOC) are generally comparable with those reported previously for sediments giving significant petroleum generation (Tissot et al., 1974).

On the whole the samples show some indications for the development of hydrocarbon source rocks in the Paleocene - Eocene strata but the vitrinite reflectance values for all the samples are less than 0.3% and generally values greater than 0.5% is required for a source rock to be sufficiently mature to generate crude oil. Even in the cases where vitrinite reflectance values of about 0.4%, crude oil generation has been proved (Connan, 1980). Better vitrinite reflectance values can be expected in the offshore part of this basin where there is greater development of the same facies in deeper levels, since maturity is influenced by depth and duration.

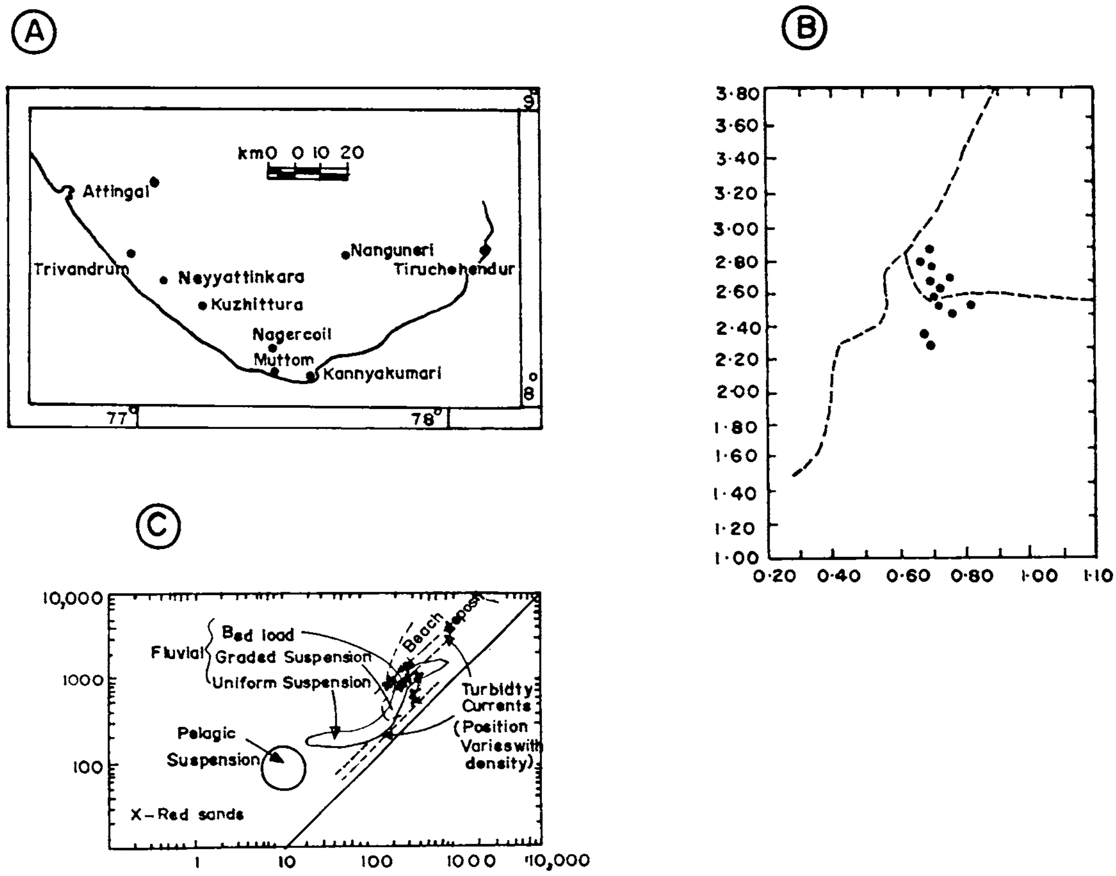
QUATERNARY SEDIMENTS

The Quaternary sediments of Kerala comprise of alluvium, beach sand deposits, lime shell deposits, red sands, peat beds, calcareous clays with shells which are underlain in the coastal area by laterite, which also marks the unconformity with the Tertiary sediments. These sediments have been distributed extensively in the low lying areas in Quilon, Kottayam, Alleppey, Ernakulam, Trichur, Calicut, Cannanore and Kasaragod districts. Occasionally, towards the inland areas these sediments are separated from the Tertiary rocks by a polymict pebble bed. These are recorded at Kundara, Attingal in the south and Nileswar and Kasaragod in the north. Main features and genetic aspects of Quaternary sedimentary units are summarized in this chapter.

X. 1. Red Sands

The red sands (Pleistocene to Recent) seen on the coastal tract of Kerala, especially around south of Trivandrum and Kanyakumari districts are locally known as 'teri'. It constitutes a distinct sequence with characteristic red colour and overlies both sedimentary and crystalline rocks. The red sands occur at Muttom sea shore (Fig. 52A) was taken up for studies. These deposits have a dome shaped form and are deposited over a wave cut rocky platform, 2 to 10 km wide belt, along the coast and has a vertical thickness of 20 to 30 metres. They contain fine to medium grained sands with more than 80% sand fraction with about 22% rounded sand grains and the rest being angular grains. Red sand of this area has an average 3.4% heavy mineral weight percentage. The major heavy mineral constituents are ilmenite and zircon with haematite. Monazite, sillimanite, rutile, leucoxene and vermiculite constitute the minor constituents. Grain size parameters and quartz morphoscopic features of the red sand at Muttom were studied to reconstruct its depositional environment.

Twelve samples from Muttom area were selected for size analysis. A hundred gram representative split (after coning and quartering) of each of the samples was run through the ASTM sieves at $\frac{1}{2}\phi$ interval for twenty minutes on a Ro-Tap shaker (Carver, 1971). Quartz surface features were studied under the scanning electron microscope. For the present study, following Friedman (1961), mean, standard deviation and skewness have been calculated based on moment measures (Table 14a).



Figure·52· A Location map of Muttom red sands·

B · Plot of Standard deviation and mean size after Friedman 1961, for red sands·

C· CM Diagram, after Passega, 1957, for red sands ·

The samples exhibit moderate standard deviation (0.67 Ø to 0.78 Ø) with a mean size, 2.15 Ø to 2.73 Ø. Four samples showed negative skewness and the rest showed positive skewness (Table 14a). As the skewness is not considered very important for discrimination (Sahu, 1983), the plot of standard deviation (sorting) against mean grain size, after Friedman (1961) has been employed (Fig. 52B). This suggests a fluvial environment of deposition and standard deviation values (Table 14a) are also similar to river sands which generally exceed 0.50 Ø, as suggested by Friedman (1961). This is further supplemented by plotting the coarsest fraction C (one percentile particle diameter measured in microns) against average grain size M, following Passega (1964). This plot also indicates that sediments have affinity towards fluvial environment (Table 14b and Fig. 52C).

Surface textures produced by chemical and mechanical processes that affect quartz sand grains are typical of different environments of deposition (Al-Saleh and Khalaf, 1982). Both angular and rounded quartz grains were selected from different size fractions. Examination of the surface textures under the scanning electron microscope reveals effects of both mechanical and chemical action on the grains. The v-shaped pits are common in the rounded grains and straight net like sutures are abundant in the angular grains (Figs 53 and 54).

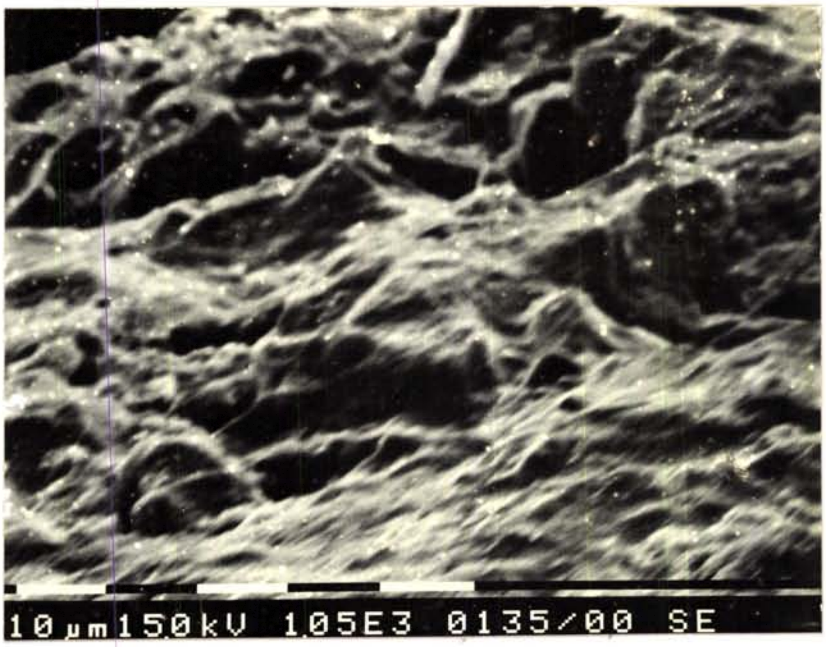
The studies indicate that the coastal red sands at Muttom were largely deposited by streams. Ridges and sutures found in the surface of angular grains (Fig. 54) which could have formed mostly due to solution of silica along microfractures in an alkaline near surface diagenetic environment. This suggests that these sediments were initially acted on by sea (alkaline) water. These deposits are now seen elevated above the high water mark which suggest subsequent regression of the sea either due to Pleistocene sea level fluctuations or due to tectonic movement. A small percentage of rounded grains present in the sediments with impact pits suggest limited wind action on the already deposited sediments after the regression of the sea.

