**QUESTION. 1**

 **MORPHOLOGICAL CLASSIFICATION OF POLLEN AND SPORES**

1. **SHAPE, SIZE AND SYMMETRY OF POLLEN:** Size and shape of pollen are important diagnostic characters. The shape may be circular, triangular, etc., in polar view, whereas it may be per-oblate, spheroidal, sub-spheroidal, sub-oblate, oblate, oblate spheroidal, pro-late, pro-late spheroidal, sub-prolate, per-prolate, etc. in equatorial view. There is a considerable variation in the size of pollen in different plants. In modern flowering plants, the size of the pollen grains varies from about 5×2.4 µm to 200 nm or slightly more in certain members of Cucurbitaceae.Regarding symmetry, they may be symmetric or asymmetric Symmetric pollen as a rule may be either radially or bilaterally symmetrical. The bilateral pollen further may be plano­convex, concavo-convex or biconvex in lateral view.
2. **POLLEN ASSOCIATION:** Pollen associations, such as their arrangement in tetrads, presence of pollinia, etc. are characteristic of several angiospermic families. They are seen in diverse families of the dicotyledons, such as Annonaceae, Droseraceae, Mimosaceae, Monimiaceae and Winteraceae.However, in the monocotyledons, they are restricted to such advanced families as the Cyperaceae and Juncaceae. Extreme cohesion of pollen in the form of pollinia is seen in the Asclepiadaceae and Orchidaceae.

 These associations can be of the following types:

1. Monads — Single pollen grains which when mature, do not remain united with other pollen grains e.g. Poaceae.
2. Dyads — Pollen grains when united in pairs e.g. *Scheuchzeria* *palustris*.
3. Tetrads — When four pollen grains are united together.

 They may be further categorized into the following types.

1. Tetrahedral — One the pollen grains lie centrally over the other three e.g., Drimys.
2. Tetragonal (isobilateral) — All pollen grains lie in one plane in a bluntly quadrangular manner e.g., in monocotyledons.
3. Rhomboidal — e.g., *Anona muricata*.
4. Decussate (cross) — The pollen grains lie pair-wise at right angles to each other e.g., Magnolia grandiflora.
5. T-shaped — In this case, the first division of the PMC is transverse and a dyad cell is formed of which either the upper or the lower dyad cell instead of undergoing a transverse division, divides vertically or longitudinally, yielding either a straight, or inverted T-shaped configuration e.g., Aristotolochia polyanthus.
6. Linear — In this case, the first division is always transverse, giving rise to two dyad cells.

 The second division is also transverse, which results in a linear tetrad e.g., Mimosa pudica.

1. Pseudomonad (crypto tetrad) — It is a degraded tetrad in which monad-like tetrads are formed without dividing walls between the four components. One nucleus is normally developed, whereas the remaining three are obliterated e.g., Cyperaceae.
2. Massula (ae) — They are also called polyads. In this case each of the tetrad cells divides once or twice resulting in a massulae of 8-64 cells, which remain together after maturity and are held together in small units e.g., Mimosaceae.
3. Pollinium (ia) — This includes a unit of all grains produced by one theca (anther loculus). The pollinium apparatus is the functional unit of a **‘corpusculum’** with its two attached arms and pollinia e.g., Cryptostegia, Calotropis
4. **POLLEN NUCLEAR NUMBER**: The number of nuclei in the pollen grains at the time of their release is a valuable taxonomic and phylogenetic character. The number of nuclei in a pollen grain may be regarded as a function of the stage at which the pollen grains are released. In the angiosperms, the pollen shows a definite pattern at which stage a pollen is released, and they may be released either:
5. At the two-nucleate stage, before the division of the generative nucleus, or
6. At the three-nucleate stage, after the division of the generative nucleus.

**Further it has been found that:**

1. The three-nucleate pollen grains have arisen from the two-nucleate ones.
2. The change is irreversible.

The stage at which the pollen is released varies in different groups of angiosperms:

**Dicotyledons:** The pollen nuclear number do not show a definite pattern.

1. Certain orders have consistently tri-nucleate pollen grains, e.g. Asterales, Caryophyllales, Plumbaginales, Polygonales.
2. Some orders are heterogenous in having both two-and three-nucleate pollen and both the types may even occur in one and the same genus, as has been observed in Burmannia, Ipomoea and Lobelia.

