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Research Article

PALYNOLOGICAL INVESTIGATION OF EARLY MIOCENE SEDIMENTS EXPOSED AT PANRUTI, CUDDALORE DISTRICT, TAMIL NADU, INDIA

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ABSTRACT
The present investigation highlights the palynological significance of the lignitie and carbonaceous shale horizon subcropping four meters below surface at the Panruti in Cuddalore District, Tamil Nadu, and India. The carbonaceous shale underlies the Cuddalore sandstones exposed along the western direction. The palynological assemblage consists of fungal bodies, pteridophytic spores and angiospermic pollen grains. The fungal spores are typically referable to *Phragmothyrites, Meliola, Diporicellaesporites, Alternaria* and other microthyriaceous fruiting bodies. The pteridophytic spores are preferable to *Dictyophyllidites, Pteridacidites, Crassoretitriletes, Todisporites, Cyathidites, Osmudacidites, Lygodiumsporites, Lycopodiumsporites,* of which *Polypodiaceaesporites,* represents the dominant taxon. The angiospermic pollen grains are referable to monocotyledons and dicotyledonous taxa. The dominant pollen grains are referable to *Ctenolophonidites, Meliapollis, Compositoipollenites, Malvacearumpollis, Longapertites, Palmidites, Margocolporites, Tricolporocollumellites, Tricolporopollenites, Quilonipollinites, Retitricolporites, Dorreenipites, Dipterocarpuspollenites, Retipollenites, Alangiopollis, Araliaceoipollenites, Albertipollenites,* and *Ornatetradites.* The palynomorphs in the present assemblage are compared with pollen and spores of the modern taxa. The distribution of the families represented by the fossil assemblage suggests a tropical-subtropical warm and humid climate with high rainfall. The study reveals that the clay underlying the lignite pocket was deposited under mangrove swamp conditions with local pockets of marine influence, with bulk of carbonaceous shale have been laid down under back mangrove conditions. A diversified palynological assemblage indicates the existence of brackish water, swamp and prograding delta complex with fresh water influx. The palynological elements associated with shale, lignite together with unconformity between Cuddalore sandstone Formation and neyveli Formation pockets appear to be early Miocene age.

***Key Words**: Panruti, Cuddalore Sandstone, Palynology, Miocene, Tamil Nadu, India*

INTRODUCTION
The sedimentary tract extending from Pondicherry in the north to south of Rameshwarm between 9° and 12° parallels considered as Cauvery basin. Sediments of Jurassic, Cretaceous, Eocene and Mio-Pliocene age are known (Blanford, 1865). Since then many workers have studied out the stratigrapgy and palaeontology of this area, excellently reviewed by Rama Rao (1956, 1964). This basin has received significant importance because of its oil potentiality. The structural and tectonic complexities of the Cauvery basin has been worked out by many worker such as Qureshy (1964), Kailasam (1958, 1961) Kailasam and Simha (1963), Ramanathan and Rao (1965), Raiverman *et al.*, (1966), Sastri and Raiverman (1968). The Cuddalore sandstones exposed in the western part of the Cauvery basin, were first proposed by Vredenberg (1908), it comprises gritty to pebbly and ferruginous sandstones and is considered as continental in origin, however, he did not commented on its age. The well known lignite deposits of Neyveli between Virdhachalam and Cuddalore occur within these sandstones. Eames (1950) considering the age of the Cuddalore sandstones believed to overlie the Karaikal beds, thus of Pontian (Mid - Miocene) age. This age was considered mainly on the basis of the occurrence of *Mesembrioxylon schmidianum*, a fossil wood occurring in Trivicary grits. The other fossil records that favored by Eames

(1950) are the occurrence of *Anadara granosa* from beds of yellada Odai for which Foote (1883) referred dough fully to Cuddalore Sandstone. This fossil is of a common occurrence in the Indo-pacific region where it is known to range from Miocene to Recent. *Crocuta* spp as described by Rao (1955) from beds at Sendurai.

Sahni (1931) described in detail *Mesembrioxylon schmidianum* (Schleiden) and records that the horizon is said to range from Eocene-Pliocene. Based on fossil evidences, it appears that there is no positive indication of attributing a Mio-Pliocene age to the Cuddalore sandstones. Ramanujam(1968) reviewed the present status of fossil woods studied in the cuddalore sandstones, he concluded that the age of the Cuddalore sandstones is not older than Middle Miocene and probably could extend up to Upper Miocene to lower Pliocene. A perusal of these records indicates that except for the *Dipterocarpaceous* woods, the other fossils range from Upper Cretaceous to Recent or in some cases Eocene to Recent.

Within the exposed area in the western side of Cauvery basin continental sediments of Cuddalore sandstones overlie the older marine formation. The sediments are represented by marine equivalents while in the region near Pattukkottai it appears to have been deposited in a transitional zone. The occurrence of lignite within the Cuddalore formation near Neyveli represents a transition phase. Cuddalore formation (Burdigalian), is so far not been precisely dated. However, it has been observed that a predominantly marine Aquitanian sequence becomes paralic 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 basin architecture and configuration of the section Oligocene sediments is likely to follow the same pattern as that of Eocene. Therefore, attention on the age has been paid in the present communication.

Geological Background

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 dolerites intrusions constitute the western fringe of the South Arcot pericratonic basin. In western part of the area, the basement rock is succeeded by the fossiliferous limestones, calcareous sandstones and marlstones of Ariyalur Group (Upper Cretaceous). The rocks are exposed in a narrow NE-SW trending belt between Ulundurpettai(11º41′ 28″ and 79º 17'28″) in the west and Pallakkottai (11º40′ 28″ and 79º 17'28″) in the east. The Cuddalore sandstone (Middle Miocene to Pliocene) occurring intermittentely along the eastern coast of South India tops the Tertiary sediments. The present study in and around Neyveli lignite and available published subsurface data subdivide the entire Tertiary sedimentary sequence of the area into two distinct lithostratigraphic unit. The Neyveli Formation and the Cuddalore Formation (Siddhanta, 1986).

