

Dispersed angiosperm cuticles from a lignitic clay bed, Sindhudurg Formation (Miocene), Maharashtra : an interpretation on taxonomy, biodegradation and environment of deposition

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ABSTRACT

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A detailed morphotaxonomic study of dispersed leaf cuticles in relation to the effect of various degradational processes have been carried out from a lignitic clay bed exposed at Amberiwadi, Maharashtra. During the investigations, cuticles under various stages of degradation caused mainly by the microbial activity were observed. Such changes have been affected in the foliage dominated organic matter during early stages of diagenesis. These studies also provide an insight into the land plant diversity and help in tracing relationship between well preserved fossil cuticles and the flora still forming a part of the forests in coastal Maharashtra. It is suggested that the deposition of organic matter took place in a shallow niche present over a narrow coastal strip.

Key-words—Dispersed cuticles, Morphology, Taxonomy, Palaeoenvironment, Sindhudurg Formation.

महाराष्ट्र के सिन्धुदुर्ग शैलसमूह के लगुडांगारीय मृत्तिका संस्तर से प्राप्त परिक्षिप्त आवृतबीजी उपचर्मों का वर्गिकीय, जैवनिम्नीकृत तथा निक्षेपणीय पर्यावरण के आधार पर निर्वचन

रजनी तिवारी, माधव कुमार, आनन्द प्रकाश, मनोज शुक्ल एवं गजेन्द्र प्रताप श्रीवास्तव

सारांश

विभिन्न निम्नीकरण प्रक्रियाओं के प्रभावों को ज्ञात करने के उद्देश्य से महाराष्ट्र के अम्बेरीवाड़ी में अनावरित लगुडांगारी मृत्तिका संस्तर से प्राप्त परिक्षिप्त पर्ण उपचर्मों का विस्तृत आकारवर्गिकीय अध्ययन किया गया। अध्ययन के दौरान मूलतः सूक्ष्म जैविक गतिविधियों के कारण निम्नीकृत होने वाले उपचर्मों की विभिन्न अवस्थाओं को प्रेक्षित किया गया। प्रसंघनन की प्रारंभिक अवस्थाओं के दौरान पर्णसमूह की प्रचुरता वाले कार्बनिक पदार्थ में ये परिवर्तन हुए हैं। ये अध्ययन भूमि पादप वैविध्य हेतु एक मार्गदर्शक का कार्य करते हैं तथा इनसे समुद्रतटीय महाराष्ट्र के वनों में अभी तक उग रहे वनस्पतिजातों तथा सुसंरक्षित अशिमित उपचर्मों के मध्य सम्बन्धन स्थापित करने में भी सहायता मिली है। यह प्रस्तावित किया जाता है कि स्थापित कार्बनिक पदार्थ का निक्षेपण एक समुद्रतटीय पट्टी पर उपस्थित एक उथले गर्त में हुआ होगा।

संकेत शब्द—परिक्षिप्त उपचर्म, आकारविज्ञान, वर्गिकीयविज्ञान, पुरापर्यावरण, सिन्धुदुर्ग शैलसमूह।

INTRODUCTION

THE Sindhudurg Formation (Miocene), Maharashtra consists of impure lignite, carbonaceous clay, laterite, iron stone bands and gritty clay. Within this sedimentary sequence lignitic clay contains abundant angiospermous cuticles and other types of organic matter. It appears that the source material was very much dominant in foliage. Such a kind of source material generally forms paper coal if other conditions remain favourable. Dispersed cuticles have recently been reported from Sindhudurg Formation (Miocene) of Ratnagiri District, Maharashtra (Tewari & Agarwal, 2002; Agarwal *et al.*, 2002) and from Upper Pliocene-Pleistocene of West Kameng District of Arunachal Pradesh (Joshi *et al.*, in press).

The vegetation growing around Amberiwadi contributed to the primary production of leaf litter and woody fragments, which were deposited in a shallow basin. The abscised leaves and small wood fragments initially accumulated over the forest floor before being transported to the site of deposition. The cuticular features are helpful in characterization of various fossil taxa. They are also helpful in correlation of beds and in biostratigraphy.

The dispersed cuticles yield information on nature of vegetation and tree types. They also preserve many features (*viz.*, shape and arrangement of epidermal cells, their arrangement around stomata, nature of anticlinal and surface walls, type of stomata, type of guard cells and nature of subsidiary cells) which are linked with the habitat, climate, environment of deposition, phases of degradation and relationship with microorganisms.

So far, little information is available on fungal action on leaf fragments and its role in the preservation of organic matter in the sediments. The decaying processes show differential rate of degradation over cellulose, lignin, lipid, proteins and carbohydrates that are the main constituents of organic matter.

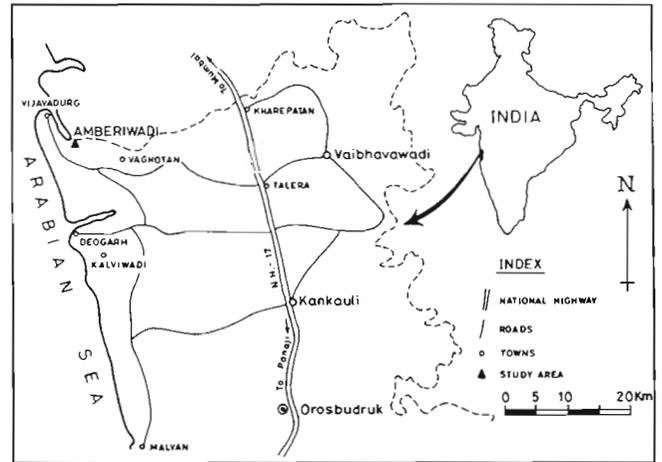


Fig. 1—Location Map.

