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Review Article

Pollen – A microscopic wonder of plant kingdom

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Abstract

Palynology is a century old science and there are many opportunities for its practical application. The study of the symmetry, polarity, shape, size, structure, sculpture and of the apertures of the sporoderm can be very useful to many other sciences (Botany, Oceanography, Limnology, Pedology, Geology, Paleontology, Ecology, Melittology, Entomology, Archaeology, Aerobiology, Allergology, Criminology, etc.). Pollen is an indicator which enables researchers to study the phytogeography of the past, plant evolution, climates, rock and soil characteristics, air pollution levels, plant-insect relationships and the botanical and geographical origin of bee products .

Keywords: Palynology, Pollen, Basic Palynology, Applied Palynology

Introduction

The pollen is the most vital part in the flowering plants with a special structure and function. In the words of Linnaeus (1751), they are microspores of seed plants. Pollen is a single cell, containing the microgametophytes of seed plants, which produce the male gametes (sperm cells). Pollen grains have a hard coat, the *exine*, which protects the sperm cells during the process of their movement from the stamens to the pistil of flowering plants or from the male cone to the female cone of coniferous plants. On the other hand, the exine embodies in it such morphological characteristics that serve to identify the plant it belongs to, thus becoming useful in studies of plant taxonomy and several other applied aspects of pollen studies. When pollen lands on a compatible pistil or female cone (i.e., when pollination has occurred), it germinates and produces a pollen tube that transfers the sperm to the ovule (or female gametophyte).

Individual pollen grains are small enough to require magnification to see detail. Thus, they are carrier of genetic material from one generation to the other and are, thus, important entities in the biological cycle of flowering plants. They are minute, almost impossible to see without a high-powered microscope, and remain hidden beyond the beauty of the flower until the moment of release.

The study of pollen is called palynology, a term introduced by Hyde and Williams in 1944, following correspondence with the Swedish geologist Antevs, in the pages of the Pollen Analysis Circular (one of the first journals devoted to pollen analysis, produced by Paul Sears in North America). Hyde and Williams chose palynology on the basis of the Greek words παλύνω paluno meaning 'to sprinkle' and παλη pale meaning 'dust' (and thus similar to the Latin word

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pollen) (Hyde and Williams, 1944). The word pollen comes from a Latin derivative meaning fine flour or dust (Jarzen & Nichols 1996). Grammatically, the word pollen is a collective noun and is always treated as a singular noun, although it refers to many individuals. A single individual is called a pollen grain(Jones and Jones, 2001). Palynology is the study of pollen grains produced by seed plants (angiosperms and gymnosperms) and spores (pteridophytes, bryophytes, algae and fungi).

Pollen structure and form

Pollen grains come in a wide variety of shapes (most often spherical), sizes, and surface markings characteristic of the species (clearly visible only under scanning electron microscopy whereas it is coarsely seen under highly magnified light microscopes). The wall of this cell is composed of primarily two layers: inner intine and outer exine. Inner wall is rich in cellulose whereas outer wall is largely composed of a tough resistant biopolymer called sporopollenin (Zetsche, 1932; Brooks, 1971; Shaw, 1971; Brooks & Shaw, 1978; Guilford *et al.*, 1988; Hemsley *et al.*, 1992; Piffanelli *et al.*, 1997, 1998; Domínguez *et al.*, 1999; Ahlers *et al.*, 2003; Boavida *et al*., 2005) which is responsible for this resilience enabling them to survive for a long time in the sediments. Exine has the rare capacity to sustain heat upto 3,000^{o}C (Shackley, 1981; Nayar, 1990). It is due to the presence of sporopollenin with its peculiar structural chemistry that spores could be located even in the Palaeozoic rocks of some 500 Ma old without being destroyed, where all other organic materials remain carbonized and distorted (Faegri and Iversen, 1989).