The basement and the Mesozoic rocks exposed in western part of the basin have not been-encountered in the eastern and southeastern part of the area. probably due to thickening of the Tertiary sedimentary sequence from west to east (Subramanyam, 1969). The palaeocene sequence unconformably overlies that of Late Cretaceous which is locally designated as Pondicherry Formation and is well exposed in narrow strips in Virdhachalam, Ariyalur and Pondicherry areas. This consist of limestones, sandy clays and sandstone. Here, the Eocene and the Oligocene marine sequence are not exposed. However, it is very well developed in subsurface where it comprises shales, sandstones and limestones. The Oligocene sediments are overlain by those of Miocene age which dominantly consists of non marine sandstones in the outcrops. The subsurface Miocene sequence is marine and adequately fossiliferous. This sequence is divided in to Early, Middle and Late Miocene age comprising sandstones, clays and limestones. The Pliocene and Pleistocene subsurface sequences are generally arenaceous and poor in fossil contents. The exposed sedimentary sequence mainly confined to the western part of the basin are marked by several sedimentary breaks. Many geologists who worked on Cauvery basin such as Ramanathan and Rao (1965), Ramanathan (1968), Banerjee (1968), Dutta and Bedi (1968), Sastri *et al.*, (1977). The stratigraphic succession and a brief account of the geology are shown in the Table 1.

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 torrential, trough shaped and plane tabular cross bedding channels sands showing small scale herringbones type cross bedding, cross lamination and ripple drift lamination.	Alluvial fan Delta complex	Middle Mio-Pliocene
		UNCONFORMITY----	----------	----------
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)	Deltaic to near shore , back swamp deposit	Palaeocene - Middle Eocene to Miocene
		UNCONFORMITY---- Ariyalur Group of rocks/ Archaean Granitoid rocks.		----------

Neyveli Formation

The basement and the Mesozoic rocks are 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 southwest of Neyveli lignite mine area. Light grey limestone with dark coloured clay, shale and occasional lignite seams have been encountered below 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 Pondicherry area has been dated as Palaeocene (Rajagopalan, 1968) or upper Palaeocene to early late Eocene (Samanta, 1968; Saxena, 1992).

Cuddalore Formation

On the basis of silicified logs and Molluscan fossils assemblage collected from the skin of the sandstone. The Cuddalore Formation overlying the Neyveli Formation is dated as Miocene-Pliocene age (Vredenburg, 1908, Krishnan, 1960 and Ramanujam, 1968). The formation occurs a distinct lithounit consisting of clay stone in outcrops, sandstone, Carbonaceous shale and traces of lignite in substrata exposed in western part of the basin and is of late Miocene – Pliocene in age. (Figure 3). Furthermore, the contact between the Neyveli formation and Cuddalore formation is marked by an unconformity.

Tertiary sediments in the Cauvery basin are very well developed in substrata. Many palaeobotanists worked on the various aspects of Cauvery basin viz. Rao(1955); Navale (1961), Navale and Misra (1979), Thiergart and Frantz (1963); Ramanujam, (1963, 1966, 1967, 1982) Chatterjee and Battacharya (1965); Deb (1972); Deb *et al*., (1973); Venkatachala (1973), Siddhanta (1980), Singh and Misra (1991a, 1991b), Saxena (1992), worked on the Neyveli lignite. Venkatachala and Rawat (1984), worked on the subsurface sediments occurring in Karaikal, Madanam and Mannargudi wells and pointed out that the subsurface sediments as Palaeocene-Eocene in age. Acharya (2000) also favored as Early Eocene age. Deb (1972), considered only on the basis of systematic palynology with little endeavor on the age of the lignite. Deb *et al.,* (1973), and Venkatachala (1973) questioned the validity of the Mio-Pliocene age of the lignite and suggested a Eocene age for the same. In this context it may be mentioned that the carbonaceous shale bed occurring above the lignite is rich in the microfloral elements and somehow escaped the attention of the previous workers.

The present paper for the first time deals with the significant evidence of palynological records in Panruti area. and has yielded a rich palynological assemblage dominated by fungal elements, pteridophytic spores and angiospermous pollen grains. Interestingly panruti section of Cuddalore area has been dated as early Miocene age.

MATERIALS AND METHODS

The material for the present study comprises over 30 samples from 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 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 photomicrographs. The material and slides have been deposited at repository of Center of Advance study in Geology, Lucknow University, Lucknow.

Palynological Assemblage

The palynological assemblage recovered from Panruti area is quite homotaxial and represented by fungal remains, pteridophytic spores and angiospermic pollen grains. The gymnosperm pollens are altogether

absent in the assemblage. The palynological assemblage consists of 62 genera and 72 species recovered from Panruti sediments are listed below. Well preserved specimens were photographed and documented. Two slides of each sample were scanned using a transmitted light microscope and the counts were made and the abundance of different palynomorphs was determined.

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
Dictyophillidites 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, Hopping andMuller, 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 Kar1985
P. operculatus Van der Hammen, 1954
P. crassimurus Kar and Kumar, 1986

Angiosperm Pollen Grains

Quilonipollenites ornatus Rao and Ramanujam, 1978
Perfotricolpites neyvelii, Navale and Misra, 1979
Dipterocolpuspollenites 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 andMisra, 1979
Pellicieroipollis langenheimii Sah and Kar, 1970
Triagulorites bellus Kar, 1985
Margocolporites dubius Ramanujam, 1966
Meliapollis triangulatus Saxena, 1979