Primarily, these substances are associated with the protective covering in the epidermal tissues. Under various catabolic processes in the sediments they are transformed in to monomers, geopolymers and also in some inorganic compounds during diagenesis and peat formation (Berner, 1980). However, some of the plant cuticles retain their original features due to the adaptability against various microorganisms while some display biodegraded stomata and presence of hyphal mats over the cells (Pl. 2.6, 7, 9; Pl. 3).

MATERIAL AND METHODS

The cuticles were isolated from lignitic clay samples by a combination of standard preparation methods suggested for the study of dispersed organic matter which include treatment with dilute HCl and HF acids and sieving through 500 mesh sieve. The residue obtained is smeared over a cover slip mixed with polyvinyl alcohol solution and dried at 60°C. The cover slips are mounted with the help of canada balsam. After the

PLATE 1

1. Cuticle of lower surface of the leaf showing straight walled, isodiametric to polygonal cells with several fungal fruiting bodies attached and large oval irregularly oriented and distributed stomata. Slide no. BSIP 12450, M34. x 450.
- 2, 4, 8. Cuticular pieces showing rectanguloid to polygonal cells with thick straight to arched walls, oval to rounded, irregularly distributed and oriented paracytic stomata, thickened areas on surface walls (figs 2, 4) and biodegradation of cells (fig. 8). Slide nos BSIP 12452, M 44; 12453, H 42; 12457, L 41. x 500.
- 3, 5. Cuticle of lower surface of leaf showing polygonal cells with straight to arched anticlinal walls, oval, anomocytic, irregularly distributed and oriented stomata. Slide nos. BSIP 12452, F52; 12453, Y 33. x 500.
6. Cuticle of lower surface showing, polygonal to rectanguloid cells with sinuous to straight anticlinal walls, elliptic to oval paracytic stomata and surface walls with thickened areas. Slide no. BSIP 12457, L 33. x 500.
7. Cuticle showing rectanguloid to polygonal cells, deeply sinuous anticlinal walls with knobbed thickening and round to oval paracytic stomata. Slide no. BSIP 12454, W25 x 250.
9. Cuticle showing straight to arched walls, isodiametric cells and longitudinally distributed and oriented stomata arranged in rows. Slide no. BSIP 12452, T 56. x 500.