**Monocotyledons:** In the Monocotyledons, the highly reduced wind-pollinated groups, aquatics and achlorophyllous saprophytes show the three-nucleate pollen grains.

1. **Apertural Forms:** The form, number, distribution and position of apertures are important palynological criteria in assessing relationships and phylogeny of plants. Almost all palynological discussions on plant relationships and phylogeny are based on the form, number, distribution and position of the apertures.Apertures are generally thin-walled areas in the outer pollen wall or exine, through which the pollen tube usually emerges at the time of germination.

 **There are two basic forms of apertures:**

 **Simple Apertures:**

 **Apertures are either long or short and rounded and may be of following types:**

1. **Sulcus:** It is an elongated latitudinal ectoaperture situated at the distal or proximal pole of a pollen grain. A sulcus has the same shape as a colpus, but differs in orientation [e.g. Nymphaea (Nymphaeaceae), Sparganium (Typhaceae)].

Sulcate grains are either:

1. Anasulcate (distal)
2. Catasulcate (proximal)
3. Zonosulcate (extend right around the grain)
4. **Ulcus:** A more or less rounded aperture situated at the distal or proximal pole of a pollen grain is termed ulcus and may be derived from a sulcus or a sulcoid aperture [e.g. Sparganium (Sparganiaceae), Typha (Typhaceae)].
5. **Colpus:** It is an aperture, which is long-furrow-like i.e. twice as long as broad (with a length and breadth ratio greater than 2) and the grain is referred to as colpate.

 Two basic types of pollen occur in the angiosperms:

1. Monocolpate — It is a characteristic of the monocotyledons and some dicotyledonous families such as woody Ranales, and have a single furrow on one side of the pollen remote from the point of contact in the tetrad.
2. Tricolpate — It is a characteristic of most of the dicotyledons, and are provided with three meridionally placed furrows.

Two other types of pollen also occur, which are considered to have been derived from both the monocolpate and tricolpate types as a result of specialization.

**They are:**

1. Acolpate -They are pollen without a furrow.
2. Pantocolpate – They are pollen with many furrows.

**PORE:** It is a circular or elliptic aperture is short with length and breadth ratio less than 2 and the pollen grain is called porate [e.g. Myrica gale (Myricaceae)].

Compound Apertures:

They are apertures consisting of an outer or marginal colpal (furrow-like) part and an inner or central distinctly delimited oral part. Ora are either circular or lalongate i.e., transversely elongated endoaperture [e.g. Filipendula (Rosaceae)] or lolongate i.e., longitudinally elongated endoaperture [e.g. Rumex spp. (Polygonaceae)]. In relation to ora, the furrows or apertures will be named colporate or perorate.

The position of the apertures varies in different groups of plants and may be:

**Proximal**: Found in uniaperturate forms and in terms of evolution are the most primitive. They are found in the gymnosperms and monocotyledons.

**Zonal:** Found in multiaperturate forms and are found in the dicotyledons. In this case the furrows or pores are situated along the equatorial line.

**Global:** Found in multiaperturate forms and are found in the dicotyledons. In terms of evolution, they are the most advanced. The furrows or pores are distributed over the entire surface in this type.

**Monoaperturate:** They are characteristic of the monocotyledons and some members of Magnoliidae. Uniaperturate pollen grains have a single germinal furrow or pore situated at the proximal or distal position.

**Triaperturate:** The triaperturate or triaperturate-derived pollen grains occur in most of the dicotyledons and are unknown elsewhere. These pollen grains have three germinal furrows, either radiating like the lines of a trilete mark from a common point or forming a triangle at the distal position. Some less common types have been derived from the triaperturate form.

**Multiaperturate:** The multiaperturate type results from cross-partitioning of one germinal furrow into several. It is found in both monocotyledons and dicotyledons.

