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PALYNOSTRATIGRAPHY OF THE CUDDALORE FORMATION (EARLY MIOCENE) OF PANRUTI, TAMIL NADU, INDIA

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ABSTRACT

Palynological studies of Cenozoic sediments from Panruti in the easternmost extension of the Cauvery Basin, Tamil Nadu, India, provide first palynological data from this region. The palynoassemblage suggests an early Miocene age. The palynoflora of Panruti subdivides the sediments into three Cenozones, namely *Pteridacidites vermiverrucatus* Cenozone, *Malvacearumpollis bakonyensis* Cenozone and *Myricipites singhii* Cenozone respectively. The assemblage indicates a tropical to subtropical humid climate with high rainfall and suggests deposition in a delta distributary channel under shallow marine influence. The terrestrial elements of upland flora and low-land vegetational flora tend to merge with fresh water constituents. The dominant pollen elements (*Spinizonocolpites, Ctenolophonidites, Brownlowia, Malvacearumpollis*) suggest evidence of brackish water mangrove swamp along the coastal line.

Keywords: Panruti, Cuddalore Formation, Palynology, Miocene, Tamil Nadu, India

INTRODUCTION

The sedimentary tract extending from Pondicherry in the north to Rameshwarm in the south between 9° and 12° parallels is considered the Cauvery Basin, comprising Jurassic, Cretaceous, Eocene and Mio – Pliocene sediments (Blanford, 1865). Previous works on the stratigraphy and palaeontology of this area have been excellently reviewed by Rama Rao (1956, 1964).This basin has received significant importance because of its oil potentiality. The structural and tectonic aspects of the Cauvery Basin have earlier been studied by Qureshy (1964), Kailasam (1958, 1961), Kailasam and Simha (1963), Ramanathan and Rao (1965), Raiverman *et al.* (1966), Sastri and Raiverma (1968).The name Cuddalore Sandstone exposed in the western part of the Cauvery Basin, was first proposed by Vredenburg (1908). It comprises gritty to pebbly and ferruginous sandstones and is considered as continental in origin; however, he did not mention its age. The well-known lignite deposits of Neyveli between Virdhachalam and Cuddalore occur within these sandstones. Eames (1950) considering the position of the Cuddalore Sandstones over the Karaikal beds, believed them to be of Pontian (Mid-Miocene) age. This age was suggested mainly on the basis of the occurrence of *Mesembrioxylon schmidianum* (Sahni, 1931), a fossil wood occurring in Trivicary grits. The other fossil record considered by Eames (1950), is the occurrence of *Anadara granosa* from the beds of Yellada Odai which were referred to as the Cuddalore Sandstone by Foote (1883). This fossil is common in the Indo-pacific region and is known to range from Miocene to Recent. *Crocuta* sp. was described by Dey (1962) from the beds at Sendurai.

Within the exposed area in the western side of the Cauvery Basin, the continental sediments of the Cuddalore Sandstone overlie the older marine formation, while in the region near Ulundurpettai it appears to have been deposited in a transitional zone (Fig.1). The occurrence of lignite within the Cuddalore Formation near Neyveli represents a transition phase. The Cuddalore Formation (? Burdigalian) is so far not been precisely dated. However, it has been observed that

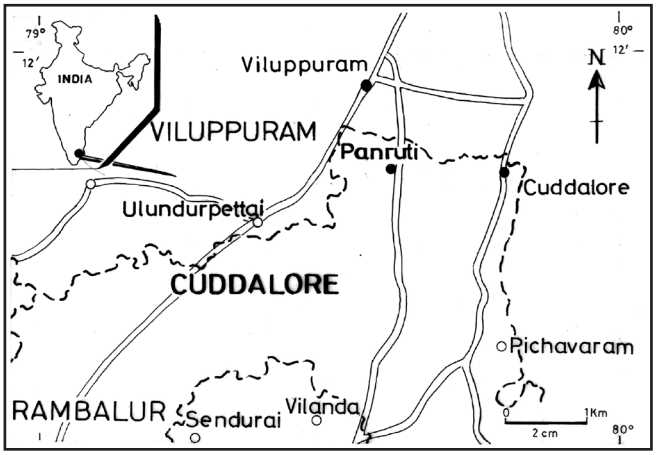

Fig. 1. Location map of the area.

a predominantly marine Aquitanian sequence becomes paralic and more continental than littoral during the transitional period between Aquitanian and Burdigalian as seen from the study of subcrops. It is therefore probable that the Cuddalore Formation may represent the continental equivalents of these subcrops. The purpose of the present paper is to present evidence of palynological records in the Panruti area which has yielded a rich palynological assemblage dominated by fungal elements, pteridophytic spores and angiospermous pollen grains. Interestingly, the Panruti section of the Cuddalore area has been dated as early Miocene in age.

REGIONAL GEOLOGY

Tertiary sediments consisting of Palaeocene (Pondicherry) and Mid-Miocene (Cuddalore) are exposed in patches on the western part of the basin, while most of the eastern part is covered by alluvium. The Archaean granitoid gneisses with pegmatite and dolerite intrusions constitute the western fringe of the South Arcot pericratonic basin. In the western part of the area,

Table.1: Geological succession and lithology of the area (Subsurface data after Subramanyam, 1969).

Formation	Thickness	Lithology	Environment	Age
Alluvium		Brown to reddish brown sand and lateritic soil		Recent to sub recent
Cuddalore Formation	+60m	Ferruginous arkosic sandstone associated with clay and gravel beds with trough shaped and plane tabular cross bedding channels sands showing small scale herringbones type cross bedding, cross lamination and ripple drift lamination. ----UNCONFORMITY----	Alluvial fan Delta complex	Middle Mio-Pliocene
Neyveli Formation	+300 m	Brown to brownish black lignite (23m thick) with occasional lensoid sand bodies and sand partings. Carbonaceous clay beds (1m thick) with erect plant roots. Semiconsolidated sandstones clay beds with occasional limestone intercalations (base not exposed) ----UNCONFORMITY---- Ariyalur Group of rocks/ Archaean Granitoid rocks.	Deltaic to near shore, back swamp deposit	Palaeocene - Middle Eocene to Miocene

the basement rock is succeeded by the fossiliferous limestones, calcareous sandstones and marlstones of the Ariyalur Group (Upper Cretaceous). Ramanathan and Rao (1965), Ramanathan (1968), Banerjee (1968), Dutta and Bedi (1968), Sastri (1977), worked on the Cauvery Basin. The stratigraphic succession is shown in the table.1.

