Pollen tetrads from Palaeocene sediments of Meghalaya, India : Comments on their morphology, botanical affinity and geological records

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Kumar M 1995. Pollen tetrads from Palaeocene sediments of Meghalaya, India : Comments on their morphology, botanical affinity and geological records. *Palaeobotanist* **43**(1) : 68-81.

The pollen tetrads of *Kielmeyerapollenites, Droserapollis, Ericipites* and two new genera, viz., *Nepenthidites* and *Pilatetradites* are studied under light and scanning electron microscopes. Each genus is tetrahedral, isodiametric and their size is relatively proportional with the size of individual grains in a tetrad. Their exine sculpture reflects that the ektexinal extension between two grains is a persistent character which plays an important role in the stability of the tetrad. Their morphological similarity with extant taxa provides additional information on symmetry, mechanism of tetrad cohesion and botanical affinities.

Key-words— Palynology, Pollen tetrads, Morphology, Palaeocene, Meghalaya (India).

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साराँश

भारत में मेघालय के पुरानूतन अवसादों से परागकण-चतुष्क : इनकी आकारिकी, वनस्पतिक सजातीयता एवं भूवैज्ञानिक अभिलेखों पर टिप्पणी

माधव कुमार

कीलमियॅरापोलिनाइटिस, ड्रोसेरापॉलिस, एरिसिपाइटिस एवं दो नई प्रजातियों – *नीपेन्थिडाइटिस* एवं *पाइलाटेट्राडाइटिस* के परागकण-चतुष्कों का प्रकाश सूक्ष्मदर्शी एवं क्रमवीक्षण सूक्ष्मदर्शी द्वारा अध्ययन किया गया है। इन सभी के बाह्यचोल के अलंकरण से इंगित होता है कि दो अवयवों के मध्य एक्टेक्साइनल विस्तार एक ऐसा स्थायी लक्षण है जिसके कारण चतुष्कों में पारस्परिक दृढ़ता बनी रहती है। वर्तमान वर्गकों से आकारिकीय समानता के कारण इनके विषय में और अधिक महत्वपूर्ण जानकारी उपलब्ध हुई है।

TETRADS are the compound pollen grains predominantly found in angiosperms. About 55 families of angiosperms bear such types of pollen grains (Erdtman, 1945, 1969). Generally primitive angiosperms bear tetragonal tetrads, while very few bear tetrahedral and linear types in advanced angiosperms.

The brief description and character evaluation of five taxa, viz., *Kielmeyerapollenites, Droserapollis, Ericipites, Nepanthidites* and *Pilatetradites,* which are very common in a palynoassemblage of Lakadong Sandstone (Palaeocene) of Meghalaya, have been given to ascertain their morphological similarity and botanical affinity with extant pollen tetrads. The mechanism of arrangement of individual grains in a tetrad, both in fossil and extant grains, provides a reliable source of phylogenetic relationship.

Baksi and Deb (1976) reported tetrad pollen of *Mulleripollis* from the Upper Cretaceous of Bengal Basin. Baksi (1962) also recorded *Tetradopites* from Simsong River, Assam. From the Palaeocene sediments of Meghalaya, Dutta and Sah (1970) and Kar and Kumar (1986) reported *Droseridites, Ericipites* and *Kielmeyerapollenites*. Sah and Kar (1974) recorded *Kielmeyerapollenites* from Palana lignite (Eocene), Rajasthan and Kar (1985) described *Spinulotetradites* from Kutch, western India. Ramanujam (1966) and Rao and Ramanujam (1982) recovered *Ericipites, Droseridites* and *Ornatetradites* from the Miocene sediments of south India.

In the tetrads of *Kielmeyerapollenites*, *Ericipites* and *Pilatetradites*, individual grains are joined through tricolpate or tricolporate apertures as well as with ektexinal connections. In *Droserapollis* (Krutzsch, 1970), apertures occur at proximal pole, while four grains of a tetrad are connected together by the proximal exine and cross walls between cycloidly arranged pores. These connections are mostly lead by the bridges or ektexinal linkage between the adjacent grains, which provide a compact stable shape to the tetrad. Therefore, the tetrad stability in these genera exhibits a kind of qualitative evolution. Similar features are also encountered in the pollen tetrads of extant genera, viz., *Kielmeyera, Drosera, Erica, Nepenthes* and *Rhododendron*.

MATERIAL AND METHODS

The palynological samples for the present study were collected from Laitryngew coal seams (Palaeocene), Khasi Hills, Meghalaya. The coal and shale samples were treated with 40 per cent nitric acid for a week and then with 10 per cent potasium hydroxide solution for 5-10 minutes. The pollen were collected using 400 mesh sieve. The polleniferous materials of extant pollen were acetolysed following the method of Erdtman (1962). For light microscope observations, the pollen preparations were smeared on glass coverslips with polyvinyl alcohol and mounted in canada balsam. For SEM observations these pollen specimens were collected on glass pellets attached on aluminium stubs and sputter coated with gold/palladium alloy. The pollen were photographed with ORWO NP 22 (35 mm) film using Philips 505 SEM instrument. The slides of fossil pollen grains are housed in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow. The terminology of Erdtman (1959), Kremp (1965) and Faegri and Iversen (1989) has been followed to describe the pollen morphology.

POLLEN MORPHOLOGY

Genus — *Kielmeyerapollenites* Sah & Kar 1974

Type species — *Kielmeyerapollenites eocenicus* Sah & Kar 1974.

Kielmeyerapollenites syncolporatus Kar & Kumar 1986

Shape and size —Pollen grains arranged in tetrahedral tetrads, triangular-subtriangular. Tetrads range between 70-85 x 80-96 μm, individual grains subtriangular-triangular, 28-35 x 40-50 μm.

Exine and surface sculpture :

Light microscope — Exine 2.0-3.5 μm thick, tectate, retipilate-retibaculate, lumina 1-2 μm in diameter, muri 1-2 μm thick (Pl.1, figs 8-10).

Scanning electron microscope — Exine coarsely reticulate, lumina circular-elongated; muri forms dentate-like bridges between two grains, thick around colpi margins (Pl. 1, figs 1-3).