X.2. Shell Deposits

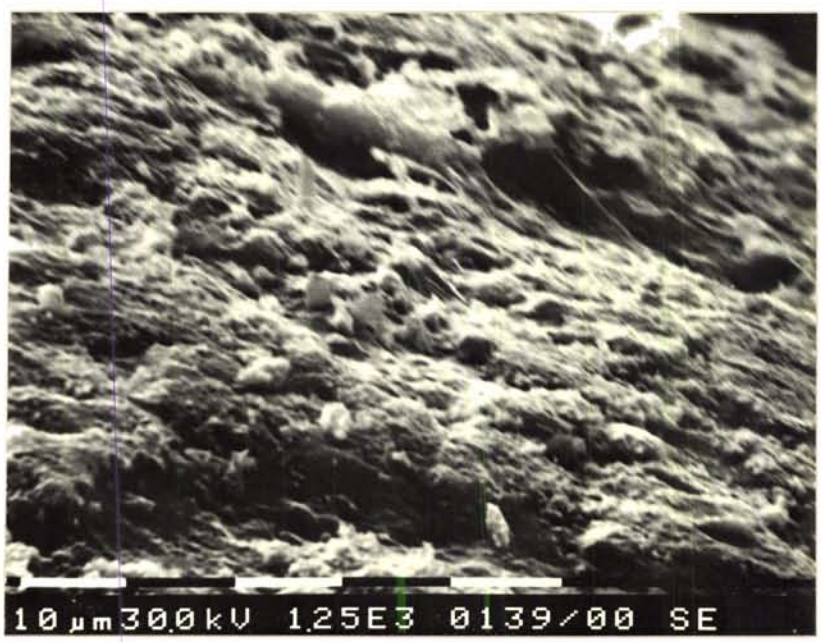
The lime-shell deposits of Kerala occur in the back waters along the coast (mostly in Vembanad Lake and Astamudi kayal) and also in

Figure 53. SEM micrograph of surface of quartz grain showing v shaped impact pits.

Figure 54. SEM micrograph of surface of quartz grain showing net like sutures.



Fig·53



Fig·54

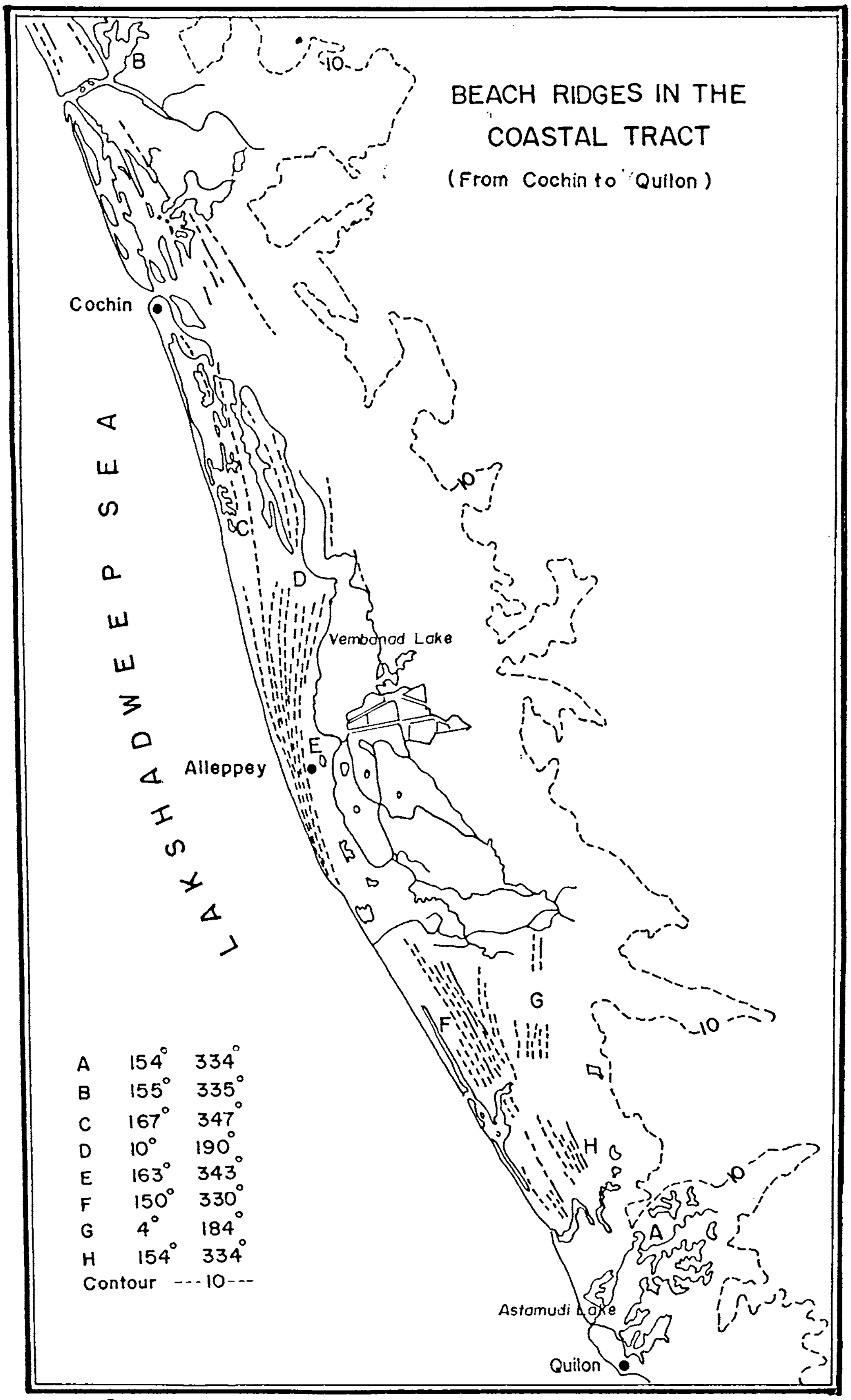
the onshore areas close to the coast (mostly around Payyannur, north Kerala). These shell deposits are recorded below a depth of 2 metres under the cover of loose sands and clays, having a thickness of 0.5 metre to 1 metre. The shells are mainly comprised of lamellibranchs and gastropods which include ostrea, gryphea, meretrix etc., the majority being ostrea shells. The radiocarbon dating (Table 15) of these shells indicated an age ranging between 4490-1330 Y.B.P.

The shell deposits which form a very rich source of lime are formed by the accumulation of dead organisms. These organisms which normally grow in marine environments might have been destroyed after the complete withdrawal of saline water after being trapped in its ecological niche which indicates cut off from the sea probably due to development of sand bars. This may also indicate an originally existed tidal flat environment in the Kerala coast where coast initially had an open access to the sea. Oldest ages of shell deposits are recorded in north Kerala in contrast to the south Kerala (Table 15). This suggests that the withdrawal of sea started initially in the north Kerala.

The age of peat (7230 Y.B.P to 6240 Y.B.P) collected from some of the localities in Kerala (Table 15) brings out the period of deposition of peat prior to shell beds. The age obtained for the peat in the present study approximately tallies with the age data (8080 Y.B.P to 7050 Y.B P) of the earlier studies (Agarwal et al., 1970; Powar et al., 1984). This is also indicative of subsidence during this period for the development of peat beds.

X.3. Beach Ridges

Linear coastal ridges can be observed in the Kerala coast upto 15 km east of the present coast beyond Vembanad Lake, Vaikom and Kumarakom. There are mainly two directions in which the palaeo sand ridges are trending (Fig. 55). One set trending in north south direction around Alleppey which changes to NNE-SSW in the east of Shertalla where the first set abutts the second set. It is possible that consequent to the deposition of the first set i.e., NNW-SSE which was later cut by the ridges in NNE-SSW direction deposited during a phase of regression. Physiographically the area falls in the coastal plains



BEACH RIDGES IN THE COASTAL TRACT
(From Cochin to Quilon)
B
10
Cochin
LAKSHADWEEP SEA
C
D
Vembanad Lake
E
Alleppey
G
F
10
H
10
A
Astamudi Lake
Quilon
A 154° 334°
B 155° 335°
C 167° 347°
D 10° 190°
E 163° 343°
F 150° 330°
G 4° 184°
H 154° 334°
Contour ---10---

Figure 55

with an elevation from 0-6 metres in the western side bordering the sea.

IX.4. Age and Genesis of Quaternary Sediments

Deposition of Quaternary sediments of Kerala are genetically related to sea level fluctuations. The red sands deposited over the raised beaches, shell deposits, peat, beach ridges offer excellent proofs for eustatic sea level changes. The peat beds (submerged forest) in the central coastal tract of Kerala indicate subsidence and transgression that occurred roughly around 8000-6000 Y.B.P. and the occurrence of thick limeshell deposits indicates regression, occurred around 5000-3000 Y.B.P. Based on these data the following stratigraphic sequence can be given for the Quaternary sediments of Kerala.

Vembanad Formation	HOLOCENE	Soil, alluvium and beach sands, Black sands, sandy calcareous clays with shells and beach ridges
		Red 'teri' sand
		Lime shell deposits
		Peat and carbonised wood
		------------unconformity-----------
	Pleistocene	Laterite pebble bed