The Cuddalore Sandstone (Middle Miocene to Pliocene) occurs intermittently along the eastern coast of South India over the lower Tertiary sediments. The present study subdivides the entire Tertiary sedimentary sequence of the area into two distinct lithostratigraphic units, the Neyveli Formation and the (Cuddalore Formation as described by Siddhanta, 1986).

Neyveli Formation

The basement and the Mesozoic rocks exposed at the western part of the basin have not been encountered in deep bore holes drilled in the southwestern and eastern parts in the Neyveli lignite mine area (Subramanyam, 1969), probably due to the thickening of the Tertiary sedimentary sequence from west to east. In a borehole drilled at about 5 km north east of Udaiyarpalaiyam 11°11' 00'': 79°17'38'' in the southwest of the Neyveli lignite mine area, the light grey limestone with dark coloured clay, shale and occasional lignite seams have been encountered below the Cuddalore Formation between 243.8m and 457.2m depths. The beds have yielded micro faunal assemblage dominantly *Discocyclina* sp. and a tentative Eocene age has been assigned to these rocks (Subramanyam, 1969). Interestingly the *Discocyclinid* limestone of the Pondicherry area has been dated as Palaeocene (Rajagopalan, 1968) or upper Palaeocene to early late Eocene (Samanta.1968; Saxena,1992).

Cuddalore Formation

The Cuddalore Formation overlying the Neyveli Formation is dated as Miocene-Pliocene in age (Vredenburg 1908; Wadia 1953; Krishnan 1960; Ramanujam, 1968). The formation occurs as a distinct lithounit consisting of claystone in outcrops, sandstone, carbonaceous shale and traces of lignite in the substrata exposed in the western part of the basin and is of late Miocene–Pliocene in age (Fig. 2). Furthermore, the contact between the Neyveli Formation and Cuddalore Formation is marked by an unconformity.

MATERIAL AND METHODS

The material for the present study comprises over 30 samples from a road-cutting section at Panruti. Majority of the samples proved to be moderately productive. The processing was carried out at the maceration chamber of the Birbal Sahni Institute of Palaeobotany, Lucknow using standard maceration techniques. The samples were crushed and washed and treated with Hydrochloric acid (35%) and Hydroflouric acid (40%) to remove carbonates and silicate particles respectively. The samples were then treated with HNO3 followed by 5% KOH. The permanent slides were prepared using 1% polyvenyl alcohol and mounted in Canada balsam. An Olympus microscope was used for the study as well as taking photomicrographs. The material and slides have been deposited at repository of Centre of Advanced Study in Geology, Lucknow University, Lucknow.

PALYNOLOGICAL ASSEMBLAGE

The palynological assemblage recovered from the Panruti area is represented by fungal remains, pteridophytic spores and angiospermic pollen grains. The gymnosperm pollens are altogether absent in the assemblage. The assemblage consisting of 64 genera and 74 species are listed below. Well preserved specimens were documented. Two slides of each sample were scanned using a transmitted light microscope and the counts

EXPLANATION OF PLATE I

1. ***Graminidites gramnioides*** Kar, 1985; 2. ***Intrapunctisporites intrapunctis*** Krutzch, 1959; 3. ***Crassoretitriletes vanraadshooveni*** Germeraad *et al.*, 1968; 4. ***Polypodiaceaesporites*** sp.; 5. ***Meliapollis navelii*** Sah and Kar, 1970; 6. ***Graminidites*** sp.; 7. ***Tricolporopilites uniformis*** Singh and Misra, 1991; 8. ***Myricipites singhii*** Rao, 1995; 9. ***Microfoveolatosporis polyaperturata*** Kar and jain, 1981; 10. ***Couperipollis kutchensis*** kar, 1985.; 11. ***Mycrothyriacites*** sp.; 12. ***Proteacidites triangulates*** Kar and Jain, 1981; 13. ***Spinizonocolpites echinatus*** Muller, 1968; 14. ***Pteridacidites vermiverrucatus*** Sah, 1967; 15. ***Triangulates bellus*** Kar, 1985; 16. ***Spinizonocolpites*** sp.; 17. ***Proxapertites crassimurus*** Kar and Kumar, 1986; 18. ***Spinizonocolpites bulbospinosus*** Kar, 1985; 19. ***Dracaenoipollis circularis*** Sah and Kar, 1970; 20. ***Ornatetradites keralaensis*** Rao, 1995.