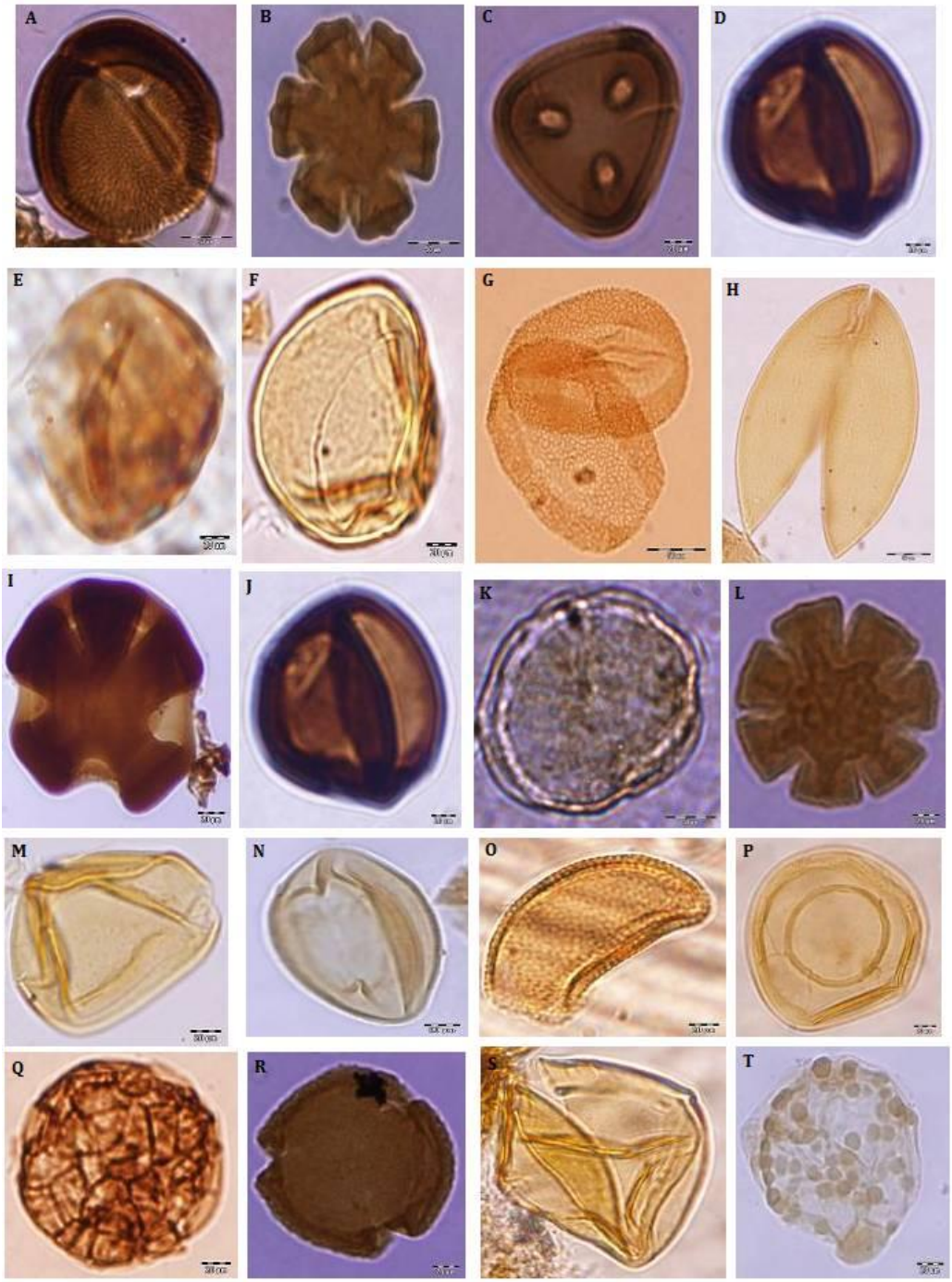

Figure 1: A) Plumbaginacipites neyvelii Navale and Misra. **B)** Ctenolophonidites costatus Ramanujam and Rao. **C)** Trilatiporites erdtmanii Ramanujam. **D and E)** Dictyophyllidites kyrtomatus Kar and Kumar. **F)** Palmidites aplicatus Kar and Kumar. **G)** Polypodiaceaesporites chatterjii Kar. **H)** Longapertites marginatus Eisawi and Schrank. **I)** Arecipites sp. **J)** Meliapollis navelei Sah and Kar. **K)** Meliapollis ramanujamii Sah and Kar. **L)** Ctenolophonidites erdtmanii Ramanujam and Rao. **M)** Alsophilidites sp. **N)** Liliacidites kaitangataensis Couper. **O)** Polypodiaceaesporites levis Sah. **P)** Verrumonosulcites foveolatus Kar and Sharma. **Q)** Proxapertites assamicus Kar. **R)** Pellicieroipollis langerhemii Kar. **S)** Intrapunctisporites intrapunctis kruisch. **T)** Verrualetes excellensus Acharya.

