ASSIGNMENT
ON
MICROPALEONTOLOGY AND PALEOECOLOGY

GEY 402

PREPARED BY

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SUBMITTED TO DR. AFOLABI,

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QUESTIONS

1. Discuss the morphological classification of pollens and spores.

2. Explain and highlight the various applications of pollens and spores in geosciences.

3. Explain the stratigraphical and paleoenvironmental applications and significance of pollens and spores in sedimentary and petroleum geology.

INTRODUCTION

The word “palynology,” which is the study of pollen, comes from the Greek word palunein (to sprinkle) in reference to the pollen that is sprinkled as dust during the blooming season. The study of pollen grains and other spores, especially as found in archaeological or geological deposits. Pollen extracted from such deposits may be used for radiocarbon dating and for studying past climates and environments by identifying plants then growing. Palynology became a scientific discipline in the early 1990s after the pioneer works of Lennart von Post, a Swedish geologist who produced the first pollen diagrams based on the identification and count of pollen grains from peat deposits, to reconstruct the postglacial vegetation of Western Europe (cf. Manten, 1967). Since then, palynology has been widely used to reconstruct the history of vegetation through time and past climate/environmental conditions. In botany and ecology, palynology is often associated with the study of pollen from flowering plants.

QUESTION 1

Morphological characteristics of pollen grains have been categorised into different groups:

1. Pollen Units

2. Polarity

3. Symmetry

4. Shape

5. Size

6. Apertures

7. Sub-Divisions of the Pollen Surface

8. Sporoderm Stratification

9. Exine Ornamentation

10. ‘LO’ Analysis.

CHARACTERISTIC # 1. POLLEN UNITS:

The pollen grains are produced within the anther of the flower. Pollen mother cells originate from the sporogenous tissue of the anther which later divide meiotically to form four pollen grains called tetrad.

The pollen grains do not remain united at maturity, and are dissociated into single pollen grain called monad. Sometimes rarer types like dyads (two pollen grains), Octads (eight pollen grains) and Polyads (many pollen grains) are also observed (Fig. 4.1).

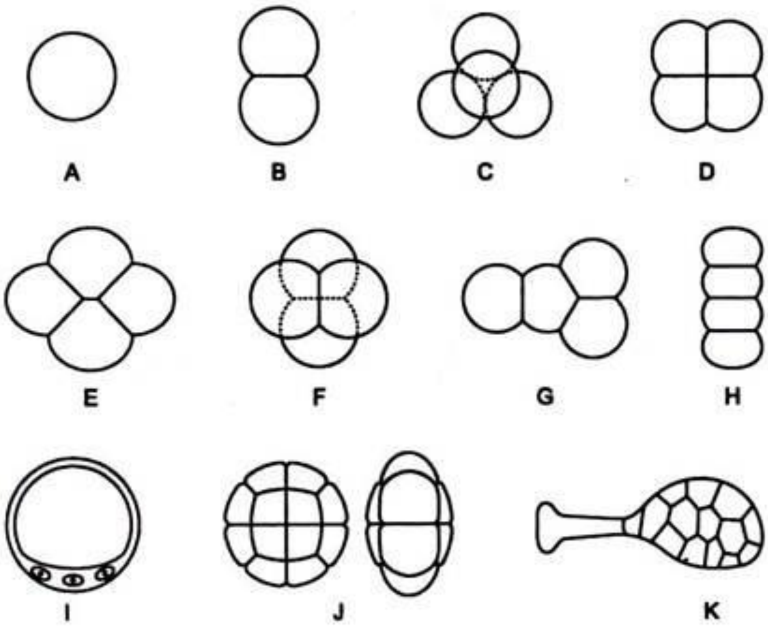


Fig. 4.1 : Pollen units (A = Monad, B = Dyads, C = Tetrahedral tetrad, D = Tetragonal tetrad, E = Rhomboidal tetrad, F = Decussate tetrad, G = T-Shaped tetrad, H = Linear tetrad, I = Cryptotetrad, J = Polyads, K = Pollinia)

Dyads:

Pollen grains which are united in pairs and shed from the anthers as doubles are called dyads (Fig.4.1). Dyads are present in Scheuchzeria palustris and other members of Podostemonaceae. The dyads are formed due to the incomplete break up of individual grain or monad.

Tetrads:

Four pollen grains are united to form tetrad. Tetrads are the unseparated product of meiosis. Tetrads maybe categorized into different types based on their arrangement (Fig.4.1).

Tetrahedral tetrad:

Pollen grains are arranged in two different planes. Three grains are in one plane and one lies centrally over the other three. In some cases, the pollen grains are released from the anther in the tetrad condition. These types of tetrads are called obligate or permanent tetrads, viz., Drymis (Winteraceae), Drosera (Droseraceae), Rhododendron Ericaceae).

Tetragonal tetrad:

All the four pollen grains are arranged in one plane e.g., Typha latifolia (Typhaceae), Hedycaria arborea (Monimiaceae).

Rhomboidal tetrad:

All pollen grains are arranged in one plane forming rhomboidal shape e.g., Annona muricata (Annonaceae).

Decussate tetrad:

Pair-wise the pollen grains are at right angle to each other, e.g., Magnolia grandiflora (Magnoliaceae).

T-Shaped tetrad:

The first division of pollen mother cell is transverse to form a dyad. The upper or lower cell of dyad undergoes a vertical or longitudinal division instead of transverse, yielding either straight or inverted T-shaped configuration, e.g., Aristolochia sp.(Aristolochiaceae), Polyanthes sp; (Amaryllidaceae).

Linear tetrad:

The first division of pollen mother cell is transverse and a dyad is formed. Each cell of the dyad again divides transversely to form a linear tetrad, e.g., Mimosa pudica.

Cryptotetrad or Pseudomonad:

Here tetrads are formed without partition walls between the four compartments. One out of the four nuclei develops normally and the rest three obliterate. Thus an apparent monad but homologous to the tetrad is formed (Fig. 4.1), e.g., Cyperaceae.

Polyads:

In most of the Mimosaceae members each of the tetrad cells divides once or twice or more, yielding a group of 8 to 64 cells which remain together after maturity. These compound grains are usually held together in small units and are called polyads (Fig. 4.1) e.g., Acacia auriculiformis, Adenanthera pavonina, Calliandra hematocephalla, Samania saman, Albizzia lebbeck.

Pollinia:

In Orchidaceae and Asclepiadaceae the whole contents of an anther or anther locule which shed as one united mass of pollen are called Pollinia (Fig. 4.1). The pollinium (singular) apparatus is the functional unit of a “corpusculum” with its two attached arms (translator) and Pollinia. e.g., Calotropis sp., Daemia sp., etc., of the Asclepiadaceae and majority of the family Orchidaceae.

CHARACTERISTIC # 2. POLARITY:

The orientation of polarity is an important criterion in identification and description of pollen grains, as apertural position is of primary phylogenetic and functional significance. All pollen grains are in tetrad stage during development and the polarity is determined in this stage, prior to their separation.

The part of the pollen grains which is nearest to the centre of the tetrad is the proximal pole and that towards the opposite side is the distal pole (Fig. 4.2). The imaginary line between the proximal and distal pole of the grain is called the Polar Axis (PA) which passes through the centre of the spore to the centre of the tetrad.

The plane perpendicular to the polar axis through the middle of the grain is the equatorial plane (equatorial diameter). Positions on the surface of the grain maybe determined by their latitude, comparing to the latitude on a regular sphere. Similarly, surface features in a pole to pole direction at right angles to the equatorial plane are called meridional.

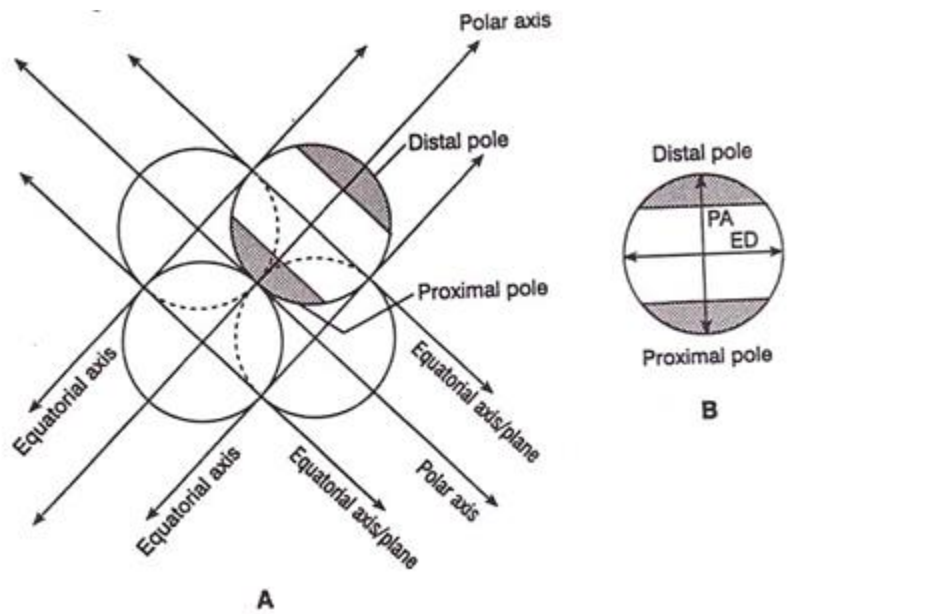


Fig. 4.2 : Polarity (A = Showing polarity in terad stage; B = Showing the length of polar axis (PA) and breadth of equatorial diameter (ED) in a monad grain)

The pollen grains maybe either apolar or polar.

In apolar spores, poles or polar regions cannot be distinguished in individual spore (monad) after separation from tetrad. Among the polar types the pollen grains are either isopolar or heteropolar depending upon the demarcation between two equal or unequal polar faces, respectively (Fig. 4.3).

In isopolar grains the distal and proximal faces (above and below the equatorial plane) look alike.

In heteropolar grains the two faces are distinctly different, either in shape, ornamentation or apertural system. Thus one face may have an opening (aperture) and the other not.

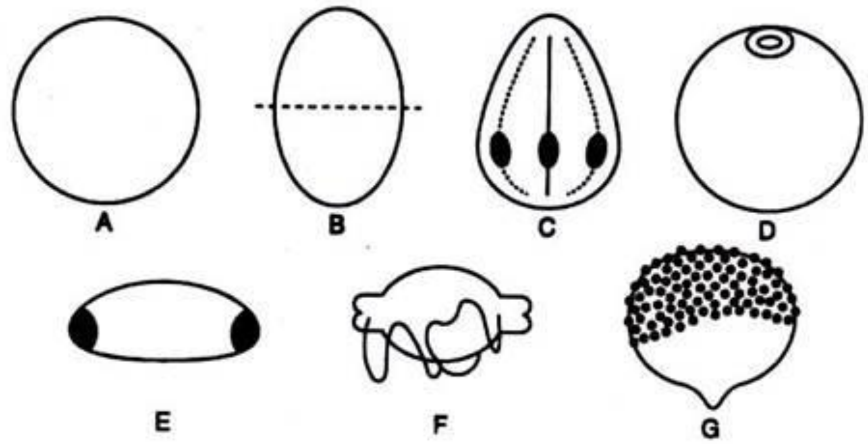


Fig. 4.3 : Polarity (A = Apolar; B = Isopolar, C&D = Heteropolar, E&F = Paraisopolar, G = Cryptopolar)

The pollen grains showing slight differences between the distal and proximal faces are also called paraisopolar or subisopolar (Fig. 4.3). Say for example, one face (distal) is convex and the other face (proximal) is plane or concave or vice versa. Their equatorial plane is usually more or less curved. Sometimes there are small differences in the surface details of the two poles viz. Carya, Ulmus, etc.