--- ---------------------- unconformity-----------

Miocene-Pliocene sediments

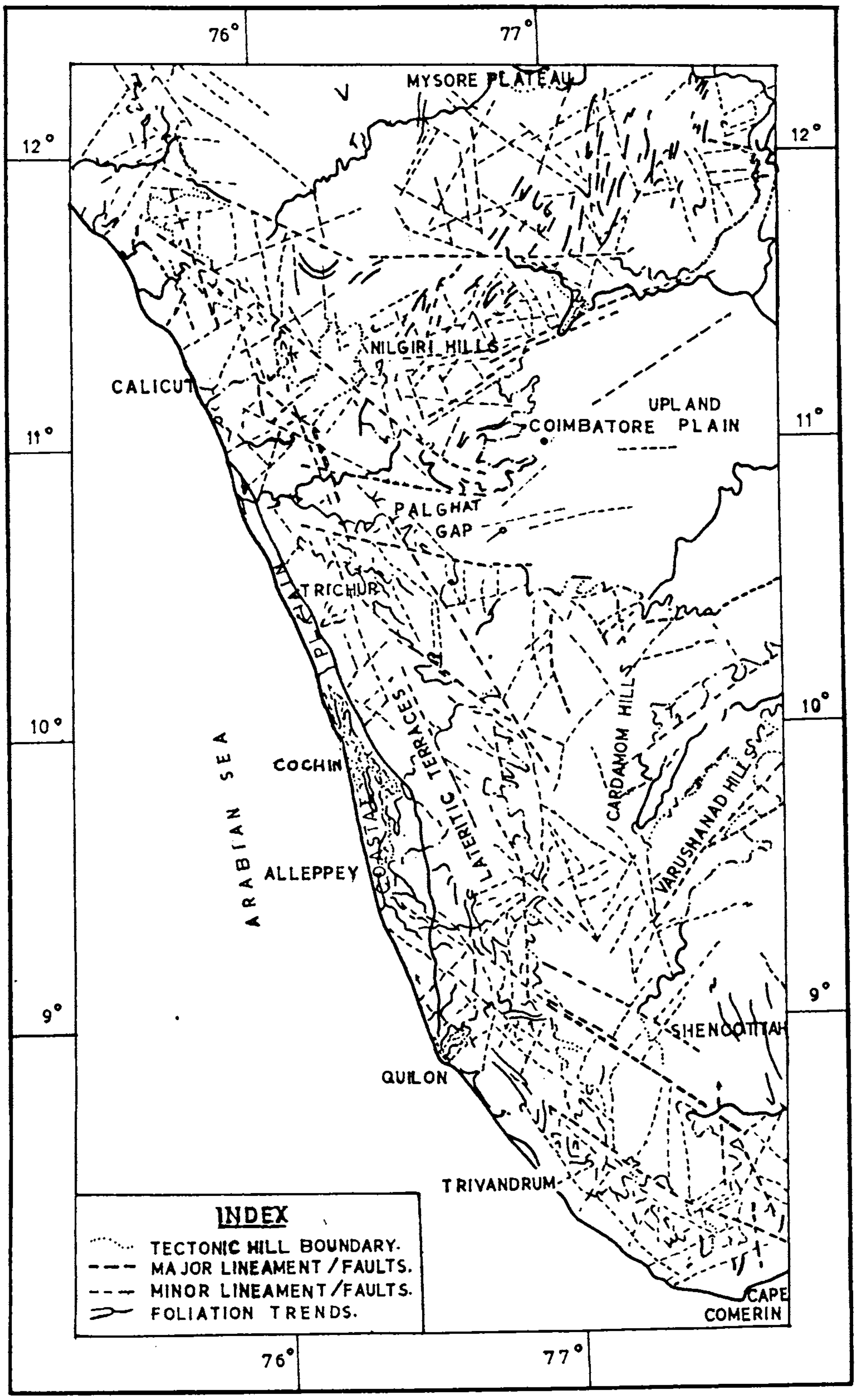
It appears that there was a development of laterite pebble bed over the Late Tertiary sediments indicating an unconformity. The Late Tertiary sediments in most cases have been eroded due to marine transgression and regression except in places like Varkala which was elevated due to neotectonic movements.

XI. STRUCTURAL SETTING OF COASTAL BASIN

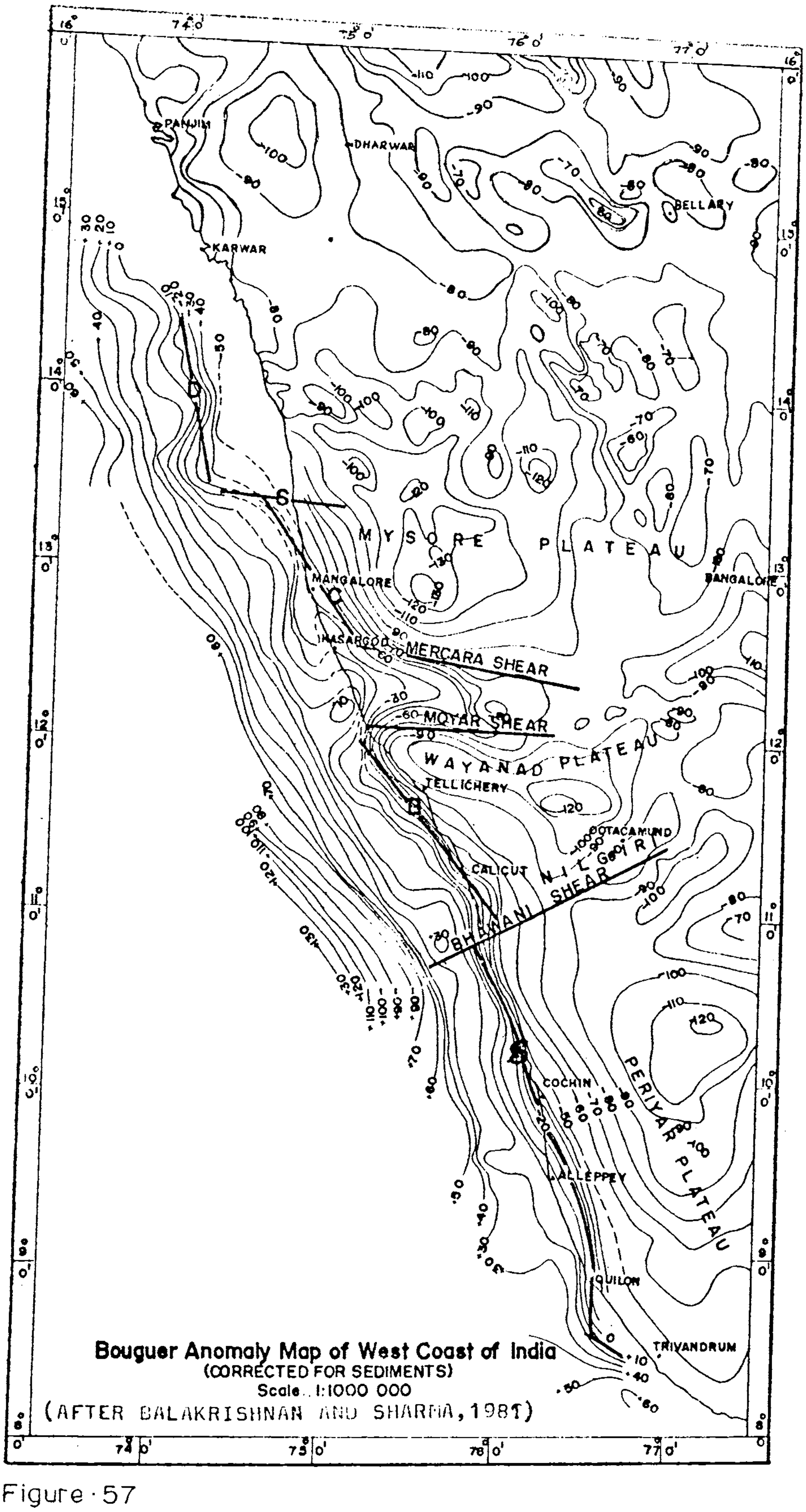
XI.1. Tectonic Elements

Kerala region is criss-crossed with a number of fractures and lineaments (Fig. 56). The major directions of lineaments are NNW-SSE, NW-SE to WNW-ESE and NE-SW (Varadarajan and Balakrishnan, 1980). The major west coast deep fault trending NNE-SSE is sheared and displaced at several places. These shearings and displacements gave rise to a number of basins all along the western coast of India (Fig. 57). The Bouguer anomaly map (Balakrishnan and Sharma, 1981) shows three major shears viz., Bhavani shear, Moyar shear and shear 'S'.

The landsat imagery of central Kerala also indicates a major lineament trending NNW-SSE (Fig. 58). Courses of the rivers which flow in the central part across this lineament show a slight offset towards north (Rajendran, 1982). The shear 'S' picked up in the Bouguer anomaly map (Fig. 57) which starts from Quilon passes east of Alleppey and then runs along the coast upto Bhavani shear. It coincides with the corresponding lineament observed in landsat imagery



Figure·56· Lineament map of Kerala (after Varadarajan and Balakrishnan,1980)



Bouguer Anomaly Map of West Coast of India
(CORRECTED FOR SEDIMENTS)
Scale.. 1:1000 000
(AFTER BALAKRISHNAN AND SHARMA, 1981)
PANJIM
DHARWAR
BELLARY
KARWAR
MYSORE PLATEAU
MANGALORE
BANGALORE
KASARGOD
MERCARA SHEAR
MOYAR SHEAR
WAYANAD PLATEAU
TELLICHERY
OOTACAMUND
CALICUT
NILGIRI
BHAVANI SHEAR
COCHIN
PERIYAR PLATEAU
ALLEPPEY
QUILON
TRIVANDRUM