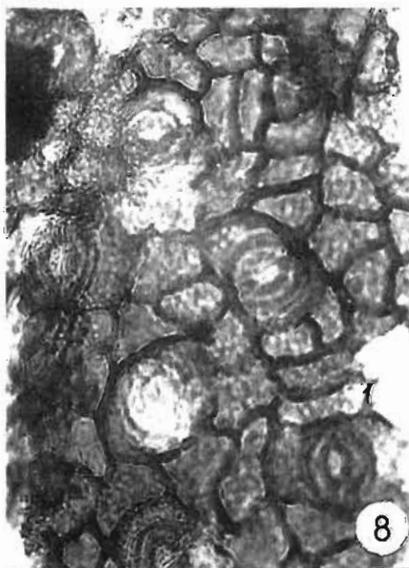
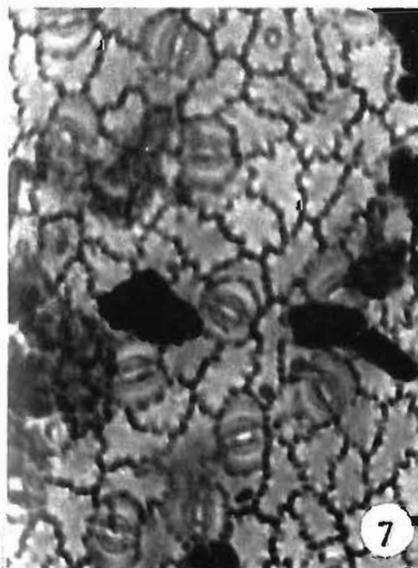
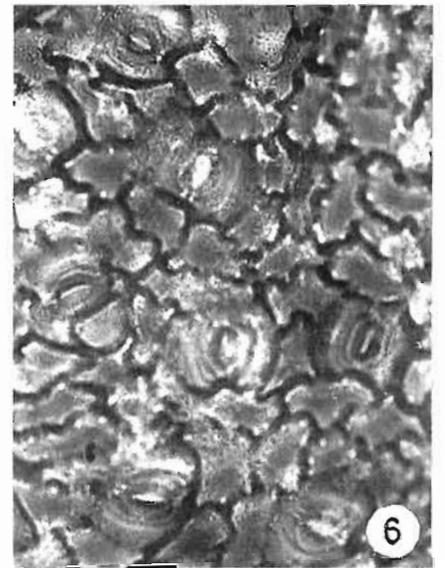
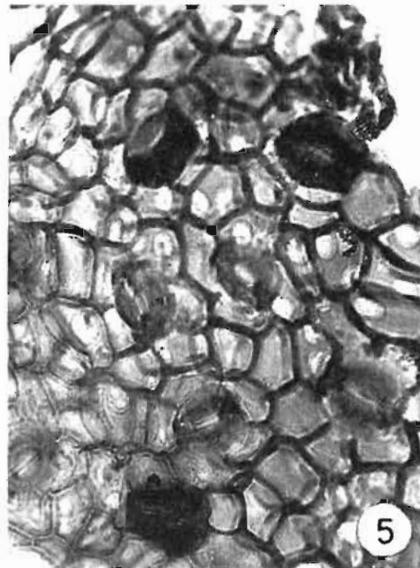
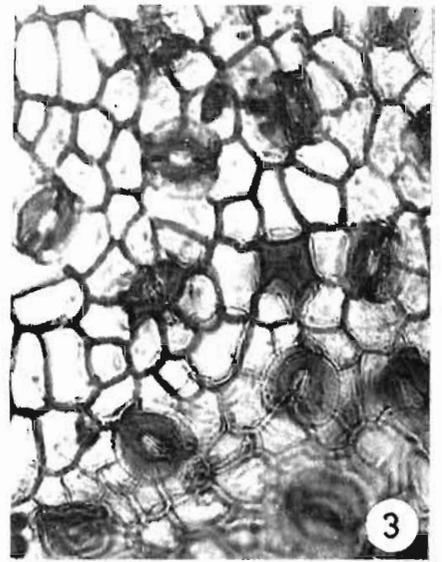
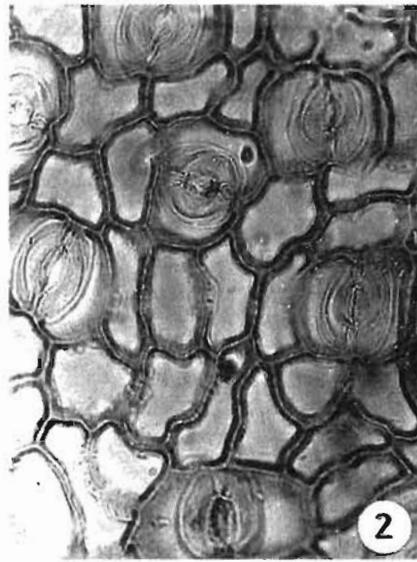
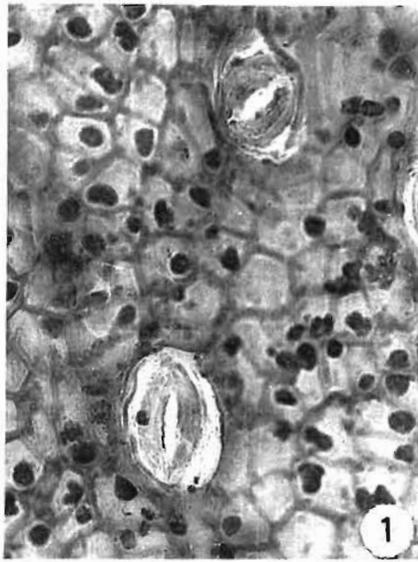
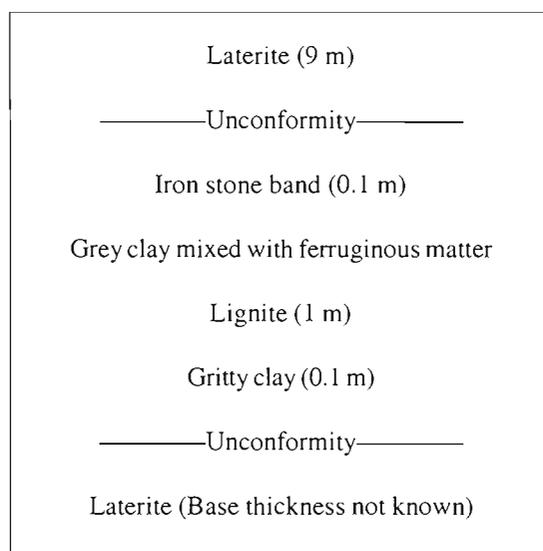


PLATE 1

preparations, the cuticles are studied considering the cells, cell walls, stomata, guard cells and subsidiary cells. The stomatal index is calculated following the methods of Dilcher (1974) and Dilcher and Daghljan (1977).

GEOLOGICAL SETTING

A sedimentary sequence forming part of Sindhudurg Formation is exposed at Amberiwadi (Lat. 16°30'20" N; Long. 73°23'20" E) near Tirlot Village in Devgarh Taluk of Sindhudurg District (Fig. 1). Saxena *et al.* (1992) and Saxena (1995) made a detailed lithostratigraphic study of a number of outcrops, well and mine sections, etc. of Ratnagiri and Sindhudurg districts of Maharashtra. The generalised sequence of sedimentary deposits is as follows :



The Sindhudurg Formation overlies Precambrian rocks on Deccan Traps and the contact is marked by an erosional unconformity. A part of lignite is mixed with soft plastic clay and contains carbonised wood remains and yields rich palynoflora of Miocene age.

SYSTEMATIC DESCRIPTION

The dispersed cuticle assemblage recovered from lignitic clays of Sindhudurg Formation shows dominance of dicotyledons and also represents a monocotyledonous family. Based on morphological features, the dispersed cuticles were assigned up to family level only and not up to generic or specific level because of uncertainty about the validity of several species and the preservation of characters in fragments. However, the present taxonomic study is likely to provide a base for evaluating the characters of dispersed fossil angiosperm cuticles and shall also help in the interpretation of palaeovegetation and environment of deposition. A detailed study based on morphotaxonomy of the dispersed cuticle is being carried out and will be published later.