In some bryophyte spores like Calobryum dentatum, Haplomitrium hookeri, the distal and proximal faces have dissimilar sculpturing and lack tetrad mark. This type of spores is called Cryptopolar (Fig.4.3).

CHARACTERISTIC # 3. SYMMETRY:

Pollen grains or spores are symmetric or asymmetric. The asymmetric grains are either non-fixiform (without fixed shape) or fixiform (with fixed shape). Asymmetrical grains have no plane of symmetry. They are rare in occurrence.

The Symmetric grains are either radiosymmetric (radially symmetrical) or bilateral (having a single plane of symmetry) (Fig. 4.4).

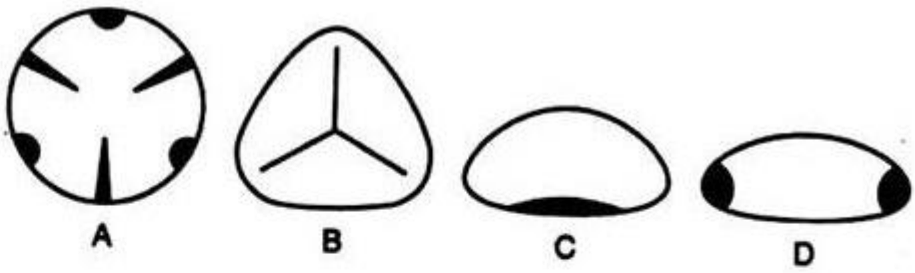


Fig. 4.4 : Symmetry (A & B = Radially symmetric, C & D = Bilateral)

In radiosymmetric grain the shape is such that any plane including the polar axis that passes through will produce identical halves. So the radiosymmetric grains have more than two vertical planes of symmetry. Radially symmetrical isopolar grains have one horizontal and two or more vertical planes of symmetry. Radially symmetrical heteropolar grains have no horizontal plane of symmetry. Bilateral heteropolar pollen grains have two vertical planes of symmetry. Bilateral isopolar grains have three planes of symmetry, one horizontal and two vertical. In some bean- shaped or boat-shaped spore/pollen there is only one vertical plane of symmetry with an opening towards the end of the grain.

CHARACTERISTIC # 4. SHAPE:

The shape of the pollen grains varies from species to species. Shape of the grains is found to be useful in spore/pollen identification. However, the shape may vary considerably within one grain type or even within one species.

Pollen grains and spores are often described by the shape (non-angular and angular) of their outline both in polar and equatorial views. The shape of the pollen/spores may be circular, elliptical, triangular, rectangular, quadrangular or in other geometrical shapes (Fig. 4.5).

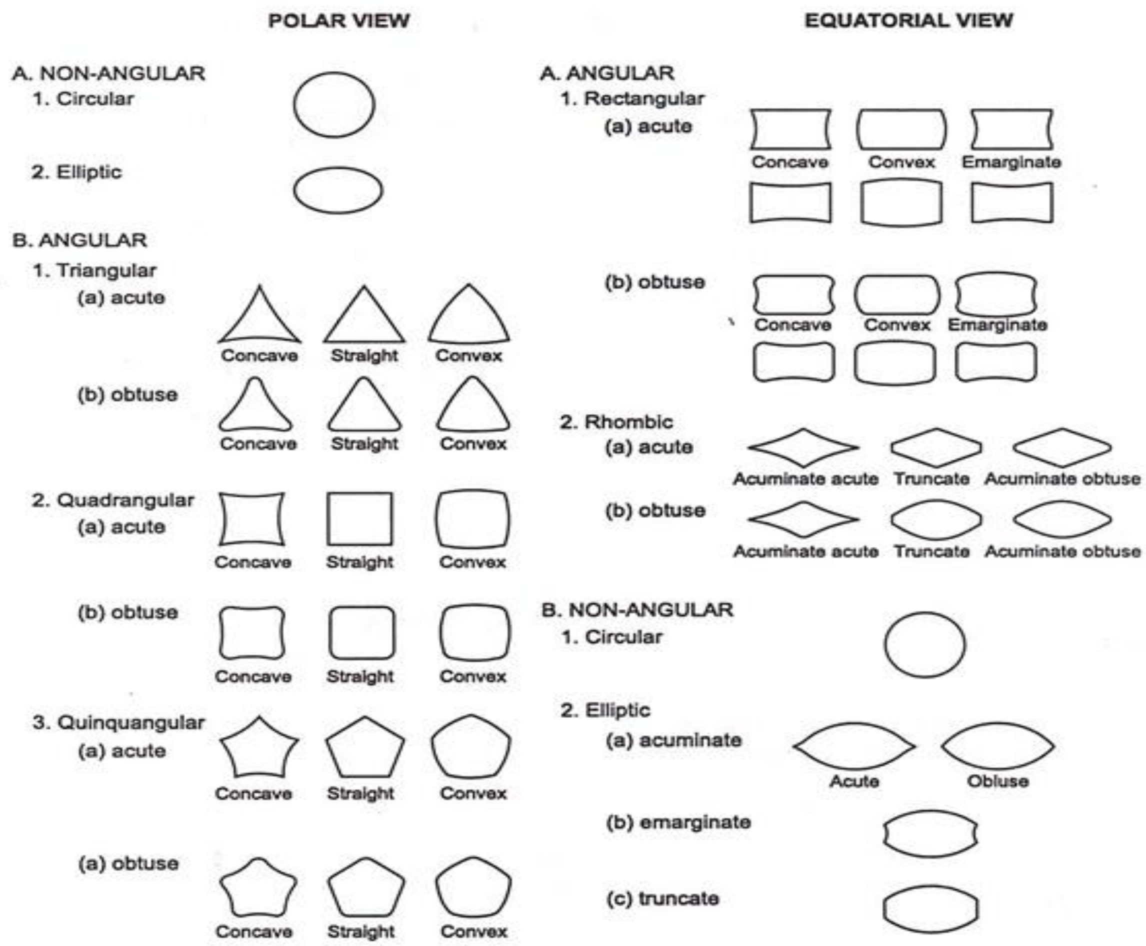


Fig. 4.5 :Shapes of grains in polar and equatorial views

G. Erdtman (1952) categorized eight shape classes based on the ratio of polar axis (PA) and equatorial diameter (ED). In the equatorial view, the ratio between the PA and ED, multiplying by 100 gives the indication of the shape.

Various PA/ED ratios are divided in it to different shape classes, e.g., Prolate, Prolate-spheroidal, Spheroidal, Sub-prolate, Perprolate, Oblate, Oblate-spheroidal, Sub-oblate, Peroblate (Table 4.1 & Fig. 4.6):

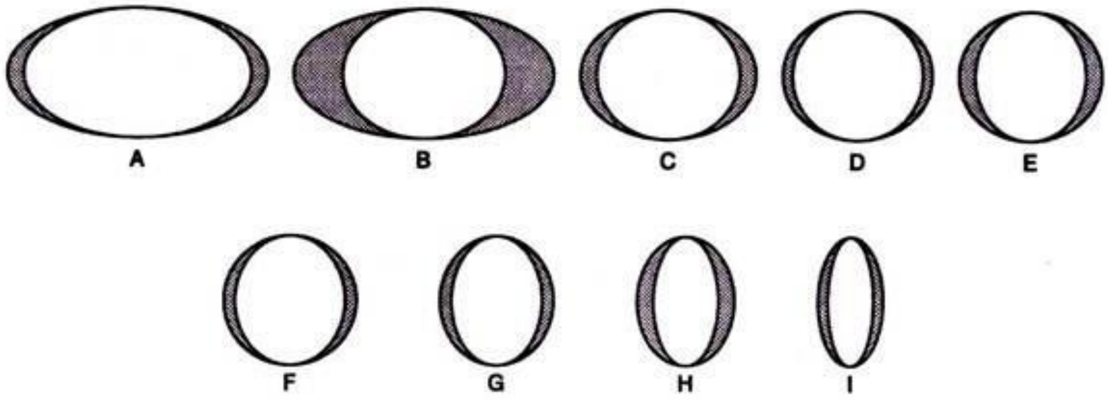


Fig. 4.6 : Shape classes (A = Peroblate, B = Obtate, C = Sub-oblate, D = Oblate-spheroidal, E = Spheroidal, F = Prolate-spheroidal, G = Sub-prolate, H = Prolate, I = Perprolate)

Table 4.1: Pollen shape classes (*after* Erdtman, 1952).

Shape classes	(PA/ED) × 100
Per-oblate	<50
Oblate	50-75
Sub-oblate	75-88
Oblate-spheroidal	88-99
Spheroidal	100
Prolate-Spheroidal	101-114
Sub-prolate	114-133
Prolate	133-200
Per-prolate	>200

In bilateral grains, pollen are plano-convex, concavo-convex or biconvex in lateral view.

CHARACTERISTIC # 5. SIZE:

Pollen grains show a great variety in their sizes. Smallest pollen grains of about 5 x 2.4 µm is noted in Myosotis palustris and some members of Boraginaceae, while the largest pollen grains (> 200 µm in diameter) are observed in Curcurbitaceae, Nyctaginaceae and Orectanthe ptaritepuiane (Abolbodaceae).

In taking measurements of size the length of polar axis (PA), equatorial diameter (ED) and sometimes equatorial breadth (EB) are considered in bilateral grains.

In radially symmetrical pollen grains the PA and the greatest ED can be measured in equatorial view, while the EB can be measured in polar view only. It is also necessary to measure exine elements, taking into consideration the thickness of exine, sexine/nexine thickness ratio and the thickness of the exine projections greater than 0.5 µm if any.

Erdtman (1945) categorized the different pollen size classes based on the size expressed as length of the longest axis (Table 4.2).

Table 4.2 : Pollen size classes (*after* Erdtman, 1945).

	Pollen size class	Length of longest axis
1.	Very small grains (*Sporae perminutae*)	<10µm
2.	Small grains (*Minutae*)	10 - 25 µm
3.	Medium sized grains (*Mediae*)	25 – 50 µm
4.	Large grains (*Magnae*)	50 – 100 µm
5.	Very large grains (*Permagnae*)	100 – 200 µm
6.	Gigantic grains (*Giganteae*)	> 200 µm

CHARACTERISTIC # 6. APERTURES:

Morphologically aperture is an opening or thinning of the exine where the in tine is usually thick; physiologically it is a germination zone or a harmomegathus (A mechanism accommodating changes in volume of the semirigid pollen exine) or both.

With regard to their position the apertures are polar, global or equatorial. The polar apertures are either monopolar (either in proximal or in distal pole) or bipolar (both in proximal and distal face). Global apertures are uniformly distributed over the pollen/spore surface. Equatorial apertures are meridionally arranged.

Some taxa have 'atreme' (trema, a Greek word means aperture) pollen/spore, i.e., they seem to have no special aperture, are termed as 'inaperturate' or non-aperturate.

Majority of the pollen grains described as 'inaperturate' seem to be 'omniaperturate', that is, the entire pollen wall is made up of a thin exine and a thick intine or at least thick as the exine, for example Canna sp. of Cannaceae. There are two types of apertures known as Pores (Porus, p1. Pori) and furrows (Colpus, p1. Colpi. or Sulcus, p1. Sulci). In most cases the furrows act as harmomegathi.

1. NPC classification:

G. Erdtman (1969) proposed NPC-System pollen/spore classification based on the apertures, their Number (N-whether single or two or many), Position (P- polar: distal or proximal; global; meridional) and Characters (C – circular or elongated) with regard to microspore tetrad (Fig. 4.7). Under this system the term 'treme' (aperture) has been used for preparing keys for the classification of the pollen grains/spores.