**Diaperturate:** The diaperturate type also results from cross-partitioning and is found in certain monocotyledons.

Nonaperturate:

The non-aperturate type results from progressive shortening and eventual elimination of the furrow and is found in both monocotyledons and dicotyledons.

The various types of apertural morphoforms provide one of the best taxonomic criteria in routine taxonomic work, being often constant, not very variable and easily visible under a microscope.

1. **EXINE STRATIFICATION:** The pollen wall or sporoderm is generally layered (stratified). In angiosperms, it consists of two layers the outer resistant layer composed of sporopollenin, known as exine and the inner more or less cellulose layer called intine.Topographically, the exine consists of two well-defined sub-layers the outer sculptured sexine or ektexine and the inner non- sculptured nexine or endexine.The sexine further consists of two main parts a partially or wholly covering layer called tectum below which, are the rods or rod like elements called bacules. According to Walker, there are three basic types of pollen based on the characteristic of tectum.

**They are:**

1. Tectate — have a continuous tectum. Tectate pollen may be either
2. Tectate-perforate
3. Tectate-imperforate
4. Semitectate — tectum is not continuous.
5. Intectate — without an apparent tectum.

The trend of exine evolution is from tectate-imperforate to tectate-perforate to semitectate and, more rarely, to intectate pollen. The sculpturing of the external substance (exine) of pollen grains presents a remarkable series of microscopic characters and may vary from family to family.

Commonly, the family and often the genus may be identified by the pollen grains. In general, angiosperm pollen grains have a massive exine and a thin intine.

However, certain taxa among Monocotyledons are unique in having a highly reduced exine and an elaborate intine e.g. Amaryllidaceae, Cannaceae, Costaceae, Heliconiaceae, Iridaceae, Marantaceae, Musaceae, Strelitziaceae and Zingiberaceae. Further the pollen in anemophilous group is smooth and thin, whereas the ones distributed by insects or -birds, are characterized by various types of sculpturing on the exine.

 **NPC CLASSIFICATION OF POLLEN AND SPORE**

NPC is an artificial system of classification of pollen and spore based on the three features of aperture only, i.e. number, position and character. Erdtman and Straka (1961) proposed NPC classification and palynologists all over the world accepted it.

According to NPC system each pollen grain has an arithmetic cardinal number consisting of three digits. The first digit reveals the absence or presence of aperture, and when present it mentions the total number of aperture(s) present in a pollen grain.

The second digit illustrates the position of aperture(s), i.e. distal, proximal, and latitudinal, meridonial, equatorial etc. The microspores reveal the position of aperture(s) with full clarity when they are in tetrad. The third digit explains the character of an aperture, i.e. circular/oval or elongated, simple or compound etc. ‘N’ from number, ‘P’ form position and ‘C’ from character of aperture compose the NPC-classification.

1. **CLASSIFICATION BASED ON NUMBER(S):** In NPC system ‘N’ denotes the number (N; L. numerus) of aperture(s) present in a pollen grain. Aperturate pollen, i.e. pollen having apertures are divided into seven groups. The groups are mentioned as N1 to N7. Each group has characteristic number of apertures, i.e. N1has one aperture and N2 has two apertures and so on. The N7 group has seven or more apertures.N1 to N7 groups are also referred to respectively as monotreme, ditreme, tritreme, tetratreme, pentatreme, hexatreme, and polytreme (Greek trema means hole, opening, aperture; pl. tremata).

There are pollen grains where apertures are absent. Such pollen grains are termed as inaperturate or atreme and they are placed in N0 group. Another special group N8—termed anomotreme is created where the pollen grains and spores have one or several irregular or irregularly spaced apertures.