The cuticles of leaves exhibit characters of internal anatomy which can be used for classification or identification of species. The leaf surfaces also show a range of cell arrangement, stomatal structure and cuticular sculpturing which can distinguish one species from another. The analysis of cuticular structures is helpful in reconstructing palaeovegetation of a specific habitat. The cuticles of moist, sheltered, shady habitats are clearly distinct from those of arid/dry conditions. The leaf development and its cuticular morphology depends on genotype and on environment.

On the basis of epidermal characters, the cuticles are referred to seven dicots and one monocot families. Among dicotyledons, the cuticles are assignable to Lauraceae, Magnoliaceae, Myrtaceae, Moraceae, Caesalpiniaceae, Loranthaceae and Symplocaceae, while Dioscoreaceae of Liliiflorae represents monocotyledons.

The epidermal characters of different types of dispersed cuticles recovered from Sindhudurg Formation, Amberiwadi and their affinities are given in Fig. 1.

The families described here are mostly characterised by hypostomatic and occasionally amphistomatic cuticles, cells are either differentiated or not differentiated into vein and mesh areas and are usually elongate, polygonal to rectanguloid and sometimes isodiametric in shape. The lateral walls are both

PLATE 2



- 1, 2. Cuticle showing rectanguloid to polygonal cells of mesh area with sinuous anticlinal walls, surface walls with numerous small rounded structures and irregularly distributed and oriented anomocytic stomata. Note 'T' pieces at poles. Slide no. BSIP 12451, G 23. x 450.
3. Cuticle showing rectanguloid, pentagonal, hexagonal cells with straight to undulate walls and anomocytic stomata with wide stomatal slit. Slide no. BSIP 12456, H51. x 500.
4. Cuticle showing polygonal thick walled cells and? algal colonies. *Incertae-sedis*. Slide no. BSIP 12456, H 56 x 450.
5. Cuticle showing small isodiametric cells with thin areas on surface and a circular trichome base. *Incertae-sedis*. Slide no. 12453, G 33 x 450.
6. Parenchymatous cells showing circular opening. Slide no. BSIP 12457, K 35. x 450.
7. Cuticle showing polygonal thick walled cells. *Incertae-sedis*. Slide no. BSIP 12452, J 45. x 450.
8. Cuticle showing rectanguloid to polygonal cells with straight to arched anticlinal walls, surface with thickened areas, large oval irregularly distributed and oriented stomata with wide stomatal slits and indistinct subsidiary cells. Slide no. BSIP 124527, L41. x 500.
9. Magnified cuticle fragment showing hexagonal epidermal cells with biodegraded and disrupted parenchymatous cells. Slide no. BSIP 12457, M33. x 250.