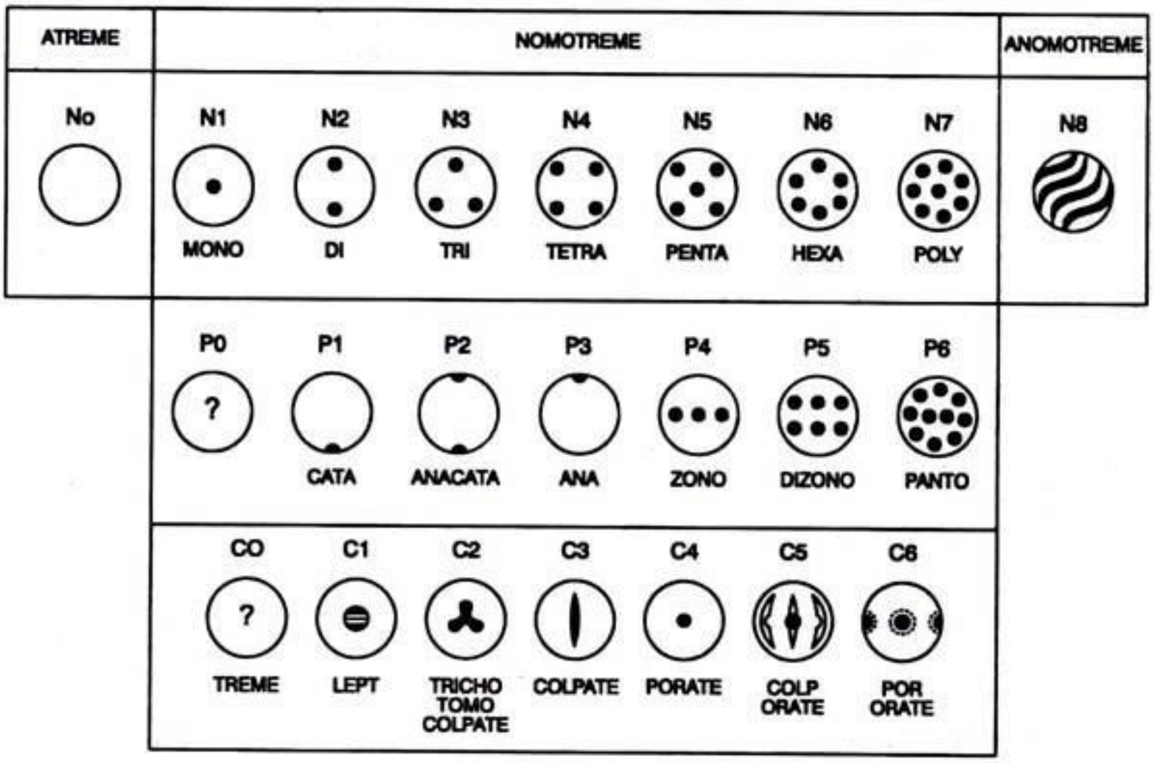


Fig. 4.7 : NPC classification of pollen (*after* Erdtman, 1969)

The pollen number (N) groups are of nine types. The grain without aperture is named "Atreme" and is designated as No. Depending upon the number of apertures, the types of pollen are Monotreme (N_1) with one aperture, Ditreme (N_2) with two apertures; Tritreme (N_3) with three apertures, Tetratreme (N_4) with four apertures, Pentatreme (N_5) with five apertures, Hexatreme (N_6) with six apertures and Polytreme (N_7) having more than six apertures. Irregularly arranged spiral apertures over the surface of the pollen irrespective of their number are designated as 'Anomotreme' (N_8).

On the basis of the position (P) of apertures, pollen are categorized into seven groups (P_0 to P_6). In 'Catatreme' (P_1) pollen aperture is in proximal face, while in 'Anatreme' (P_3) it is in distal face. The pollen are designated as Anacatatreme' (P_2) where apertures are both in proximal and distal faces.

The pollen grains are referred to as 'Zonotreme' (P_4), when the apertures are located on the equatorial zone. 'Dizonotreme' (P_5) are like zonotreme, but with two rows of apertures on the equatorial region. In 'Pantotreme' (P_6), apertures are globally distributed all over the pollen surface. Like position groups the character (C) groups are of seven types (C_0 to C_6). If the character of the aperture is not known, it is designated as C_0. Pollen having an aperture like thin area or Leptoma is designated as C_1. Pollen with one leptoma is called Monolept, it may be called Cataleft if present in the proximal face, or Analeft if in the distal face.

Pollen with three- slit like colpus are called Trichotomocolpate which belongs to C_2 category. The remaining character classes i.e., C_3, C_4, C_5 and C_6 include Colpate (with colpa i.e. furrow),

Porate (with pore i.e. circular aperture), Colporate (both with colpa and pore/ora apertures), Pororate (aperture with pore and ora) respectively.
Based on NPC classification, each pollen type is designated by using a three digit number (Fig. 4.8). The first digit denotes the number of aperture, for example, 100 is assigned to monotreme, 200 to ditreme, 300 for tritreme, 400 for tetratreme, 500 for pentatreme, 600 for hexatreme, 700 for polytreme, and 8 for anomotreme and 9 for atreme.

The second digit denotes the position of the aperture, e.g. 010 to proximal aperture, 030 for distal aperture, 040 for equatorial aperture, 060 for global aperture. The third digit denotes the characters of the aperture, e.g., 002 for trilete, 003 for colpate, 004 for porate, 005 for colporate. Therefore, the number 112 is assigned to trilete grains, similarly 133 to monosulcate grains, 343 to tricolpate and 345 to tricolporate grains, etc. (Fig. 4.8).

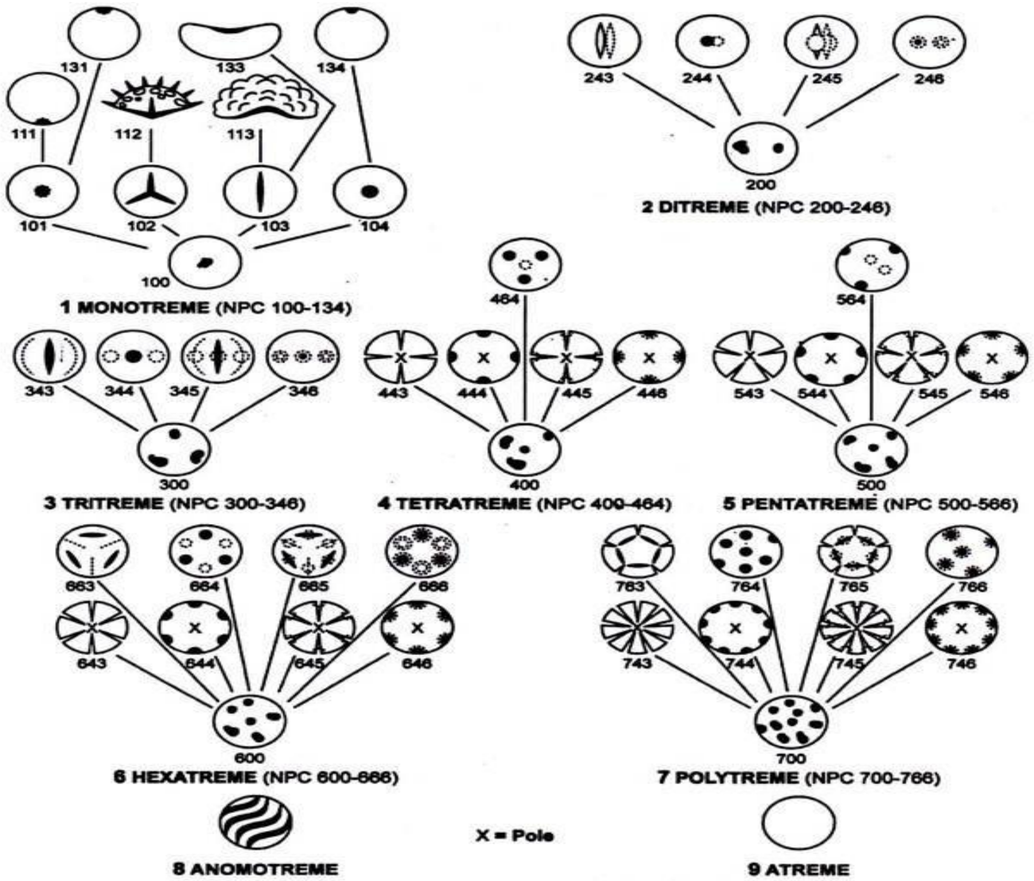


Fig. 4.8 : Pollen types designated by three digit numbers

2. Apertural types:

Apertures are of two basic types namely, Simple aperture i.e. with one type of aperture and Compound aperture i.e., with two different types of apertures.

Simple aperture:

Simple opening or thinning overlaying a thick intine. Say for example, lete, porus, orus, ulcus, sulcus, colpus, etc. (Fig. 4.9).

Lete:
Slit like aperture situated at the proximal end viz. pteridophytes spores. Spore with one slit is called monolete, e.g., Psilotum, Polypodium, etc., and spore with triradiate slit is called trilete, e.g., Lycopodium, Dryopteris, etc.

Porus:
Equatorial simple circular aperture with length/breadth ratio <2. The pollen grains with porus apertures are referred to Porate e.g., Urticaceae, Ulmaceae, etc.

Periporus:
Global simple circular aperture with length/breadth ratio <2. The pollen grains of this apertural type are called Pantoporate or Periporate, e.g., Amaranthaceae, Chenopo- diaceae, Malvaceae etc.

Ulcus:
Distal simple circular aperture with length/breadth ratio <2 and restricted to less than half the distal surface. The pollen grains with this aperture are referred to Ulcerate, e.g., Poaceae.

Sulcus:
Distal simple elongated boat-shaped aperture, generally with tapering ends showing length/breadth ratio>2. The aperture is parallel with the equatorial breadth. Pollen grains with sulcus aperture are called Sulcate e.g., Arecaceae, Magnoliaceae etc.

Sulculi:
Sulculi are sulcoid apertures, parallel to equator and usually situated between the equator and the distal pole. If united apically, the sulculi form a zone, or ring parallel to the equator, e.g., Eupomatia, Cephalostemon, Atherosperma etc.

Colpus:
Meridional simple long furrow-like aperture with length/breadth ratio >2. Aperture is facing pole to pole direction. The pollen grains of this apertural type are referred to Colpate, e.g., Lamiaceae, Brassicaceae.

Pericolpus:
Global simple, long furrow-like aperture with length/breadth ratio >2. The pollen grains with pericolpus apertures are aperture and the branches are more than twice referred to Pantocolpate/Pericolpate, e.g., Portulacaceae, Martyniaceae.

In addition to these, there are few other simple apertures in angiosperms (Fig. 4.9), these include:

Trichotomosulcate:

Distal simple trifurcated as long as broad, e.g., Elaeis gidneensis (Arecaceae).

Syncolpate:

Colpi anastomose at polar region only, e.g., Bauhinia.

Parasyncolpate:

In the polar region colpi are bifurcated and the adjacent branches meet with each other, leaving an isolated apocolpial field of regular shape (generally triangular), e.g., Mvrtaceae, Nymphoides peltata (Gentianaceae).

Brevicolpate:

Pollen grains with more or less short colpi. The length of colpi is equal to or shorter than the total distance from colpi apices to pole, e.g., Dillenia (Dilleniaceae).

Pseudoaperture:

Thinning or opening in the exine not associated with intine thickening and is called pseudoaperture, e.g., Acanthaceae. Exine lamellation may also be used as a criterion to distinguish an aperture from a pseudoaperture.