Figure·57

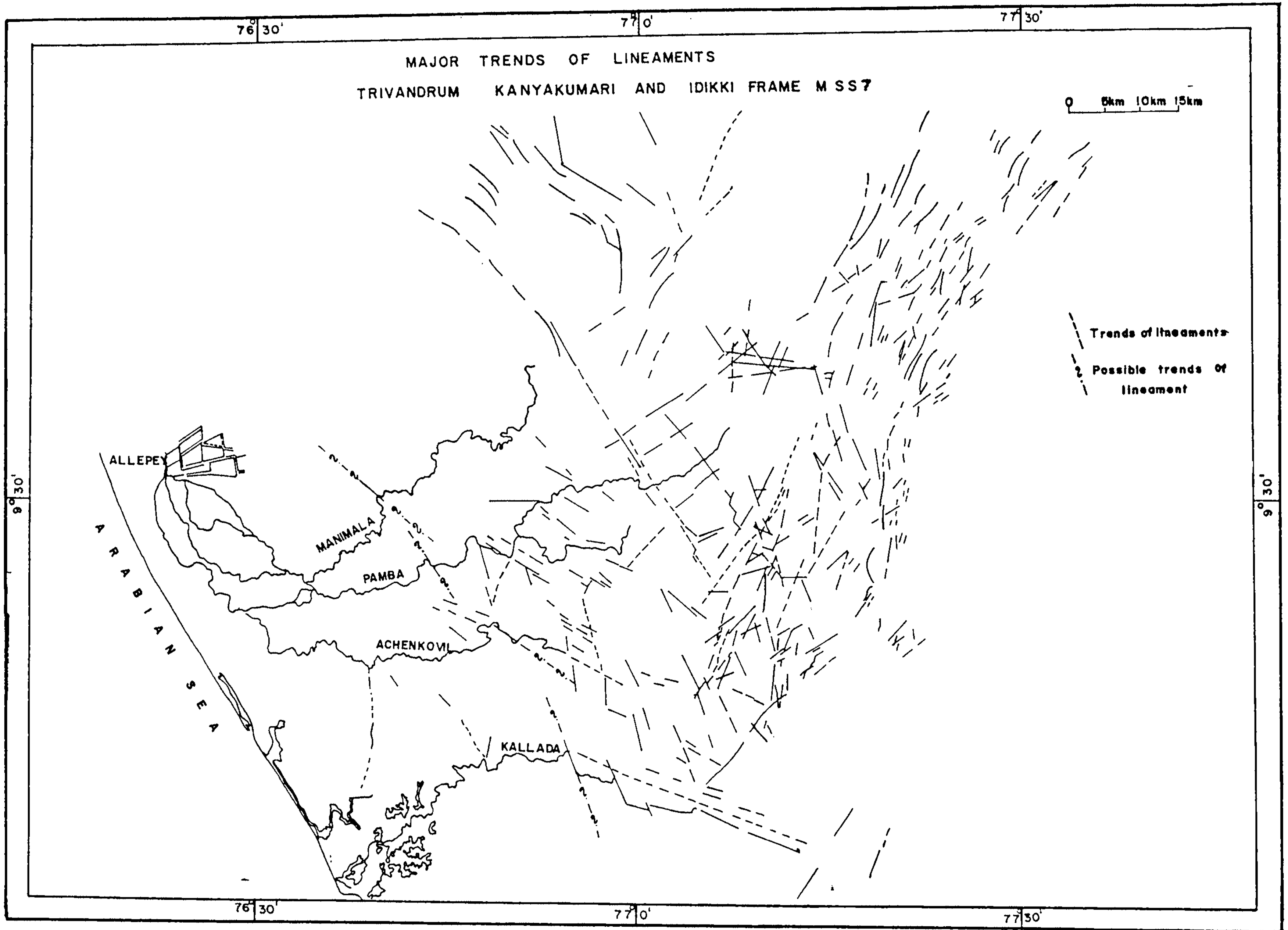

76° 30'
77° 0'
77° 30'
MAJOR TRENDS OF LINEAMENTS
TRIVANDRUM KANYAKUMARI AND IDIKKI FRAME MSS7
0 5km 10km 15km
Trends of lineaments
Possible trends of lineament
9° 30'
ALLEPEY
MANIMALA
PAMBA
ACHENKOVIL
KALLADA
ARABIAN SEA

Figure · 58

The deep sedimentary basin formed around Alleppey and off Alleppey must be due to this basin margin fault. The periodic uplifts of the Western Ghats and corresponding subsidences in the coastal areas led to the foundering of the basin between Kerala and Lakshadweep.

X 2. Tectonism and Sedimentary Facies

Tectonic evolution of west coast basin appears to have gone through two main structural-stratigraphic stages. The first mainly confined to Late Mesozoic was dominated by taphrogenic fragmentation and block uplift along the dominant NNW-SSE basement trends. The first stage culminated in the second episode of west coast fault in Early Eocene which also led to the initial transgression of the sea.

The bauxites and laterites which occur under the sedimentaries owe its present position to the west coast faulting. Presence of bauxite/laterite under the sedimentaries indicates that there was a long period non deposition during Late Mesozoic period. The basal clastics in Kerala region and adjoining areas of west coast of India can be regarded as the clastic wedges formed along the flanks of uplifted Western Ghats during Late Cretaceous/Paleocene period.

Carbonate platform over a basal clastic sequence started developing landwards in basinal parts of Kerala basin from Early Oligocene and attained its maximum development during Early to Middle Miocene during the transgressive phases of sea, when the clastic input was minimum. During Late Oligocene and Miocene there was further deepening of the sea as indicated by the submergence of the uplifted areas with its Miocene limestone outcrops in the adjoining areas around Quilon, being the relict of the Early Miocene transgression. By the end of Miocene, the region witnessed a reactivation of the basin margin fault which brought some of the coastal marginal areas like Varkala cliffs to higher elevation and consequent regression of the sea. Carbonate sedimentation was arrested towards the end of Miocene due to rejuvenation of clastic source. The regression of the sea led to considerable erosion of the already deposited limestone and the lateritization over the sedimentaries was initiated.

The lateritic beds are overlain by marine, coastal and lagoonal deposits of Quaternary age, which are related to Flandrian sea level changes. The mud samples from off Alleppey indicated presence of spores and pollen of once existed extensive mangrove vegetation in coastal part of Alleppey (Kar, personal communication). Presence of relict mangrove forest has also been reported (Ramachandran et al., 1986). This mangrove was probably flooded during transgression of the sea during 8000-6000 Y.B.P. which gave rise to extensive peaty soil. The deposition of red sands over the elevated terraces along some parts of the coast suggest tectonic movement of the coast during Holocene period.

XII. SUMMARY AND CONCLUSIONS

Major sedimentary outcrops of Kerala are located at Karuchal, Varkala, Thonnakal, Kundara, Padappakkara, Edavai, Paravur, around Kottayam, Cannanore, Palayangadi, Cheruvathur and Nileswar. Mostly the sections are consisted of variegated sandstones and kaolinitic clays with lignitic seams with isolated occurrences of limestone around Quilon. In the peripheral parts of the basin in the east, a sequence of ferruginous gritty sandstone could be traced which is considered as basal Tertiary sequence. Lateritic zones and occassionally bauxites have been observed under the basal ferruginous sandstones at several places in Kerala. Apart from the scattered outcrops, thick subsurface section of Cenozoic sediments (more than 600 metres) have been recorded in the coastal plain around Alleppey. The litho units recorded in the outcrops extend and attain its maximum development in this area and further extend into the offshore areas.

Sedimentary structures like horizontal bedding, graded bedding and cross stratification could be identified in the outcrops. These stratifications observed in the outcrops have been related to flow conditions. Based on the structures it is suggested that these sediments were deposited in shallow braided streams as point-bar and channel fill sequences.

Ferruginous gritty sandstones, traced in various locations in the peripheral parts of basin are coarse and gritty and well indurated and comprise angular to sub-angular grains of quartz in a hematitic matrix. Major heavy mineral constituents are ilmenite and leucoxene. Litho-facies analyses of the basin based on outcrop and subcrop data indicate that these sandstones form the lowest unit of the Tertiary sedimentary sequences of this region. The deposition of these sandstones occurred in a warm oxidising environment possibly during Late Cretaceous-Early Tertiary times.

Lateritic zones underlying these ferruginous sandstones with predominance of gibbsite in this laterite suggest initiation of desilication or bauxitisation under some favourable conditions. At a later stage, the desilication process stopped and lateritization process was started.

The low incidence of kaolinite and quartz in the laterites overlying the sediments indicates that the process of breaking up and leaching of silica and resultant concentration of alumina has not taken place in the laterites occurring above. The intensity of chemical weathering was very high for the older laterites under the sedimentaries. Two events of lateritizations, the first spell during Late Mesozoic prior to the deposition of sedimentaries and the second spell of lateritization during Late Tertiary developed over the sedimentaries, have been proposed for the Kerala region.

North-south and east-west cross sections across various parts of the subsurface and outcrop sections, brought out the relationships of sedimentary facies of the onshore basin of Kerala. A major stratigraphic marker unit is the laterite horizon which covers the Tertiary sediments. This also forms the unconformity between Tertiary and Quaternary sediments. This laterite horizon is underlain by a sequence of coarse to medium grained sandstones interbedded with clays, lignites and carbonaceous clay beds. A thick sequence of limestone and calcareous clays forms a prominent horizon beneath the sequence of sandstones, clays and lignites. The sediments underlying the carbonate facies mostly comprise of sandstone, clays and lignitic beds. The carbonate facies well developed in the western extremity of the onshore basin pinches out in the eastern margin and totally disappears. The terrigenous sedimentary units occurring above and below the carbonate facies in western part become a single unit in the eastern part, because of the absence of carbonate unit in the middle.

A new stratigraphic classification modifying the existing one has been proposed for the onshore sedimentary units of Kerala (Table 16). The three sedimentary units developed in the western part of the basin have been classified as Mayyanad Formation (terrigenous), Quilon Formation (marine) and Ambalapuzha Formation (terrigenous), from the bottom upwards. These three Formations have been put under Warkalli Group. The Warkalli Group overlies the Karuchal Formation and underlies the Vembanad Formation (Table 16).

The clay mineral assemblage of the subsurface sediments consists of kaolinite, montmorillonite, goethite, gibbsite and illite. Predominance of kaolinite must be due to heavy influx of this mineral from the continental sources. As the heavy minerals are concerned, opaques form the major part along with zircon, sillimanite, monazite, garnet, epidote, rutile and vermiculite. Terminally rounded zircons are found to be associated with these sediments, probably derived from the pre-existing sedimentary rocks. Increase of opaques in the top most Vembanad Formation is attributed to the uplift of source area during Late Tertiary - Early Quaternary period. Geochemically SiO_2 and Al_2O_3 are high in the sequence overlying and underlying the calcareous unit. It gets depleted in the calcareous unit. In the calcareous unit, the increase in SiO_2, Al_2O_3 and Fe_2O_3 corresponds to a decrease in CaO and MgO. The presence of trace elements like Ba and Mn in the calcareous sediments is found to have a relation to the depositional environment. Broadly the presence, the absence or the decrease of individual elements have a link with the magnitude of marine influences in the sedimentation.

Texturally the limestones that occur in this basin have been classified as biomicrites, sparse biomicrites and biocalcarenites. The petrographic characters indicate that the deposition was in a quiet, protected shelf environment free from much winnowing action of the waves. Dolomitic nature of the carbonates has been observed at Mayyanad and Padappakkara. This suggests that the carbonates were forming inside embayments with barrier reef near Padappakkara, the eastern most extent of the fossiliferous carbonate facies.

Glauconite occurs as pellets and blebs in the thin sections of the limestones and also as infillings in the chambers of the microfossils. Glauconites were formed in a neutral to alkaline pH conditions in a reducing micro-environments inside the fossil tests, as an authigenic mineral. Presence of glauconites suggests that the carbonates were formed in inner shelf environments at depths not exceeding 400 fathoms.

Palaeontologic studies indicate that the outcrops and the lower part of the Quilon Formation (200-270 m) in the bore holes are characterised by Archaias malabarica, Miogypsina sp, Lepidocyclina sumatrensis Globigerina quadrilobatus trilobus, Globigerinoides fohsi peripheroronda, suggesting Early Miocene to Middle Miocene.