Apertural complex and tetrad configuration — Aperture tricolpate or tricolporate, colpi 14-18 μm long, extended up to the poles. The tetrads show cohesion between proximal exine of adjoining grains with some common ridges formed by extension of muri. The aperture of neighbouring grains aligned in accordance with Fischer's law.

The morphology of pollen tetrads of following two extant taxa, viz., *Kielmeyera angustifolia* and *K. tomentosa* have been studied and it has been observed that the extant species show close similarity in tetrad configuration with fossil tetrad pollen of *Kielmeyera*.

Genus —*Kielmeyera* Mart.

Kielmeyera angustifolia Pohl.

Shape and size— Pollen tetrads subtriangular-triangular, 55-80 x 45-60 μm; each grain subcircular to subtriangular, 30-40 μm.

Exine structure and sculpture :

Light microscope — Exine 2-3 μm thick, tectate, punctate to microreticulate or retiverrucate (Pl. 2, fig. 9).

Scanning electron microscope — Exine coarsely reticulate with verrucae; verrucae of two adjacent grains merge at the contact. Interverrucae spaces granulate-microreticulate. Muri thick around colpus margins (Pl. 3, figs 1, 4, 6, 8-10).

Apertural complex and tetrad configuration — Individual grains tricolporate, colpus 12-18 µm long with thickened margin, colpi of two adjacent grains merged and appear like single colpus. Pore circular to oval, 6-10 µm in diameter, equatorially elongated and wider than colpi. Pores of two adjacent grains in united colpi are separated by a ridge. The apertures meet with two and two at six points according to Fischer's law. The extension of verrucae forms the ektexinal bridges between two grains.

Kielmeyera tomentosa Cambess

Shape and size — Pollen tetrad triangular-subtriangular, 55-75 µm; individual grains subcircular, 30 x 45 µm.

Exine and surface sculpture :

Light microscope — Exine 2.5-3 µm thick, tectate, microreticulate to retibaculate, baculae 1.0-1.5 µm high; colpi elongated, pore margin thickened, lalongate.

Scanning electron microscope — Exine reticulate, muri 1.5-2.5 µm thick, smooth lumina of various shapes, smaller near colpi margins. The contact area of two grains are ridged due to fusion of extended muri (Pl. 3, figs 2, 3, 5, 7).

Apertural complex and tetrad configuration — These features are very similar with *K. angustifolia.* Colpi 10-12 µm long; pores about 10 µm in diameter, oval to elliptical.

Remarks — The bridge connections in *Kielmeyera tomentosa* are comparatively less as compared to *K. angustifolia*. However, *Kielmeyerapollenites syncolporatus* Sah & Kar 1974 consists of similar type of bridge connections as observed in *K. angustifolia*.

Genus — *Droserapollis* Krutzsch 1970

Type species — *Droserapollis lusaticus* Krutzsch 1970.

Droserapollis khasiensis sp. nov.

Holotype — Pl. 2, fig.1; Slide no. BSIP 9423.

Paratype — Pl. 2, fig. 2; Slide no. BSIP 9430.

Basionym — *Droseridites* sp. Kar & Kumar 1986, pl. 11, fig. 6.

Type locality — Laitryngew Coalfield, Lakadong Sandstone (Palaeocene), Khasi Hills, Meghalaya.

Specific diagnosis — Pollen grains in tetrahedral tetrads, size 55-75 µm; spinulate, spinules 2-2.5 µm long. Polyporate, pores cycloidly arranged in each grain, 7-10 in number, pores open between two grains with surrounding radial plates.

Comparison — The species differ with other spinulate tetrads by its cycloidly arranged aperture and comparatively bigger size.

Remarks — The name of the species is derived by its occurrence in the Palaeocene sediments in Khasi Hills, Meghalaya.

Droserapollis khasiensis sp. nov.

Shape and size — Pollen grains in tetrahedral tetrads, subcircular-rhomboidal, 55-60 x 65-75 µm; individual grains subcircular-subtriangular, 30-35 µm in diameter (excluding processes).

Exine structure and sculpture :

Light microscope — Exine tectate, less than 1 µm thick; spinulate, spinules up to 2.5 µm long, wide at the base. Interspinular spaces laevigate (Pl. 2, figs 1-3).

PLATE 1 →

1. *Kielmeyerapollenites syncolporatus* Kar & Kumar showing tetrahedral tetrad and interconnecting bridges between two grains (SEM x 1200).
2. Enlargement (SEM photograph x 1850) of fig.1 showing details of cohesion between grains.
3. Attachment of grains in polar area (SEM x 2000).
4. *Ericipites laevigatus* sp. nov. (SEM x 1850).
5. Enlargement of fig. 4 showing junction of colpi and a ridge between two united pores (SEM x 3500).
6. *Droserapollis khasiensis* sp. nov. showing tetrahedral tetrad and opening of pore channels between two grains (SEM x 1000).
7. *Ericipites laevigatus* (x 1000), Slide no. BSIP 11012.

8, 9. *K. syncolporatus* showing microreticulate ornamentation (x 1000), Slide no. BSIP 11013.