The pollen wall protects the sperm while the pollen grain is moving from the anther to the stigma; it protects the vital genetic material from drying out and solar radiation. The pollen grain surface is covered with waxes and proteins, which are held in place by structures called sculpture elements on the surface of the grain. The outer pollen wall, which prevents the pollen grain from shrinking and crushing the genetic material during desiccation, is composed of two layers (fig. 1). These two layers are the tectum and the foot layer, which is just above the intine. The tectum and foot layer are separated by a region called the columella, which is composed of strengthening rods (Erdtman, 1952; Faegri, 1956) (fig. 1).

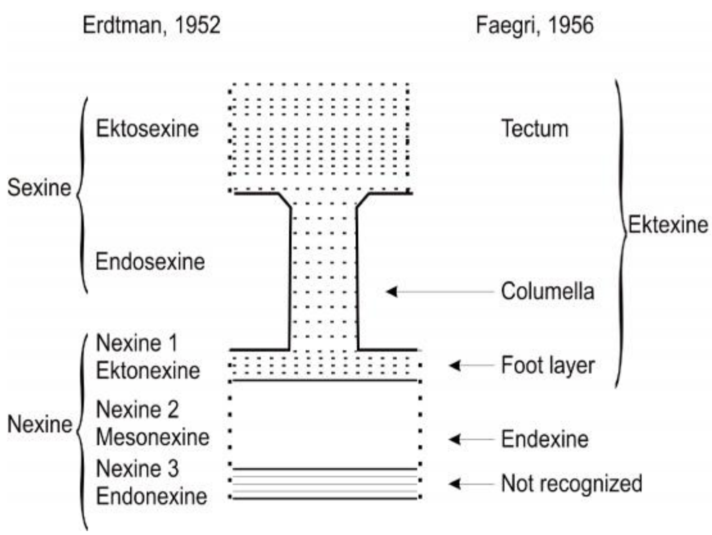

Fig. 1. Pollen wall stratification

Traditional palynology usually characterizes apertures by their number (numerus), position (position) and shape (character); the NPC system is fundamental in pollen description (Erdtman, 1969). The pollen tube passes through the wall by way of structures called apertures. Pollen apertures are various modifications of the wall of the pollen grain that may involve thinning, ridges and pores. They serve as an exit for the pollen contents and allow shrinking and swelling of the grain caused by changes in moisture content. Morphologically it is an opening or a thinning of exine (except in operculate apertures) where the intine is thickened; physiologically it could be either a germinative zone or a harmomegathus, or both (Thanikaimoni, 1987). The elongated meridonial apertures/ furrows having length/breadth ratio >2 in the pollen grain are called colpi (singular: colpus), which along with simple pores with length/breadth ratio <2, are a major criterion for the identification of classes of pollen. It is called as germinal furrow by Erdtman (1943). The pores are equatorial in position. When they are distributed over the entire surface of the pollen grain, then it is termed as periporate (Thanikaimoni, 1987). No aperture condition is termed as Omniaperturate where the entire surface of the pollen being apertural in nature with an uniformly thin ±1 membranous exine (excluding the sculptural elements, if any) underlain by an uniformly thick intine (except when fully not developed) (Thanikaimoni, 1978; Thanikaimoni *et al.*, 1984) (fig. 2).