1. **CLASSIFICATION OF APERTURE BASED ON POSITION:** In NPC system ‘P’ denotes the position (P; L. position) of aperture in a pollen grain and spore. The position may be proximal, distal and equatorial. There are seven groups of apertures based on position namely –P0 to P6. Pollen grains having P0 group have uncertain or unknown position of aperture. P1 groups of pollen and spores are catatreme (Gr. Kata = down; -treme is suffix used as a synonym of aperture). Catatreme pollen grains have one aperture that occurs on the proximal part of a grain. The proximal (L. proximus, nearest) part is the face of a pollen grain or spore that faces inward/nearest or toward the center of tetrad. P2 groups of pollen and spores are anacatatreme (Greek ana = up). Anacatatreme pollen and spores have two apertures.One aperture with its center occurs at the proximal pole. The other aperture with its center occurs on the distal pole. The distal (L. distalis, remote, outer) part is the face of a pollen grain and spore that faces outward, i.e. away from the center of tetrad and opposite the proximal part (Fig. 4.31). P3 groups of pollen and spores are anatreme, i.e. the aperture is distal in position.P4 groups of pollen and spore are zonotreme. A zonotreme (zono-a prefix used to indicate the equatorial/subequatorial region) pollen grain is characterized in having apertures on equator or sub-equator. The equator is the part of a pollen grain or spore that runs midway between the proximal and distal poles and perpendicular to polar axis. P5 groups of pollen and spore are dizonotreme. Dizonotreme pollen grains have apertures arranged in two or more zones. The apertures occur parallel to equator. P6 groups of pollen and spore are pantotreme (Greek pan, gen. Pantos, all, wholly). Pantotreme pollen grains have apertures scattered over the whole surface uniformly. As a rule, pantotreme pollen grains are spheroidal.



1. **CLASSIFICATON BASED ON CHARACTER:** In NPC-system ‘C’ denotes the character (C; L. character) of an aperture in a pollen grain and spore. The character groups of pollen and spore are seven and they are mentioned as C0toC6. C0 groups have apertures whose character cannot be established with certainty. C1 groups of pollen and spore have leptoma (Greek leptoma means thin place).Leptoma is a thin area, aperture like and functions like an aperture. Pollen grains having one leptoma are termed as monlept. The leptoma may occur on either proximal-or distal face of a pollen grain and spore and accordingly termed as catalept and analept. C2 groups are trichotomocolpate (Gr. Tricha, in three parts; tome, cut; kolpos, depression, furrow).Trichotomocolpate is a three- branched aperture, the branches of which are more than two times longer than breadth. Trichotomocolpate pollen and spores having aperture on porximal face are termed as trilete.The group C3 has colpate grains. The group C4 comprises porate pollen grains. The group C5 comprises colporate pollen. The group C6comprises pororate pollen. C3, C4, C5 and C6 groups of apertures are previously discussed under aperture.



In NPC classification a grain is mentioned in three-digit number (Figs. 4.28, 4.29 & 4.30), e.g. 343 instead of N3P4C3. Pollen grains having NPC 343 are tritreme zonocolpate, which is also described as tricolpate pollen.

NPC 764 characterizes those pollen grains that are polytreme pantoporate, which are also described as pantoporate or polyporate. Pollen grains of Amaranthaceae, Chenopodiaceae etc. have NPC 764. Examples of tricolpate pollen grain, i.e. NPC 343 are Rumex, Vitex, Tectona, Argem one etc.

**QUESTION. 2**

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

 **SIGNIFICANCE OF POLLEN AND SPORES IN GEOSCIENCES**

Most pollen grains consist of three distinct parts. The central cytoplasmic part is the source of nuclei responsible for fertilization. The other parts [constituting](https://www.merriam-webster.com/dictionary/constituting) the wall of the grain are an inner layer, the [intine](https://www.britannica.com/science/intine), and an outer layer, the [exine](https://www.britannica.com/science/exine). The intine consists, at least in part, of [cellulose](https://www.britannica.com/science/cellulose) or [hemicellulose](https://www.britannica.com/science/hemicellulose). The outer and most durable layer, the exine, is very resistant to disintegration; treatment with intense heat, strong acids, or strong bases has little effect upon it. The [constituents](https://www.merriam-webster.com/dictionary/constituents) of the exine have been termed [sporopollenins](https://www.britannica.com/science/sporopollenin). The internal parts of the pollen grain are easily broken down, whereas the exine layer, and thus the general form of the pollen grain, is easily preserved in various kinds of sediments; the quality of preservation may vary with different [environments](https://www.merriam-webster.com/dictionary/environments).