10. Enlargement of fig. 8 (x 2000).

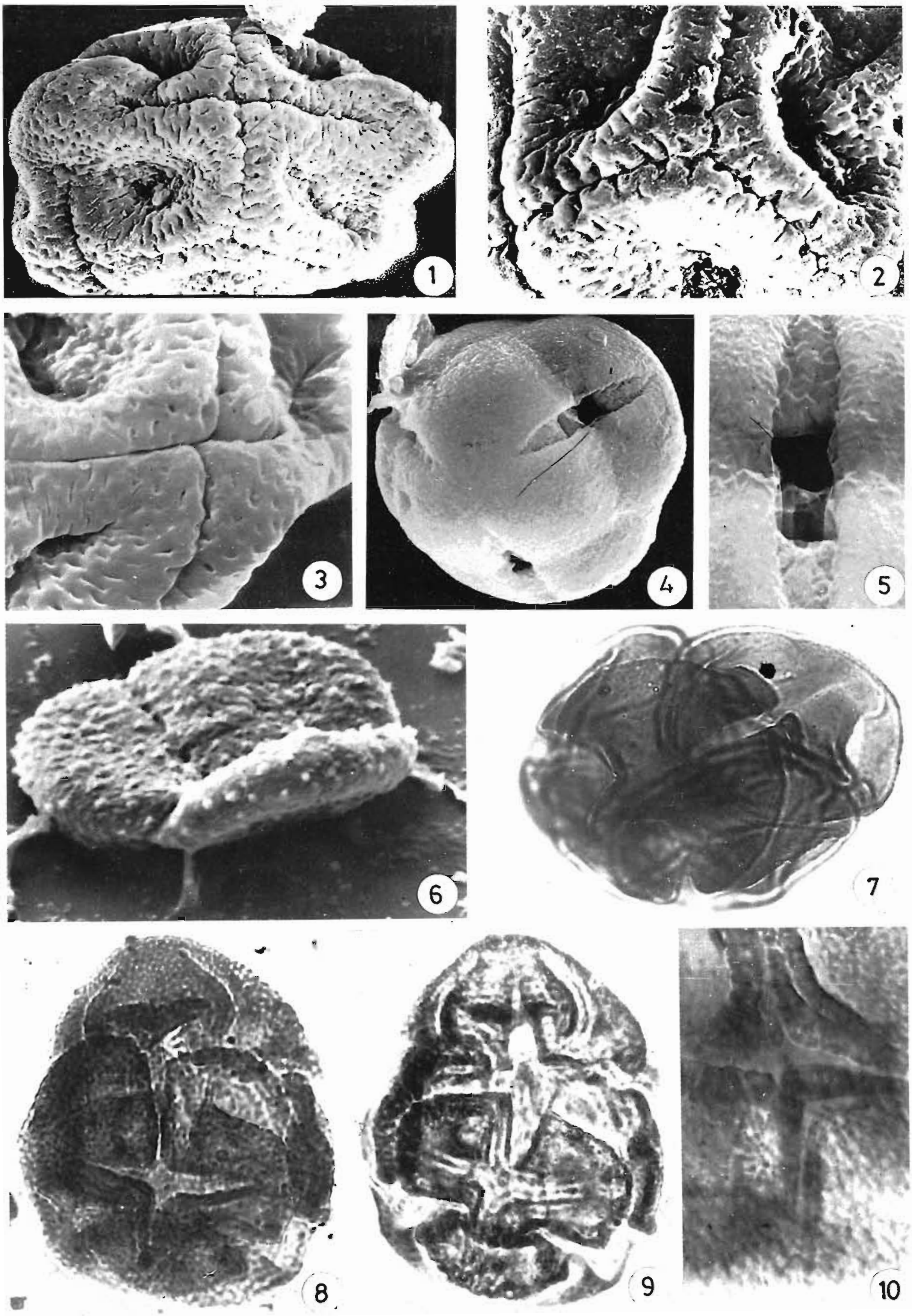

PLATE 1

Scanning electron microscope — Exine spinulate, spinule tips blunt, interspinular spaces microgranulate. Pore channels open between the junction of two grains (Pl. 1, fig. 6).

Aperture complex and tetrad configuration — Each grain in a tetrad is polyporate, provided with more than seven cycloidly arranged circular to oval pores; pores 3.5 -5.0 µm in diameter and surrounded by radial plates. The pores of two adjacent grains separated by a cross wall and open in a channel.

To find out the close similarity between the extant and extinct species, following one extant species *Drosera burmanii* has been studied in detail. This species closely resembles the fossil species.

Genus — *Drosera* Linn.

Drosera burmanii Vahl.

Shape and size — Pollen grains in tetrahedral tetrads, rhomboidal, subcircular-subtriangular, 55-60 x 65-75 µm; grains subcircular, 40 x 50 µm (excluding processes).

Exine structure and sculpture :

Light microscope — Exine 1.5-2.0 µm thick, spinulate, spinules 3-4 µm long, foot layer of the sexine bears spinules.

Scanning electron microscope — Spinules pointed, wider at the base, densely placed, interspinular spaces microgranulate. Pores proximally situated with channel opening between two grains (Pl. 4, figs 2, 4).

Aperture complex and tetrad configuration — Each grain of the tetrad possesses cycloidly arranged more than seven pores situated opposite to cross walls. Two grains of a tetrad occur with simple cohesion. At the contact points the exine of these two grains are united to form connective bridges. Cross wall and channel openings are more distinct.

Genus — *Nepenthidites* gen. nov.

Type species — *Nepenthidites laitryngewensis* gen. et sp. nov.

Holotype — Pl. 2, fig. 7; Slide no. BSIP 9431.

Type locality — Laitryngew Coalfield, Lakadong Sandstone (Palaeocene), Khasi Hills, Meghalaya.

Basionym — Kar & Kumar, 1986; pl. 11, figs 2,5.

Junior synonyms :

1970 *D. parvus* Dutta & Sah 1970; pl. 7, figs 6-8.

1986 *Droseridites major* (Krutzsch) Kar & Kumar; pl. 11, figs 2, 5.

Generic diagnosis — Pollen grains in tetrahedral tetrads, 60-70 µm, subtriangular. Individual grains subtriangular-subcircular, 40-50 µm, inaperturate. Exine spinulate, spinules up to 2 µm long, interspinular area microreticulate.

Comparison — *Nepenthidites* may be compared with *Droseridites* Cookson 1947. The type species *Droseridites spinosa* is an inaperturate pollen grain. Potonié (1960, syn. III, p. 139) tagged this species with *Drosera peltata*. Takahasi and Sohma (1982) and Chanda (1965) explained that the grains of *D. peltata* (Smith) are aperturate and possess 13-16 channel opening. *Droserapollis* (Krutzsch, 1970) possesses multi-cycloporate grains, while *Droserapites* (Huang, 1978) shows densely clavate and baculate processes with reticulate sexine. The genus *Ornatetradites* (Rao & Ramanujam, 1982) is clavate-gemmate or verrucate with 4-8 pores. *Spinulotetradites* (Kar, 1985) has tricolporate-tricolporoidate grains. *Inaperturotetradites* (van-Hoeken- Klinkenberg, 1964) is inaperturate with microreticulate sculpture.