Pre-Miocene foraminifers have been recorded at various depths in the subsurface sections around Alleppey. The Oligocene sequence (290 metres to 350 metres) is marked by the planktonic foraminifera like Globigerina binaiensis, Globigerina sellii, Globigerina cf ampliapertura and Globorotalia opima opima. Eocene (454 metres to 494 metres) is marked by the larger foraminifera like Actinosiphon sp., Penoperculoides sp., and Assilina sp.

The foraminiferal studies were supplemented by the palynological studies. The samples from depths of 506 metres to 509 metres and 461 metres to 464 metres from the subsurface sections were found to contain Palmaepollenites, Couperipollis, Proxapertites, Polycolpites, Meliapollis, Verrutricolporites, Retitribrevicolporites, Palaeosantalaceaepites, Striatocolporites and Proteacidites. These forms together with palm pollen indicate Eocene age from 509 metres to 461 metres. The presence of Crassoretitriletes, Trisyncolpites and Bombacacidites demarcate Oligocene in the depths from 443 metres to 276 metres. Occurrence of Malvacearumpollis, Hibisceaepollenites, Psiloschizosporis and Quilonipollenites, in the subsurface sediments from

278 metres and upwards indicate Lower Miocene. Age of outcrops has also been obtained through the palynological studies on the lignitic and carbonaceous clay samples from Thonnakal, Kundara, Padappakkara, Varkala, Edavai, Paravur, Cannanore and Palayangadi.

Age and correlation of the outcrops have been established on the basis of Miocene assemblage of palynomorphs. The presence of older Tertiary pollen genera, viz., Couperipollis, Lakiapollis, Retitribrevicolporites Triangulorites, Pseudonothofagidites etc., in the outcrop sections suggests that during Miocene, the Eocene sediments were eroded and redeposited in the coast of Kerala.

The silicified fossil remains, encountered in the Warkalli (Type area) sediments and the Thachankonam bore hole behind the Varkala section, are of reworked nature. In situ lignitisation of trees are observed at Kundara in the eastern periphery of the basin whereas lignites at the Varkala cliff are observed to be of drifted origin. This is further substantiated by the occurrence of lignitic pieces embedded in the limestones outcropped at Padappakkara and Paravur. On the basis of the occurrence of drift assemblage of silicified fossil tests in the Warkalli sediments (type area) it is proposed that during a regressive phase of the sea, possibly in the Late Miocene the sediments including lignitic pieces and fossils were eroded and redeposited in the littoral area. Based on this, it is surmised that the overlap sequence at Varkala type area should necessarily be younger (Late Miocene-Pliocene) than the sediments occurring around Kundara, Padappakkara, Paravur and Edavai having an age of Early Miocene.

Based on the available data on the offshore geology of Lakshadweep sea, off Kerala and the onshore geology of Kerala, it is concluded that upto Late Paleocene, the area including the parts of Lakshadweep ridge area continental shelf off Kerala and onshore area was a single unit and under similar type of depositional processes.

The source rock potential of the sediments from Paleocene - Eocene strata from one of the bore hole has been analysed. The samples constitute organic remains derived from continental plants and in the diagenesis stage. The sediments show some indications for source rock potential but the vitrinite reflectance values are very low and not suffiently mature to generate hydrocarbons. The source rock potential is expected to improve in the offshore region since maturity is influenced by depth and duration of burial.

The Quaternary sediments of Kerala comprise of alluvium, beach sand deposits, calcareous clays with shells, red sands, limeshell deposits and peat beds, which are underlain by laterite, which also marks the unconformity with the Tertiary sediments. The coastal red sands occur in southern parts of Trivandrum district were largely deposited by streams in the littoral area to be acted upon by sea. These deposits are now elevated above the high water mark suggesting subsequent regression of the sea either due to Pleistocene sea level fluctuations or due to tectonic movement. The limeshell deposits and peat deposits from different localities of Kerala indicate an age ranging between approximately 8000 Y.B.P. to 1000 Y.B.P. The organisms which build up the limeshell deposits, gave an age ranging from 4490 Y.B.P. to 1330 Y.B.P. These organisms which normally grow in marine environments might have been destroyed after the complete withdrawal of saline water after being trapped in its ecological niche. The peat was dated older than limeshells (7280 Y.B.P. to 6240 Y.B.P). The coastal sand ridges in Shertallai coast exhibit two directions, NNE-SSW and NNW-SSE. The NNW-SSE set, presumably formed first is abutted by the second set.

The above evidences prove the sea level fluctuations during Quaternary times in the Kerala coast. The peat beds in the coastal region indicate transgression that occurred around 8000 Y.B.P. and the occurrence of thick limeshell deposits indicates regression around 4000-3000 Y.B.P. The above data is employed for elucidating the stratigraphy of the Quaternary sediments of Kerala.

The deep sedimentary basin around Alleppey owes its origin to the NNW-SSE trending basin margin fault. The evolution of the basin started with the taphrogenic fragmentation and block uplift along the NNW-SSE basement trends. The presence of laterites and bauxites under the sedimentaries points to the long period of non-deposition during Late Mesozoic times. The lowest unit of basal clastics in the sedimentary sections of the region formed as a response to the uplift of the source area associated with rifting. Initial transgression in Early Eocene was related to the first major subsidence of the region. The carbonate platform developed landwards from Early Oligocene and attained its maximum development during Early Miocene. The end of Miocene witnessed the regression of the sea and reactivation of the basin margin fault. The occurrence of Holocene sediments on the elevated terraces of the coast suggests tectonic movement during this period.

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APPENDIX - 1

Methods used for laboratory treatment of microfossils

The rocks (of uniform weight) containing microfossils are crushed to smaller fragments. Lumps of soft rock such as sand, sandy clay and shales are soaked in water and made to disintegrate. These samples are boiled in weak solution of washing soda (about a table spoon full of soda to an average sample) for half to three hours. Thus foraminiferal tests are cleaned and separated from the matrix.

The fossils are separated from disintegrated material by washing. This material is wet sieved through a set of sieves of 40, 80, 120, 200 mesh size. The contents retained in the sieves are dried. The dried samples are kept in separate bags with details of samples and mesh size noted on them. Washed material is thinly spread under a binocular microscope and microfossils are picked up using a moistened thin brush and mounted on to the faunal tray for further studies. For the present study 180 samples from the outcrops and the sub surface sections were analysed to understand the microfossil content.

APPENDIX - 2

Preparation of palynological samples

The samples (100 gms each) are crushed to pass through 60 mesh. The crushed sample is taken in a beaker and added concentrated HNO_3. Hydroflouric as well as Hydrochloric acid are added to some samples depending upon the impurities present in the samples. The acid is washed off by centrifuging and decanting. The process is repeated several times till traces of acid are washed off and clear liquid is seen. After washing, 5-10% solution of potassium hydroxide is added to the clear liquid and washed the material for five minutes to remove traces of potassium hydroxide. The material is transferred to a watch glass and remove the water slowly after fifteen minutes. Some of the material from the watch glass is transferred to the cover slip and rinsed with a solution of polyvenyl alcohol. The coverslip with the material is put on a thermostat to dry. When it is dried, the coverslip is mounted in Canada balsam.

For the present study 200 samples covering the entire sequence of 600 m deep bore-holes near Ambalapuzha and Trikunnapuzha and part of the sequence at Thottappally were macerated out of which 100 samples yielded spores, pollen grains, microplanktons and some fungal bodies. Forty lignitic and carbonaceous clay samples for palynological studies were collected from the outcrops at Thonnakal, Kundara, Padappakara, Varkala, Edavai, Paravur, Cannanore and Palayangadi.

APPENDIX - 3

Sample preparation for XRD analysis

The clay sample is taken in a beaker with 50 ml of water and stir it well. This is brought to the boiling point by keeping it over a hot plate for 30 minutes. The clear liquid is decanted. Carbonate is removed by adding a drop of HCl. To remove the organic matter, 5 ml of H_2O_2 is added and stirred it. This process is repeated several times until the reaction is stopped. The sample is suspended in distilled water in a 1000 ml jar for about 24 hours. Clear liquid is decanted off and fresh distilled water is added. This process is repeated till suspension of the clay particles is obtained. About 100 ml of the water column containing suspension is taken out in a beaker with the help of a pipette. Excess water is allowed to evaporate at less than 80° C. The slurry was evenly spread on glass slides and dried at room temperature.

APPENDIX - 4

Chemical analysis of sediment samples

Samples are washed thoroughly and powdered. Powdered samples are coned and quartered for analysis. Major elements are analysed by wet chemical methods at the CESS Chemical Laboratory. Trace elements are analysed by Atomic Absorption Spectrophotometer (Perkin Elmer 4000) at the CESS Chemical Laboratory.

Decomposition of sample and determination of SiO_2

0.5 gm of the sample (W) is transferred to a crucible and add 2 to 3 gm of anhydrous sodium carbonate and mixed well. This is heated over a burner till an almost viscous liquid is obtained and cooled.

This is transferred to a porcelain basin and added some water and a few drops of ethyl alcohol. This is covered with watch glass and added 50 ml 1 + 1 HCl and place the basin over a water bath and content allowed to evaporate until the residue is free from fumes of hydrochloric acid. Transfer the basin with its contents to an oven for 1 hour at 110°C. After this, add 10 ml of HCl acid and 100 ml of hot water to the residue and is heated for 10 minutes, stirred well until the salts are in solution.

The solution is filtered through a whatman No.42 filter paper and collect the solution in a 250 ml standard flask. The precipitate is washed 10-12 times with hot water until the filterate is free from chloride. Reserve the paper and residue (I) and also the combined filtrate and washings (II).

Transfer the residue to a platinum crucible and incinerate. Place the crucible with cover in a furnace and heat the crucible at 950° C for 15 to 20 minutes. This is allowed to cool in a desiccator and weigh (A). The content is moistened with water and add some drops of 1+1 H_2SO_4 converting all the contaminating bases to sulphates and to prevent loss of titanium and zirconium as fluorides. Add 10 ml Hydrofluoric acid and evaporate slowly upon a steam bath. Then ignite the crucible at 1000°C for 1 or 2 minutes. Allow to cool in a desiccator and weigh (B)

The weight difference (A-B) = weight of silica

Percentage of silica $= \frac{(A-B) \times 100}{W}$

Add a little potassium pyrosulphate to the crucible and the residue is melted. The contents are dissolved by adding water and heating in a low flame. After dissol- add it to the main filtrate(II). Make up the solution to 250 ml.