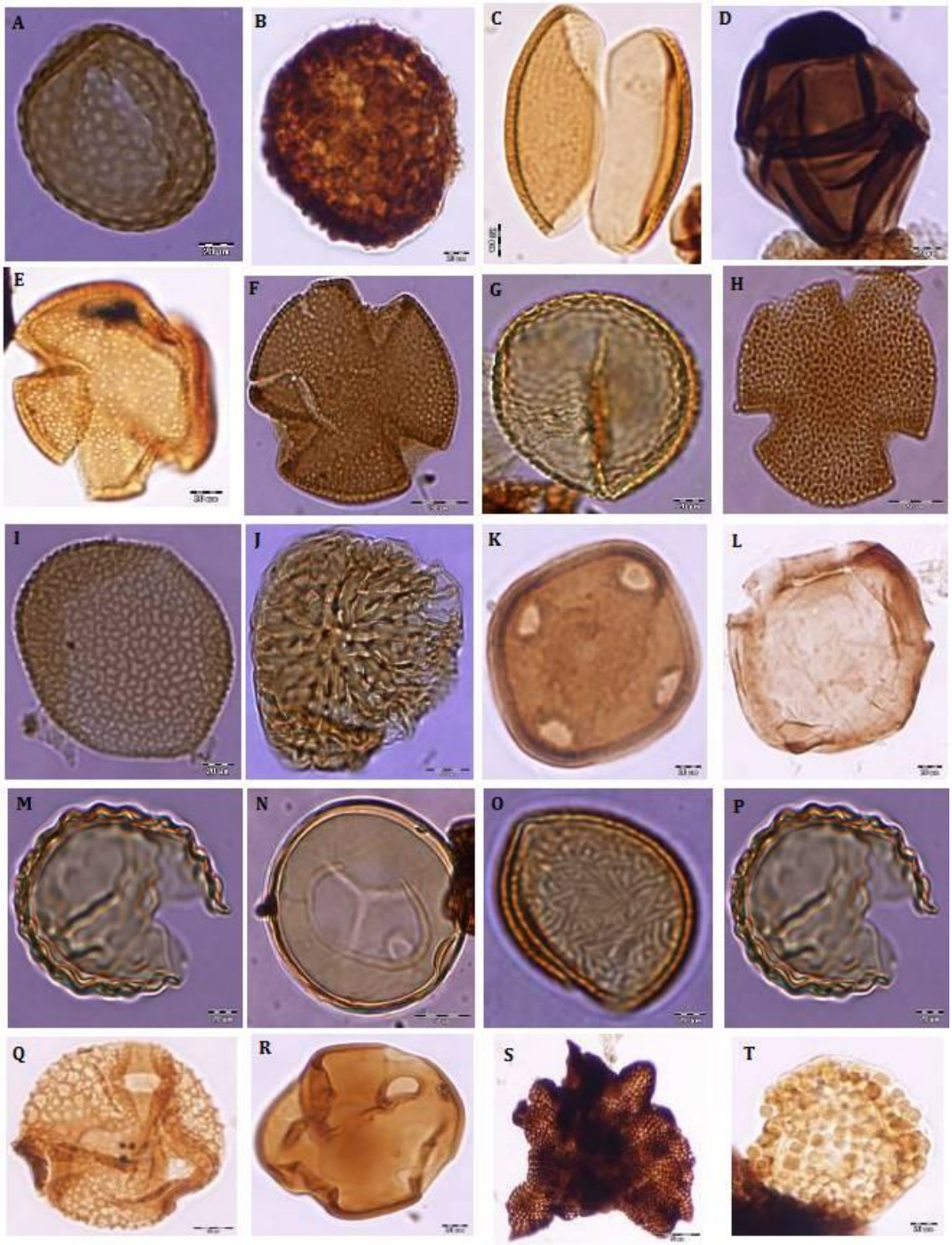

Figure 2: A) Assamialetes sp. **B)** Compositoipollenites rudis Kar. **C)** Quilonipollenites ornatus Rao and Ramanujam. **D)** Inapertisporites kedvesii Sheffy and Dilcher. **E)** Meliapollis triangulates Saxena, 1979. **F)** Tricolpites retibaculatus Saxena. **G)** Clavaperiporites jacobii Ramanujam. **H)** Retitricolporites sp. **I)** Proxapertites cursus Sharma. **J)** Crassoretitriletes ornatus Rao and Ramanujam. **K)** Dorreenipites distinctus Navale and Mishra. **L)** Tetracolporites sp. **M and N)** Pteridacidites vermiverrucatus Sah. **O)** Lygodiumsporites lakiensis Venkatachala and Kar. **P)** Liliacidites sp. **Q)** Margocolporites vanwijhei Germeraad, Hopping and Muller. **R)** Tricolporocolumellites psilatus Kar. **S)** Microthyriaceous sp. **T)** Tricolporopilites uniformis Singh and Mishra.

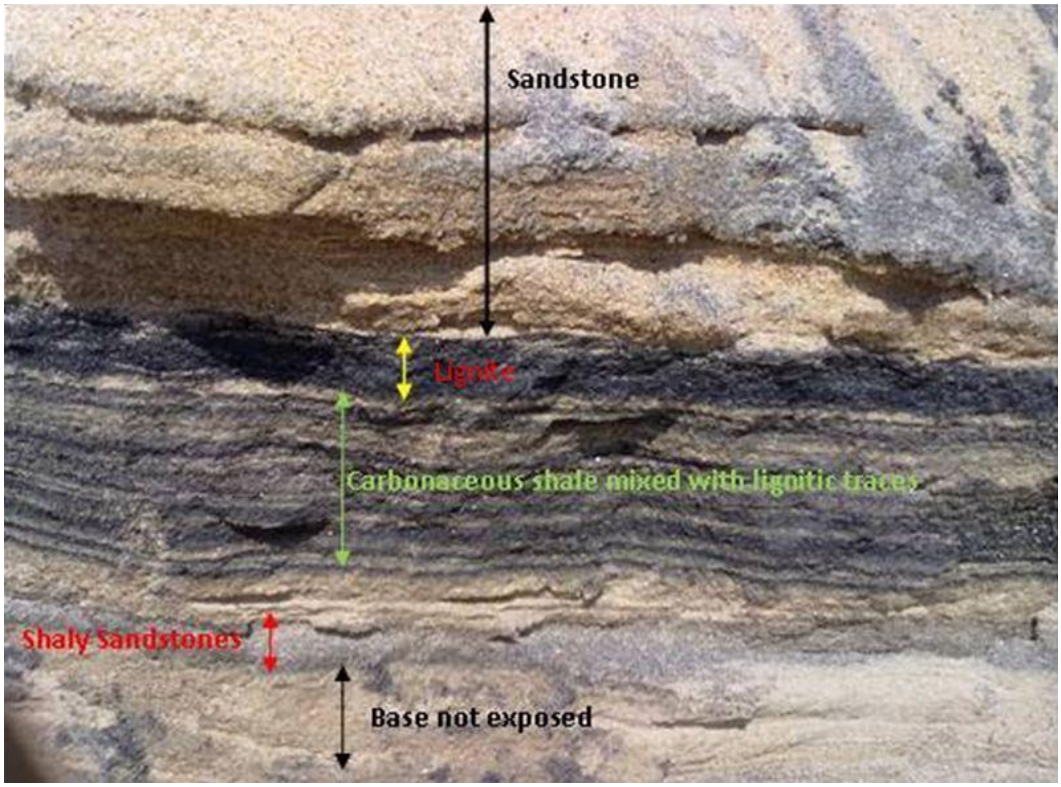

Figure 3: Panruti field photograph showing Sandstone, Lignite, Carbonaceous shale mixed with lignite traces, Shaly Sandstones and Base not exposed.