The name of the species is derived by its occur-

PLATE 2 →

(All photographs are magnified ca. x 750, unless otherwise mentioned)

1.2. *Droserapollis khasiensis* sp. nov., Slide nos. BSIP 9434, 9430.
3. *D. khasiensis* showing cycloid arrangement of pores in individual grain (in interference contrast). Slide no. BSIP 110.11.
4. *Rhododendron lepidotum*. Slide no. BSIP 1931 (Herbarium).
5.6. *R. lepidotum* in different focii of fig. 4.
7. *Nepenthidites laitryngewensis* sp. nov., pollen tetrad showing microreticulate exine between spinules, Slide no. BSIP 9431.
8. *Pilatetradites meghalayensis* sp. nov., Slide no. BSIP 9398.
9. Tetrahedral pollen tetrad of *K. angustifolia*.
10. Enlargement of fig. 4 in different focii showing union of two colpi and retipilate exine (x 1500).
11 Enlargement of fig. 8 (x 1500).
12. Pollen tetrad of *Erica arborea*.

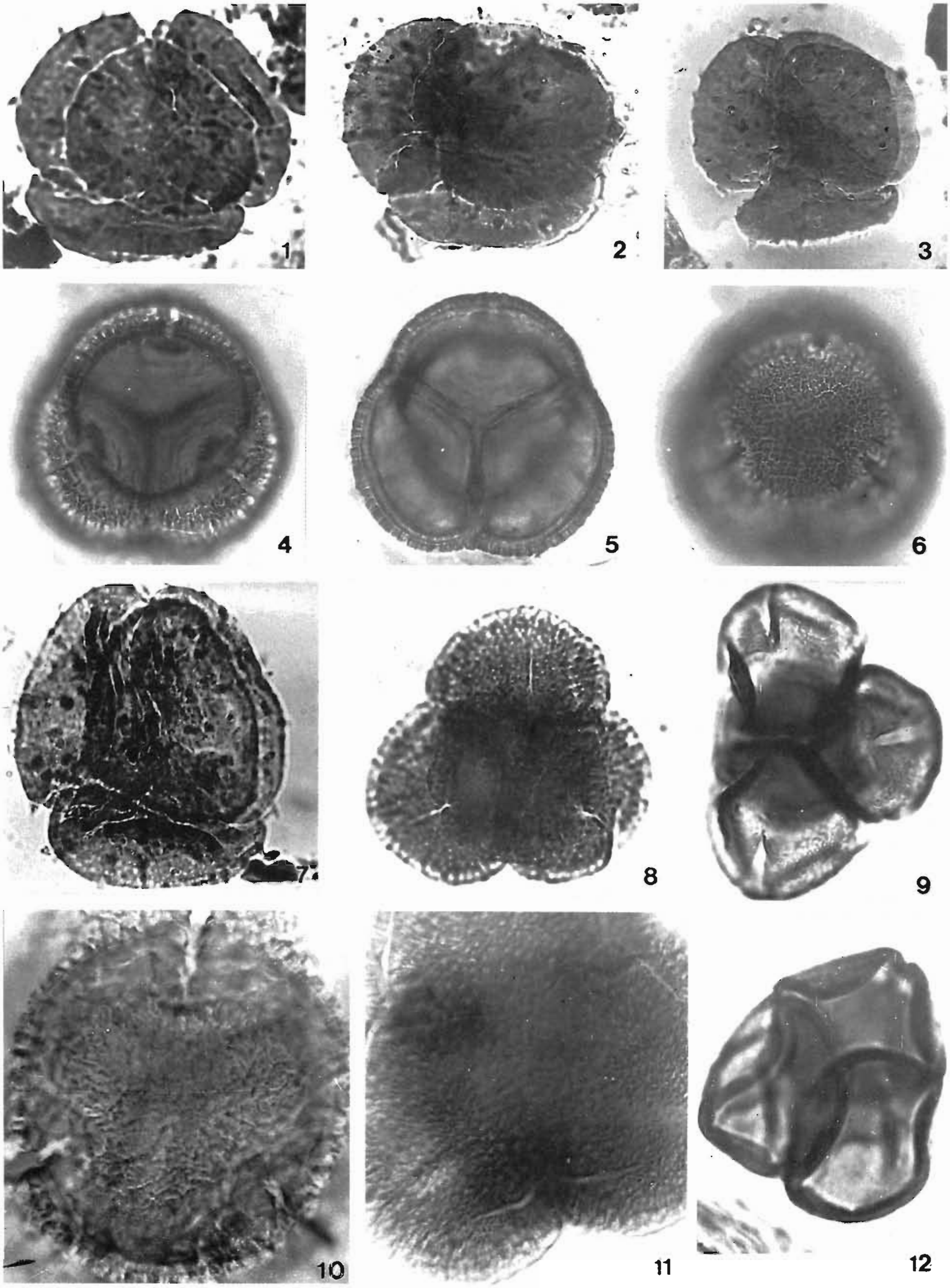

PLATE 2

rence in Laitryngew Coalfield, Khasi Hills, Meghalaya.

Remarks — *Droseridites parvus* Dutta & Sah 1970 (Pl. 7, figs 6-8) and *D. major* (Krutzsch) Kar & Kumar 1986 (Pl. 11, figs 2, 5) are inaperturate spinulate tetrads and differ from the pollen tetrads of *Drosera*. *Nepenthidites laitryngewensis* is a tetrahedral tetrad pollen with no aperture and shows close affinity with extant pollen tetrad of *Nepenthes khasiana* Hooker.

Nepenthidites laitryngewensis sp. nov.

Specific diagnosis — Pollen grains in tetrahedral tetrads, subtriangular-subcircular, size 60-70 μm. Inaperturate; exine up to 1 μm thick, spinulate, spinules 2 μm long. Interspinal spaces laevigate to microgranulate.