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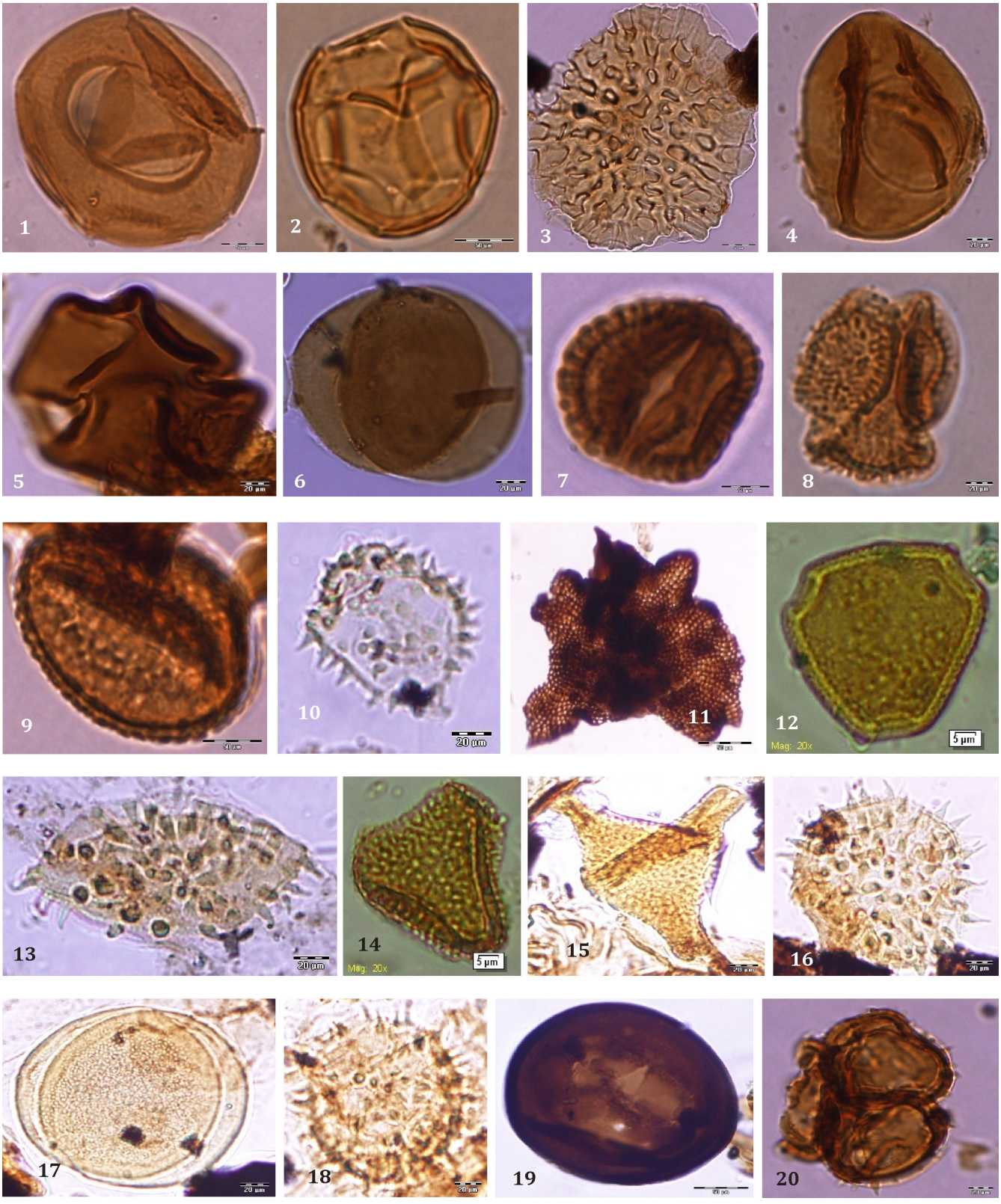
Plate I



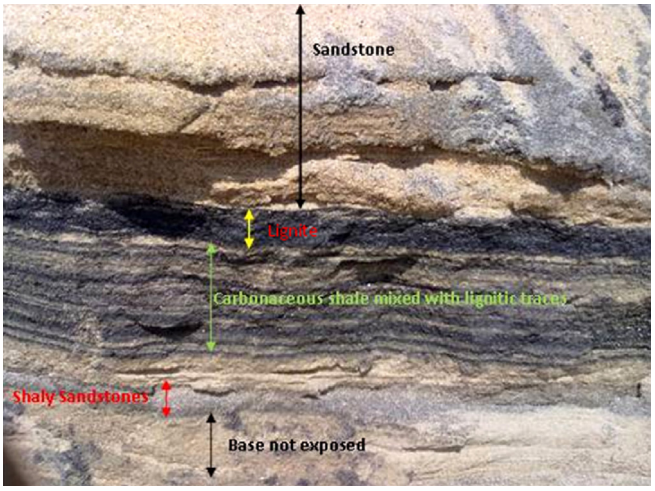


Fig. 2. Panruti field photograph showing sandstone, lignite, carbonaceous shale mixed with lignite traces and shaly sandstones (Base not exposed).

were made for the abundance of different palynomorphs. The check list of the palynotaxa are shown in Table 2.

Check list of palynotaxa

Fungal Elements

Phragmothyrites eocaenicus, Kar and Saxena, 1976
Microthyriacites ramanujamii Saxena and Misra, 1990
Trichothyrites setiferus Saxena and Misra,1990
Parmathyrites indicus Jain and Gupta, 1970
Kutchiathyrites eccentricus Kar, 1979
Inapertisporites kedvesii Sheffy and Dilcher, 1971

Pteridophytic spores

Lygodiumsporites lakiensis Sah and Kar,1969
Dictyophyllidites kyrtomatus Kar and Kumar, 1986
Dictyophyllidites granulates Saxena, 1978
Cheilanthoidspora monoleta Sah and Kar, 1974
Pteridacidites vermiverrucatus Sah, 1967
Polypodiisporites constrictus Kar, 1979
Polypodiisporites ornatus Sah, 1967
Polypodiaceaesporites chatterjii Kar, 1979
Crassoretitriletes vanraadshooveni Germeraad *et al,* 1968
Crassoretitriletes ornatus Rao and Ramanujam, 1978
Cyathidites minor Couper, 1953
Todisporites major Couper, 1958
Leptolepidites major Couper, 1953
Deltoidospora subtriangulata Kar and Kumar, 1986
Lycopodiumsporites globatus Kar, 1985
Intrapuctatisporites intrapuctis Krutzsch, 1959
Verrumonoletes excellensus Acharya, 2000
Proxapertites assamicus Kar,1985
P. operculatus Van der Hammen, 1954
P. crassimurus Kar and Kumar, 1986
Striatriletes susanae Kar, 1979