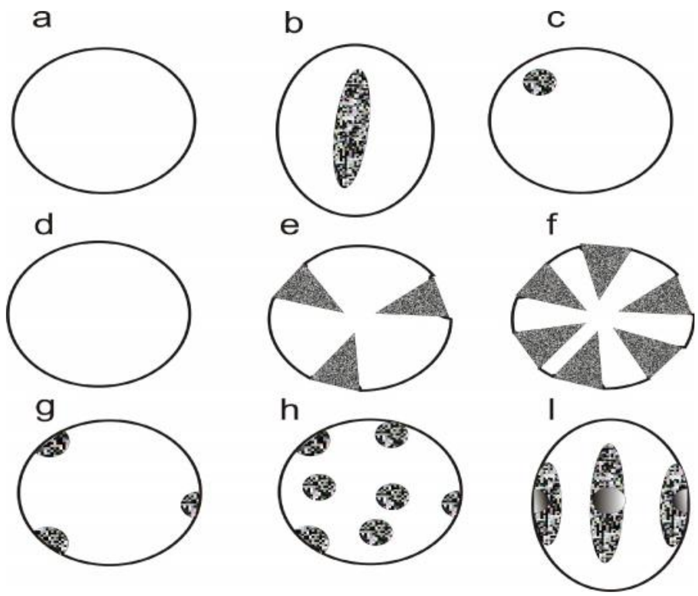

Fig. 2: Apertural morphology of pollen grains most often encountered in the monocots (a-c) and the dicots (d-i). a=inaperturate/omniaperturate; b =monocolpate; c =monoporate; d =inaperturate; e =tricolpate; (polar view); f =polycolpate (polar view); g =triporate (polar view); h=pantoporate (many scattered pores); i=tricolporate (equatorial view).

Pollen is a 3-D structure and having different size and shape. Pollen polarity refers to the spatial difference in the shape, structure and function of pollen grains. At first the pollen grains resulting from the meiotic division of mother cells are gathered into groups and they can remain like this; forming diads, tetrads or polyads (Fig. 3). The tetrads (four granules) can be tetragonal (*Typha*), tetrahedrical (*Erica*) or rhomboidal (*Calluna*); the polyads can be formed by a larger number of granules (8-10-12-16-24-32) (*Acacia*). Observing the position that the pollen grain first has in the tetrahedrical agglomerate, 2 poles are noted: the proximal and the distal. If the poles are equal, the pollen is defined as isopolar and if they are unequal as anisopolar. Spherical pollens have no polarity (apolar).

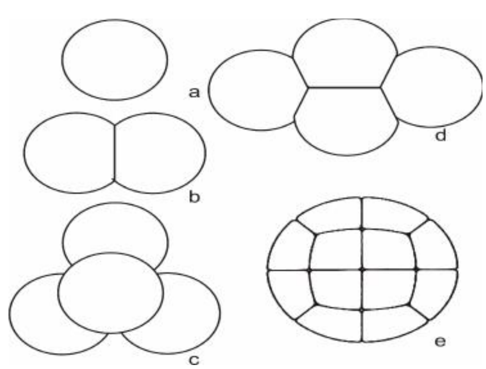

Fig. 3: Main kinds of pollen: a) monad; b) diad; c) tetrahedric tetrad; d) tetragonal tetrad; e) polyad.

Polar axis is a imaginary line between the proximal and distal poles whereas equatorial axis is the greatest axis, perpendicular to the polar axis, except when pollen is considered at the equator (Thanikaimoni, 1987) (fig. 4). The ratio between the polar axis and the equatorial diameter of a pollen gives us the shape of the pollen. Pollen shapes have been classified as follows (Erdtman, 1952) (Table 1):

Table 1. Shape classes and suggested relations between polar axis (P) and equatorial diameter (E) (Erdtman, 1952):

Shape classes	**P/E**	**100*P/E**
Peroblate	<4/8	<50
Oblate	4/8-6/8	50-75
Suboblate	6/8-7/8	75-88
Oblate spheroidal	7/8-8/8	88-100
Prolate spheroidal	8/8-8/7	100-114
Subprolate	8/7-8/6	114-133
Prolate	8/6-8/4	133-200
Perprolate	>8/4	>200

When observed in polar view, a pollen grain will have one of the following shapes: circular, semiangular, interexagonal, angular, interangular, semilobate, intersemilobate, lobate, interlobate, exagonal, intersemiangular, subangular and intersubangular (Kremp, 1965; Faegri and Iversen, 1989). Size of the pollen grains vary greatly, but are generally divided into six categories, although this number could be increased (Kremp, 1965) (Table 2):

Table 2. Size category of pollen grains (Kremp, 1965):