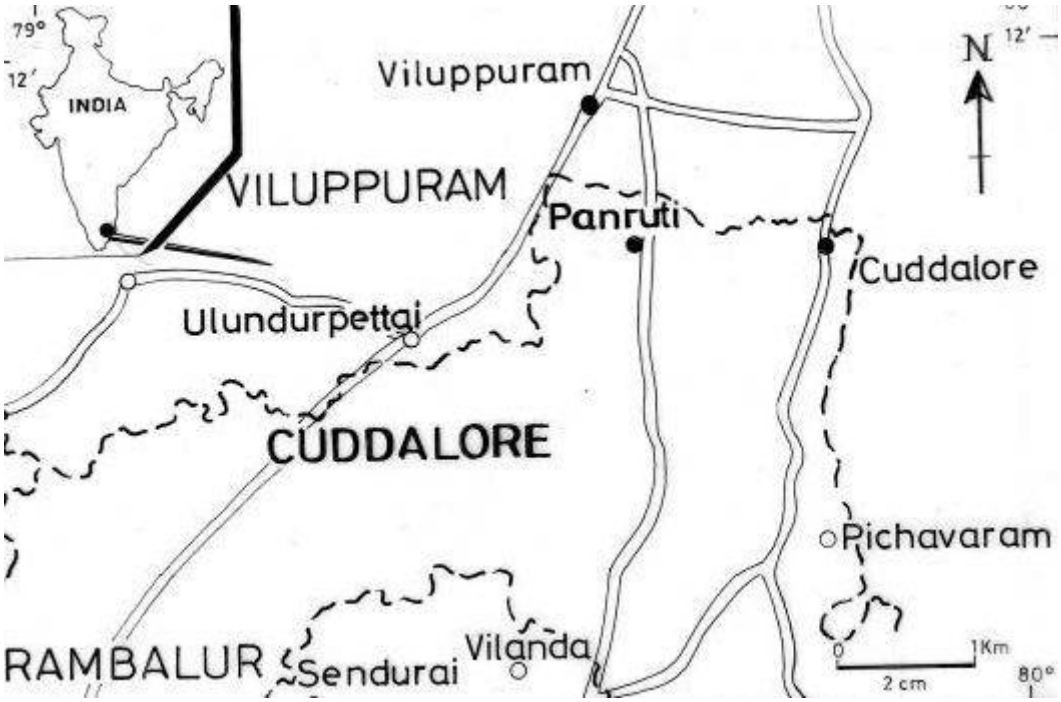

Figure 4: Showing the locality of the area.

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, Hopping and Muller, 1968
M. sitholeyi Ramanujam, 1966
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 and Sharma, 2001
Psilastephanocolporites psilatus Kar and Kumar, 1986
Retipilonapites arcotense Ramanujam, 1966
Araliaceoipollenites sp nov.
Verrutriporites gregarus Kar andJain, 1981
Tribrevicolporites eocenicus kar, 1885
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 exellensus 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 palyaperturata Kar and Jain, 1981
Proteacidites triangulatus Kar and Jain, 1981
Palaeomalvacearumpollis mamilatus Kar, 1985
Dracaenoipollis circularis Sah and Kar, 1970
Ornatetradites keralaensis Rao, 1995

Palynofloristic Analysis

The palynoflora of the Cuddalore sandstone deposit encompasses 62 genera and 72 species of fungal remains, pteridophyte spores and angiospermous pollen grains respectively. An attempt has been made to assess and evaluate botanical affinities of spore and pollen type by comparing the fossil pollen with reference to pollen of modern taxa. The following (Table 2) is the list of various spore and pollen taxa of Cuddalore sandstone in Panruti areas.

Table 2: The botanical affinities of selected pollen and spore recognized in this study and the ecological preferences of their parent plants

Phragmothyrites eocaenicus	Microthyriaceae	Warm andHumid
Trichothyrites sp.	--------, , ---------	Tropical climate
Kutchiathyrites sp.	---------, , ---------	----------, , ----------
Cyathidites minor	Cyathiaceae	Tropical to subtropical.
Cyathidites australis.		
Gleichenidites neyvelii.	Gleicheniaceae	Tropical – subtropical.
Todisporites major.	Osmundaceae	
Todisporites minor.		
Lygodiumsporites lakiensis.	Schizaeaceae	Cosmopolitan
Crassoretitriletes – vanraadshooveni.	(Lygodium)	
Dictyophyllidites sp.	Dicksoniaceae	Tropical – subtropical.
Polypodiaceaesporites levis	Polypodiaceae	
Polypodiaceaesporites sp.		
Pteridacidites vermiverrucatus.	Adiantaceae	Cosmopolitan
Margocolporites dubius		
M. tsukadai.	Caesalpinaceae (Peltophorum)	Tropical – subtropical.
Meliapollis triagulatus.		
Malvacearumpollis bakonyensis.	Meliaceae (Azadirachta)	Tropical – subtropical.
Polyporina multiporosa.	Malvaceae	Tropical - temperate
Clavaperiporites jacobii.	Cheno /Amaranthus	
Tricolpites crassireticulatus.	Thymeliaceae	Cosmopolitan
Plumbaginacipites neyvelii.	Gunneraceae	
Alangiopollis jemmatus.	Plumbaginaceae	Tropical - temperate
Spinizonocolpites echinatus.	Alangiaceae (Alangium)	
Tricolporocolumellites sp.	Arecaceae (Nypa)	Tropical - subtropical
Dipterocolpuspollenites	Euphorbiaceae	Cosmopolitan
retipilatus.	Dipterocarpaceae	Tropical - subtropical
Perfotricolpites neyveli	Plumbaginaceae	Tropical—Temperate
Quilonipollenites ornatus	Arecaceae (*Eugessonia*)	Pantropical - subtropical
Polygonacidites fregnens	Polygonaceae (*Polygonum*)	Tropical-Subtropical
Graminidites annulata	Poaceae	---------, , ----------
Liliacidites sp.	Liliaceae	---------, , ----------
Longapertites microfoveolatus	Palmae (Arecaceae)	---------, , ----------
Proteacidites singalii	Proteaceae (*Isopogan*)	---------, , ----------
Proxapertites operculatus	Palmae (Arecaceae)	---------, , ----------
Ctenolophonidites keralensis	Ctenolophonaceae	----------, , ----------
Retipilonapites arcotense	Potamogetonaceae (*Potamgeton*)	---------, , ----------
Palmipollenites ovatus	Palmae (Arecaceae*) Cocos*	----------, , ----------
Arecipites sp.	Palmae (Arecaceae)*Syagrus*	----------, , ----------
Trilatiporites erdtmanii	Arecaceae (*Sclerosperma*)	----------, , ----------.
	Myrcinaceae (*Myrcina*)	Cosmopolitan
Polymorgocolporites	Labiatae	----------, , ----------