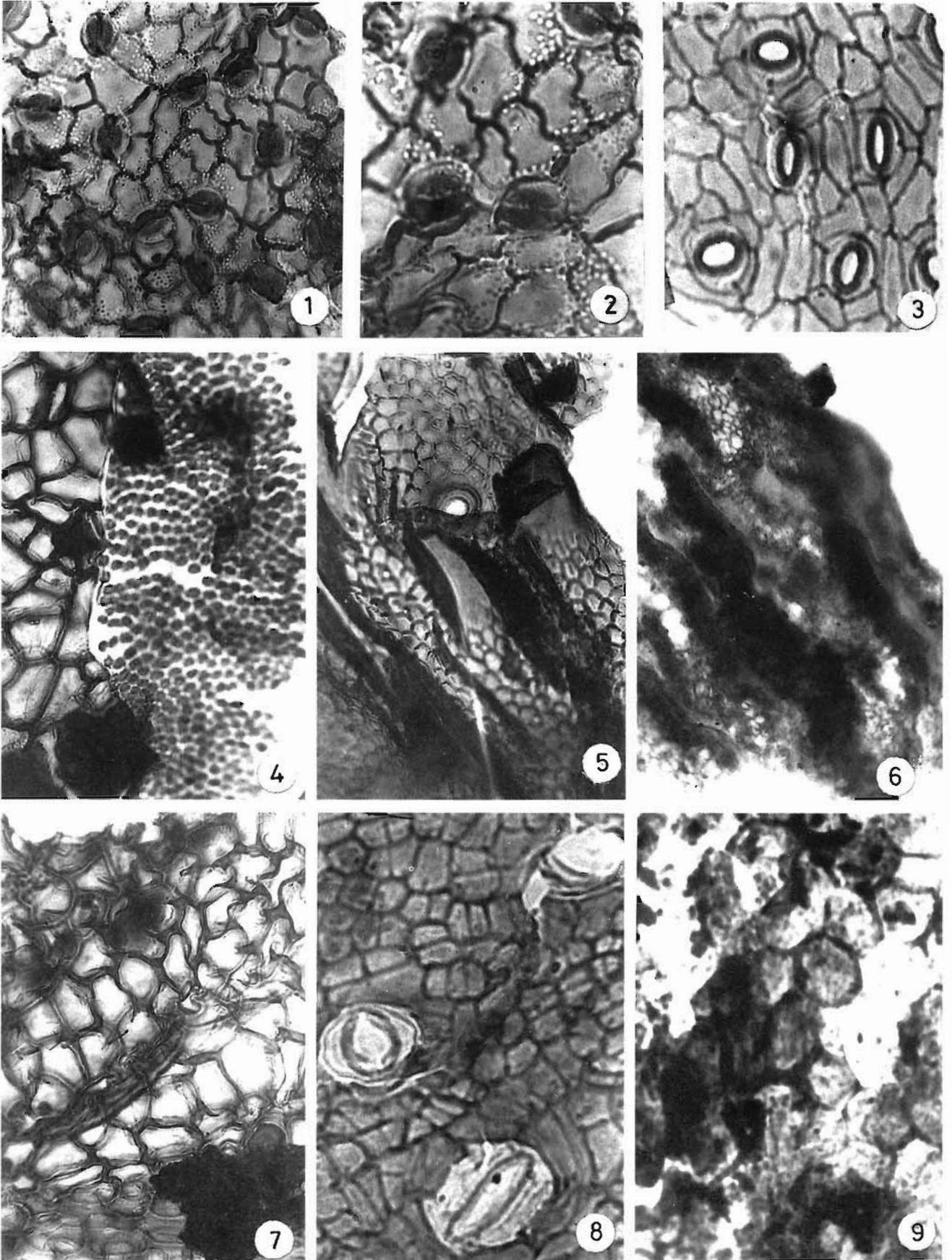


PLATE 2

straight and sinuous and sometimes thickened. The surface walls are usually non-papillate. However, when papillae are present they are either single, dome shaped or numerous, small and rounded on each cell. The stomata are usually oval, anomocytic, rarely paracytic, irregularly distributed and oriented. Sometimes, they are also rounded to semi-circular in shape and distributed in longitudinal rows (in case of monocot family). The guard cells are usually superficial, sometimes thickened, and with distinct 'T' pieces at poles. Stomatal index varies between 1.2–31. The subsidiary cells are unspecialised.

Cuticular characters like shape and size of cells, straight, arched and sinuous lateral walls, types of papillae on surface walls, stomatal size, type of stomata (whether anomocytic or paracytic), distribution and frequency, presence of trichomes and their organization and type of subsidiary cells are useful diagnostic characters which are often considered of great taxonomic importance. All these characters are genetically controlled (Stace, 1965). However, some epidermal characters are of eminent ecological significance, for example, large epidermal cells are found in leaves of humid and shaded conditions (Yapp, 1912; Salisbury, 1927; Watson, 1942) and reduced cell size is characteristic of dry conditions (Odell, 1932).

Similarly, thick cuticle, sunken stomata with raised lobes over arching the suprastomatal cavity, high frequency of stomata, straight cell walls, high trichome density, sunken guard cells, rough surface walls, strong papillae and distinct papillate subsidiary cells with papillae over arching stomata are important xeromorphic characters. These features provide protection against water loss and are particularly efficient in assisting water movement, when there is an adequate supply. The rough surface assists reflection and scattering of light and heat and helps the plants from overheating. On the contrary, characters like thin cuticle, undulate cell walls, smooth surface walls, fewer epidermal hairs, superficial, large stomata and unspecialised subsidiary cells are mesomorphic characters found on leaves which grow in moderate and humid habitats (Stace, 1965; Cutler, 1982).

The cuticular characters observed in the present study are clearly indicative of moderate ecological conditions, since they reflect both humid and dry climate, e.g., thin cuticle,

undulate to sinuous lateral walls, non-papillate or smooth surface walls, fewer epidermal hairs, normal stomata and unspecialised subsidiary cells indicate tropical conditions with sufficient rainfall. Hypostomtic nature too, reflects heavy precipitation, humidity and shade. However, some cuticular pieces show xeric characters like straight anticlinal walls, papillate surface walls and high frequency of stomata. Presence of both xeric and mesic characters in some plants indicates intermediate habitat, i.e., plants grew under both exposed and humid conditions. Such a condition may also reflect on the capability of plants to adapt during unfavourable climate.

DEGRADATIONAL CHARACTERISTICS

Plant cuticles and wood fragments preserve several anatomical features characteristic of the nature and habitat of parent plants. The degradation of cuticles at various stages indicates the effect of environmental factors and their relationship with other organic remains present in the sediments.

Broadly, three types of degradational agencies exist, namely, physical, chemical and biological.

(i) Physical

The organic matter is degraded physically during its transport to depositional sites and abrasion due to clastic material. The degree of mechanical degradation is proportional to the distance travelled and energy of the agency of transport. Physical degradation causes tearing, fracture abrasion and breakage of larger particles in small pieces.

(ii) Chemical

The breakage, pitting and dissolution of cellular parts observed on epidermal surfaces are apparently caused by the chemical precipitation of salts, calcite, dolomite and formation of pyrite etc. The physical or chemical reaction may also occur between portions of the cell walls and the adjacent peat fluids resulting in precipitation, impregnation, dissolution, etc. (Cohen & Spackman, 1980).

PLATE 3



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|-------|---|-------|---|
| 1. | Highly biodegraded organic matter with black debris and terminal zoosporangium with hyphae. Slide no. 12452, H 31. x 100. | 6. | Biodegraded terrestrial organic matter with net like structures of septate dark hyphae. Slide no. BSIP 12452, H 43 x 500. |
| 2, 3. | Biodegraded organic matter showing fungal fruiting bodies and hyphae. Slide no. BSIP 12452, Q 32 x 400, x 250. | 7. | Leaf tissue showing <i>Meliolinites</i> sp. with fruiting bodies. Slide no. BSIP 12455, Q 20 x 250. |
| 4. | Biodegraded matter showing fruiting bodies (<i>Notothyrites</i> sp.), ascomata and hyphae embedded in the cells disrupting the tissues. Slide no. BSIP 12452, H 43. x 500. | 8, 9. | Infected wood fragment showing net like structure of hyphae and fruiting bodies. Slide nos. 12452, R 27. x 250. |
| 5. | Leaf surface showing hyphae net. Slide no. BSIP 12452, H 43 x 500. | 10. | Showing biodegraded stomata and accessory cells. Slide no. BSIP 12454, K 51. 150. |