Size (μm)	**category**
<10	very small pollens (*Myosotis*)
10 – 25	small pollens (*Salix*)
25 – 50	medium pollens (*Quercus*)
50 – 100	large pollens (*Zea*)
100 – 200	very large pollens (*Cucurbita*)
> 200	giant pollens (*Mirabilis*)

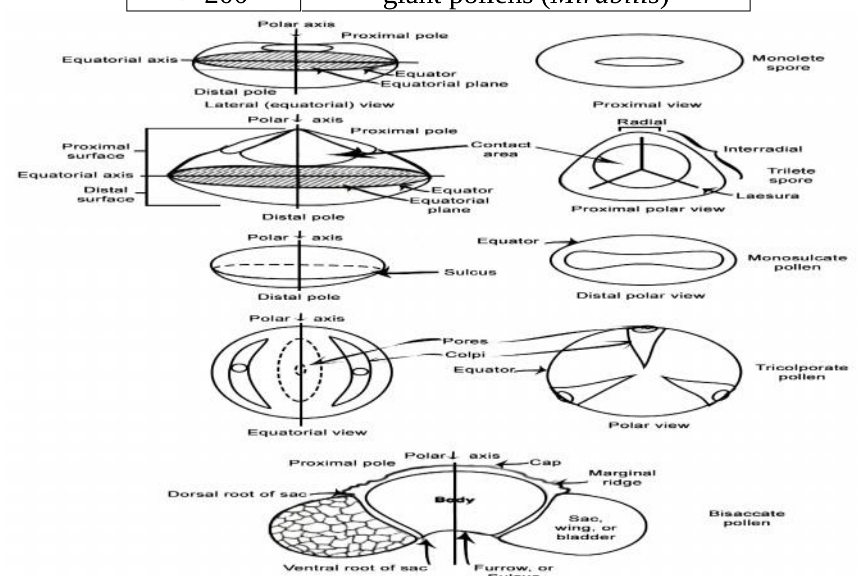

Fig. 4. Polarity and shape of pollen and spores modified after Tschudy & Scott, 1969; Sandersen, 2003.

Divisions of Palynology

Palynology can broadly be categorized into basic palynology and applied palynology. Basic palynology deals mainly with the morphology of pollen and spores, the theoretical aspects of applied palynology, productivity, viability and the resistance of pollen and spores. Applied palynology is further classified into several subdivisions. Advances in microscopy have enhanced its application potential to the extent of various botanical and geological sciences. Palynology is used for a diverse range of applications, related to many scientific disciplines:

- Entomopalynology – study of pollen found on the body or in the gut of insects.
- Melissopalynology – the study of pollen and spores found in honey.
- Aeropalynology – the frequency and distribution of pollen and spores in air.
- Iatropalynology – Allergy studies: Studies of the geographic distribution and seasonal production of pollen can help sufferers of allergies such as hay fever.
- Pharmacopalynology – role of pollen and spores in drugs.
- Forensic Palynology – the study of pollen and other palynomorphs for evidence at a crime scene.
- Copropalynology – pollen and spores in excrements.
- Palynotaxonomy – Taxonomy and evolutionary studies.
- Geo or palaeopalynology
- Biostratigraphy and geochronology.
- Palaeoecology and climate change.
- Organic palynofacies studies.
- Geothermal alteration studies.
- Archaeological palynology.

Entomopalynology

Entomopalynology is the branch of palynology which studies the pollen found on the insect body or in the gut of insects, and provides important information on their migratory activity as well as their feeding behavior (Pendleton *et al.*, 1996; Jones, 2006). Pollen can be used to determine pollination mechanisms, foraging resources, migration routes and source zones of insects and other pollinators (Jones and Jones, 2001). This study is highly important as the invasive insects pose threats to native biodiversity, fruit and wine production and human health (Brown & Miller, 1998; Colunga-García and Gage, 1998; Yarbourgh *et al.*, 1999; Koch, 2003; Galvan *et al.*, 2008). A detailed extraction procedure for pollen recovery from insects can be found in Jones (2012a, 2012b). A pollen atlas (Jones *et al.*, 1995) also was published to assist research involving the association of pollen and insects.