Shape and size — Pollen grains in tetrahedral tetrads, subtriangular-subcircular in shape, 60-70 μm; individual grains subtriangular, 40-50 μm.

Exine structure and sculpture:

Light microscope — Exine up to 1.5 μm thick; spinulate, spinules 1.5 μm long, sparsely placed, interspinular sexine weakly microreticulate to microgranulate (Pl. 2, fig. 7).

Tetrad configuration — The tetrad shows simple type of cohesion. Individual grains are inaperturate, each grain has three proximal flattened faces where one face of a grain is fused with other at few places by extension of sexine at the equatorial plane.

One species of modern *Nepenthes khasiana* Hook. has been studied in detail to compare the morphological features.

Genus — *Nepenthes* Linn.

Nepenthes khasiana Hook.

Shape and size — Pollen grains tetrahedral tetrads, subtriangular-subcircular, 20-30 μm; individual grains inaperturate, subtriangular, 17-25 μm in diameter.

Exine structure and sculpture :

Light microscope — Exine up to 1 μm thick, spinulate, spinules 1-1.5 μm long.

Scanning electron microscope — Interspinular spaces laevigate, spinules tip blunt; grains show simple cohesion in proximal basal layer (Pl. 4, figs 5, 7).

Tetrad configuration — The grains in a tetrad are attached together by the fusion of sexine. No pore channels are developed in between the contact area of grains. Sexine very thin at the contact regions, while intine is indistinct.

Remarks — The pollen tetrads of *Nepenthes* (Nepenthaceae) have been regarded as similar to the pollen of Droseraceae (Erdtman, 1952; Chanda, 1962; Basak & Subramaniam, 1966). According to Takahasi and Sohma (1982), the intine at the junction of two grains is interrupted and has no pore channels. The cohesion of grains in the tetrads of *Nepenthes* differs from *Drosera*, because the contact area of the adjacent grains in the tetrad pollen of *Drosera* shows cross walls and pore channels, which are completely absent in the pollen of *Nepenthes* L.

Genus—*Ericipites* Wodehouse 1933

Type species — *Ericipites longisulcatus* Wodehouse 1933.

Ericipites laevigatus sp. nov.

Holotype — Pl. 1, fig. 7; Slide no. BSIP 11012.

Type locality — Laitryngew Coalfield, Lakadong Sandstone (Palaeocene), Khasi Hills, Meghalaya.

Specific diagnosis — Pollen grains in tetrahedral

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PLATE 3

1. *Kielmeyera angustifolia*, tetrahedral tetrad showing union of colpi between two gains (SEM x 1250).
2. *K. tomentosa*, a single grain with 3 distinct colpi (SEM x 2000).
3. Enlargement of fig. 2 showing detail sculpture and lalongate pore (SEM x 4500).
4. *K. angustifolia* (SEM x 1250).
5. *K. tomentosa* showing junction of three grains - enlarged (SEM x 3500).
6. Enlargement of fig. 4 (SEM x 5000).
7. *K. tomentosa* showing tetrad symmetry (SEM x 850).

8, 10. Enlargement of fig. 1 showing ektexinal bridges between two grains (SEM x 2500, 4000 respectively).

9. *K. angustifolia* showing details of exine sculpture (SEM x 4000).