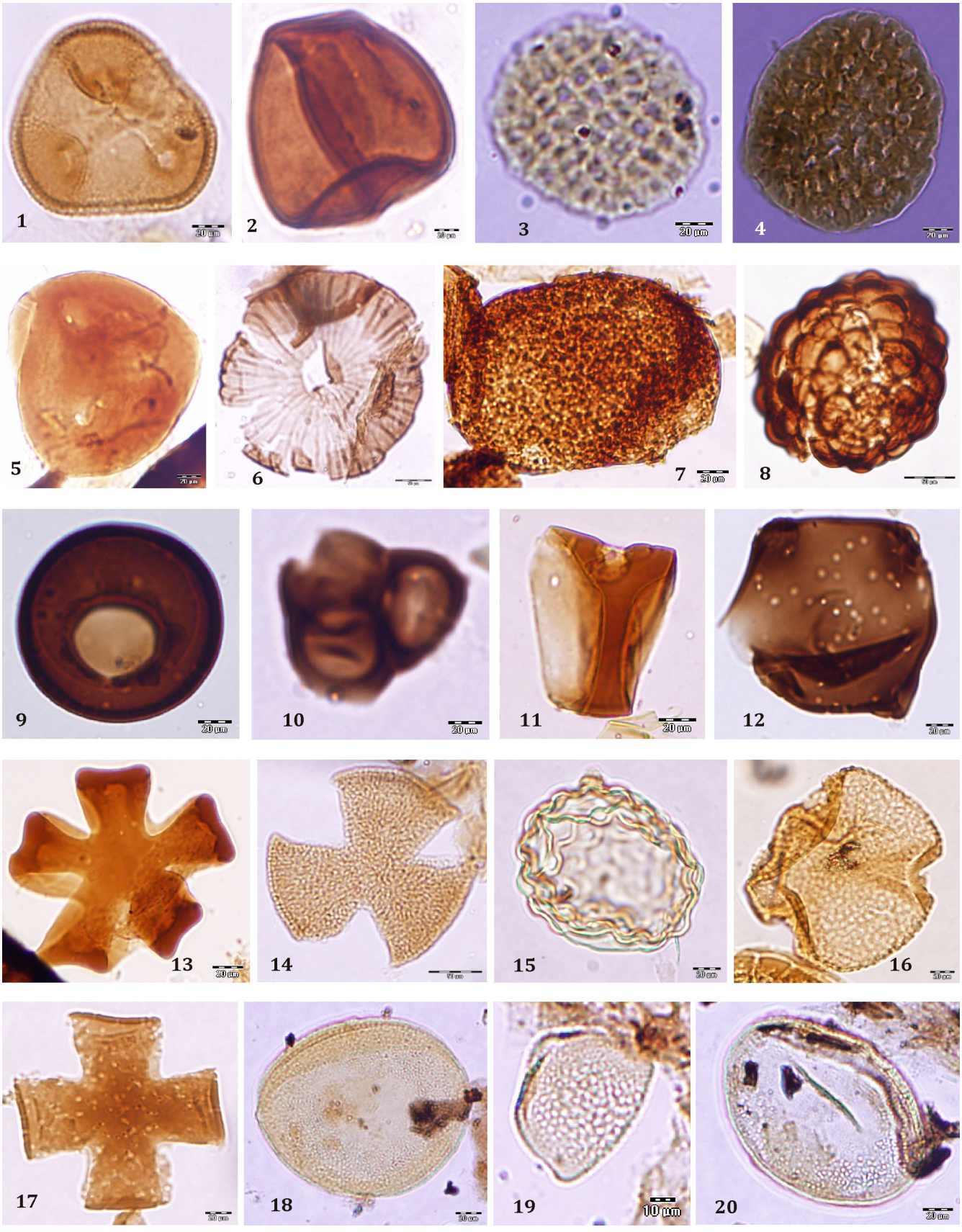
Angiosperm Pollen Grains

Quilonipollenites ornatus Rao and Ramanujam, 1978
Perfotricolpites neyvelii, Navale and Misra,1979
Dipterocarpuspollenites retipilatus, Kar, 1992
Polygonaceaepites frequens Sah and Dutta, 1966
Malvacearumpollis bakonyensis Nagy, 1962
Spinizonocolpites echinatus Muller, 1968
Plumbaginacipites neyvelii Navale and Misra, 1979
Alangiopollis gemmatus Navale and Misra, 1979
Pellicieroipollis langenheimii Sah and Kar, 1970
Triangulorites bellus Kar, 1985
Margocolporites dubius Ramanujam, 1966
Meliapollis triangulatus Saxena,1979
M .navelii Sah and Kar, 1970
M. ramanujamii Sah and Kar, 1970
Polyporina multiporosa Kar, 1985
Clavaperiporites jacobii Ramanujam, 1966
Ctenolophonidites costatus Ramanujam and Rao, 1973
Longapertites marginatus Eisawi and Schrank, 2008
Arecipites bellus Kar, 1985
Caryophilidites warkalliensis Ramanujam, 1987
Liliacidites kaitangataensis Couper, 1953
Margocolporites vanwijhei Germeraad *et al*, 1968
M. sitholeyi Ramanujam, 1966
Myricipites singhii Rao, 1995
Compositoipollenites rudis Rao, 1995
Trilatiporites retibaculatus (Saxena) Kar, 1985
Dorreenipites distinctus Navale and Misra, 1979
Tricolporocolumellites psilatus Kar, 1985
Tricolporopilites uniformis Singh and Misra, 1991
Graminidites gramnioides Kar, 1985
Tuberculozonisulcites retibaculatus Kar & Sharma, 2001
Psilastephanocolporites psilatus Kar and Kumar, 1986
Retipilonapites arcotense Ramanujam, 1966
Araliaceoipollenites descretus Venkatachala and Rawat, 1984
Verrutriporites gregarus Kar and Jain, 1981
Tribrevicolporites eocenicus kar, 1985
Trilatiporites erdtmanii Ramanujam, 1966
Verrumonosulcites foveolatus Kar and Sharma, 2001
Pilapolycolporites verrucatus kar and Sharma, 2001
Periretitricolpites anambraensis Jan Du Chene *et al*, 1974
Longapertites cuddalorense Ramanujam, 1966
Retidiporocolpites excellensus Kar and Sharma, 2001
Albertipollenites aquifoliaceaeformis Mandal and Rao, 2001
Sastripollenites trilobatus Kar and Kumar, 1986
Palmaepollenites keralaensis Rao and Ramanujam, 1978
Tricolporopilites pseudoreticulatus Kar, 1985
Microfoveolatosporis polyaperturata Kar and Jain, 1981
Proteacidites triangulatus Kar and Jain, 1981
Palaeomalvacearumpollis mamilatus Kar, 1985
Dracaenoipollis circularis Sah and Kar, 1970
Ornatetradites keralaensis Rao, 1995

EXPLANATION OF PLATE II

1. ***Trilatiporites erdtmanii*** Ramanujam, 1966; 2. ***Dictyophyllidites*** sp.; 3. ***Retipilonapites arcotense*** Ramanujam, 1966; 4. ***Polygonaceaepites frequens*** Sah and Dutta, 1966; 5. ***Periretitricolpites anambraensis*** Jan Du Chene *et al*, 1974; 6. ***Phragmothyrites eocaenica*** Kar and Saxena, 1976; 7. ***Dermatobrevicolporites dermatus*** kar, 1985; 8. ***Leptolepidites major*** Couper, 1953; 9. ***Graminidites gramineoides*** Kar, 1985; 10. Pollen tetrad type; 11. ***Dictyophyllidites kyrtomatus*** Kar and Kumar, 1986; 12. ***Tuberculozonisulcites retibaculatus*** Kar and Sharma, 2001; 13. ***Psilastephanocolporites psilatus*** Kar and Kumar, 1986; 14. ***Dipterocarpuspollenites retipilatus*** Kar, 1992; 15. ***Polyporina multiporosa*** Kar, 1985; 16. ***Retibrevicolporites*** sp.; 17. ***Meliapollis raoi*** Ramanujam, 1966; 18. ***Longapertites marginatus*** Eisawi and Schrank, 2008; 19. ***Proxapertities*** sp.; 20. ***Palmaepollenites keralaensis*** Rao and Ramanujam, 1978.