Determination of total Iron:

Pipette out 25 ml filtrate to a 250 ml beaker, dilute to 40 ml add 10 ml con. HCl to oxidise all iron to Fe^{3+} state. Boil the solution and add stannous chloride solution till the solution becomes colourless. The solution is then rapidly cooled to about 20° C. Add 10 ml saturated mercuric chloride solution to remove the excess stannous chloride. The solution is allowed to stand for five minutes, add 20 ml 1:1 H_2SO_4, 5 cc orthophosphoric acid and a few drops of barium diphenylamine indicator. Titrate with standard 0.01 N potassium dichromate solution until the pure green colour changes to grey green. Then add dichromate dropwise until the first tinge of blue-violet, which remains permanent on shaking, appears.

$$Fe_2O_3 \text{ (Total)} = \text{vol. of } K_2Cr_2O_7 \times \text{Factor} \times \frac{100}{W}$$

FeO

Take 0.2 gm sample in a 250 ml conical flask add 10 ml 80% H_2SO_4 and 5 ml HF and heat the flask for

5 minutes in an atmosphere of CO_2. Cool the flask in ice cold water. Add 15 ml of saturated solution of boric acid to remove excess HF. Add a few drops of barium diphenylamine sulphonate indicator and 5 ml of ortho-phosphoric acid and titrate with standard 0.01 N potassium dichromate solution until the colour changes to blue violet.

$$FeO = \text{vol. of } K_2Cr_2O_7 \times \text{Factor} \times \frac{100}{W}$$

$$\text{Net } Fe_2O_3 = Fe_2O_3 = Fe_2O_3 \text{ (Total)} - FeO \times 1.1113$$

Aluminium

Pipette out 25 ml solution of the filtrate from the separation of SiO_2 to a 250 ml beaker add a few drops phenolphthalein indicator and add 20% NaOH till just alkaline add 5 ml more and boil for a few minutes. Cool and filter the solution through a whatman No. 40 filter paper and wash the filtrate with hot water. Collect the filtrate and washings in a 400 ml beaker.

Neutralise the filtrate by adding 1:1 HCl till the solution becomes colourless. Add very dilute NaOH in drops to the solution to change it just alkaline. Add 15 ml 40% ammonium acetate and 10 ml 0. 1M EDTA and boil in a low flame for 30 minutes. Cool in ice, add 1 ml acetic acid, 1 or 2 drops xylenol orange indicator and titrate with 0.1 M Zn solution until the colour changes from lemon-yellow to red colour.

1 ml. 0.1 M EDTA = 2.697 mg Al = 5.095 mg Al_2O_3

Al_2O_3 % = (B-V) x Factor x $\frac{100}{W}$

CaO and MgO

Pipette out 25 ml solution of the filtrate from the separation of SiO_2 to a 250 ml beaker. Add 1 gm ammonium chloride and 10 to 15 ml NH_3. Boil a few minutes and filter through a whatman No.40 filter paper and collect the filtrate in a 100 ml flask and wash with hot water and collect the washing also in the same flask. Make up the solution to 100 ml.

Pipette out 25 ml solution to a 100 ml china dish, add 2 ml ammonium chloride ammonia buffer and 1 or 2 drops Eriochrome Black T indicator and titrate with standard 0.01 M EDTA till the colour changes from wine red to blue. The titre value (A) corresponds to Ca & Mg.

Take another 25 ml add 2 ml 5% NaOH solution and 2 drops muroxide indicator. Titrate with 0.01 M EDTA till the colour changes to violet.

Titre value (B) corresponds to Ca

(A-B) corresponds to Mg

CaO = Bml x $\frac{Factor}{W}$

MgO = (A-B) ml x $\frac{Factor}{W}$

Solution for Trace

Take 0.5 gm sample to a platinum dish add a few drops H_2SO_4 and 25 ml HF. Evaporate to dryness. Add 30 ml 1:1 HCl and heat to boil. Transfer the solution to a 100 ml standard flask and make upto the mark. Trace elements are determined by Atomic Absorption Spectrophotometer.

Na_2O and K_2O are determined by AAS using the solution for trace elements determination.

Moisture and LOI

Weigh a clean heated, cooled platinum crucible with lid accurately (A) add about 1 gm sample and weighed again (B). (A-B) given the weight of sample. Place the crucible with lid in an oven for 1 hour at 105-110° C. Cool in a desiccator and weight (C). B-C given the loss of weight

$$\text{Moisture \%} = \frac{(B-C) \times 100}{\text{Weight of sample}}$$

After the moisture determination place the crucible in a muffle furnace at 1000° C for 30 minutes cool and weigh (D).

$$\text{Loss \%} = \frac{(C-D) \times 100}{\text{Weight of sample}}$$

P_2O_5

Take 0.5 gm sample and 2 gm potassium pyrosulphate in a test tube fuse well and cool. Add 10 ml 1:1 HNO_3 and boil in a water bath. Filter and collect in a 50 ml standard flask. Take a suitable volume of the solution add 5 ml vanadate molybdate reagent and compare the colour with a standard using spectrophotometer.

$P_2O_5\% = \text{Factor} \times 2.29$

Determination of organic matter in sediments

A small quantity of the sample, about 5 g was transferred to a dry 500 ml conical flask. Add 10 ml of 1N. K_2Cr_2O7 solution into the sample from a burette and 20 ml of conc. H_2SO_4. The mixture is thoroughly swirled for about one minute and kept on a hot asbestos surface for about 30 minutes to allow oxidation of the organic matter to proceed. The solution is allowed to cool and add 200 ml distilled water along with 5 ml orthophospheric acid and one ml of barium diphenylamine indicator solution and is shaken vigorously. Ferrous sulphate solution is added until the colour of the solution changes from blue to green. Potassium dichromate (0.5 ml) is then added, changing the colour of the solution back to blue. Ferrous sulphate solution was then added drop by drop with constant shaking until the colour of the solution just changes to green

Organic matter (percentage by weight) = $\frac{0.67\ V}{W}$

where

W = weight of the sample taken for analysis

V = 10.5 (1 - Z/X)

Z = total volume of ferrous sulphate used in the titration

X = total volume of ferrous sulphate used for standardisation

APPENDIX - 5

INDEX TO LOCALITIES

Ambalapuzha	..	9°23'50"	:	76°21'50"
Cannanore	..	11°50'30"	:	75°21'00"
Changanacheri	..	9°28'	:	76°32'
Cape Comerin		8°04'	:	77°33'
Chathannur		8°52'	:	76°00'
Chavara		8°59'30"	:	76°31'00"
Chengannur		9°18'	:	76°38'
Cheruvathur		9°48'40"	:	76°16'30"
Edavai		8°46'00"	:	76°41'30"
Ernakulam		9°59'	:	76°17'

Haripad	9°1'17"	76°28'
Kalarkod	8°47'45"	76°40'40"
Kallara	9°42'00"	76°29'00"
Karuchal	8°20'40"	75°09'40"
Kasaragode	12°30'	74°59'
Kidayangara	8°55'25"	76°42'30"
Kottayam	9°35'	76°17'
Kundara	8°57'	76°04'
Kurichi	9°30'30"	76°30'30"
Manjur	9°42'45"	76°29'45"
Mangalore	12°42'	74°50'
Mayyanad	8°50'	76°39'
Meenkunnu	11°54'30"	75°19'15"
Nedungolam	8°51'8"	76°41'75"
Nileswar	12°13'25"	75°07'00"
Othara	9°21'15"	76°41'45"
Padappakkara	9°58'	76°38'
Palayangadi	12°1'30"	75°15'00"
Paravur	9°49'	76°40'
Pattanakkad	9°44'	76°18'
Payyannur	12°05'	75°12'
Ponnani	10°02'	75°56'
Puvanthuruthi	9°32'30"	76°31'45"
Puliyur	9°18'15"	76°35'15"
Quilon	8°53'	76°55'
Thonnakkal	8°37'	76°56'
Thottappally	9°17'17"	76°28'
Tiruvalla	9°23'	76°34'
Trikaruva	8°45'10"	76°36'20"
Trikunnapuzha	9°15'30"	76°24'40"
Trivandrum	8°20'	76°57'
Udupi	13°25'	74°48'
Vaikom	9°45'	76°24'
Varkala	8°44'	76°43'
Vettur	8°43'30°	76°43'40"

TABLE 1

Stratigraphic Succession of Cenozoic Formations, Kerala
(after Paulose and Narayanaswami, 1968)

Recent to Sub-recent		Soils and alluvium Beach and dune sand deposits. Lime-shell deposits in back-waters. Older red 'teri' Sands. Sub-Recent marine and estuarine formations - sands, peat bogs with semi-carbonised wood, black sticky and sandy calcareous clays with shells, etc.
		Laterite

---Unconformity---

Upper Tertiary (Miocene to Pliocene)	Warkalli Beds (Mio-Pliocene)	Current-bedded friable variegated sandstones, interbedded with white plastic clays and variegated clays.
		Carbonaceous clays with lignite seams and alum clays
		Gravels and pebble beds
		Base generally marked by gibbsitic sedimentary clays (white laterite) and china clays (kaolinised gneiss)
	Quilon Beds (Middle Miocene) (Burdigalian)	Fossiliferous shell limestone (Padappakkara limestone) alternating with thick beds of sandy clays, calcareous clays and sands
		(Base unknown

---Unconformity---

Archaean	Khondalites, leptynites, charnockites, mica-hornblende gneisses and migmatites; locally Dharwar Schists in North Kerala.