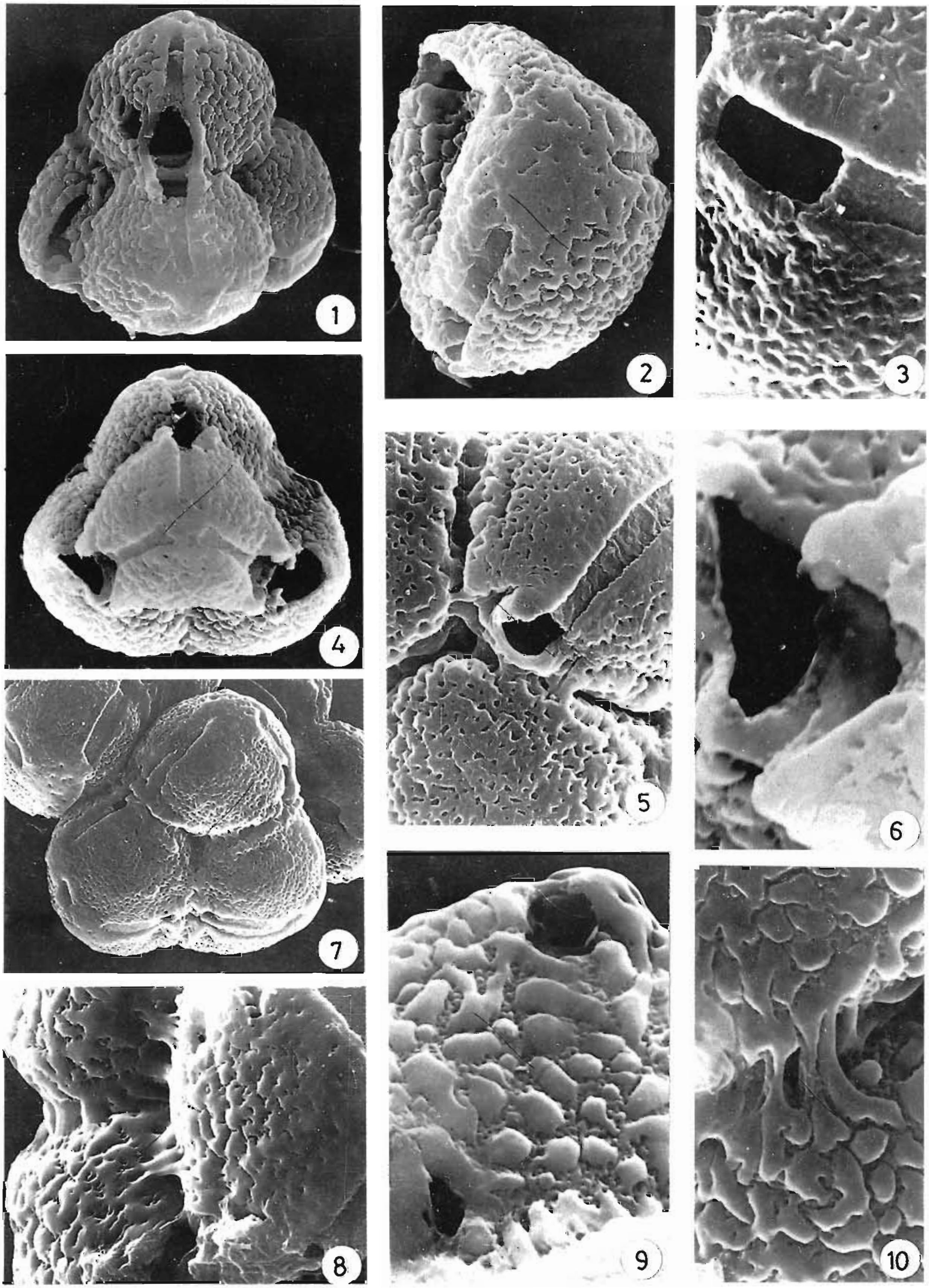

PLATE 3

tetrads, subtriangular in shape, size 35-70 μm. Exine 1-1.5 μm thick, laevigate to scabrate. In tetrahedral tetrad the aperture of individual grains meet at six places.

Comparison — *Ericipites laevigatus* differs from *E. discretus* and *E. bidasensis* Nagy 1969 as latter are characterized by their baculate to intrabaculate exine. This species is also distinct from *E. granulatus* Salujha *et al.* 1972 by its laevigate to scabrate exine. *E. scabratus* (Harris, 1965 = *E. scabratus* Mathur & Chopra 1987) is comparatively small in size.

Shape and size — Pollen grains in tetrahedral tetrads subcircular-spheroidal, 35-45 x 65-70 μm; grains circular-subcircular or lobed, 35-45 μm.

Exine structure and sculpture ·

Light microscope — Exine 1-1.5 μm thick, tectate, laevigate. Endexine thicker than ektexine. Interconnecting channels between grains distinct. Pore margin thickened (Pl.1, fig. 7).

Scanning electron microscope — Exine laevigate, extended between two grains demarcated with sparsely microperforated line; colpi show granulate/baculate ornamentation (Pl. 1, figs 4, 5).

Aperture complex and tetrad configuration — Indiviual grain of a tetrad possesses tricolporate, colpi small, elliptical, slightly open, 12-18 μm long; pores small with thickened margin, 5-8 μm in diameter; ora protruded. The two colpi of adjacent monads are united to form 10-15 μm long colpus. The pores of each longicolpus are separated by a common ridge. Three apertures of a grain in a tetrad meet by two and two at six places following Fischer's law.

To compare the morphological features of fossil pollen species the following one species of *Erica* has been studied, which shows closest resemblance with the fossil pollen species.

Genus — *Erica* Linn.

Erica arborea Linn.

Shape and size — Pollen grains in tetrahedral tetrads, subcircular, 30-40 μm; grains subtriangular, 20-25 μm.

Exine structure and sculpture ·

Light microscope — Exine 1.5-2.0 μm thick, tectate, laevigate, endexine thicker than ektexine; interconnecting channels between two grains well developed. Pore circular with thickened margin, exine around pore 2-2.5 μm thick. Endocracks have also been observed in nexine at equatorial regions (Pl. 2, fig. 12).

Scanning electron microscope — Exine microrugulate, colpi slit-like, closed or open. The joining area of two grains shows ektexinal extension (Pl. 4, figs 6, 8).

Aperture complex and tetrad configuration — Individual grains tricolporate, furrows short, slender, slightly open, tapering at apices. Pores equatorially elongate with slightly protruded ora. Three apertures of a grain meet by two and two at six places in a tetrad following Fischer's law

Genus — *Pilatetradites* gen. nov.

Type species — *Pilatetradites meghalayensis* gen. et sp. nov.

Holotype — Pl. 2, fig. 8; Slide no. BSIP 9398.

Type locality — Laitryngew Coalfield, Lakadong Sandstone (Palaeocene), Meghalaya.

Basionym — Pollen tetrad type B, Kar & Kumar, 1986; pl. 11, fig. 10.

Generic diagnosis — Pollen grain tetrahedral tetrad, subtriangular, 50-70 μm. Grains circular or subcircular-subtriangular, 30-40 μm, tricolporate.

PLATE 4

1. *Drosera indica* tetrahedral tetrad (SEM x 1250).
2. *D. burmanii* (SEM x 1250).
3. Enlargement of fig. 1 showing microbaculate interspinal spaces (SEM x 4600).
4. Enlargement of fig 2 showing opening of pore channels between two grains (SEM x 4000).
5. *Nepenthes khasiana* tetrahedral pollen tetrad (SEM x 2000).
6. *Erica arborea* (SEM x 1850).
7. Enlargement of fig. 5, granulate sculpture between spinules (SEM x 4000).
8. Enlargement of fig. 6 showing union of two colpi of grains and details of microgranulate exine (SEM x 3500).