Plate II



PALYNOLOGICAL RESULTS

Palynoassemblage of the Cuddalore Sandstone (Formation) at Panruti is rich and diverse. The palynoflora contains 64 genera and 74 species of pollen-spores as well as fungal remains. Reworked Palaeozoic and Mesozoic pollen grains are totally absent in the sequence. The distribution of the taxa (Table 2) reveals that in the lower part of the sequence spores are dominant but the pollen representation is meagre; however, their variety and frequency increase about 70 – 80%. A number of vesicle-like structures with various ornamentation also occurs largely in the lower part of the sequence.

The important palynotaxa of the assemblage are *Lygodiumsporites lakiensis* Sah & Kar 1969, *Dictyophyllidites kyrtomatus* Kar and Kumar 1986, *Pteridacidites vermiverrucatus* Sah 1967, *Polypodiisporites constrictus* Kar 1979, *Polypodiaceaesporites chatterjii* Kar 1979, *Crasssoretitriletes vanraadshooveni* Germeraad *et al.* 1968, *Lycopodiumsporites globatus* Kar 1985, *Verrumonoletes excellensus* Acharya 2000. The dominant angiosperm pollen grains are *Malvacearumpollis bakonyensis* Nagy 1962, *Spinizonocolpites echinatus* Muller 1968, *Alangiopollis gemmatus* Navale and Misra 1979, *Margocolporites dubius* Ramanujam 1966, *Ctenolophonidites costatus* Ramanujam and Rao 1973, *Compositoipollenites rudis* Rao 1995, *Dorreenipites distinctus* Navale and Misra 1979, *Sastripollenites trilobatus* Kar and Kumar 1986, *Palmaepollenites keralaensis* Rao and Ramanujam 1978, *Tricolporopilites pseudoreticulatus* Kar 1985, *Ornatetradites keralaensis* Rao 1995 etc. Pteridophytic spores are more numerous but less varied, while pollen grains show reverse representation (Table 2). Fungal remains occur in all the samples and overwhelmingly dominate the assemblage. The common angiospermous pollen are *Malvacearumpollis bakonyensis* Nagy 1962, and *Dipterocarpuspollenites retipilatus* Kar 1992, *Tricolporopilites pseudoreticulatus* Kar 1985, *Myricipites singhii* Rao 1995, *Ornatetradites keralaensis* Rao 1995, *Spinizonocolpites echinatus* Muller 1981, whereas other taxa occur sporadically.

PALYNOSTRATIGRAPHIC ZONATION

First and last occurrences of taxa and their maximum development, decline, absence and restricted occurrence have helped to subdivide the Cuddalore Formation in the Panruti area into three cenozones in ascending order; these are 1. *Pteridacidites vermiverrucatus* Cenozone 2. *Malvacearumpollis bakonyensis* Cenozone 3. *Myricipites singhii* Cenozone respectively. Each cenozone has been formally instituted in accordance with the International Stratigraphic Guide (Hedberg, 1976). A brief account of each cenozone is discussed below. The palynofloral composition of each of the three cenozones are distinctly different. The zonation of the Cuddalore Sandstone is totally based on palynomorph frequency (Fig. 3). For the qualitative analysis 100 specimens per sample were counted. Percentage frequencies of all the species were calculated and plotted under four categories namely rare (1 -5%), common (6 -10%), abundant (11 -20%) and predominant (above 20%).

Pteridacidites vermiverrucatus cenozone

The lithology of the cenozone is represented mainly by the sandstone, clay, streaks of carbonaceous shale with thickness of about 10 m. This cenozone overlies the upper Palaeocene sandstone (base is not noticed) which is unconformably overlain by the sandstone bed. The significant restricted taxa of this cenozone are: *Dictyophillidites kyrtomatus, D. granulates, Cheilanthoidspora monoleta, Pteridacidites vermiverrucatus, Polypodiisporites constrictus, P. ornatus, Polypodiaceaesporites chatterjii, Crassoretitriletes vanraadshooveni, Todisporites major, Leptolepidites major, Deltoidospora subtriangulata, Lycopodiumsporites globatus, Intrapunctisporites intrapunctis, Proxapertites operculatus. P. crassimurus, Pteridacidites vermiverrucatus* and other significant species of this cenozone. The important feature of this cenozone is the dominance of pteridophytic spores over the angiosperm pollen and fungal remains. *Couperipollis kutchensis* is about 20% in lower part and absent in upper part of the cenozone. However, microthyriaceous fungal remains are abundant throughout the cenozone.

Malvacearumpollis bakonyensis cenozone

This cenozone occurs between 10 and 15 m. The lithology consists mainly of calcareous sandy clay with a lignitic band. The upper part consists of thick sandstone and is conformably overlain by the calcareous clayey sand yielding *Myrticipites singhii* of the above cenozone. The characteristic palynofossils in this cenozone include *Crassoretitriletes vanraadshooveni, Margocolporites dubius, Ctenolophonidites costatus, Couperipollis kutchensis, Trilatiporites erdtmanii, Malvaceaerumpollis bakonyensis, Psilostephanocolporites psilatus, Retipilonapites arcotense, Liliacidites kaitangataensis, Retidiporocolpites excellensus,* etc. The appearance of *Crassoretitriletes* and *Malvacearumpollis* is significant in these sediments. *Malvacearumpollis* and *Psilastephanocolpites* are restricted to this cenozone. Sah (1967) studied in detail the distinctive grains of *Malvacearumpollis grandis* and provided as evidence of the presence of this family. Malvaceae is richly represented in the present-day tropical and subtropical vegetation. Germeraad *et al.* (1968) studied in detail the distribution of the genus generally occurring in the lower Oligocene and reach up to the Miocene. *Triangulorites* is an important taxon in the Eocene–early Miocene sequence in Alleppey district, Kerala (Rao, 1995) and a Cenozone *T. bellus* has been designated after it. *Dictyophyllidites kyrtomatus, Todisporites major* and *Pteridacidites vermiverrucatus* are rare in the lower part of the section and gradually decrease towards the top of the cenozone. *Ctenolophonidites, Polyporina, Liliacidites, Trilatiporites, Clavaperiporites, Meliapollis, Alangiopollis, Longapertites, Pellicieroipollis, Margocolporites* are abundant in this cenozone.