Because of their high resistance to decay, their widespread dispersal by wind and water, and their abundant production by [plants](https://www.britannica.com/plant/plant), pollen grains are very commonss constituents of geologic [sediments](https://www.britannica.com/science/sedimentation-geology), both recent and ancient. Because of these features, pollen grains have provided much information on the origin and geologic history of terrestrial plant life. Additionally, given their remarkably symmetrical structure and surface patterns, fresh and preserved pollen grains are readily recognizable under the [microscope](https://www.britannica.com/technology/microscope). Characteristics such as the exine sculpturing and the size and number of apertures through which the pollen tubes grow are useful as taxonomic tools. The structure of a pollen grain is oftentimes so distinctive that in some cases species may be identified by pollen grains alone. Nearly all [angiosperm](https://www.britannica.com/plant/angiosperm) and [gymnosperm](https://www.britannica.com/plant/gymnosperm) plant families and many genera can be identified solely by their pollen grains. The study of pollen and [spores](https://www.britannica.com/science/spore-biology) is known as [palynology](https://www.britannica.com/science/palynology).

 **SIGNIFICANCE OF POLLENS AND SPORES IN PETROLEUM GEOLOGY**

Pollens and spores in the oil industry is a stratigraphic tool especially useful in the study of rocks deposited in continental, coastal, and shallow-marine settings.

Pollen and spore analyses are used mainly for chronostratigraphic correlations, paleoenvironmental studies, and the evaluation of potential source rocks. The integration of palynology with other geoscience disciplines, such as sedimentology, geophysics, geochemistry, and Petro physics, 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. This also will enhance detection of hydrocarbon accumulation in subtle traps and permit better prediction of the lateral variability in quality of reservoir rock than is achievable only with the classical litho-seismic stratigraphic approach, thereby leading to increased oil reserves.

The study of fossil flora record of sedimentary rocks has diverse range of applications in geology including biostratigraphy, geochronology (to correlate strata and determine the relative age of a bed, horizon, formation or stratigraphic sequence), paleoecology and climate change, organic palynofacies studies, geothermal alteration studies (to examine the color of palynomorphs extracted from rocks to give the thermal alteration and maturation of sedimentary sequences). This is especially true because the floristic component of layered rocks occur in high abundance permitting the use of only little amount of sample and statistical analysis.

 **APPLICATION OF POLLENS AND SOPORES IN STRATIGRAPHY AND**

 **STRATIGRAPHY**

Pollens and spores offers a plethora of applications in the study of the evolution of life, relative dating (biostratigraphy), paleobiology, paleoenvironment, paleogeography, paleoclimatology, and geological resources (hydrocarbon production). Because acid dissolution of a rock or sediment sample is a chemically selective process, the resulting organic residue is usually composed of a broad variety of material of plant and animal origin within the same sample. It is not uncommon to recover marine palynomorphs from terrestrial settings by erosion and redeposition of older marine rocks, and terrestrial palynomorphs can be transported by air and water into nearshore marine settings.

* Pollen and spores represent the most important group of microfossils in terrestrial settings. Beside scolecodonts, they differ from any other palynomorph group as they do not represent individual organisms, but rather reproductive structures produced during the life cycle of plants. Spores (Playford and Dettemann, 1996) are produced by cryptogams (the so-called lower plants), which include bryophytes (mosses, liverworts, and hornworts) and pteridophytic vascular plants (ferns, lycopsids, and Methods in Paleopalynology and Palynostratigraphy 131 horsetails).
* Pollen (Jarzen and Nichols, 1996), on the other hand, is produced by seed plants, the

gymnosperms (conifers and older relatives) and angiosperms (flowering plants). Because terrestrial plants are affixed to their substratum, their reproduction and dispersion relies on the propagation of pollen and spores, which are produced in vast numbers and released into the environment, traveling widely and rapidly in wind and/or water, and eventually settling on the surface of the land and on water bodies, including places where preservation is most likely, such as at the bottom of ponds, lakes, rivers, and oceans. The fact that they are very resistant, microscopic, produced in large numbers, and disseminated over large areas makes them an ideal biostratigraphic group. The outer wall of pollen and spores (the exine), is made of sporopollenin, one of the most resistant and chemically inert biopolymers. Whereas pollen and spores are mostly produced by land plants (embryophytes), it is not uncommon to recover them from nearshore marine deposits where they may be transported by river systems into estuaries and coastal lagoons. The broad range of dispersal of pollen and spores make terrestrial to marine correlation possible, and is one of their most valuable biostratigraphic functions.