Entomopalynology can be categorized into two based on the analyses: Internal pollen analyses and External pollen analyses. Internal pollen analyses include examination of the digestive tract or alimentary canal of insects such as boll weevils, *Anthonomus grandis* Boheman, (Cate and Skinner 1978, Rummel *et al.*, 1978; Benedict *et al.*, 1991, Jones *et al.*, 1992, Jones *et al.*, 1993), hoverflies, *Melanostoma* spp. (Holloway, 1976; Gilbert, 1981; Cowgill *et al.*, 1993; Wratten *et al.*, 1995; Irvin *et al.*, 1999), and lady beetles *Chilocorus kuwanae* (Silvestri), (Nalepa et al 1992) is an effective technique in determining foraging resources. External pollen analyses include examination of exterior of the insects especially moth (Lingren *et al.*, 1993; Luo *et al.*, 2011), butterflies (Gilbert, 1972; Boggs *et al.*, 1981; Estrada and Jiggins, 2002; Hikl and Krenn, 2011), wasps (Jones and Pucci, 2012) and Spider (Smith and Mommsen, 1984).

Melissopalynology

Melissopalynology is the branch of palynology which studies the botanical and geographical origin of honey by subjecting honey sediment, and therefore pollen and the other fungi imperfecti contained therein, to microscopic analysis. Microscopical analysis of honey provides information about the geographical origin of honey and about the botanical origin of honey. Microscopical analysis allows additional information about any contamination of honey with brood, dust, soot, etc.; about the yeast content (fermentation); and about other microscopic particles not usually present in honey (Louveaux *et al.*, 1978). Some years ago researchers realized that melissopalynology could be used not only to ascertain whether a honey sample was produced in Italy or elsewhere and whether it was unifloral or multifloral, but also to designate its geographical origin quite precisely and so the idea of quality honeys with controlled geographical denomination began to take shape (Ricciardelli D'Albore, 1987, 1997, 1998).

The earliest research on the pollen analysis of honey was undertaken by Pfister in 1895; since then various other researchers have devoted themselves to this subject (Fehlman, 1911; Armbruster and Oenike, 1929; Armbruster and Jacobs, 1934-35; Griebel, 1931). The most authoritative of these researchers is certainly Zander, whose works (1935, 1937, 1941, 1949, 1951) are still the main reference point for whoever is interested in this subject.

For an indicative sample evaluation the computation of about 100 pollen grains should be sufficient. It is necessary to count 200-300 pollen grains to determine the frequency classes. The following nomenclature is used when determining the frequency classes (Louveaux *et al.,* 1978):

Table 3. Pollen frequency class (Louveaux *et al.,* 1978):

Frequency class	**Percentage**
very frequent pollen	>45%
frequent pollen	16-45%
isolated pollen	4-15%
rare pollen	<3%

For a precise percentage calculation 1000-1200 pollen grains have to be counted (Vergeron, 1964; Louveaux *et al.,* 1978) and the following terms are adopted:

Table 4. Pollen frequency class (Vergeron, 1964; Louveaux *et al.*, 1978):

Frequency class	**Percentage**
predominant pollen	>45%
accompanying pollen	16-45%
important isolated pollen	4-15%
isolated pollen	<3%

According to the total number of plant elements, honeys are placed into one of the following 5 classes (Von Der Ohe *et al.,* 2004):

- Class I: N ≤ 20 × 103, includes unifloral honeys with under-represented pollen.
- Class II: 21 × 103 ≤ N ≤ 100 × 103, includes most of multifloral honeys, honeydew honeys and mixtures of flower and honeydew honeys.
- Class III: 101 × 103 ≤ N ≤ 500 × 103, includes unifloral honeys with over-represented pollen and honeydew honeys.
- Class IV: 501 × 103 ≤ N ≤ 106, includes unifloral honeys with strongly over-represented pollen and some pressed honeys.
- Class V: N > 106, includes almost only pressed honey.