Myricipites singhii cenozone

The lithology of the cenozone is sandstone with traces of lignitic bands, fine-grained sandstone intercalated with shale, grey clay mixed with calcareous sandstone. The characteristic taxa include *Myricipites singhii, Compositoipollenites rudis, Polyporina multiporosa, Quilonipollenites ornatus, Perfotricolpites neyvelii, Spinizonocolpites echinatus, Plumbaginacipites neyvelii, Alangiopollis gemmatus, Clavaperiporites jacobii, Arecipites bellus, Trilatiporites retibaculatus, Dorreenipites distinctus, Graminidites gramnioides, Retipilonapites arcotense. Tricolporocolumellites psilatus, Albertipollenites aquifoliaceaeformis, Sastripollenites trilobatus* and *Dipterocarpuspollenites retipilatus* appear for the first time in and are restricted to this cenozone, whereas *Malvacearumpollis* and *Lycopodiumsporites, Dictyophylidites, Deltoidospora, Pteridacidites* are absent. The relative increase in *Spinizonocolpites echinatus, Trilatiporites retibaculatus, Graminidites gramnioides, Psilastephanocolpites psilatus,*

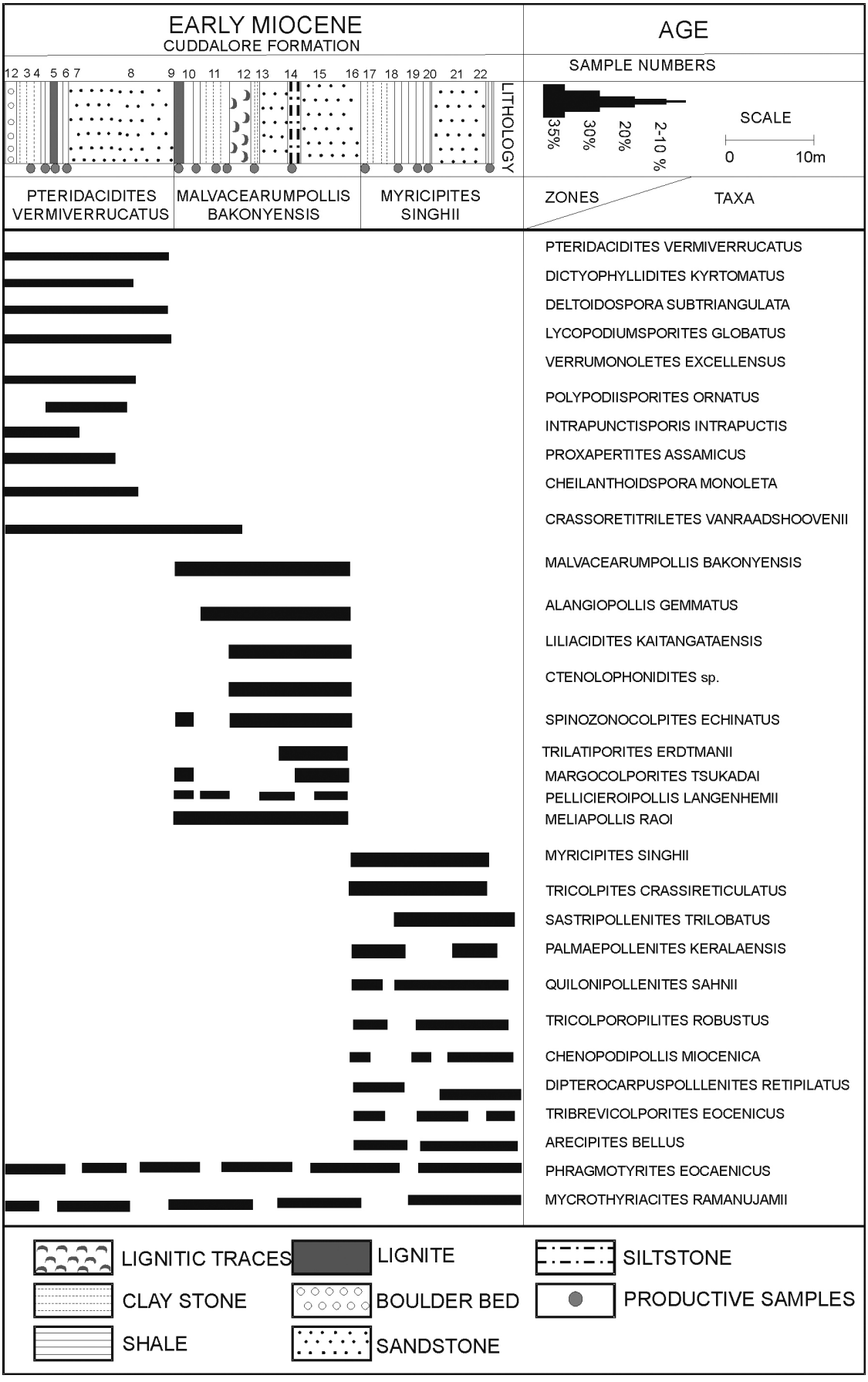


Fig. 3. Palynostratigraphic zonation of the Cuddalore Formation, at Panruti, Tamilnadu, India.

Araliaceoipollenites, Verrutriporites gregarus, Palmaepollenites karakaensis, Perfotricolporites neyvelii has been documented. Pollen grains referred to *Myricipites singhii* suggest the presence of Myricaceae family in the assemblage. Although the family is well represented in temperate regions and higher altitudes of the tropical regions, it is comparatively poorly represented in the assemblage. From the fossil records, it seems that the genus *Myrica* apparently played an important part during the early Tertiary times. Its poor representation in the assemblage does not necessarily mean rarity of the parent plant. It can well indicate considerable distance between the natural habitats and place of deposition.