The pteridophytic spores comprise both monolete and trilete forms represented by 14 genera 19 species. The palynoassemblage referable to the angiosperms include well preserved nonaperturate, monocolpate, dicolpate, tricolpate, stephanocolpate, triporate, pseudocolpate and show various exine ornamentations. The presence of certain important palynotaxa where the fossil palm pollen have been affiliated to modern taxa like *Quilonipollenites* (=*Eugeissonia*), *Trilatiporites* (=*Sclerosperma*), *Ctenolophonidites (=Ctenolophon*) etc. The taxa *Eugeissonia* and *Sclerosperma* are coastal palms confined to South East Asia and tropical Africa, The genus *Ctenolophon* is tropical African element (Thanikaimoni, 1970). The occurrence of significant pollen referable to Cuddalore Formation is indicative of their extensive geographical distribution during Miocene period. Palynomorphs predominantly occuring in clay and carbonaceous shale along with the trilete spores and nonaperturate pollen . The monolete spores are however in a higher frequency at the upper part of the lignitic patches while triporate pollen types are fairly common to both lignite and shaly sediments.

Table 3: Showing the various ecological groups

Ecological Groups	Palynotaxa
Low land elements	*Lakiapollis* *Tricolpites* *Meliapollis* *Margocolporites* *Polycolpites*
Freshwater, swamps and water edge elements	*Lygodiumsporites* *Todisporites* *Dictyophyllidites* *Crassoretitriletes* *Pteridacidites* *Polypodiaceaesporites* *Polypodiisporites* *Polygalacidites* *Ctenolophonidites* *Margocolporites* *Polygonacidites* *Retipilonapites*
Montane elements	*Clavaperiporites* *Proteacidites* *Retitribrevicolporites*
Shady Beach Elements	*Spinizonocolpites* *Palmaepollenites* *Liliacidites*
Mangrove and Back mangrove elements	*Alangiopollis* *Malvacearumpollis* *Araliacoipollenites* *Meliapollis sp.* *Retitricolpites* *Spinizonocolpites*
Sand dune and beach elements	*Trilatiporites* *Palmaepollenites* *Quilonipollenites* *Longapertites* *Arecipites* *Polyporina*

Research Article

Palaeo-Environmental Significance

The palynoassemblage contains a variety of palynotaxa assignable to plants of various ecological communities such as lowland, freshwater swamps and water edge, montane, backmangrove and sandy beach elements. An analysis of ecological groups of the Cuddalore Formation reveals that the freshwater swamps and water edge elements are dominant over the lowland element. The lowland taxa are dominant in the lower part of the formation but decrease in the middle part and again increase at the top. The freshwater elements are dominant throughout the assemblage. Mangrove and the back mangroves elements are dominant in the lower part and decrease at the top whereas the frequency of montane elements is less in the lower part of the sequence. The taxa included in palynoasseblage are shown in the Table 3.

The palynoflora belonging to various ecological groups such as freshwater swamps and water edge (*Lygodiumsporites, Crossoretitriletes, Polygonacidites etc*), low land *(Perfotricolpites, Dipterocarpuspollenites, Tricolporopollenites etc.), sandy beach elements Polygoncidites etc.)*, low land *(Perforicolpites, Dipterocarpuspollenites, Tricolporopilites etc.), Sandy beach elements (Quilonipollenites, Spinizonocolpites, Palmaepollenites, Dracaenoipollis etc)*, back mangrove elements *(Malvacearumpollis).* The pteridophyte taxa generally favors a moist and shady habitat. Presence of Todisporites, *Cyathidites, Lygodiumsporites, Pteridacidites* and *Crossoretitriletes* are indicative of freshwater swamps and lakes conditions near the site of deposition. Freshwater and marshy conditions are also indicated by the presence of *Polygoncidites* (Polygonaceae). The pollen grains belonging to Arecaceae suggest plants with luxuriant growth and contributed to the development of rich vegetation in the area. The back mangrove is well represented by *Malvacearumpollis* (Malvaceae). The vegetation pattern support that the deposition of Cuddalore Formation took place near shore (coastal environment) with lagoon or swampy conditions in the vicinity.

Age Connotation

A review of the data obtained from Cuddalore Sandstonme Formation clearly demonstrates that a number of taxa in common with those from Cauvery basin and closely comparable to those encountered elsewhere in the Quillon Formation and is dated as Miocene in age (Ramanujam, 1982). Majority of the taxa are known from the Oligocene; although some of them have been reported from the sediments ranging in age from Palaeocene to Miocene. Key taxa are the spores of *Crossoretitriletes vanraadshooveni* have been widely recorded from the Neogene sediments of south America, Carribbian area, Nigeria and Borneo. *C. vanraadshooveni* is a characteristic element of Upper part of Lower Miocene in Carribbian area. In Borneo and Nigeria its first appearance is slightly earlier within the lower Miocene than in the Carribbian area. In northern America it disappears at the base of Middle Miocene. Germeraad, Hopping and Muller (1968) have instituted a discrete pantropic stratigraphic unit designating as C. *vanraadshooveni* zone marking the upper part of Lower Miocene. The Indian land mass is clearly demarcated geographical regime circumscribed by effective barriers like seas and the lofty Himalayas. The diversity of its climate and its characteristic geographic position at the junction or meeting place of important floristics flows migratory routes have facilitated the invasion or penetration of Malaysian, African and other floral elements in to 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 precipitation. 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 Upper Cretaceous time and soon differentiated to *C. engleri* and *C. parvifolius* type. The available data indicate that plants of the *C. engleri* type migrated eastwards sometimes during the Miocene period as evidenced by the occurrence of *Ctenolophonidites costatus* pollen in Upper Miocene of Warkalli lignite of South India. (Ramanujam *et al*., 1973), from deposits younger than Upper Miocene age. One may assume to infer that after a brief period of existence along the west coast of South India during Upper Miocene age, the genus became extinct during Miocene epoch. Reinvestigation of *C. erdtmanii* the present assemblage of Panruti deposits extends the earlier