Spiraperturate:

It is ‘anomotreme’ aperture, referred to as N_8 in the NPC classification. Here the spiral apertures are irregularly arranged over the surface of the pollen, irrespective of their number, e.g., Thunbergia (Acanthaceae), Eriocaulon (Eriocaulaceae).

Compound or Composite Apertures:

Composite aperture is an opening or thinning in the outer exine ektexine (Ectoaperture, Colpi or Pore) which is not congruent with that in the inner exine, that is, endexine (endoaperture, Ora).

Composite apertures are of two types: Colporate (Ora in Colpi) and Pororate (Ora in Pore). Ora are located centrally in the endexine region. Ora may be Circular (Fig. 4.9) or lalongate (elongated laterally at right angles to the colpus) [Fig.4.9] or lolongate (elongated meridionally or longitudinally) [Fig. 4.9].

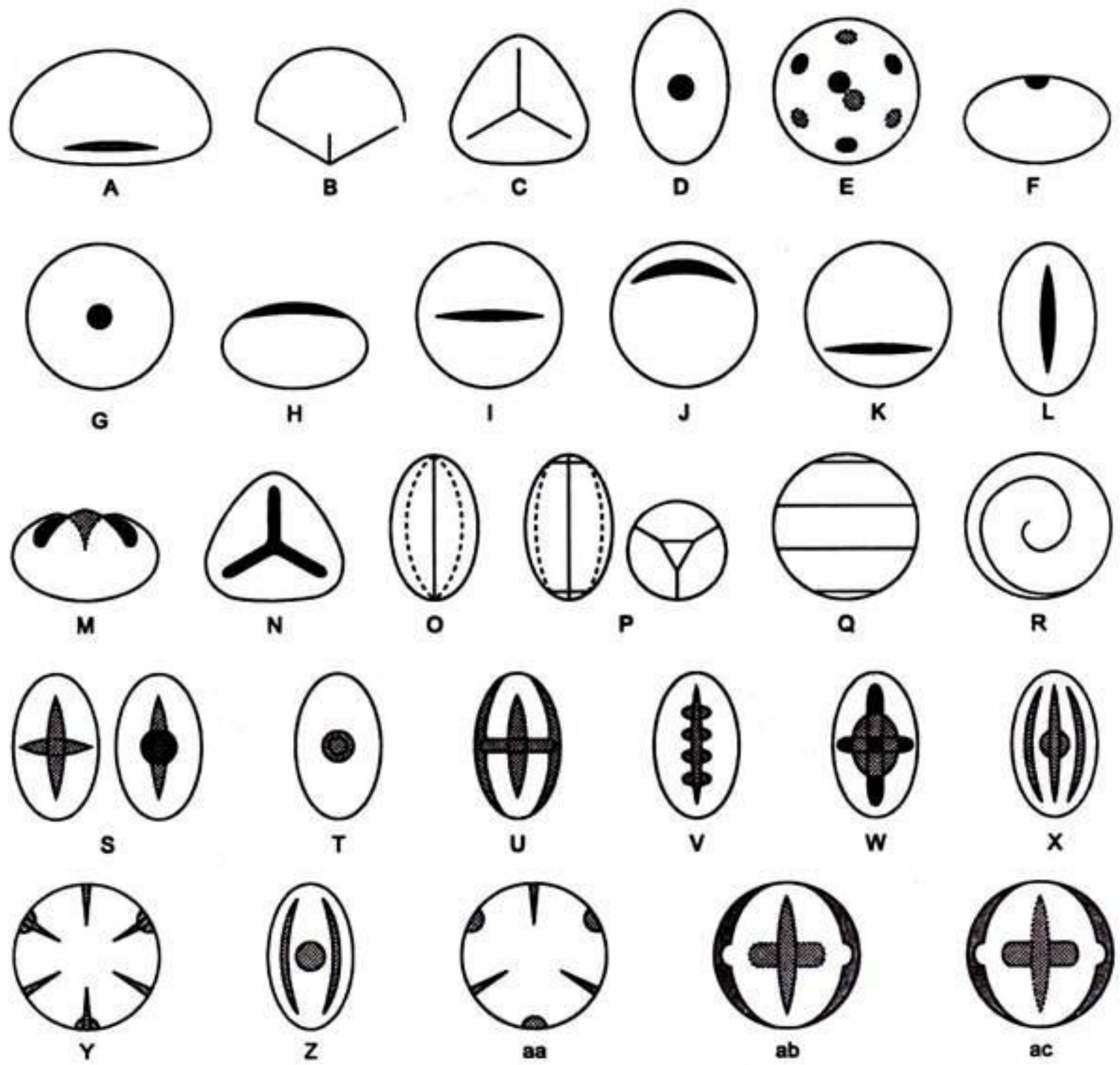


Fig. 4.9 : Pollen apertures [A=Monolete, B&C=Trilete, D=Porus, E=Periporus, F&G=Ulcus, H&I=Sulcus, J&K=Sulculus, L=Colpus, M&N=Trichotomosulcate, O=Syncolpate, P=Parasyncolpate, Q&R=Spiraperturate,S =Colporus, T=Pororate, U=Synorate, V=Multiorate, W=Colpororate, X&Y=Heterocolpate, Z&aa=Porocolpate, ab=Colporoidate, ac=Colpoidorate]

The following composite apertural types may be distinguished (Fig. 4.9):

Colporus:

Meridional composite aperture (Ora in Colpi) with ectoapertures (Colpi) length/breadth ratio >2. The pollen grains of this apertural type are called Colporate, e.g., Asteraceae, Fabaceae, Solanaceae etc.

Pericolporus:

Global composite aperture (Ora in Colpi) with ectoaperture (Colpi) length/breadth ratio >2. Pollen grains with this apertural types are called Polycolporate.

Pororus:

Meridional composite aperture (Ora in Pore) with ectoaperture (Pore) length/breadth ratio > 2. The pollen grains with this apertural type are called Pororate, e.g., Betula, Casuarina.

Pollen grains with other intermediate types are also noted, and they include:

Synorate or Svnclinorate:

Pollen with lalongate ora anastomose latitudinally, e.g., Poly gala, Solanum.

Multi orate:

Pollen with two or more ora found latitudinally along the length of the colpus, viz., Congea, Viticipremna.

Colporoidate:

Pollen have well developed colpi with weakly developed ora (= Oroids) e.g., Rex canariensis, Salix myrsinites, Phalline lucida.

Colpoidorate:

Pollen have weakly developed colpi (= Colpoids) with well developed ora, e.g., Alangium villosum.

Pororoidate:

Pollen have well developed pores with weakly developed ora (=Oroids).

Poroidorate:

Pollen have weakly developed pores (= Poroids) with well developed ora.

Colpororate:

A compound aperture characterized by an ectoaperture, a shorter lolongate mesoaperture and a lalongate endoaperture. viz., Sonchus (Compositae).

Heterocolpate:

Pollen grains have both simple and compound colpi viz. Lythrum, Peplis (Lythraceae), Myosotis (Boraginaceae).

Porocolpate:

Pollen grains with an arrangement of apertures in which colpi alternate with pores round the equator, viz., Pardoglossum (Boraginaceae).

3. Edges of apertures:

Annulus:

A distinct ring-like thickening or thinning of the ektexine bordering the pore is called annulus (Fig.4.10). A halonated area around a pore is found in Poaceae.

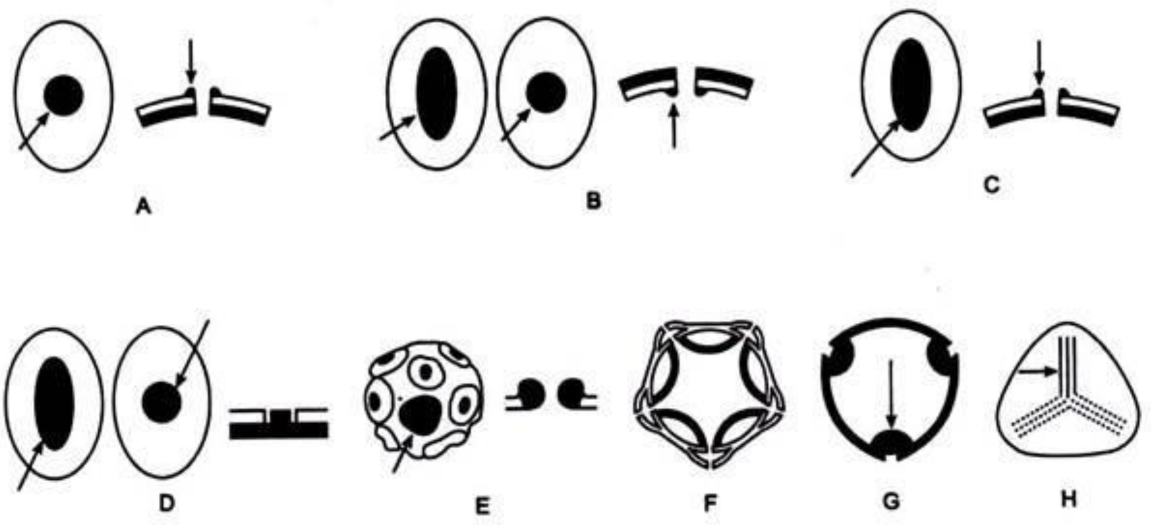


Fig. 4.10 : Edges of apertures (A=Annulus, B=Costa, C=Margo, D=Operculum, E=Vestibulum, F=Arcus, G=Oncus, H=Laesura)

Costa:

A distinct rib-like thickening of the endexine bordering the aperture is called Costa (Fig.4.10). Costae colpi maybe transverse i.e. Costae – transversales, or, if they are continuous around the equator in uninterrupted, equatorial rings, they are called Costae-equatorials.

Margo:

A distinct thinning or thickening of the ektexine bordering the aperture (furrow) with length/breadth ratio >2 is called margo (margin.) [Fig. 4.10].

Operculum:

The thick membrane, either of ektexinous, endexinous or both, covering the aperture is called Operculum (Fig. 4.10). This may be circular, elliptical, annular or bridge-like. The panto-opercular nature of the pollen may be ascertained by studying the intine thickening under the panto-operculum.

It has been established thatpollen grains of Giamaerops humilis are monosulcate-panto-operculate and the erroneous interpretation that they are dicolpate has been corrected.

The presence of an equatorial panto-operculum is Sindora has also been ascertained based on their initial thickening. By the same criterion, Chanda (1978) have demonstrated the presence of more than one operculum in the monosulcate pollen of Calectasia.

Vestibulum or Aspidote:

The apertures or at least their outermost parts are borne on small, more or less circular, shield-shaped areas (aspidote), protruding as round domes from the general surface of the grains viz., Betula, Dorstenia (Fig. 4.10).

If the chamber (space) is formed between an outer (ectopore) and inner (endpore) aperture opening, it is called an atrium. Here endopore is much larger than ectopore. In this condition apertures are also referred to as oriferous colpi e.g., Myrica.

Arcus:

In Alnus, Rhoiptelea pollen grains, band-like locally thickened parts of ektexine extending in a sweeping curves (arcus) from one aperture to another. Pollen having such arcus are referred to as arcuate type (Fig. 4.10).

Oncus:

Oncus is a lens-shaped structure that is not resistant to acetolysis and occurs beneath the aperture of many kinds of pollen grains (Fig.4.10), viz. Corylus (Betulaceae).

Laesura (p1. Laesurae):

Laesurae (Fig. 4.10) are the tetrad scars of moss and fern spores which show the contact of spores with their neighbours in the original tetrad from which they were separated. Laesura may be trilete or monolete.

A laesura has a centre suture or commissure which serves the purpose of providing a zone of weakness for rapture upon germination. The separated arms of trilete laesura are called radii, and the terminal ends of radii are forked.