* Pollen and spores are also useful paleoecological and paleoenvironmental markers when they can be linked to a parent plant, and when the ecology of that parent plant is known.
* pollen and spores are referred to using the term miospores, sporomorphs, or sometimes sporopollen in the Chinese literature. Spores appear very early in the fossil record, associated with the colonization of land by the first terrestrial plants. The oldest known forms of spore like bodies are called cryptospores, from the Middle Cambrian (500 million years old, Strother, 2016). The first trilete spores appear in the late Ordovician.

Whereas palynological evidence is the oldest indication for the existence of true land plants, the first fossils of macroscopic land plants, the Cooksoniales, is recorded later during the Middle Silurian (!425 million years,). The temporal disconnect or delay between the first appearance of a plant group in the palynological record and its later appearance as macrofossils is a recurrent observation in the rock record. This delay can be simply explained by a taphonomical bias, as pollen and spores offer a better preservational potential than the presumably small and delicate parent plants. Although some cryptospores resemble the spores of modern bryophytes (Gray, 1985; Richardson, 1992; Renzaglia et al., 2015), their botanical affinity is still highly debated. Nonetheless, they remain of great use for biostratigraphy and correlation of early Paleozoic terrestrial and nearshore marine deposits (Richardson, 1996; Streel and Loboziak, 1996; Loboziak et al., 2004). Just as paleontologists have subdivided the Phanerozoic into three major eras, the Paleozoic, Mesozoic, and Cenozoic, each representative of revolutions in faunal assemblages, introducing the next revolution initiated by the emergence of the gymnosperms (conifers, cycadophytes, pteridospermaphytes, Caytoniales, etc.) and their associated corte`ge of pollen grains during the late Carboniferous (Clayton, 1996; Owens, 1996;). One of the notable characteristics of the late Paleozoic floras is the appearance of taeniate (¼ striated) pollen near the end of the Carboniferous, which persists up to the end of the Triassic (Warrington, 1996a,b; Playford and Dino, 2004). The last floral revolution is marked by the first significant appearance of angiosperms (flowering plants) in the early Cretaceous and a rapid diversification from the mid-Cretaceous (Batten and Koppelhus, 1996; Batten, 1996a; Frederiksen, 1996;).

Pollen and spores are retrieved from and isolated in sediments, disconnected from their parent plants, meaning that their natural affinities are often obscure. The principle of anatomical connection (e.g., extracting pollen from a fossilized cone or flower), or the use of modern analogues (comparison with extant plants), can help to elucidate the botanical relationship of specific pollen and spores taxa. As is common in paleobotany, where organs are preserved individually and disconnected rather than in the form of entire organisms, a paranomenclatural system based on form taxa has been developed, similar to the way that vertebrate paleontology has its own naming conventions for ichnotaxa and ootaxa. Potoni!e developed an informal, artificial classification of spores and pollen based on morphological traits, called the turmal system. The problem of identifying parent plants has led to major differences in methods employed for Quaternary (palynology) and pre-Neogene (paleopalynology). In the former, almost all taxa recorded are from extant species, whereas Methods in Paleopalynology and Palynostratigraphy 133 in the latter, the taxa are almost invariably extinct. Thus palynologists use natural genera and species whereas paleopalynologists use form taxa, and many use the turmal system, especially for Paleozoic and Mesozoic taxa. In a similar way, palynologists use a very different approach to palynostratigraphy. Quaternary dating and correlation strongly rely on relative abundance counts (formally called pollen analysis, and represented in a pollen diagram) and the recognition of changing climate indicated by shifts in marker species, whereas studies in deep time traditionally rely on the description of the first and last occurrence of taxa (originations and extinctions) in the stratigraphic record (albeit the benefit of using relative abundance counts is being acknowledged.