Aeropalynology

The term aerobiology was coined as early as 1930s by F. C. Meier who was the plant pathologist working in the Department of Agriculture, United States of America.

Aerobiology involves the study of airborne bioparticles, that is, particles of biological origin (both from plants as well as animals). Subsequent to the 1930s, aerobiology was classified basically into indoor aerobiology and outdoor aerobiology. Some aerobiologists preferred to segregate the study of airborne pollen into a sub branch of aerobiology termed as 'aeropalynology'. The mycologists and plant pathologists preferred to study airborne fungal spores under a separate sub branch of aerobiology termed as 'aeromycology' (Agashe and Caulton, 2009).

Aeropalynology is a branch of palynology that focuses on the study of pollen grains and spores (palynomorphs) that are dispersed into the atmosphere. "Palynomorphs" may include cysts of algae, small structures of animal origin, or other unknown minute fossil objects. Aeropalynological studies are important in under- standing pollen dispersal mechanisms and, more importantly, the role of pollen in human allergic reactions. Identifying the sources of offending substances is a necessary prerequisite to development of effective treatments for respiratory allergies (Biesboer, 1977).

Iatropalynology

The application of medical methods to the alleviation of pollinosis, assumes the elative predictability of spores/pollen in the air in a given area at a given time (Traverse, 2008). Studies on the monitoring of airborne rice pollen and the intensity of the released allergen in agricultural fields are helpful to identify and alert the people working and living in agricultural fields about the seasonal trigger of hay fever and respiratory allergy (Sen *et al.,* 2003). Immunotherapic medicines were developed from grass pollen grains. Oralair® is the only tablet composed of five grass pollen extracts that correspond to the epidemiological exposure of patients. It is a sublingual immunotherapy tablet consisting of five purified and calibrated pollen extracts corresponding to the epidemiological characteristics of patient exposure: rye grass (*Lolium perenne* L.), meadow grass (*Poa pratensis* L.), timothy grass (*Phleum pratense* L.), cocksfoot (*Dactylis glomerata* L.) and sweet vernal grass (*Anthoxanthum odoratum* L.) (Gradnik, 2012).

Pharmacopalynology/Pollen in pharmaceuticals

Pollen to deliver drugs - Pollen capsules that can be filled with nanomaterials could be used for drug delivery. The method will allow sporopollenin, the material that makes up the outer layer of pollen, to be used in pharmaceutical and cosmetic formulations. In this, sporopollenin capsules are used as chemical microreactors, adding starting materials and then allowing a chemical reaction to generate the product inside the pollen (Paunov *et al.,* 2007). Living cells can be encapsulated inside sporopollenin microcapsules derived from *Lycopodium clavatum*. The encapsulation of living cells inside sporopollenin can be used for many different purposes in the food and pharmaceutical industries, including protection of probiotics in foods and delivery of live vaccines for pharmaceutical applications (Hamad *et al.,* 2011).

Sporopollenin exine capsules (SEC) from spores of *Lycopodium clavatum* were shown to encapsulate ibuprofen as a drug model, with 97 ± 1% efficiency as measured by recovery of the loaded drug and absence of the drug on the SEC surface by scanning electron microscopy (SEM). The SEC were shown to provide significant taste masking of encapsulated ibuprofen in a double blind trial with 10 human volunteers (Diego-Taboada *et al.,* 2013). The exine coatings of spores can be used to encapsulate drug molecules. It was demonstrated that exine coatings of spores can be used to encapsulate drug molecules these microcapsules can be filled with a commercial gadolinium (III) MRI contrast agent (in this proof of concept study Gd–DTPA–BMA was used) which is slowly released in plasma due to enzymatic digestion of the capsule (Lorch *et al.,* 2009).