4. Views of grains with reference to apertures:

Polar view:

In this view the pollen/ spores are viewed with one of the poles exactly uppermost i.e. with the polar axis directed straight towards the observer (Fig. 4.11). In polar view lete/sulcus/ulcus type of apertures will be observed centrally as they are situated at polar region. The polar axis will not be viewed here. The zonal apertures like colpi, pore, etc. will be viewed in the circumference of the pollen grains.

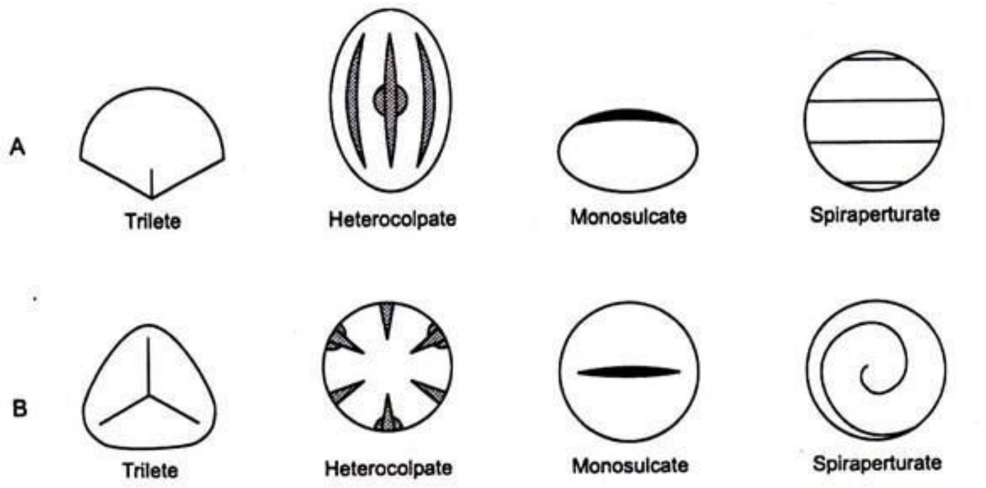


Fig. 4.11 : Views of grains (A=Equatorial view, B=Polar view)

Equatorial view:

In this view the apertures are arranged meridionally-pole to pole at right angles to the equator (Fig. 4.11). Both polar axis and equatorial diameter will be viewed and they can be measured in this view.

Amb:

Outline i.e. contour or circumference of the grain in polar view is called amb (ambit, L. ambitus) which is viewed with one of the poles exactly uppermost directed towards the observer. In isopolar, equatorially non-constricted grain amb is as same as equator, while in equatorially constricted grain amb does not coincide with equator.

Amb of radiosymmetric pollen grains are of different types based on the nature of circumference and arrangement of apertures (Fig. 4.12):

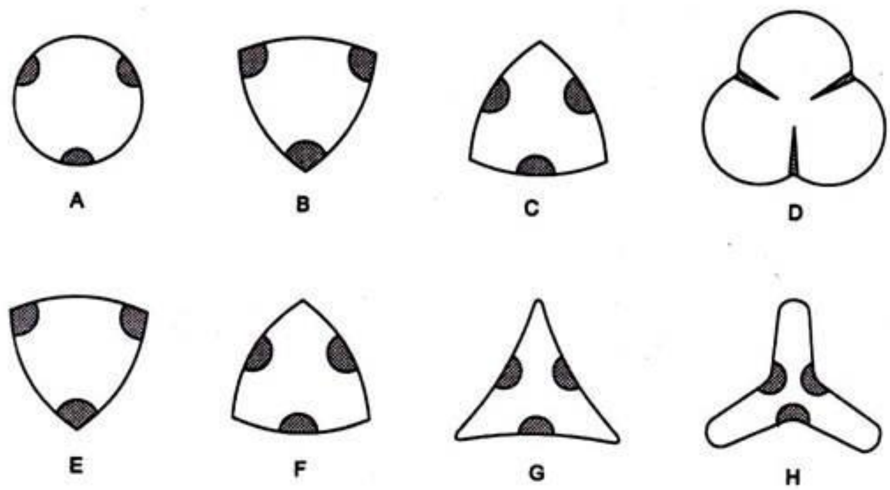


Fig. 4.12 : Amb (A=Peritreme, B=Goniotreme, C=Pleurotreme, D=Ptychotreme, E=Angulaperturate, F=Planaperturate, G=Sinuaperturate, H=Fossaperturate)

Peritreme:
Apertures are more or less uniformly distributed along a circular amb e.g., Solarium.

Goniotreme:
Amb is angular and the apertures lie at the angles of the grain, viz., Myrtaceae, Proteaceae, etc.

Pleurotreme:
Amb is angular like the goniotreme, but the apertures are situated at the mid-points of the sides and the sides are more or less straight, viz., Bombax, Ceiba of Bombacaceae.

Ptychotreme:
The sides of the amb are concave or lobate and the apertures are situated half way between the angles, viz., Gunnera.

Pollen grains with equatorial apertures and angular amb may be categorized (Fig. 4.12) into following types:

i. Angulaperturate:
Apertures are situated at the angles of the amb (sides of amb convex, straight or concave) viz. Proteaceae, Olacaceae.

ii. Planaperturate:
Apertures are situated at the mid-points of the sides of the amb (sides of amb straight), viz., Bombax.

iii. Sinuaperturate:
Apertures are situated equally halfway between the angles (side of the amb concave).

iv. Fossaperturate:
Apertures are situated at the ditch-like indentations between the lobes of lobate amb, viz., Anomopanax (Araliaceae).

CHARACTERISTIC # 7. SUB-DIVISIONS OF THE POLLEN SURFACE:
The areas on a pollen grain that are not occupied by apertures are given names depending on whether they are adjacent to colpi or pori.

According to Erdtman, (1952) Apocolpium (Fig. 4.13) is a region at the pole of a zonocolpate pollen grain delimited by lines connecting the apices of the colpi. Similarly Apoporium (Fig. 4.13) is an area at the pole of a zonoporate pollen grain that is delimited by a line connecting the borders of the pores.

Iversen and Troels -Smith (1950) used the term Polar area as synonym of apocolpium. Punt (1974) proposed a term Apocolpial field (Fig. 4.13) for a region at the pole of a parasyncolpate pollen grain, delimited by the margins of the anastomosing colpi.

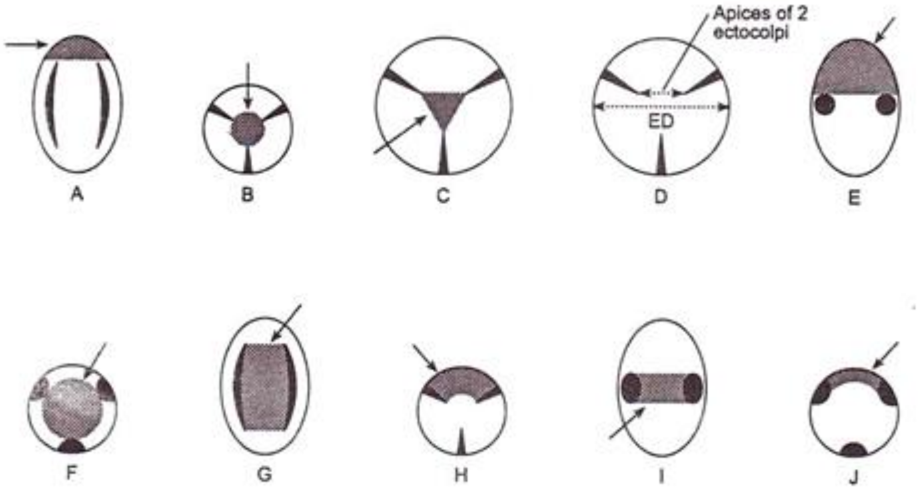


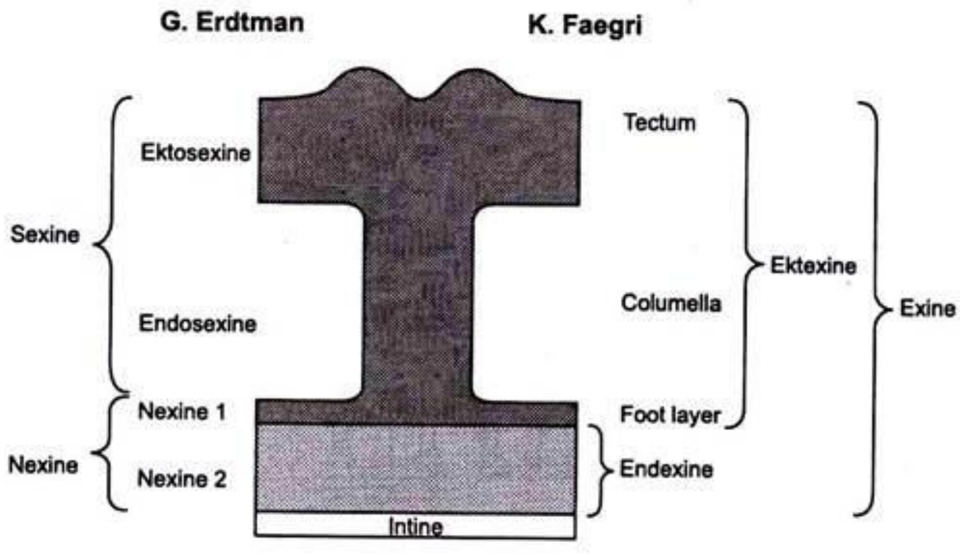
Fig. 4.13 : Pollen surface (A&B=Apocolpium, C=Apocolpial field, D=Apocolpium index, E&F=Apoporium, G&H=Mesocolpium, I&J=Mesoporium)

Mesocolpium (Fig. 4.13) is the area of a pollen grain surface delimited by lines between the apices of adjacent colpi. Similarly Mesoporium is the area of a pollen grain surface delimited by lines between the margins of adjacent pores.

Apocolpium index (Synonym, Polar area index) is used to determine the ratio of the distance between the apices of two ectocolpi of a zonocolpate pollen grain to its equatorial diameter (Fig. 4.13).

CHARACTERISTIC # 8. SPORODERM STRATIFICATION:

The pollen wall, the sporoderm is generally stratified i.e. layered (Fig. 4.14). The walls of the mature pollen, at least in angiosperms, consists of two fundamentally different layers, intine and an outer acetolysis resistant layer exine composed of sporopollenin.



Structure of Pollen Wall

Fig. 4.14 : Sporoderm stratification

The exine covers the entire pollen surface except germinal apertures where it is absent or greatly reduced. The exine of pollen grains can be divided into an outer sculptured sexine and an inner unsculptured nexine (Fig. 4.14).

Sexine again consists of two layers: the outer, ectosexine and inner, endosexine. The sexine is generally constituted of a set of radially-directed rods supporting a roof-like structure (tectum or tegillum), which may be partially perforated or completely absent.

Rods supporting the tectum are known as columella, and rods not supporting anything but standing vertically on the nexine are called bacula. Columella are usually simple, but may be branched. In Compositae the columellae are either distally branched (digitate) orproximally branched (conjunctate) or sometimes the columella hang down from the tectum, e.g., Caryophyllaceae (Fig.4.15).