palaeogeographical distribution of *Ctenolophonidites* (Ramanujam and Rao, 1973) toward east coast and establish that the genus not only existed in western coast but also in the east coast of India during Miocene period. It may be inferred from this finding that the genus *Ctenolophonidites* might have migrated eastward from Africa to Indonesian Archipelago 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 cosmopolitan genus while *Onychium* has a tropical to subtropical distribution. The geological records of the *Pteridacidites* dates back to Miocene. The positive evidence for the presence of genus *Compositoipollenites* throughout the sequence of Panruti section. The family Aesteraceae is regarded as younger family with first occurrence dating back to Miocene. The members grow in all situations. Kuyl, Muller and Waterbolk (1955), opined that on the basis of palynological record, Asteraceae emerges as one of the youngest developments within the angiosperms. The fossil wood of *Dipterocarpus* of Dipterocarpaceae is one of the common elements of Neogene sediments of India. *Dipterocarpus indicus* Beddome at present is confined to the evergreen forests of eastern and western Ghats of Kerala and Karnataka. The fossil pollen *Dipterocarpuspollenites retipilatus* (Kar and Jain, 1981) is also known from Kerala. It seems that from Miocene period, this taxon is growing in the region as an endemic one.

Germeraad *et al.,* (1968), observed that Asteraceae though widespread in the present day tropical countries are more common in open vegetation types, such as Savannah, or higher montane vegetation than in closed lowland rain forest. The pollen grains *Malvacearumpollis* Nagy (1962) represent the geological history dated back to middle upper Eocene onwards and rich up to middle Miocene respectively. Croizat (1952), thought that Malvaceae originated in south America and the southern Atlantic and then migrated toward Europe. Germeraad *et al.,* (1968), reported Malvaceae pollen from late Oligocene of Africa while Hekel (1972), recorded it from Miocene of Australia. The distinctive pollen of *Malvacearumpollis grandis* (Sah, 1967), are fairly conclusive evidence by the presence of this family indicates a tropical to subtropical vegetation. The Poaceae pollen in the fossil state have been designated as *Graminidites*, this genus has also been described here from Oligocene. The grass pollen in Kutch is very rare and it seems up to Miocene they were habituating panruti region in large numbers. Regali Uesugui and Santos (1974), as early as recorded grass pollen from Palaeocene of Brazil. In lower Eocene according to Muller (1981). This type of pollen grains becomes more frequent and reach up to Miocene particular in Africa and also encountered in other regions.

The fossil pollen of *Nypa* is known as *Spinizonocolpites* Muller (1968) from Senonian (Maastrichtion) in age of Borneo. Nypa had a wide geographical distribution during the past but at present grows in a narrowly restricted areas of tropical coasts of south east Asia in mangrove ecosystem. Fossil representation of this genus is also well documented in 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 Cretaceous – Tertiary transition comes from south – east Asia (Muller, 1968). In Eocene sediments Spinizonocolpites is widely reported from North America, Europe, Australia, Malaysia, Pakistan and India. During Miocene *Nypa* disappeared from most parts of world and almost reached its present status. *Nypa* (*=Spinizonocolpites)* also reported from the Miocene of Ratnagiri of Maharashtra (Kulkarni and Phadtare, 1981) also reported from Miocene sediments of Bhuban Formation of Mizoram (Mandaokar, 2000). The fossil pollen of Nypa is helpful in deciphering the palaeoecology of the sediments as it could grow only in the limited ecological conditions in Sunderban, India.

DISCUSSION

The cuddalore sandstones exposed at the western part of the Cauvery basin comprises palynotaxa fungal remains (fruiting bodies, spores and hyphae) Pteridophytic spores, angiospermous pollen, salt loving

plants and other organic debries. The palynomorphs have been critically studied and compared with modern plants/families. Some of the fossil taxa show the affinities with the modern counter parts. Only 12 comparable extant families could be observed. Of these eight families are restricted to tropical to subtropical environment whereas a few are cosmopolitan. The family Arecaceae is tropical while potamogetonaceae is tropical – temperature.