AGE OF THE CUDDALORE FORMATION

A review of the data obtained from the Cuddalore Formation clearly demonstrates that a number of taxa from the Cauvery Basin are closely comparable to those encountered in the Quilon Formation dated as Miocene in age (Ramanujam, 1982). Majority of the taxa are known from the Oligocene, although some of them have also been reported from the sediments ranging from the Palaeocene to Miocene in age. A key taxon is represented by the spores of *Crassoretitriletes vanraadshooveni* widely recorded from the Neogene sediments of south America, Caribbean area, Nigeria and Borneo. *C. vanraadshooveni* is a characteristic element of the upper part of Lower Miocene in the Caribbean area. In Borneo and Nigeria, its first appearance is slightly earlier within the lower Miocene than in the Caribbean area. In northern America, it disappears at the base of Middle Miocene. Germeraad *et al*. (1968) have instituted a discrete pantropic stratigraphic unit designated as *Crassoretitriletes vanraadshooveni* zone marking the upper part of the Lower Miocene. The Indian land mass is clearly a demarcated geographical regime circumscribed by effective barriers such as seas and the lofty Himalayas. Its climate and characteristic geographic position at the junction or meeting place of important floristic migratory routes have facilitated the invasion or penetration of Malaysian, African and other floral elements into the country. Thus, the Tertiary flora of southern India continued to be encountered even now towards its eastern or western flanks depending upon the annual quantum of precipitations. The genus *Ctenolophonidites* is undoubtedly related to the modern riparian tropical taxon *Ctenolophon* of the extant family Ctenolophonaceae. According to Germeraad *et al*. (1968), *Ctenolophon* probably originated in Africa during the Upper Cretaceous and soon differentiated into *C. engleri* and *C. parvifolius* type. The available data indicate that plants of the *C. engleri* type migrated eastwards sometime during the Miocene as evidenced by the occurrence of *Ctenolophonidites costatus* pollen in the Upper Miocene of Warkalli lignite of south India (Ramanujam and Rao, 1973). One may infer that after a brief period of existence along the west coast of south India during the Upper Miocene, the genus became extinct. Reinvestigation of *C. erdtmanii* in the present assemblage of the Panruti deposits extends the earlier palaeogeographical distribution of *Ctenolophonidites* (Ramanujam and Rao, 1973) towards east coast and establishes that the genus not only existed in the western coast but also in the east coast of India during the Miocene. It may be inferred from these findings that the genus *Ctenolophonidites* might have migrated eastward to Indonesian Archipelago from Africa via west and east coast of south India.

The presence of *Pteridacidites africanus* and *P. vermiverrucatus* in the assemblage shows a considerable resemblance to some members of Pteridaceae. The genus *Pteridacidites* has undoubtable Pteridacean affinity and all of them are probably related to *Pteris* or *Onychium* where *Pteris* is a cosmopolitan genus and *Onychium* has a tropical to subtropical distribution. The geological records of the *Pteridacidites* dates back to Miocene (Sah, 1967). The positive evidence for the presence of genus *Compositoipollenites* throughout the sequence of the Panruti section is from upper Eocene. The family Aesteraceae is regarded as a younger family with first occurrence dating back to Miocene growing in all situations (Kuyl *et al*., 1955). They opined that Asteraceae emerges as one of the youngest developments within the angiosperms. Germeraad *et al*. (1968) observed that Asteraceae, though widespread in the present-day tropical countries, are more common in the open vegetation types, such as Savannah, or higher montane vegetation than in closed lowland rain forest. The fossil wood of Dipterocarpaceae is one of the common elements of the Neogene sediments of India. *Dipterocarpus indicus* at present is confined to the evergreen forests of eastern and western Ghats of Kerala and Karnataka (Beddome, 1972). The fossil pollen *Dipterocarpuspollenites retipilatus* is also known from Kerala (Kar and Jain, 1981). It seems that from the Miocene Period, this taxon has been growing in the region as an endemic one.

The genus *Malvacearumpollis* Nagy (1962) represents the geological history dating back to middle upper Eocene to middle Miocene. Croizat (1952) thought that Malvaceae originated in South America and the southern Atlantic and then migrated towards Europe. Germeraad *et al.* (1968) reported Malvaceae pollen from the late Oligocene of Africa, while Hekel (1972) recorded it from the Miocene of Australia. The distinctive pollen of *Malvacearumpollis grandis* (Sah, 1967) provide a fairly conclusive evidence of the presence of this family indicating a tropical to subtropical vegetation. The Poaceae pollen in the fossil state has been designated as *Graminidites* (Kar, 1979) and has also been described from the Oligocene. The grass pollen in Kutch is very rare and it seems that up to Miocene they were inhabiting the Panruti region in large numbers. Regali, Uesugui and Santos (1974) recorded grass pollen from the Palaeocene of Brazil and Muller (1981) reported it from the lower Eocene. The presence of these pollen grains become more dominant and reach up to the Miocene in other regions.

The fossil pollen of *Nypa* is known as *Spinizonocolpites* Muller (1968) from the Senonian (Maastrichtian) of Borneo. *Nypa* had a wide geographical distribution in the geological past but at present grows in the restricted areas of tropical coasts of South Asia in mangrove ecosystem. Fossil representation of this genus is also well documented in the Late Cretaceous to Eocene sediments from South America (Germeraad *et al.*, 1968), Venezuela and Colombia (Regali *et al.,* 1974), Brazil (Jandine and Magloire, 1963), Cameroon and Borneo (Muller, 1968), South Arabia (Schrank, 1984) and India (Venkatachala and Sharma, 1974; Baksi and Deb, 1981, Nandi, 1990). Its record from the Cretaceous–Tertiary transition comes from south–east Asia (Muller, 1968). In the Eocene sediments, *Spinizonocolpites* is widely reported from North America, Europe, Australia, Malaysia, Pakistan and India. During the Miocene, *Nypa*

disappeared from most parts of world and almost reached its present status. *Nypa* (=*Spinizonocolpites*) has been reported from the Miocene of Ratnagiri of Maharashtra (Kulkarni and Phadtare, 1980). *Spinizonocolpites echinatus* was also reported from the Neyveli lignites and associated sediments (Saxena, 1992; Singh *et al.,* 1992) as well as from the Miocene sediments of the Bhuban Formation, Mizoram (Mandaokar, 2000). This genus is helpful in determining the palaeoecology of the sediments as it grows only in the limited ecological conditions at Sunderban in India.