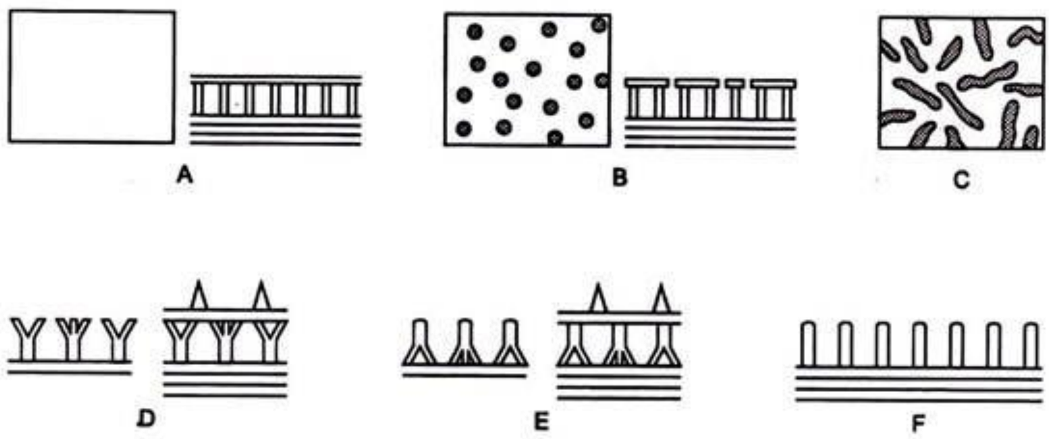


Fig. 4.15 : Nature of tectum (A=Tectum imperforatum/solidum (Tectate/eutectate), B=Tectum perforatum (Semi-tectate), C=Tectum perfossulatum, D=Digitate columella, E=Conjunctate, F=Intectate)

The nexine has been divided into two layers namely nexine I and nexine II. Knut Faegri (1964) proposed an alternative terminology for exine stratification (Fig. 4.14).

He recognized two layers of exine, the outer ektexine (including sexine and nexine I) and endexine (nexine II). He designated nexine I as foot layer and considered it to be the basal part of ektexine for its identical chemical composition and staining property as that of sexine.

Faegri's ektexine is quite different from the endexine because the former contains more dense sporopollenin and stains more deeply. The ektexine may be regarded as a three-layered structure in which the granules form small columns, columella, thus dividing an outer tectum and an inner foot layer strata. The endexine is often well developed in dicots, but is virtually absent or have it only in the apertural region in monocots.

In some pteridophyte spores (e.g. Polypodiaceae) and a few gymnosperms pollen (e.g., Taxodium) there is a hyaline loosely organized sporopolleninous envelope called Perine covering the exine(Fig. 4.16). The perine maybe continuous or sometimes folded in various ways. In some gymnosperms, especially among conifers, the ektexine enlarges to form bladdery wings (Saccus, P1.Sacci) generally two (Pinus, Cedrus, Abies, Picea etc.) or one (Tsuga) in number.

Types of Pollen in respect to Sporoderm:

The pollen grain with a tectum which covers most of the surface of the grain is called tectate. Here the structural elements fused distally forming a continuous roof (Tectum).

Faegri and Iversen (1964) divided tectate grains into three categories (Fig.4.15):

(a) Tectum solidum (unbroken tectum with or without supratectal processes viz., Betula, Zea).

(b) Tectum perforatum (perforated tectum, viz., Stellaria).

(c) Tectum perfossulatum (fossulated tectum viz., Saxifraga oppositifolia)

Pollen grains without an apparent tectum are called intectate (Fig.4.15). Here the structural elements are free or absent. Intectate grains may be either (a) without granules (e.g., Juncus) or (b) with granules (e.g., Ilex). The granules maybe more or less crowded (e.g., Populus trimula), or somewhat scattered (e.g., Callitriche).

They may be evenly dispersed or form patterns (e.g., Croton) with a great variations in their shape, club-shaped type (e.g., Ilex, Croton etc.) being the predominant. The graules are generally simple, but occasionally branched and anastomose (e.g., Geranium).

Some of the pollen grains are considered to be an intermediate between tectate and intectate grains. They are called semitectate or sub- tectate (Fig.4.15) in which tectum is not continuous i.e., tectum is partially absent. Here columellae are generally found underneath the fragmentary tectum, but they may also exist as free granules that do not support a tectum.

Semitectate grains maybe (a) Per-reticulate (where structural elements fused distally forming an open reticulum, e.g., Salix), (b) Frustillate (synonym of areolate) (where structural elements fused distally forming isolated frustillae, e.g. Populus balsamifera). Angiosperm exines show a middle layer of distinct, well-defined columella. Gymnosperm pollen can be distinguished from the angiosperm pollen due to the presence of an irregular spongy, alveolate middle layer in stead of columella (Fig. 4.16). In addition, the endexine of angiosperm pollen is relatively homogenous, whereas in gymnosperm it is typically laminate. Morphologically the spores of bryophytes and pteridophytes can easily be distinguished from the pollen of gymnosperms and angiosperms. The walls of bryophyte and pteridophyte spores often appear to be laminated throughout their thickness and without having wall stratification (there is no ektexine/endexine division in spore). The spores have either one long slit-shaped aperture (monolete) or with a trifurcated slit (trilete) forming 'Y' shape. In some pteridophytes a loose outer layer called perine or perispore surrounding the exine is often noticed (Fig. 4.16).

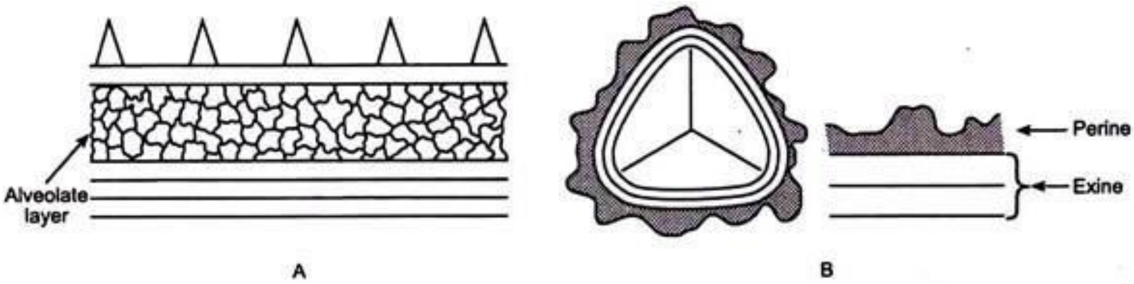


Fig. 4.16 : Gymnosperm and Pteridophyte sporoderm (A=Alveolate layer of Gymnosperm pollen, B=Perine and exine of Pteridophyte spore)

CHARACTERISTIC # 9. EXINE ORNAMENTATION:

There are two different types of exine ornamentation, the structure or texture and the sculpturing. The structure comprises of all the internal (infratectal) baculae of various form and arrangements. All the ektexine characters belong to the structural features, while the sculpturing comprises external (supratectal) geometric features without reference to their internal construction.

1. Supratectal sculpturing:

There are several external textural modifications of the exine of pollen grains and spores (Fig. 4.17). The sculpture is an usual feature of the ektexine, but may be a perine character. Tectum may be smooth i.e., psilate or with processes or excrescence of various kind like spinules, spines, pila, verruca, gemma, clava, granules, etc. Tectum provided with the processes are referred to their respective terminology (Fig 4.17).

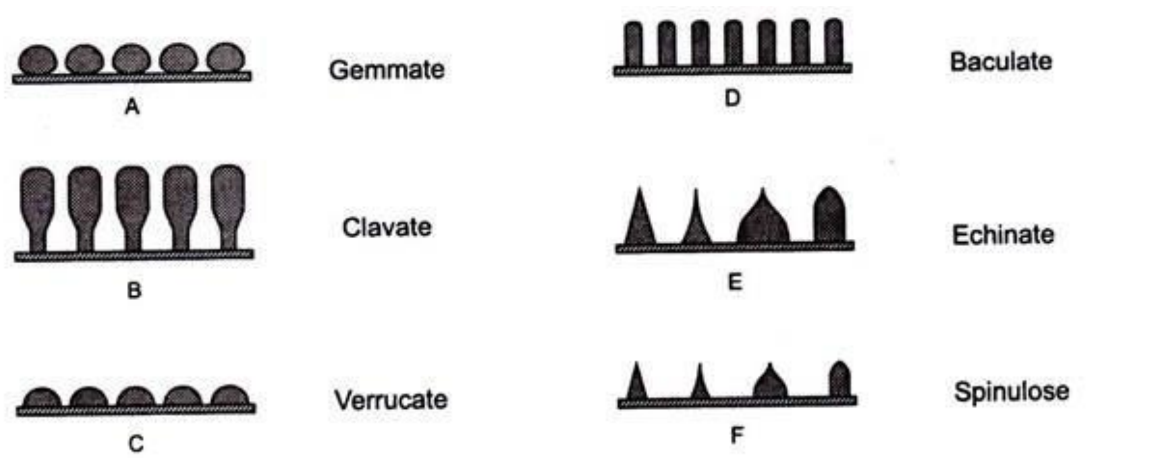


Fig. 4.17 : Supratectal sculpturing (A=Gemmate, B=Clavate, C=Verrucate, D=Baculate, E=Echinate, F=Spinulose)

Say for example, tectum with spinules is referred to as spinulate, with spine called echinate, with pila called pilate, with verruca called verrucate, with gemma called gemmate, with clava called clavate, with granules called granulate, etc., Faegri and Iversen (1964) proposed a key for identification of various sculpturing types (Table 4.3).

In tectate grains the sculpturing types are given the prefix supra. So the supra-reticulate grain means a reticulation on the outside of the tectum, while in infra-reticulate grain columellae form a reticulation beneath the tectum.

Table 4.3 : Sculpturing Types (*after* Faegri & Iversen 1964)

A. Sculpturing elements absent.

B.	Surface even or diameter of pits < 1µm	psilate
BB.	Surface pitted, diameter of pits ≥ 1µm................	foveolate
BBB.	Surface with grooves	fossulate

AA. With sculpturing elements

B. Radial projection of sculpturing elements ± isodiametric.

C. No dimensions ≥ 1μm .... scabrate

CC. At least one dimension ≥ 1μm

D. Sculpturing elements not pointed.

E. Lower part of elements constricted.

F. Greatest diameter of radial projection equal to or greater than height of element .... gemmate

FF. Height of element greater than greatest diameter of projection, club-shaped............................. clavate

EE. Lower part of element not constricted.

F. Greatest diameter of radial projection equal to or greater than height of element,wart-like............ verrucate

FF. Height of element greater than greatest diameter of projection, element cylindrical.................. baculate

DD. Sculpturing elements pointed

E. Spines long, more than 3μm long .... echinate

EE. Small spines, less than 3μm in length .... spinulose/ spinulate

BB. Radial projections of sculpturing elements elongated (length at least twice the breadth).

C. Elements irregularly distributed .... rugulate

CC. Elements parallel .... striate

BBB. Sculpturing elements forming a reticular pattern .... reticulate

2. Sculpturing on subtectate sexine:

In subtectate or semitectate grains the tectum may be provided with minute perforations having a diameter of more or less 1.0 pm called puncta and the tectum is referred to as punctate (Fig. 4.18) If the width of such perforation is more and the sexine displays a net-like pattern usually forming a honey-comb like hexagonal meshes, it is called a reticulum (Fig. 4.18).