The Cuddalore Formation overlying the Neyveli Formation is dated as Mio-Pliocene based on the studies of carbonized logs (stems and other megafossil records) as well as the molluscan fossils collected from the skin of the sandstone (Vredenberg, 1908; Krishnan, 1960; and Ramanujam, 1968). The Neyveli and Cuddalore Formations occur as two distinct lithounits and is Mio-Pliocene in age. The palynomorphs from the sandstone lithofacies are poorly preserved and scanty. They tend to be degraded and broken at the periphery suggesting a higher energy transport than other shale and coal lithofacies (Mandaokar, 2000). It is surprising that no reworked Gondwana elements have been detected in this area, as has been recorded from other Neogene sediments. Furthemore, the time gap and the contact between Neyveli Formation and Cuddalore Formation is marked by an erosional unconformity. Trunks of fossil woods ranging up to 2. 8m long and 0. 75m in diameter are (Ramanujam, 1968) reported from Cuddalore sandstone of Cauvery basin. Here the sediments are represented by marine equivalents in the region near Pattukkottai, the sediments appear to have been deposited in a transitional zone. Thus the Cuddalore Formation has yet not been precisely dated. However, it has been observed that a predominantly marine Aquitanian sequence become paretic more continental than littoral during the transitional period between the Aquitanian and Burdigalian as evident from the visible outcrop at Panruti. Among the angiosperms of the Cuddalore Sandstone monocotyledonous fossils are known by a few species of woods recorded *Mesembrioxylon schmidianum* and *Palmoxylon pondicherriensis* (Sahni, 1931); *P. arcotense* and *P. puratanum* (Ramanujam, 1953, 1958) of these *P. arcotense* shows some resemblance with extant *Livistona.* The fossil wood resembling to dicot families have been reported from SouthArcot district eg: Guttifereae (Clusiaceae) Dipterocarpaceae, Simaroubiaceae, Celastraceae, Sapindaceae, Fagaceae, Anacardiaceae, (Ramanujam, 1953, 1960 and 1964; Navale, 1955, 1963; Lakhanpal and Awasthi 1963, 1964). The Cuddalore sandstones exihibit the characters of shallow estuarine deposits, are overlain in the coastal tract and various river valleys by deltaic alluvium and coastal sand, although it is considered by all the Tertiary sediments. According to Wadia (1953) a great part of this formation is Pliocene age. Krishnan (1960), included under Upper Miocene age. The molluscan fossils (Dey, 1962 and Dutta , 1981) are indicative of Pliocene age. Further, the geological history of Dipterocarpaceae clearly indicates that almost all the species have been from the Miocene or Mio-Pliocene strata (Schweitzes, 1958, Ramanujam, 1960). The totality of the Palaeobotanical evidences strongly indicate that the Cuddalore sandstones cannot be older than Middle Miocene and are most probably Upper Miocene or even Lower Pliocene age.

Within the lignite traces underlying the Cuddalorre sandstone a major lignite seams but at Panruti we observed traces of lignite ranging 0. 5 to 1 meter thick. The palynoflora of these lignites viz. , *Dracaenoipollis, Ctenolophonidites* and fungal spores (*Phragmothyrites eocaenicus*) are abundant. It is important to note that though *Spinizonocolpites, Retistiphanocolpites, Margocolporites* and *Ctenolophonidites* occur in younger horizon. in other tropical countries as stated by Germeraad *et al.* (1968). Possibly the genus *Ctenolophon* type pollen disappeared from India during Early Miocene period and have been noted in the sediments of Warkalli beds of Kerala (Ramanujam and Rao, 1973). The pteridophytic spores generally favour moist and shady habitat. The presence of *Todisporites, Cythidites, Polypodiaecaesporites, Lygodiumsporites, Lycopodiumsporites* indicative of fresh water swampy and lake conditions near the deposition site. Species of *Crassoretitriletes vanraadshooveni* have been widely recorded from the Neogene sediments of South America, Carribbean area, Nigeria and Borneo. In northern south America it disappears at the base of Middle Miocene. Germeraad *et al*. (1968) instituted a discrete pantropical biostratigraphic unit designated as *Crassoretitriletes vanraadshooveri* zone marking Upper part of Lower Miocene of the above area *C. vanraadshooveni* has not been recorded to date from

sediments older than lower Miocene. The presence of rich characterstic taxon in the Neyveli, Warkalli and Panruti deposits thus indicative of not older than lower Miocene. *Trilatiporites* (=*Sclerosperma)* of Arecaceae family is a coastal element found occasionally in the present samples. The palynoflora is also characterized by some swamp dwelling fossil pollen corresponding to *Nypa* (=*Spinizonocolpites*) belonging to Arecaceae. The Miocene sequence shows presence of taxa characterstic of lower Middle to Upper Miocene. The important taxa are *Longapertites, Quilonipollenites, Polygonacdites* and *Perfotricolpites.* These pollen grains belonging to Arecaceae suggest a luxuriant growth of vegitation and contributed in development thick forest in the area.

A rich and varied palynofloral sequence of shale and clay show the continuity showoff occurrence of *Malvacearumpollis, Quilonipollenites, Dorreenipites, Trilatiporites, Proxapertites, Tricolporopollenites* etc. mostly delineate lower Miocene. It may be mentioned here that in (Khari Nadi Formation) in Kutch, western India. Recovery of *Malvacearumpollis, Hibiceaepollenites, Liguilifloridae* considered as marker of Lower Miocene (Kar, 1985). The genus is poorly represented in Kerala and other Miocene sediments of Mizoram, Meghalaya, Assam and Arunachal Pradesh. It is found as one of the most dominant elements. Back mangrove is represented by *Malvacearumpollis bakonyensis* (Malvaceae). Salt loving plant *Polyporina globosa* have also been recorded from the assemblage . A critical ecological analysis of the palynofossils based upon their known botanical affinities has brought to light the presence of mangrove and back mangrove taxa viz. *Retricolporites, Araliaceoipollenites, Malvacearumpollis, Spinizonocolpites, Tricolpites retibaculatus*, the low land elements eg: *Margocolporites tsukadae, Pellicieroipollis langenhemii, Triangulorites bellus* and *Clavaperiporites jacobii,* the fresh water swamp and water edge elements e. g. *Ctenolophonidites, Margocolporites Longapertites.* The sand dune and salt marsh element e. g. *Palmaepollenites, Polyporina* and *Proxapertites* etc are also notable. The Miocene palynoflora of Panruti section of Cauvery basin clearly signifies the prevalence of tropical humid climate with high precipitation along east coast of India. Presence of microthyriaceous fruiting bodies *Phragmothyrites, Microthyrites, Trichothyrites,* and other fungal spores of *Inapertisporites* are typical epiphyllous fungi and their occurrence in the present assemblage indicates the existence of a terrestrial plant ecosystem and represent a warm and humid climate with heavy rainfall. The palynofloristic spectrum of Panruti in South India clearly indicates occurrence of discrete pockets of brackish water or estuarine mangrove swamps adjacent to the coast line also presence of forests vegetation. The surrounding areas particularly in Panruti areas is at present has scrub jungle thickets with dry evergreen and deciduous elements (Meher Homji, 1974). Thus the study reveals that claystone underlying the lignitic traces was deposited under mangrove swampy conditions with local pockets of marine influence having bulk of carbonaceous shale that have been laid down back mangrove conditions.

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