COMPARISON

The palynoassemblage of the Cuddalore Formation (Panruti area) can be compared with the palynological zone V mentioned by (Baksi, 1972) and zone III by Deb (1970, 1972) of the Bengal Basin having common occurrence of Striatriletes in high frequency. However, important taxa like *Cheilanthoidsporites monoleta, Meliapollis navelii, Quilonipollenites ornatus, Trilatiporites retibaculatus, Spinizonocolpites echinatus* and pollen representing Malvaceae are absent in this assemblage. The common important taxa of Oligocene and Miocene palynoflora from Assam, Meghalaya and Tripura described by (Banerjee *et al.* 1973; Kar, 1991; Kar *et al.* 1994; Kumar *et al.* 2001 and Saxena *et al.,* 1987) are *Striatriletes susanae, Crassoretitriletes vanraadshooveni, Malvacearumpollis bakonyensis, Pteridacidites vermiverrucatus,* and pollen of Malvaceae.

Thiergart and Frantz (1963) and Siddhanta (1986) described spores and pollen from the Tertiary brown coal of Neyveli in India. The palynoflora occurs as a distinct lithostratigraphic unit below a thick apron of the Cuddalore Sandstone in South Arcot District, Tamil Nadu. The common palynotaxa viz. *Ctenolophonidites costatus, Psilastephanocolporites psilatus, Meliapollis ramanujamii, Spinizonocolpites echinatus* represent the Miocene in age. Many palynotaxa such as *Schizaeoisporites phaseolus, Crotonopollis neyvelii, Marginipollis kutchensis, Pentacolpites turaensis, Margocolporites sitholeyi, Dorreenipites selling,* etc are absent in the present assemblage. Saxena (1992) considered three cenozones under the Neyveli Formation which, in ascending order, are viz, 1. *Neocauperipollis* sp. cenozone 2., *Triangulorites bellus* cenozone and 3. *Trilatiporites selling* cenozone. None of these cenozones show complete similarity with the present cenozones described here.

Rao (1995) studied the palynostratigraphic zonation and correlation of Eocene–Early Miocene sediments in Alleppy District along the western coast of Kerala. Out of 18 species of pteridophytes recorded by him, one species, i.e. *Lygodiumsporites lakiensis* and of 44 species of angiosperm pollen, only 5 species (*Dermatobrevicolporites dermatus, Triangulorites bellus, Sastripollenites trilobatus, Tricolporopilites pseudoreticulatus, Margocolporites tsukadae, etc*) are common between the two palynoassemblages. Further, Rao (2001) described three cenozones from Arthungal, Kalarakod bore holes of Quilon and Warkalli and recognized three cenozones, viz. *Triangulorites bellus* cenozone, *Crassoretitriletes vanraadshooveni* cenozone and *Malvacearumpollis bakonyensis* cenozones indicating an early to middle Miocene. The typical palynoflora like *Proxapertites operculatus, Triangulorites bellus, Sastripollenites trilobatus, Tricolporopilites uniformis* represent sediments of Palaeogene–Neogene times in India. Based on above analysis, the palynoflora recovered from the subsurface sediments of the Kerala Basin and the present area confirm an early Miocene age.

PALAEOCOLOGICAL IMPLICATIONS

The early Miocene palynoflora from the Cuddalore Formation comprises mainly the land-derived spore and pollens indicating terrestrial sources. Palynomorph recovery generally diminished in the late Oligocene. This may be attributed to facies control (sandy intervals) and preservation potential due to subaerial oxidation. The early Miocene is characterized by abundant black to dark brown debris, partially degraded subordinate cuticles and little amorphous materials. These suggest deposition in distal facies of a fluvial system. A shift to predominantly lacustrine environment and deposition possibly in anoxic conditions, is inferred from the abundant amorphous organic matter with black specks and common pteridophytic spores at the top of the interval. *Crassoretitriletes vanraadshooni* (the spores of fresh water fern, Germeraad *et al.,* 1968) and *Pteridacidites vermiverrucatus* both are consistent in this part of the section and are indicative of aquatic habitats (coastal swamps and floodplain). Abundant spores of *Lygodiumsporites, Lycopodiumsporites, Polypodiisporites, Cyathidites, Todisporites, Glechenidiites* are indicative of humid conditions (Mandaokar, 2000).

Palynofossil assemblage from the *Malvacearumpollis bakonyensis* interval are generally dominated by light brown amorphous organic matter. Fern spores decrease and fresh water pollen become dominant. This assemblage suggests deposition in shallow, fresh water lakes, possibly under anoxic or dysoxic conditions. The presence of redundant pteridophytic spores are suggestive of warm and humid conditions. Similar spores have been reported from the south west Arthungal borehole (Rao, 1995). This interpretation is supported by the high kaolinite content from the coeval strata in the Neyveli Lignite of the Cauvery Basin (Deb *et al.,* 1973; Siddhanta, 1986). Gramineae pollens are present throughout this interval. According to Germeraad *et al.* (1968), this increase in graminaceous pollen indicates open vegetation and development of grassland areas in a generally dry climate.

Occurrence of brackish water *Spinizonocolpites, Mavacearumpollis, Clavaperiporites* together with fern spores and fresh water pollen suggest deposition under hyposaline conditions during a brief marine incursion. A possible coeval marine transgression in the Cauvery Basin, as pointed out by Siddhanta (1986), started in the late Oligocene and reached its peak during deposition of the Cuddalore Formation in early Miocene. This contention also supports the present work. The low recovery of organic matter in the uppermost zone may be due to poor preservation of organic matter, for example, in sandy and subaerially exposed setting. The terrestrial elements of upland flora and lowland vegetational flora that tend to merge with fresh water constituents of the total assemblage. The dominance of *Spinizonocolpites echinatus, Ctenolophonidites costatus* and *Malvacearumpollis grandis* suggests deposition in brackish-water (mangrove swamp) environment all along the coastal line.

CONCLUSIONS

1. Presence of early Miocene in the subsurface sediments of the Cuddalore Formation in the Panruti section, is established on the basis of marker palynological taxa.
2. The palynosequence in the Cuddalore Formation can be divided into three Cenozones, viz, *Pteridacidites vermiverrucatus* Cenozone, *Malvacearumpollis bakonyensis* Cenozone and *Myricipites singhii* Cenozone.
3. The reported genera and species enhanced our knowledge of palaeopalynology.
4. The palynoflora suggests a humid, tropical climate with plenty of rainfall during deposition of the Cuddalore sediments.
5. Cenozoic sedimentation during the early Miocene shows evidence of marginal marine conditions of deltaic environment where mangrove incursions prevailed in the Panruti area.

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