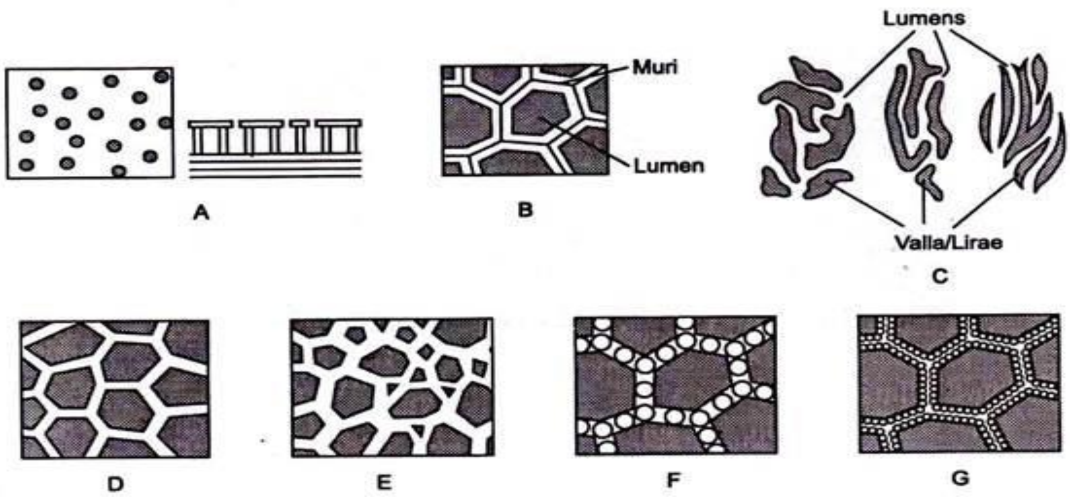


Fig. 4.18 : Sculpturing types of sub-tectate sexine (A=Punctate, B=Reticulate, C=Striate, D=Homobrochate, E=Heterobrochate, F=Simplibaculate, G=Duplibaculate)

A typical reticulum comprises of a system of ridges called muri (sing, murus), separated by empty roofless interspaces called lumina (Fig. 4.18). The lumina have the nexine as floor and muri as walls.

The muri have an upper tectal part and a lower part consisting of baculae (infratectal) standing between the outer surface of nexine and the lower surface of tectum. A mesh consists of a lumen and the adjoining half of the muri which separate that particular lumen from other lumina.

A mesh is referred to as brochus (plu.brochi). A reticulum maybe homobrochate (Fig. 4.18) (with brochi of more or less the same size) or heterobrochate (Fig. 4.18) (with brochi of more or less distinctly different sizes).

The muri in which the upper tectal part is supported by a single row of baculae is called simplibaculate (Fig. 4.18) and the muri supported by two rows of baculae is called duplibaculate (Fig. 4.18) (e.g., Avicennia). In some cases, a negative reticulum is observed where sexine areas are separated by narrow reticulately arranged grooves (Fig. 4.18).

On the basis of the nature of lumina, the surface ornamentations are of different types (Fig. 4.19) namely, scrobiculate (very small circular, distantly placed lumina separated by sexinous streaks, scrobiculate is a synonym of punctate), foveolate (circular, closely placed lumina, diam. of pits more or less 1.0 µm), rugulate (ridges run more or less irregularly, lumina parallel and anastomosing), fossulate (elongated lumina, surface with irregular grooves).

In striate ornamentation, the ridges run more or less parallel in stead of forming a network. In this case the ridges are often called lirae (sing, lira) or valla (sing, vallum) and the streak-like furrows between them are called striae (sing, stria) (Fig. 4.18). If the lira forms a definite reticulation, the pattern is called striato- reticulate. Elements are very irregularly distributed. If pila instead of muri form a reticulum, then the sexine pattern is called retipilate(Fig. 4.19).

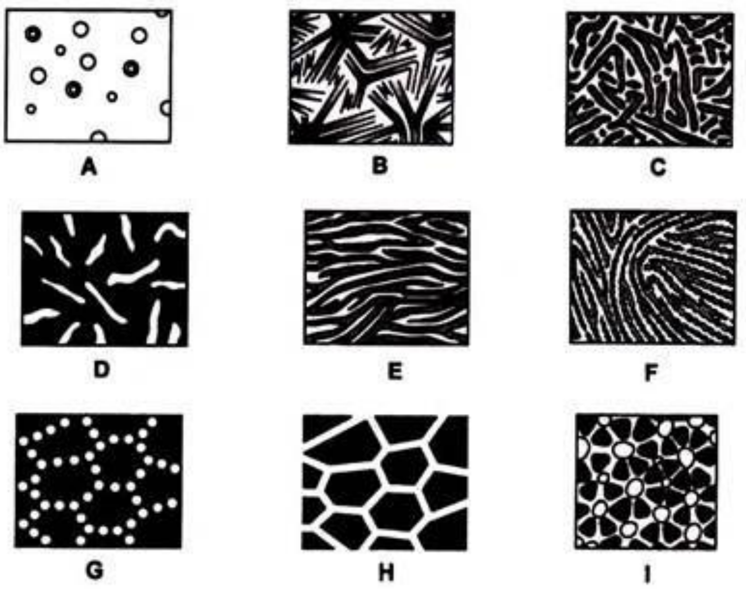


Fig. 4.19 : Sculpturing types (A=Foveolate, B&C=Rugulate, D=Fossulate, E&F=Striato-reticulate, G=Retipilate, H=Negative reticulum, I=Crotonoid pattern)

Crotonoid pattern is a characteristic type of ornamentation comprising of five or six (sometimes more) raised, often triangular, sexine elements arranged around a circular area, usually formed by pila (Fig.4.19). Viz., Croton, Jatropha (Euphorbiaceae), Callitriche antarctica (Callitrichaceae), Pimelea arenaria (Thymelaceae).

It is observed that two or more grain types show same surface ornamentations (Fig. 4.20). Say for example, regulate, striate or reticulate can have very different fine structure. One grain type is tectate with ornamentation on the top of the tectum, and the other is sub-tectate where surface ornamentations are formed of columellae.

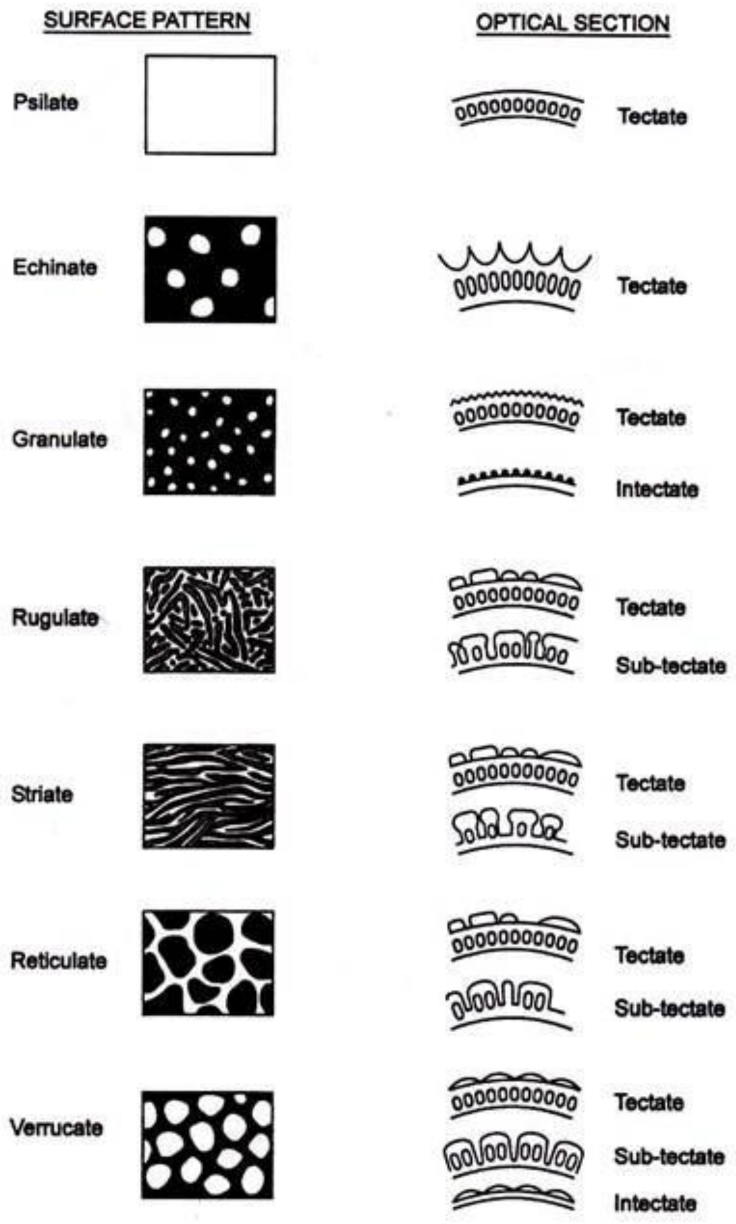


Fig. 4.20 : Sculpturing types visible in surface view and optical section (All raised areas are shown light and lower areas or holes are shown dark)

The verrucae sculpturing may be produced by three different exine structures (tectate, semitectate and intectate) (Fig.4.20).The optical section would determine the type of the grain (whether tectate or semitectate). The other sculpturing types namely, psilate or echinate are produced only by tectate grains, while granulate type is formed of by two different exine types (tectate and intectate) (Fig 4.20).

3. Other exine patterns (Fig. 4.21):

Areolate:

An ornamentation feature where the ektexine is composed of circular or polygonal areas separated by grooves which form a negative reticulum. Viz. Phyllanthus (Euphorbiaceae), Apama (Aristolochiaceae).

Caveate:

In some Compositae like Ambrosia, a cavity is formed between two layers (ektexine and foot layer) of the exine extending to the colpus margin where the layers meet. The cavity is called cavea or cavum and the pollen of such type is termed as caveate or cavate. When cavea is highly developed the pollen grain is said to be vesiculate or saccate.

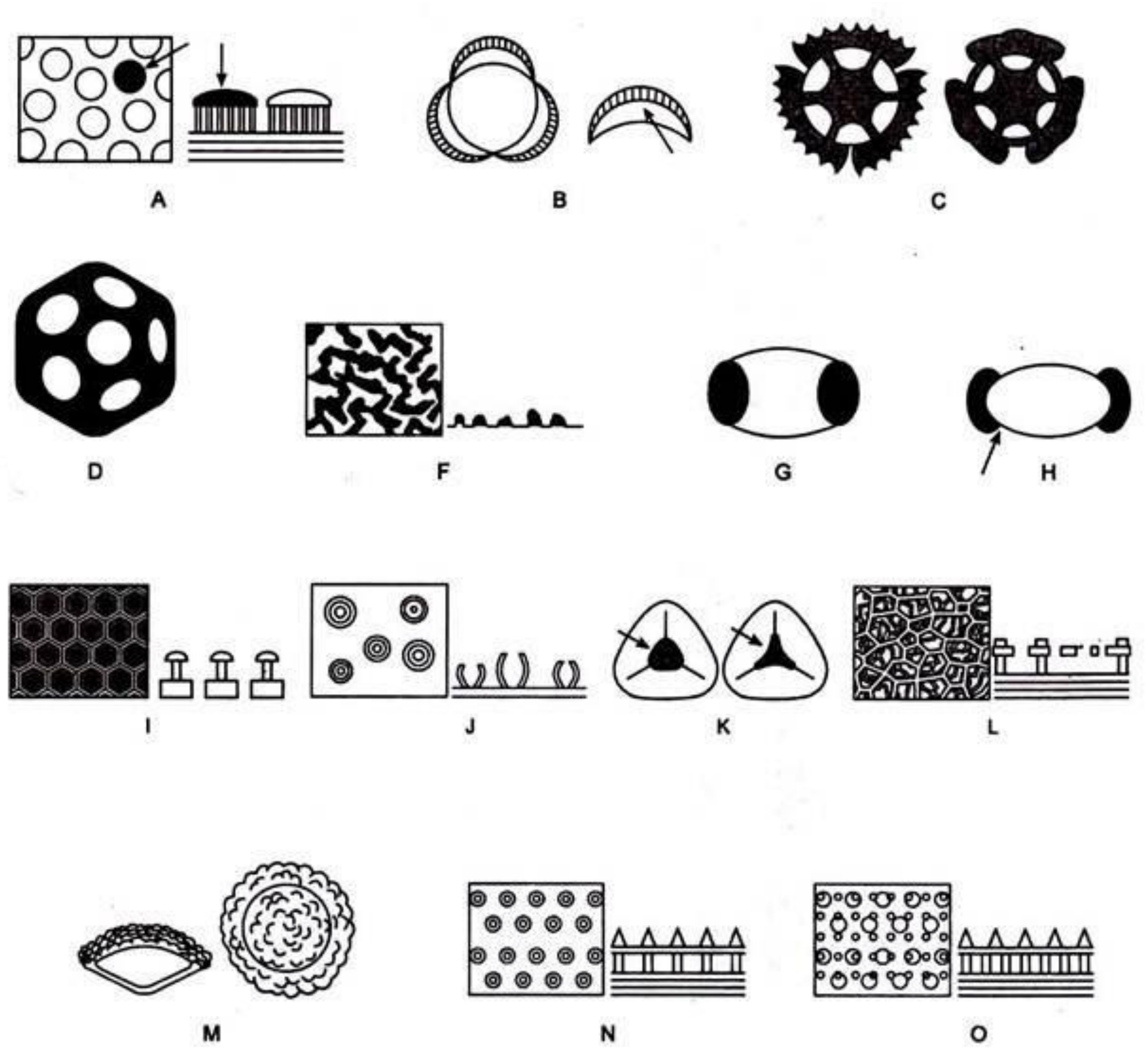


Fig. 4.21 : Other exine patters (A=Areolate, B=Caveate, C=Lophate, D=Fenestrate, F=Hamulate, G=Haploxylonoid, H=Diploxylonoid, I=Metareticulate, J=Urceolate, K=Polumbra, L=Bireticulate, M=Velum, N=Concordant pattern, O=Discordant pattern)