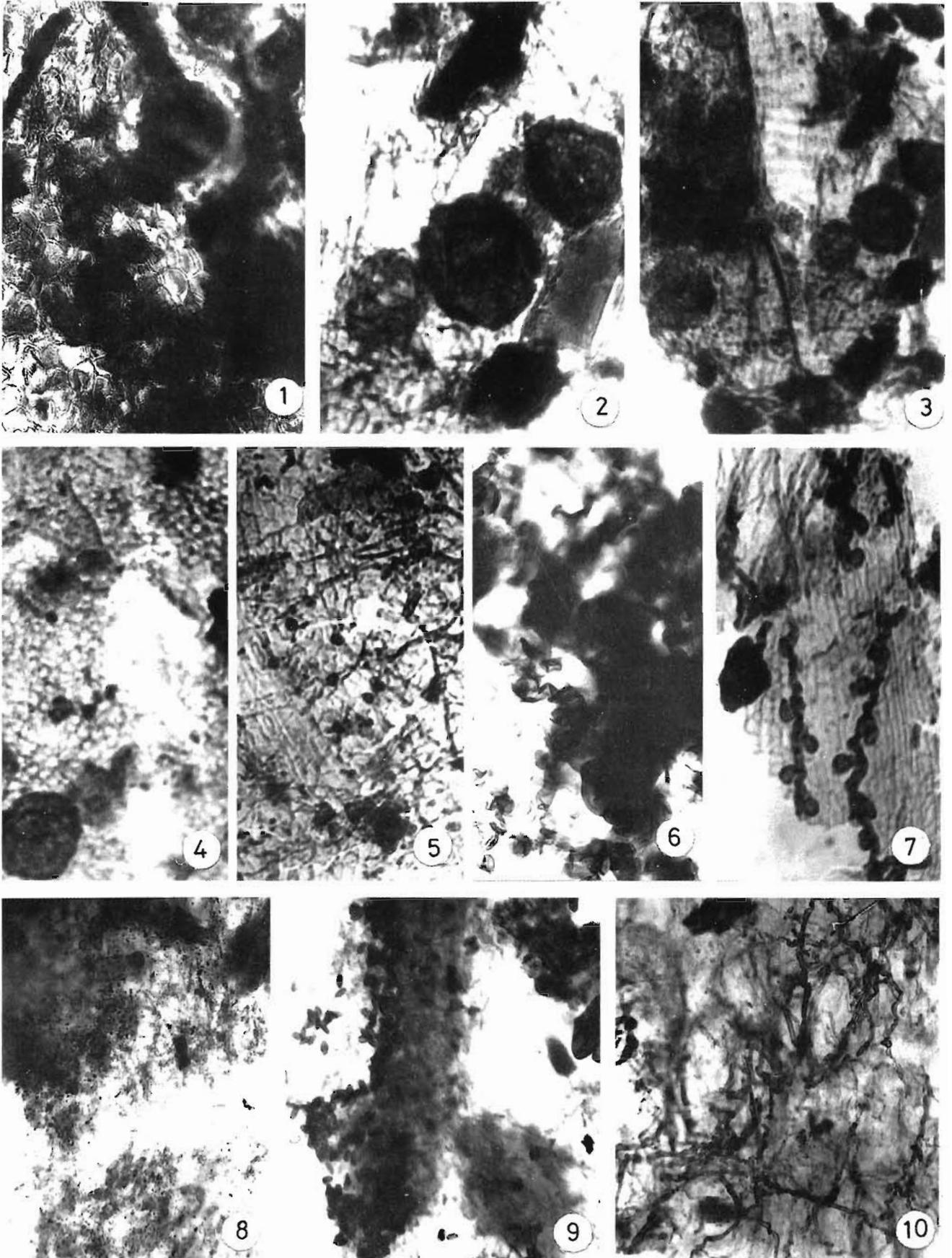


PLATE 3

Cuticle	Nature of cells	Nature of anticlinal walls	Nature of surface walls	Type of stomata	Size of stomatal apparatus	Guard cells	Size of stomatal slit	Stomatal Index	Subsidiary cells	Probable affinity
Type I A	Isodiametric cells, undifferentiated into vein and mesh areas; size of cells of upper surface 24-33 x 15-21 µm; size of cells of lower surface 12-33 x 9-21 µm	Straight; 1.5-6 µm wide	Non-papillate	Large, anomocytic, irregularly distributed and oriented	33-51 x 33-48 µm	Superficial 33-51 x 9-12 µm in size; width of guard cell wall 9 µm	24-33 x 3-9 µm	1-2-3-8	Indistinct	Family Lauraceae (Dilcher, 1963, 1974; Giessen, 1971)
Type I B Pl. 2.3	Narrow, elongate, polygonal to rectangular cells, undifferentiated into vein and mesh areas; size of cells 24-30 x 6-7.5 µm	Straight, 1 µm wide	Non-papillate	Oval, paracytic, irregularly distributed and oriented	30-36 x 12-15 µm	Thickened guard cells with distinct 'T' pieces at poles; 30-36 x 3-6 µm in size	15-27 x 9-10-5 µm	13	2, parallel to guard cells	Family Lauraceae (Dilcher, 1974)
Type I C Pl. 1.3, 5	Cells divided into vein and mesh areas, cells over to polygonal, irregularly arranged. 12-33 x 9-24 µm in size; cells over vein areas rectangular to elongate, polygonal and arranged end to end in rows, 18-42 x 6-15 µm in size	Undulate to arched, 3 µm wide	Rarely papillate, papillae dome-shaped, each cell with a single papilla, 6-7.5 µm long, 4-5 to 6 µm wide at base, 3 µm wide at apex	Oval to round, anomocytic, irregularly distributed and oriented	18-39 x 15-30 µm	Thickened guard cells with distinct 'T' pieces at poles; 18-39 x 6-9 µm; width of guard cell wall 3 µm	9-30 x 3-9 µm	2-6-14	5-6 in number, like other epidermal cells	Family Lauraceae (Dilcher, 1963)
Type I D Pl. 2.5	Cells undifferentiated into vein and mesh areas; elongate, rectangular, hexagonal, pentagonal, arranged irregularly; size 15-30 x 15-21 µm	Straight to undulate, 3 µm wide, undulations 'U' and 'V'-shaped	Non-papillate, sometimes trichome bases measuring 15-48 x 18-39 µm in size are present	Oval to elliptic; anomocytic; irregularly distributed and oriented	24-27 x 27-30 µm	Superficial 24-27 x 12-15 µm; width of guard cell wall 3 µm	12-15 x 4-5-18-5 µm	13	5 in number, like other epidermal cells	Family Lauraceae (Dilcher, 1963, 1974)
Type I E Pl. 1.6 Pl. 2.1, 2	Cells undifferentiated into vein and mesh areas;	Sinuuous, 3 µm wide,	Surface wall with numerous,	Semi-circular to oval;	21-24 x 15-21 µm	With laminar thickening and	12 x 3-6 µm	18	5 to 7 in number, like	i) Family Lauracea

	rectanguloid to polygonal, arranged irregularly; 15-36 x 15-24 μm in size	sinuosities 'U' and 'V' shaped	small rounded structures (papilla)	anomocytic, irregularly distributed and oriented	30-39 x 27-42 μm	sometimes with distinct 'T' pieces at poles; 21-24 x 6-9 μm in size, width of guard cell wall 3 μm	other epidermal cells	(Litke, 1968) (ii) Family Magnolia- ceae, (Baranova, 1972)