Forensic palynology

Forensic palynology is the study of modern and fossil spores, pollen and other acid resistant micro-plant remains in a legal context. Forensic palynology has been used regularly as evidence in criminal trials in Australia (Milne, 2000), New Zealand (Mildenhall, 1990; Bryant and Mildenhall, 1998) and the United Kingdom (Wiltshire, 2004), Canada (Mathewes, 2006), United States of America (Bryant and Jones, 2006), NE Bosnia (Brown, 2006) in particular, and probably far more sparingly elsewhere (Bryant *et al.,* 1990; Haile, 1990; Szibor *et al.,* 1998). The enormous published case histories demonstrate the use of forensic palynology in cases as broad as forgery, rape, homicide, genocide, terrorism, drug dealing, assault and robbery, arson, hit and run, counterfeiting, and illegal importation, as well as civil cases involving geopreservation, illegal fishing, and pollution (Mildenhall and Skinner, 2009).

In general, palynology can be used to (Mildenhall, 1990; Milne *et al.,* 2004; Mildenhall *et al.,* 2006):

- relate a suspect to the scene of a crime or discovery scene,
- relate an item left at the crime scene or discovery scene to a suspect,

- relate an item at the discovery scene to the crime scene,
- prove or disprove alibis,
- narrow down a list of suspects,
- determine the travel history of items, including drugs (Stanley, 1992),
- provide information as to the environment that an item has come from,
- provide information as to the geographic source of items,
- aid police in their lines of inquiry,
- help locate clandestine graves and human remains (Szibor *et al.,* 1998; Brown, 2004),
- help determine the peri-mortem fate of a victim (Wiltshire, 2004) and
- help to determine the deposition period of human remains.

Pollen is not the only potential acid-resistant palynomorph recovered from evidential and control samples. On occasions, by eliminating various stages in the normal laboratory extraction technique, it is possible to recover a wide range of other types of materials including: fungi (e.g. Microthyriaceae, Tuberaceae), liverworts (Ricciaceae), hornworts (Anthocerotales), mosses such as *Sphagnum*, leaf hairs, plant cuticles, phytoliths (siliceous crystals produced by many plants, especially grasses), various types of specialized plant cells (tracheids, fibres, vessels), resins, diatoms, algae (including marine and freshwater acritarchs, dinoflagellates, solitary cysts of algae{*Debarya Mougeotia*, *Closterium* (desmid), *Spirogyra*, Zygnemataceae, etc.}, and colonial coenobia of green algae like *Botryococcus* and *Pediastrum*), charcoal and fly ash, chitin, other types of animal remains (including insects, foraminifera, and shell [mollusc and egg] fragments), particles of rubber and foam, finger-nails, and other types of material as well. The ‘‘ghosts’’ of Foraminifera are also often seen and identified. Attempts to recover all of these other types of materials should be considered as on occasions they could also prove important in determining the geographical environment and source. Limited processing in the recovery of pollen can also assist in the determination of a broad time frame by study of the nature of the cell contents remaining in the individual pollen or spore, but cell contents can remain in pollen grains after being stored under ideal conditions for over 20 years (Mildenhall *et al.,* 2006).

Forensic palynology traced some of the fake drugs to southern China, close to the border with Vietnam, Laos and Myanmar, formerly Burma (Newton *et al.,* 2008). Counterfeit artesunate contained subtherapeutic quantities, which could fool simple screening tests can be easily identified using pollen analysis. These cheap counterfeit drugs demand life of poor people in Asia and Africa (Newton *et al.,* 2006).

Copropalynology

Analysis of pollen and spores in excrements is dealt under the banner of copropalynology. Copropalynology is a relatively new approach to know the prehistoric dietary pattern of humans and animals. Human copropolites were analysed palynologically only after Callen and Cameron (1960) for archaeological purpose. They established this technique to reconstruct the aboriginal diet patterns by analyzing human excreta and subsequent examination of plant and animal remains in copropolites (Bryant, 1974b). This analysis not only reveals the dietary pattern but also enlighten the food economy of prehistoric period. Several studies have been carried out to know the prehistoric diet (Martin and Sharrock, 1964; Napton and Kelso, 1969; Riskind, 1970; Bryant, 1970, 1974a).