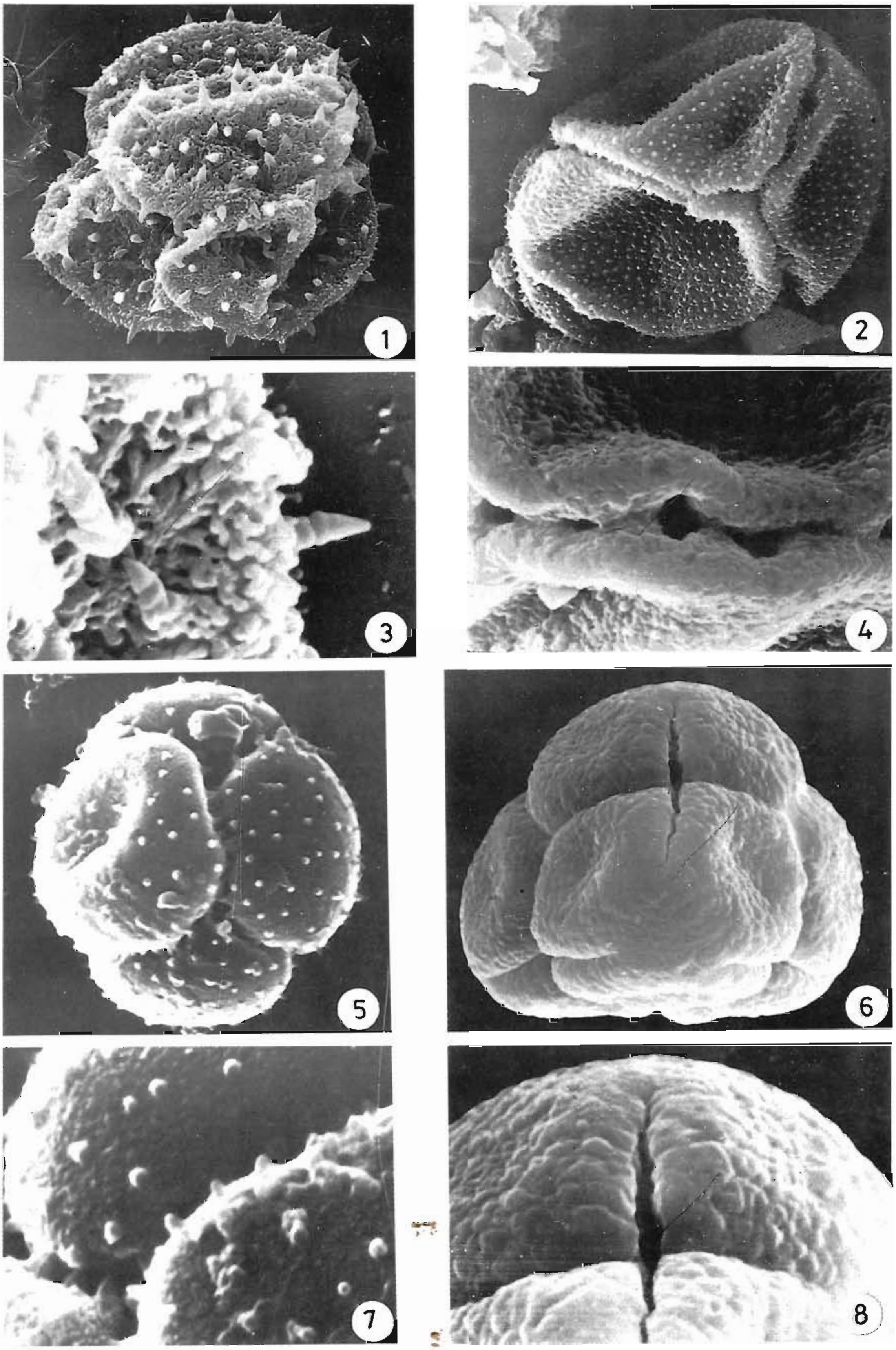

PLATE 4

Exine 2-3 µm thick, semitectate, pilate, pila heads fused to form microreticulate ornamentation.

Comparison — The genus *Pilatetradites* is comparable with *Ericipites*, Wodehouse, 1933, but later differs due to its smooth exine. *Laxipollis* Krutzsch 1970 is distinguishable by free colpi in the individual grain. *Simplicaepollis* Harris 1965 has porate apertures and comparatively smaller in size. *Senectotetradites* Dettman 1973 differs in the size of lumina and thick colpi margins.

Pilatetradites meghalayensis sp. nov.

Specific diagnosis — Tetrahedral pollen tetrads 50-60 µm. Eine retipilate, sexine thicker than nexine. Idividual grain tricolporate, colpi long, united with colpi of adjacent grains.

Shape and size — Pollen grains in tetrahedral tetrads, subtriangular, 55-65 µm; grains subcircular, 30-35 µm.

Exine structure and sculpture :

Light microscope — Exine 1.5-2.5 µm thick, sexine thicker than nexine, pilate, pila 2-3.5 µm high, pila heads fused to form microreticulate meshes (Pl. 2, figs 8, 11).

Aperture complex and tetrad configuration — The individual grains of tetrad are tricolporate, colpi narrow, inter-radial, meridionally arranged, meeting in tetrads with two and two at six points, following Fischer's law. The sexine of each grain united and lumina becomes smaller at the union point between two grains.

Fossil pollen genus *Pilatetradites* shows closest resemblance with the following species of *Rhododendron*.

Genus — *Rhododendron* Linn.

Rhododendron lepidotum Wall.

Shape and size — Pollen grains in tetrahedral tetrads; subtriangular-subcircular, 60-75 µm, grains subtriangular-subcircular, 40-45 µm.

Exine structure and sculpture :

Light microscope — Exine 2.5-4 µm thick, semitectate, retipilate, pila 2-3 µm long. Pila heads fused, sometimes show reticulations. Circumcoastal mudcracks occurs on sexine (Pl. 2, figs 4-6, 10).

Aperture complex and tetrad configuration — The grains are tricolporate, colpi small, elongated, pore circuar, lalongate. In tetrahedral tetrad configuration each individual grain is attached with three inter-radial apertures and meets with two and two at six points following Fischer's law. Sexine united to form bridges between two grains in a tetrad.

BOTANICAL RELATIONSHIP

The pollen tetrads of *Kielmeyerapollenites* Sah & Kar 1974 resemble the pollen tetrads of extant *Kielmeyera* (family Clusiaceae). Muller (1981) and Thanikaimony *et al.* (1984) also suggested its possible affinity with *Kielmeyera*. Both fossil and living pollen possess a conspicuous reticulum with more or less isodiametric lumina, which show junctions between neighbouring grains by the common ridges. SEM observation (Pl. 1, figs 1-3) explains that the grains possess dentate ektexine connections near the aperture in *Kielmeyerapollenites*, whereas *Kielmeyera angustifolia* shows ektexinal verrucae.