Type II Pl. 1.2, 4, 8	Cells undifferentiated, tetragonal, pentagonal, hexagonal, polygonal, irregularly arranged, measure 27-39 x 27 μm in size	Straight to arched, 4-5-7.5 μm wide	With thickened areas, non papillate	Biconvex, paracytic, irregularly distributed and oriented	30-39 x 27-42 μm	Superficial, 27-33 x 3 μm 30-39 x 9 μm , width of guard cell wall 3-4.5 μm	Family Loranthaceae (Peters, 1963)	
Type III	Cells differentiated into vein and mesh areas, cells over mesh areas irregular, rectanguloid to polygonal, arranged irregularly, measure 12-30 x 9-21 μm in size; cells over vein areas elongate, polygonal, arranged end to end in rows, 15-33 x 12-15 μm in size	Straight to undulate, 1.5 μm wide	Non-papillate with thin areas	Squarish to irregular, anomocytic, irregularly distributed and oriented	13.5-18 x 12-18 μm	Indistinct 3-9 x 3-4.5 μm	5 in number, similar to other epidermal cells	Family Myrtaceae (Bandulska, 1931)
Type IV Pl. 1.7 Pl. 2.8	Cells undifferentiated, rectanguloid to polygonal, arranged irregularly, measure 30-60 x 18-39 μm in size	Deeply sinuous, sinuosities 'U' shaped, numerous, small knobbed thickenings, measuring 3 μm in diameter present on cell walls	Non-papillate	Round to oval, paracytic, irregularly distributed and oriented	30-33 x 24-27 μm	Thickened, 15 x 9 μm 30-33 x 6-9 μm in size, width of guard cell wall 6 μm	2, parallel to guard cells	Family Caesalpiniaceae (Peters, 1963)

Type V	Cells undifferentiated, irregular, rectangular to polygonal, arranged irregularly, 18-45 x 12-18 μ m	Sinuuous to undulate, sinuositities 'U' & 'Y' shaped, 3 μ m wide	With thickened area	Elliptic to oval in shape, paracytic, appear rectangular together with subsidiary cells, irregularly distributed and oriented	21-24 x 18-21 μ m	Superficial, 21-24 x 6-9 μ m, width of guard cell wall 3 μ m	18 x 3 μ m	31	2, parallel to guard cells	Family Symplocaceae (Litke, 1968)
Type VI Pl. 1.1	Upper and lower surfaces present, hypostomatic, cells of upper surface undifferentiated, isodiametric to rectangular, polygonal, arranged irregularly, 24-33 x 15-21 μ m; cells of lower surface undifferentiated, isodiametric to polygonal, arranged irregularly, measure 12-24 x 12-18 μ m in size	Straight, 3 μ m wide	Upper surface papillate, with numerous, rounded knobs (papillae); lower surface non-papillate, attacked by fungal spores	Large, oval, irregularly distributed and oriented	33-51 x 36-48 μ m	Superficial, 33-45 x 9-10 μ m	24-27 x 9 μ m	4	Indistinct	Family Moraceae (Peters, 1963)
Type VII Pl. 1.9	Cell outlines not clear	Papillate, papillae biconvex, arranged in longitudinal row, orientation of papillae straight, parallel to cell surface, measure 6-7.5 x 3-4.5 μ m in size	Large, oval, longitudinally distributed and oriented							Family Dioscoreaceae (Peters, 1963)

Fig. 2—Epidermal characters of dispersed cuticles recovered from Sindhudurg Formation, Amberiwadi and their affinities.