Lophate:

Describing a pollen grain in which the outer exine is raised in a pattern of ridges (lophae) surrounding depression (lacunae).viz. Taraxacum, Hieracium (Compositae). A lophate pollen grain with echinate (spines) ridges is called echinolophate, while a lophate pollen grain which lacks spines is known as psilolophate.

Fenestrate:

Describing a class of pollen grains characterized by large, window-like spaces lacking a tectum. The term is accepted as a category in the classification of Iversen and Troels-Smith (1950) which includes lophate pollen grains. This term is not recommended in descriptions and such pollen grains can be described as lophate.

Halo:
A clear zone around a well-defined feature such as spine or an aperture. Viz. Ranunculus (Ranunculaceae), Valeriana (Valerianaceae).

Hamulate:
Describing a form of rugulate ornamentation consisting of irregularly arranged, winding, or angular rounded muri of varying thickness, which do not form a distinct reticulum, but rather a maze-like pattern. Viz. Lycopodiella inundata (Lycopodiaceae). This term is mostly used in spore terminology.

Haploxylonoid (= Haploxylon-type):
Describing a bisaccate pollen grain in which the outline of the sacci in polar view is more or less continuous with the outline of the corpus, so that the grains appear a more or less smooth ellipsoidal form. Viz., Pinus, Picea (Pinaceae).

Diploxylonoid (= Sylvestris-type):
Describing a bisaccate pollen grains in which the outline of the sacci in polar view is discontinuous with the outline of the corpus, so that the grains seem to consist of three distinct, more or less oval parts.

Metareticulate:
A reticulum which is characterised by the consistent presence of one porate aperture in each lumen. Viz. Kallstroemia mexicana (Zygophyllaceae), Froelichia floridana (Amaranthaceae).

Urceolate:
Describing a type of ornamentation consisting of urn-shaped elements situated on the foot layer. Viz., Pinanga aristata (Arecaceae).

Polumbra:
A darkened triangular or subcircular area centred on the proximal pole. This feature appears to be most commonly observed in specimens that have lost a perisporal outer exoexinal layer. Viz., Retusotriletes distinctus.

Bireticulate:

A two layered reticulum consisting of a suprareticulum supported by a microreticulate tectum. viz., Entelea arborescens (Tiliaceae), Phyllanthus oppositifolius (Euphorbiaceae), Salvia azurea (Lamiaceae).

Velum:

A feature of a monosaccate pollen grain in which the saccus is convoluted. Viz., Tsuga (Pinaceae). The pollen having this feature is called velate.

Concordant pattern:

A pattern in a tectate pollen grain in which the arrangement of the columellae is the same as that of the elements upon the tectum. Viz. Lilium (Liliaceae).

Discordant pattern:

A pattern in a tectate pollen grain in which the arrangement of the columellae is different from that of the elements on the tectum. Viz. Geranium (Geraniaceae).

CHARACTERISTIC # 10. 'LO' ANALYSIS:

An optical section does not always make the fine structure of the sexine as clear as one might expect. A careful focusing through the sculpturing and patterning presented in a surface view of the grain provide a good deal of information.

Erdtman (1952) proposed the term LO-analysis (derived from two Latin words: lux means light and obscuritas means darkness) which is a method for analysing patterns of sexine organisation by means of light microscopy. This method is valuable for elucidating exine patterns. The surface types show the holes or lower areas to be dark and any raised areas or projecting elements to be light (Fig. 4.22).

On focusing carefully down through the exine their appearance would change due to a changing that diffraction images produced. For example, when focused at high level, raised sexine elements appear bright, whereas holes in the tectum are relatively dark (Fig. 4.22).

At lower focus holes become lighter and the sexine elements become darken (Fig. 4.22). If a reverse sequence occurred i.e. a pattern of ornamentation that appears to show "dark islands" at high focus and that become bright at low focus, it is given the term "OL- pattern". This system works very well as long as the pollen grains are embedded in such a medium having lower refractive index.

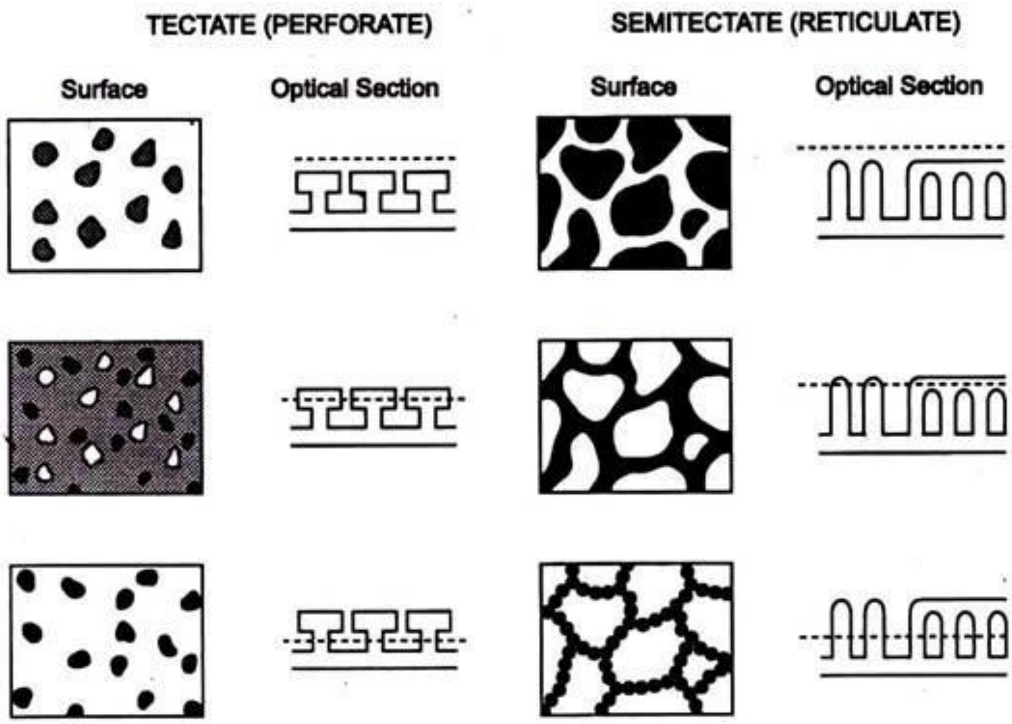


Fig. 4.22 : LO-analysis

QUESTION 2

There are a few geological fields in which palynology (i.e. pollens and spores) can be applied to, here are the major fields:

- Geochronology
- Biostratigraphy
- Paleoecology
- Quaternary Palynology

Geochronology - dating of rocks. Palynoflora are used to date rocks. Palynomorphs are great indicators of narrow time ranges because of the rapid evolution of the samples. Because they are present in rocks that don't usually have fossils, the microscopic fossils are used as a time range instead of waiting for complicated lab results.

Biostratigraphy - correlation of rock sections. This aspect of palynology is the most important economically. Proper identification of indicative palynomorphs could lead to the discovery of oil, coal, and gas deposits. In fact, fossilized pollen was first discovered in a coal thin section. Because pollen and spores have the tendency of being dragged along with migrating petroleum through porous rocks - they are good indicators that petroleum isn't too far away. The small sizes of palynomorphs are ideal for drill core samples. The colouration and type of palynomorph represents the thermal maturity and hydrocarbon potential of the area.

Paleoecology - past environments. Because palynomorphs are sensitive to any minor fluctuation in their surroundings, they are highly indicative of the environment in which they are deposited. The advantage of palynomorphs over other fossils is their widespread distribution; they can be found in either terrestrial, freshwater, saltwater, and estuary sources of sedimentary rocks.

Quaternary palynology - Although very similar to the purposes of paleoecology, Quaternary deals more with more recent environmental and climate change. This field of study uses quantitive analysis and precise dating for correlating stratigraphic sequences and reconstructing rats of environmental change. Studies show that the most influenced environmental changes have occurred since the appearance of humans.

Non-geological uses - archeaological palynology, forensic palynology.

QUESTION 3

As pollen and spores are produced in large numbers and dispersed over large areas by wind and water, their fossils are recoverable in statistically significant assemblages in a wide variety of sedimentary rocks. Moreover, because pollen and spores are highly resistant to decay and physical alteration, they can be studied in much the same way as the components of living plants. Identification of pollen and spore microfossils has greatly aided delineation of the geographical distribution of many plant groups from early Cambrian time (some 541 million years ago) to the present. Palynological studies using fresh or non-fossilized samples have also been useful in establishing a location or seasonal time frame for crime scenes and have served to determine the agricultural practices and other plant-related activities that occurred at archaeological sites.

Important, too, is the fact that the evolutionary sequence of organisms based on the large fossil remains of plants in sedimentary rocks is recorded by the sequence of plant microfossils as well. Such microfossils are thus useful in determining geologic age and are especially important in sediments devoid of large fossils. Because of their abundance and minute size, microfossils can be extracted from small samples of rock secured in drilling operations. Palynological analysis therefore is of practical application to petroleum exploration and to other geologic research involving subsurface sediments and structures. Palynology is also invaluable to evolutionary and taxonomic research and can help to delineate phylogenetic relationships between fossilized and extant plants.

In the oil industry, palynology is a stratigraphic tool especially useful in the study of rocks deposited in continental, coastal, and shallow-marine settings. Palynological analyses are used mainly for chronostratigraphic correlations, paleoenvironmental studies, and the evaluation of potential source rocks. The integration of palynology with other geological disciplines, such as sedimentology, geophysics, geochemistry, and petrophysics, is needed for geological modeling and petroleum system studies, which in turn are essential for planning and developing better exploration strategies and for optimizing reservoir exploitation.

The recent development of new geological concepts and methods, such as sequence stratigraphic analysis and high-resolution three-dimensional (3-D) seismic technology, has caused significant changes in stratigraphic work. In palynology, and in general in biostratigraphy, the classical qualitative or semiquantitative studies based on selected marker taxa have been enhanced with modern quantitative methods that use the whole palynological assemblage (including particulate organic matter), high-resolution sampling, and multivariate statistical methods.