TABLE 2

A comparative study of the various schemes of stratigraphic classification of the Cenozoic Sediments of Kerala

King (1882)	Menon (1967)	Paulose and Narayanaswamy (1968)	Desikachar (1976)	Nair and Rao (1980)
		Recent to Sub Recent soil and alluvium beach sand limeshell, sand, peat, black steaky and sandy calc. clays	KAINAKARI FORMATION Soil, alluvium beach sand, peat black peaty clays	Unit IV Beach sand and alluvial clays
WARKALLI BEDS	WARKALLI BEDS	WARKALLI BEDS (Mio-Plio)	AMBALAPUZHA FORMATION	Unit III A Laterite,
(Sandstones, arkose, clays lignite)	Coarse sandstones clays and lignite beds (with laterite top)	Current bedded friable sandstones carb. clays with lignite, gravel and pebble clays, base with gibbsitic sandy clays	Arkosic sand, kaolinitic sandy clay, black clays and peat with plant remains	ferruginous sandstone and clay. Unit III. Arkosic sand clays with lignite
QUILON BEDS Limestone	QUILON BEDS Limestones sandstones and clay	QUILON BEDS Fossiliferous shell limestone alternating with sandy clays and clay, clay and sands.	AZHEEKAL Fm. Limestones Assoc. with calc. clays and sands.	Unit.II Limestone with sand and clays
			MAYYANAD Fm. Sandstones and sandy clays with lenses of clay and peat.	Unit I Pebbly sands and sandy clays with black clays lignite

TABLE 3

Chemical Analysis of Ferruginous sandstones of the sedimentary basin of Coastal Kerala

Sl. No.	Locality	SiO_2%	FeO%	Fe_2O_3%	Al_2O_3 %	TiO_2%	P_2O_m ppm
1	Thiruvalla	46.24	0.25	40.40	6.12	0.17	630
2	Chengannur	35.78	0.14	49.74	6.16	0.18	690
3	Karuchal	38.26	0.18	25.56	6.08	0.26	620
4	Kottayam	48.4	0.27	40.23	6.23	0.13	518
5	Cheruvathur	30.54	0.21	53.64	7.51	1.80	115
6	Nileswer	44.4	0.26	38.16	6.98	0.32	117

TABLE 4

Lithologic Units Exposed at Cheruvathur, Karyangote and Nileswar

Lithology	Thickness in metres (approx)
Laterite	4.50 m - 12 m
Red Ferruginous fine grained and cross bedded sandstone	1.0 m - 3.5 m
Kaolinite clay admixed with sand	0.50 m - 3.5 m
Ferruginous gritty sandstone	0.50 m - 1.5 m
Laterite	2.0 m - 4.0 m
Kaolinitic clay	2.0 m - 3.0 m

(base not exposed)

TABLE 5

Major Elements in the Laterite Samples, Kasargod District, Kerala

Samples	Locality	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	Moist	LOI
C-1-A	Cheruvathur-laterite-I	43.8	13.57	26.98	0.10	0.10	0.005	0.65	0.23	1.89	12.34
C-1-B	Cheruvathur-laterite II	12.41	43.90	23.93	0.15	0.10	0.01	1.05	0.20	2.44	14.86
N-1-A	Nileswar-Laterite-I	45.61	12.33	24.95	0.10	0.10	0.005	0.65	0.24	2.68	12.90
N-2-B	Nileswar Laterite-II	15.60	48.01	23.93	0.10	0.10	0.005	0.58	0.26	2.14	9.24

TABLE 6

Sedimentologic parameters of sandstones of various localities

Locality	Sr. No	Sample No. (depth in m)	Mean size (phi)	median (phi)	standard deviation	inclusive graphic skewness	Graphic kurtosis
Mayyanad Ambalapuzha	1	MND 10 m	-0.45	-0.85	1.46	0.30	0.17
	2	NKM 34 93 - 97 m	-0.70	-0.70	0.90	0.07	0.92
	3	NKM 34 102-104 m	-0.46	-0.60	0.90	-0.35	1.32
	4	NKM 37 110-113 m	-1.10	0.30	1.13	0.17	0.72
	5	NKM 139-142 m	-0.92	-1.00	0.88	0.22	1.13
	6	NKM 50 151-154 m	-0.10	-0.30	1.70	-0.08	0.89
	7	NKM 53 160-163 m	-0.72	-0.70	0.72	0.05	1.14
	8	NKM 57 172-176 m	-0.26	-0.40	0.75	0.15	1.06
	9	NKM 60 183-186 m	-0.97	-0.95	0.58	0.08	2.23
	10	NKM 63 193-196 m	-1.06	-1.30	0.87	0.47	1.11
	11	NKM 65 200-203 m	-1.16	-1.40	0.87	0.90	1.02
Quilon Formation							
	12	NKM 103 326-330 m	0.07	-0.10	0.81	0.35	1.06
	13	NKM 104 a 330-331 m	-0.22	-0.15	0.95	0.34	0.84
	14	NKM 113 359-362 m	-0.87	-0.90	0.80	0.13	1.31

Locality	Sr. No	Sample No, (depth in m)	Mean size (phi)	median (phi)	Standard deviation	Inclusive graphic skewness	Graphic kurtosis
	15	NKM 137 408-414 m	-0.35	-0.25	1.20	0.14	1.05
	16	NKM 140 455-458 m	-0.43	-0.55	0.88	0.24	1.19
	17	NKM 161 522-525 m	-0.73	-0.70	1.30	0.19	1.05
	18	NKM 170 554-557 m	0.08	-0.15	1.16	0.28	1.02
	19	NKM 181 595-598 m	-0.13	-0.30	1.29	1.06	1.06
	20	NKM 182 597-600 m	0.13	0.05	1.00	1.63	0.99
Mayyanad	21	MND 36-37m	-0.26	-0.48	0.78	0.49	1.33
	22	MND 150 m	-0.35	-0.60	0.96	0.47	1.62
	23	MND 146 m	0.06	-0.25	1.20	0.45	1.29
	24	MND 80 m	0.39	0.00	1.39	1.52	0.91
Karruchal (Basal sandstones)							
	25	KCH 8	0.12	0.00	1.03	0.34	1.17
	26	KCH 9	0.30	0.20	1.03	1.09	1.03
	27	KCH 10	-1.25	0.30	1.09	0.53	1.10
Varkalai (From topddownwards)							
	28	Varkalai 13	2.21	2.55	0.93	-0.46	0.76
	29	Varkalai 14	1.73	1.70	0.98	0.04	0.68
	30	Varkalai 16	2.66	2.80	0.58	0.23	1.19
	31	Varkalai 17	2.43	2.50	0.67	0.12	0.83
	32	Varkalai 18	0.86	0.80	1.08	0.02	0.88
	33	Varkalai 24	2.91	2.90	0.45	-0.74	1.59
	34	Varkalai 25	0.70	0.75	1.48	-0.08	0.84
	35	Varkalai 26	1.13	0.90	1.05	0.33	0.92
	36	Varkalai 27	-0.60	-0.90	1.16	0.47	1.56

Note:Samples at Mayyanad (Sr.No.1 and at Ambalapuzha Sr.No. 2-11 and 28-36, are those of Ambalapuzha Formation (overlying Quilon Formation) and Sr.No.12-24 represent the Mayyanad Formation occurring below the Quilon Formation.

TABLE 7

Lithostratigraphic classification of the Cenozoic Sedimentary sequence of Kerala coastal region.

Supergroup	Group	Formation	Lithology
MALABAR SUPERGROUP		Vembanad Formation (3-60 m)	Soil and alluvium. Beach and dune sands, lime-shell deposits, older red "teri" sands, marine and estuarine deposits, peat and sandy calcareous clays, gravel beds with lateritic gravels at places
		Unconformity (lateritic and conglomeritic horizons)	
	Warkalli Group	Ambalapuzha Formation (3-140 m)	Pebbly and coarse sand with peat and variegated and mottled clay. Gray clay and lignite. Alternations of sand and steaky gray and carbonaceous clay often with lignite bands, with coarse sand near the base.
		Quilon Formation (0.5-130 m)	Limestone with bands of calcareous clay and sand in various proportions, gray fossiliferous and calcareous clay near the base.
		Mayyanad Formation (1.0-270 m)	Coarse to medium grained sandstones with interbedded gray and white clay and lignite beds. Facies grades laterally to sand-clay alternations with lignitic bands towards the central part of the basin
		Unconformity (conglomeretic horizons)	
		Karuchal Formation (2-20 m)	Hard and compact ferruginous sandstones with overlying arkosic sandstones and clays
		Unconformity (bauxitic/lateritic horizons)	

Basement
(Gneisses, charnockites, leptynites etc)

Table 8 Major, minor and trace elements of subsurface clay samples, Ambalapuzha

Sl.No	Depth in metres	SiO_2%	Al_2O_3%	Fe_2O_3%	FeO%	CaO%	MgO%	Na_2O%	K_2O%	TiO_2%	Mn ppm	Cu ppm	Bi ppm	Ga ppm	Sr ppm	Pb ppm	B ppm	Ba ppm	Ln ppm	Tl ppm	Organic matter
1	44-47	40.03	23.96	12.14	2.69	1.12	0.67	0.55	0.20	0.64	156	69	213	84	8.0	135	425	121	121	3813	-
2	47-51	35.02	23.96	19.33	4.74	0.67	0.48	0.41	0.41	0.57	97	69	223	70	6.5	129	275	98	75	3438	-
3	85-88	62.00	12.74	13.87	1.89	0.22	0.48	0.25	0.24	0.77	114	30	198	43	4.5	116	275	95	88	4625	-
4	113-117	53.00	23.96	8.50	0.93	0.22	0.34	0.37	0.25	1.03	18	18	140	26	7.8	66	300	89	14	6175	-
5	136-139	68.32	17.84	3.16	0.75	0.22	0.48	0.25	0.11	1.88	61	24	230	38	9.5	110	263	73	47	1250	
6	241-263	10.75	4.59	1.16	0.97	40.32	1.28	0.37	0.10	0.22	150	21	210	30	317	94	375	25	116	1300	nd
7	440-443	44.55	28.04	1.99	1.44	3.14	0.48	0.31	0.08	1.41	83	26	203	40	8.4	98	200	68	64	2450	nd
8	503-506	29.62	17.84	0.50	3.33	2.90	0.48	0.29	0.12	1.29	279	35	176	44	11	108	388	61	nd	nd	39.19
9	506-509	22.94	15.00	0.51	2.36	2.46	0.48	0.28	0.10	1.10	169	33	165	44	10	109	288	84	51	nd	51.26
10	509-513	18.75	5.61	0.18	0.62	2.24	0.64	0.38	0.10	0.55	101	34	200	13	13	115	450	55	nd	nd	69.52
11	522-525	31.82	29.06	1.52	3.52	0.67	0.48	0.26	0.08	1.31	118	36	238	49	10.5	148	163	74	91	7813	-
12	561-564	29.85	16.82	0.24	2.16	2.46	0.48	0.40	0.11	1.47	262	40	175	41	9	108	250	63	nd	nd	45.69
13	573-576	15.95	9.69	0.28	1.32	2.02	0.96	0.28	0.08	0.74	110	31	134	40	11	95	363	181	33	nd	63.38
14	577-581	31.44	18.86	0.56	2.37	2.69	0.80	0.29	0.10	1.53	222	40	1194	31	9	101	275	83	24	nd	39.60
15	581-585	21.33	15.80	0.32	1.60	2.69	0.80	0.30	0.10	0.98	151	31	160	38	11	95	263	51	nd	nd	50.32
16	589-594	28.52	18.86	0.47	2.88	2.24	0.80	0.28	0.11	1.21	199	35	155	54	11	73	388	76	21	nd	41.00

n.d = not determined

Table 9 Major, minor and trace elements of sub surface calcareous sediments, Thottappally