(iii) Biological

The microorganisms play a critical role in the degradation of cuticular pieces in the aerial, sub-aerial and under water conditions. These organisms (fungi & bacteria) affect plant tissues and change them from structured tissues to non-structured amorphous. The fungi and bacteria grow quickly in aerobic conditions. During the initial burial stages the meshes of fungal hyphae spread over the cuticles (Pl. 3.1, 4, 6) and enter the spongy mesophyll and palisade layers through stomatal slit (Pl. 3.1). They start degrading entire leaf parts and cuticular layer. Apparently, they reproduce here and convert these tissues in to an amorphous structureless mass (Pl. 3.3). This is evident by the presence of several fruiting bodies, which are found embedded in the biodegraded tissues of leaf and wood fragments (Pl. 3.2, 3, 5, 7 & 8-10). Later, when oxygen supply becomes limited or is exhausted, anaerobic bacteria (Demaison & Moore, 1980) continue the degradation process.

The bacteria present on outer cell membrane accelerate exchange of cellular substances across this membrane. This, in turn, enhances degradation of cell membrane. It can also be presumed that a considerable amount of metabolic activities accelerated the process. During metabolism the complex biopolymers, e.g., cellulose, lignin, proteins, lipids and carbohydrates which are present mostly in leaves, stems, and roots, transform into monomers such as amino acids, fatty acids and some inorganic compounds. These compounds are finally transformed into geopolymers such as fulvic and humic acids during the process of peat formation (Berner, 1980).

PALAEOVEGETATION

Amberiwadi lignitic clay contains rich cuticles and woody fragments. Leaf fragments occurring here are probably the part of accumulated litter formed by falling of leaves. The woody fragments are the part of stems that were broken from the tree and transported to a nearby depositional site. These entities suggest an autochthonous accumulation of vegetal matter, which yields information on plant types and palaeovegetation in the area prior to deposition. The plants of families Lauraceae, Moraceae and Myrtaceae, Caesalpiniaceae are woody trees, while Loranthaceae, Symplocaceae and Magnoliaceae are represented by trees/shrubs. The only monocot family Dioscoreaceae identified here is a climber in nature. The plants of these families widely occur in tropics and subtropics to warm temperate areas (Cullen, 1997). Saxena (1995), Saxena and Misra (1990) and Saxena *et al.* (1992) recorded palynofossils of 25 angiosperm families from Sindhudurg Formation, of which 14 families were of tropical to subtropical region and others of cosmopolitan habitat.

DEPOSITIONAL ENVIRONMENT AND DIAGENESIS OF ORGANIC MATTER

The cuticles and other types of dispersed organic matter recovered from Sindhudurg Formation, Amberiwadi show affinities with the plants growing along the Maharashtra Coast. The basin appears to be a brackish water body within access to sea as well as to fresh water. Small streams contributed fine clastic sediments with silty clayey material. These streams also brought large quantity of abscised leaves from vegetation growing around the basin. A number of woody fragments, biodegraded and amorphous organic matter observed at the base of the section indicates that this layer was formed at near shore region. A few marine dinoflagellate cysts (Dr MR Rao, personal communication) and algal colony (Pl. 2.4) have also been recorded in this section which further affirms the marine influence.

The channel connected with the depositional area was affected by the cyclic tidal influx of brackish water from Arabian sea. During the deposition of middle layer, foliage from the nearest forested area was transported to the depositional site along with fine argillaceous matter. Thus, due to short transport the plant fragments were often preserved in their original form. This indicates that the swamp area was subjected to periodic overflows and occasional dewatering which reduced the size of humic detritus and also allowed less biodegradation of plant material in comparison to that of basal part. The leaf fragments present in this sequence reveal exclusive dominance of angiospermic remains. It suggests that the incursion of forest litter was higher than the material brought by the other sources to the depositional site. This resulted in the formation of lignitic clay deposit of Amberiwadi, Maharashtra Coast. However, the nature (lensoid shape) of lignitic clay bed shows that the deposition seems to have taken place in a shallow depression located close to the shoreline. Further the thickness and lateral extent of the lignitic clay indicates that the sedimentation could not have continued for a long time. Probably, the basin became shallower and shallower due to the regional uplift of the western coastal margin of India. Saxena (1995) and Saxena *et al.* (1992) suggested that the substrate was not much wet for a longer time or may be seasonally flooded here.

The cuticles of some plants of Lauraceae, Myrtaceae and Moraceae are apparently more resistant to degradation than the plants of other families probably because of the richness of biopolymers in their cellular parts. Chemically, the cuticles of higher plants are heterogeneous in nature. They consist of wax fraction, soluble in common organic solvents and an insoluble cuticular matrix forming the framework of the cuticle. Two biopolymers viz., cutin and cutan exhibit different behaviour when subjected to degradation processes that affect during diagenesis. They show resistance against fungal and

bacterial decays (Tagelaar *et al.*, 1991). Cutin is an insoluble lipid polyester and is a main constituent of cuticular membrane associated with protective covering of aerial parts of leaves, fruits and non woody stems (Holloway, 1982). The plants of Lauraceae and Myrtaceae contain aromatic oil-glands, whereas, milky juice is found in the plants of Moraceae (Hutchinson, 1973; Cullen, 1997). The cuticles of these plants are preserved with original features which indicates that the aromatic compounds and milky sap make epidermal tissues more resistant to decay.

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