The pollen tetrads of *Droserapollis* Krutzsch 1970 possess very complex structure. They are morphologically distinct from other known pollen tetrads and seldom occurs in dispersed fossil forms. Both, fossil form *Droserapollis khasiensis* and extant pollen grains — *Drosera burmanni* are identical showing tetrahedral form and cycloidly arranged pores in individual grain. Takahasi and Sohma (1982) made a comprehensive pollen morphological study of the family Droseraceae and discussed its phylogenetic relationship. They also suggested that there are two types of mechanism in the tetrad cohesion — (i) simple cohesion where each grain of tetrad is connected by proximal exine, and (ii) each grain of a tetrad attached with cross wall between adjacent grain seems to be the most distinct structure. In maximum number of pollen tetrads, where aperture occurs at the proximal pole, the grains are connected together by a cross wall around the pore margin. Kuprinova (1973) observed that "isthmus" (a tubular aperture) of each grain meets with the adjoining grains and also plays an important role in cohesion mechanism. Erdtman (1945) opined that the proximal apertures are distinct features in this genus which seldom occurs in other angiosperm pollen tetrads.

The pollen tetrads of *Ericipites laevigatus* and *Pilatetradites meghalayensis* closely resemble extant pollen tetrads of *Erica arborea* and *Rhododendron lepidotum* (family Ericaceae), respectively. These tetrads are generally encountered in tetrahedral stage. The individual grain in the pollen tetrads of *Kielmeyerapollenites, Ericipites, Pilatetradites* and extant pollen of *Kielmeyera, Erica* and *Rhododendron* are arranged in accordance with Fischer's law.

GEOLOGICAL RECORDS AND PHYTOGEOGRAPHY

The fossil pollen of Droseraceae have been recorded in India by several workers (Rao & Ramanujam, 1982; Kar, 1985; Kar & Kumar, 1986). Croizat (1952) stated that *Drosera* migrated to India through Malaysia during Upper Cretaceous and then spread to other tropical regions. According to Hutchinson (1969) and Good (1953), these insectivorous plants have much ecological tolerance and presently distributed in the marshy and bog habitat of low lying areas of temperate and tropical regions in both the hemispheres.

The pollen of *Kielmeyerapollenites* had a very limited geographic range and its history of origin may confine to Palaeocene of India. Muller (1981) stated that the tetrad of *Kielmeyerapollenites* from Lower Tertiary of India closely compares with the pollen of South American genus *Kielmeyera* which is endemic to Brazil. This means that the genus *Kielmeyerapollenites* represents an Indian Tertiary relict.

The genus *Nepenthes* represents the monotypic taxon of Nepenthaceae. The plant is widely distributed in Malaya Peninsula, Sumatra and Island of New Guinea, Phillipines, north eastern Australia and India (Croizat, 1952; Good, 1953). *Nepenthes*

Table 1—Occurrence of pollen tetrads of *Kielmeyerapollenites, Ericipites, Droserapollis, Nepenthidites* and *Pilatetradites* from the Tertiary sediments of India

Taxa	Palaeocene		Eocene	Oligocene		Miocene				Authors
	Kutch	Meghalaya	Kerala	Bengal Basin	Cambay Basin	Neyveli lignite	Ratnagiri	Bengal Basin	Cambay Basin	
Kielmeyerapollenites										
K. eocenicus	+	+								Sah & Kar, 1974; Kar, 1985 Naskar & Baksi, 1978
K. syncolporatus		+								Kar & Kumar 1986; Mandal, 1987
Kielmeyerapollenites sp.		+								Sah & Kar, 1974; Kar & Kumar, 1986
Ericipites										
E. sahnii						+				Ramanujam, 1966
E. granularis		+								Salujha et al.
E. longisulcatus							+			Phadtare & Kulkarni, 1984
E. scabratus				+				+		Mathur & Chopra, 1987
E. laevigatus sp. nov.		+								
Ericipites sp.			+							Raha et al.
Ericipites sp.					+				+	Venkatachala & Rawat, 1973
Droserapollis										
D. khasiensis		+								
Nepenthidites										
N. laitryngewensis sp. nov.		+								
Pilatetradites										
P. meghalayensis sp. nov.		+								

khasiana (Hooker) is an endemic species of Meghalaya (India) where it is abundantly found (Kanjilal *et al.*, 1940). Anderson and Muller (1975) recorded the fossil pollen of *Nepenthidites* from the Holocene peat of New Borneo. Krutzsch (1989) pointed out that such fossil pollen grains are also found in the Eocene of Europe. Raven and Axelrod (1974) opined that the plants distributed in the Indian Ocean may not reflect any great antiquity and indubitably tropical Laurasian in origin.

The pollen of *Ericipites* have been widely recorded from the post Cretaceous sediments. Manum (1962) recorded its pollen from the Lower Tertiary of Greenland and Iceland and Nagy (1969) from the Miocene of Hungary. The records of this taxa from the Indian Tertiary sediments are given in Table 1. From post-Tertiary sediments Vasanthy *et al.* (1980) and Vasanthy and Pocock (1987) recorded the pollen of *Rhododendron nilgiricum* from the clayey peats (6,000 yrs B.P.) of Palani and Nilgiri Hills, India. Presently, the members of Ericaceae are distributed worldwide in lower and upper montane forests of both terrestrial and epiphytic habitat (Sleumer, 1966). They are predominantly distributed in north temperate region to tropical Asia and scarcely found in Africa and Australia (Good, 1953).

CONCLUSION

The study of fossil and extant pollen indicates that pollen tetrads show close similarity in a exinal as well as aperture characters. The pattern and symmetry of individual grains in the tetrad and their cohesion by exinal bridges and apertural fusion are very important factors for maintaining these tetrads in a stable shape. The arrangement of aperture in a grain is much related to the position of the aperture of other grain in the tetrad arrangement. The more compact arrangement provides more stability. Size of apertures, ornamentation of sexine and dimension of individual grains are responsible for making compact and stable arrangement of tetrads.

ACKNOWLEDGEMENTS

The author is grateful to Mrs C. Tissot, French Institute, Pondicherry (India) and Dr G.P. Sinha, Botanical Survey of India, North-East Zone, Shillong for providing polleniferous material.

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