Sl.No	Sample Depth in metres	SiO_2%	Al_2O_3%	CaO%	MgO%	Fe_2O_3%	FeO%	K_2O%	Na_2O%	Sr ppm	Cu ppm	Ba ppm	Ga ppm	Bi ppm	Pb ppm	Mn ppm
1	174-177	42.83	9.18	13.22	0.97	3.78	1.55	0.62	0.44	236	7.8	164	60	84	26	49
2	204-208	8.92	1.53	42.56	3.54	0.72	0.36	0.04	0.73	834	2.2	40	40	56	7.0	50
3	208-211	3.51	2.55	49.28	2.42	0.12	0.68	0.03	0.73	800	1.0	10	80	64	23	41
4	211-215	12.00	4.59	33.60	3.62	2.39	1.15	0.14	1.25	540	5.8	112	40	28	13	39
5	214-218	4.96	2.04	49.28	2.42	0.26	0.61	0.03	0.71	660	3.7	8	100	48	2.0	46
6	218-222	0.67	0.51	46.48	2.01	0.60	0.25	0.02	0.84	626	n.f	30	100	20	8.0	49
7	222-225	1.47	1.53	49.84	2.82	0.20	0.47	0.02	0.85	610	1.9	42	20	68	n.f	73
8	232-235	5.97	2.55	**42.56**	**3.22**	**3.99**	**0.43**	0.05	0.92	670	3.1	20	140	40	3.0	70
9	235-238	4.00	2.55	48.16	2.42	0.72	0.50	0.04	0.93	668	1.7	22	60	54	20	46
10	238-242	16.92	3.06	39.20	2.01	1.64	0.54	0.07	0.50	440	2.0	20	120	42	3.0	50
11	242-245	7.56	3.57	44.24	2.01	1.26	0.58	0.07	0.70	678	3.6	80	80	112	18	23
12	245-249	10.99	4.07	35.84	2.01	1.83	0.86	0.08	0.82	686	2.2	76	100	104	13	21
13	249-252	3.21	1.53	45.92	1.61	1.36	0.07	0.04	0.81	732	1.3	52	200	94	25	33
14	259-263	9.38	2.55	45.36	2.01	0.80	0.36	0.02	0.81	640	1.0	12	140	82	34	12
15	263-266	13.38	1.53	49.28	2.42	0.40	0.79	0.04	0.92	654	0.4	72	140	106	40	15
16	266-270	5.55	1.53	47.60	2.01	0.48	0.43	0.03	0.82	670	1.10	10	100	124	23	33
17	270-274	1 .02	2.04	49.28	2.82	1.00	0.25	0.03	0.93	678	0.7	16	160	66	37	49
18	256-259	8.02	1.02	47.04	0.81	0.80	0.36	0.03	0.92	642	0.5	66	80	76	33	59

n.f. not found

TABLE 10

Chemical analysis of Quilon limestone showing variation in CaO and MgO

Sample No.	Locality	Lithology	CaO%	MgO%	Acid in sol.%
24	Padappakkara	Biomicrite	16.26	20.56	9.88
23	Padappakkara	Biocalcarenite	20.47	12.50	20.76
M-1	Mayyanad	Biomicrite	21.87	10.[illegible]3	18.78
M-2	Mayyanad	Biomicrite	25.80	8.06	17.90
NKM 71	Ambalapuzha	Biomicrite	45.71	3.02	6.35
NKM 81	Ambalapuzha	Biomicrite	40.30	2.82	12.52
NKM 86	Ambalapuzha	Biocalcarenite	22.89	1.96	37.06

Table 11

Lithounits of site 219 (Whitmarsh et al., 1974)

Lithology	
Units	Subunits
I. Gray, greenish-gray detrital silty clay, nanno ooze with upper and lower foram rich portions	
II. White foram ooze and chalk	
III White oozes and chalks containing nannos, forams, rads and micarb in varying proportions	a. White foram nanno ooze b. White foram rich nanno micarb ooze and chalk c. White rad-rich micarb nanno ooze and chalk d White nanno-rich rad micarb ooze and chalk with chert layers
IV. Grayish-yellow to yellow brown micarb chalk and ooze, limestone and chert	
V Green and black limestone sandstone and siltstone	a. Grayish-green Limestone - glauconite bearing b. Yellowish green to grayish-green and dark gray calcareous cemented sandstone, silt stone and clayey siltstone. Gray to greenish-black clayey silt stone and silty sandstone

Table 12

Lithostratigraphy and biostratigraphy of Kerala off shore well

(after Madanmohan and Kumar, 1980

Age	Zone	Dominant lithology
		Present bathymetry 37 m
		155 m
Post Early	*Ammonia beccarii* Acme Zone	Fine to medium grained sandstone
Miocene		200 m
	Upper poorly fossiliferous zone	Coarse grained sandstones, clayey lower part
	Unconformity	
	Miogypsina	Clay/sandstone alternations with occasional carbonate
		353 m
Late Early Miocene	(*Lepidosemicyclina*) *sumatrensis* Assemblage Zone	Carbonate with thin sandstones and sandy clay bands
		405 m
		sandstone with clay bands and a carbonate band in the lower part
	? Unconformity	448 m
Basal Miocene to Late Oligocene	Lower Poorly fossiliferous Zone	sandstone/clay alternation with lignitic/coal bands
	? Unconformity	690 m
Eocene to Late Paleocene		sandstone with lignitic/coal bands
	Unconformity	803 m
Early Paleocene to Late Cretaceous		sandstone-clay bands and basalt flows. Drilling terminated around 1743 m.

Table 13

Source rock characteristics of sub surface sediments, Ambalapuzha

Sample No	Depth (m)	Vitrinite reflectance (%)	T max (oC)	TOC %	HC/TOC (mg. hc/ g. org. c)
NKM-C-1	503-5●6	0.23	401	3.24	104
NKM-C-2	509-513	0.23	408	20.59	258
NKM-C-3	548-551	0.28	399	0.91	52
NKM-C-4	571-575	0.20	387	0.39	78
NKM-C-5	591-594	0.29	390	0.77	29

Table 14a

Grain size parameters (moment measures) of 'Teri' red sands of Muttom, Kanyakumari district

Sample No.	Mean (1st moment)	Standard deviation (2nd moment)	Skewness (3rd moment)
MUT 0-1	2.73	0.73	-0.32
MUT 1-1	2.80	0.70	-0.86
MUT 1-2	2.67	0.75	-0.58
MUT 1-3	2.73	0.73	-0.65
MUT 1-4	2.53	0.75	-0.35
MUT 1-5	2.53	0.83	0.42
MUT 1-6	2.41	0.77	0.01
MUT 1-7	2.50	0.75	0.07
MUT 1-8	2.64	0.78	-0.36
MUT 2-1	2.15	0.67	0.34
MUT 2-2	2.27	0.72	0.70
MUT 2-3	2.24	0.73	0.58

Table 14b

CM values (in millimetres) of Teri red sands
Muttom, Kanyakumari district

Sample No.	C (one percentile)	M (median)
MUT - 0 - 1	1.000	0.180
MUT - 1 - 1	0.900	0.180
MUT - 1 - 2	1.150	0.210
MUT - 1 - 3	0.840	0.210
MUT - 1 - 4	1.000	0.250
MUT - 1 - 5	1.500	0.250
MUT - 1 - 6	1.250	0.290
MUT - 1 - 7	0.840	0.290
MUT - 1 - 8	1.000	0.240
MUT - 2 - 1	1.000	0.350
MUT - 2 - 2	0.900	0.320
MUT - 2 - 3	0.800	0.300

Table 15

Radiocarbon Dating

Sl.No.	Material	Locality	Age
1	Lime-shell	Payyannur	4490 ± 90 Y.B.P.
2	Lime-shell	Payyannur	4370 ± 100 Y.B.P.
3	Lime shell	Vechoor (Vembanad Lake)	3710 ± 90 Y.B.P.
4	Lime shell	Velithuruthi (Astamudi kayal)	1330 ± 100 Y.B.P.
5	Lime shell	Muhamma (Vembanad Lake)	3130 ± 100 Y.B.P.
6	Carbonised wood	Tannisseri (Trichur)	6420 ± 120 Y.B.P.
7	Carbonised wood	Tellicherry	7230 ± 120 Y.B.P.

TABLE 16

A revised Stratigraphic Classification
of sedimentary sequence in Kerala

Super Group	Group	Period	Formation	Lithology
MALABAR SUPER GROUP		Holocene (Pliestocene)	Vembanad Fm.	Beach sands, alluvium red ('teri') sands, peat beds with semi-carbonised wood, calcareous clays etc.
		---Unconformity---		
	WARKALLI GROUP	Pliocene to Middle Miocene	Ambalapuzha Fm.	Sandstones, clays lignites
		Middle Miocene to	Quilon Fm.	Limestones, marls, calcareous clays and sands
		Paleocene	Mayyanad Fm.	Sandstones, coarse gravelly sands, clays, lignites
		---Unconformity---		
		Early Paleocene to ? Late Cretaceous	Karuchal Fm.	Hard, compact, ferruginous gritty sandstones with clay interbeds
		---Unconformity---		

Precambrian crystalline rocks