Palynotaxonomy

Pollen characters provide important information for plant taxonomy, evolution, pollination and plant breeding. Pollen research is helpful to understand the systematic and evolutionary relationships of various groups of flowering plants. The forms of pollen grains are as useful as any other characters in the classification of plants; as a general rule they serve best in distinguishing and showing relationships among the higher groupings, as families, tribes, and genera, but sometimes they are also useful among species (Wodehouse, 1928). Morphological characteristics of pollen grains also can be useful characters in studies of plant taxonomy because many pollen traits are influenced by the strong selective forces involved in various reproductive processes, including pollination, dispersal, and germination (Erdtman, 1952; Moore *et al.*, 1991; Nowicke and Skvarla, 1979; Stuessy, 1990; Oswald *et al.*, 2011). Nair (1974) proposed a classification of plant kingdom into three different classes on the basis of apertural morphoforms. Angiosperms were grouped into three well-defined evolutionary stocks (*i.e.* Monocot stock, Magnolia dicot stock and Ranalian stock) on the basis of the triphyletic theory of angiosperms (Nair, 1979).

The significance of pollen morphology in plant systematics has been stressed by a number of workers, especially by Lindley (1830-40), Fritzsche, (1832), Mohl (1835), Fischer (1890), Selling (1946-1947), Cranwell (1952), Erdtman (1952, 1957), Blackmore, (1996) and Nair (2004). Palynological analysis represents an efficient tool in taxonomical studies of the family Asteraceae (Wodehouse, 1926, 1928; Wells, 1971; Tomb *et al.,* 1974; Feuer and Tomb, 1977; Skvarla *et al.,* 1977; Vezey *et al.,* 1994; Perveen, 1999; Wortley *et al.,* 2007). The family Malvaceae s.s. is most closely to Bombacaceae, and the two are separated primarily on the basis of pollen characters (smooth or rugose in Bombacaceae, spiny in Malvaceae). The taxonomic potential of pollen morphology in Bignoniaceae has long been appreciated, and Urban’s (1916) early palynological study of Bignoniaceae is a classic. Pichon (1945), Gomes (1955) and other subsequent workers followed Urban’s lead in proposing numerous new genera based on palynological differences (Gentry and Tomb, 1979). Dr. Thanikaimoni initiated the Bibliographic index on angiosperm pollen morphology in 1972, eight volumes of which have appeared until 1999 (Thanikaimoni, 1972, 1973, 1976, 1980, 1986; Tissot, 1990; Tissot & van der Ham, 1994; Thanikaimoni & van der Ham, 1999).

Geo or Palaeopalynology

Essentially this branch of study is deals with the fossil palynomorphs. Traverse (1988) defines it as now interpreted broadly by most to include study of a wide range of fossil microscopic, usually organic bodies, such as, dinoflagellate cysts, acritarchs, chitinozoans, and scolecodonts, together with particulate organic matter (POM) and kerogen found in sedimentary rocks and sediments in addition to spores and pollen.

Dinoflagellates have a complex life cycle which includes a resting cyst stage, it is this cyst which is preserved (correctly termed a dinocyst). They are extremely important biostratigraphic and palaeoenvironmental tools especially in the Mesozoic and Cenozoic. They are composed of dinosporin, similar to sporopollenin but peculiar to dinoflagellates. The name derives from the Greek "dinos" meaning whirling and refers to the characteristic flagella, which propels them in a spiral motion.

Acritarchs, an artificial group, coined by Evitt in 1963, (the name means "of uncertain origin") includes any small, organic walled microfossil which cannot be assigned to a particular group. They are characterised by varied sculpture, some being spiny and others smooth. They are believed to have algal affinities, probably being the cysts of planktonic eukaryotic algae. They are valuable Palaeozoic biostratigraphic and palaeoenvironmental tools.

Chitinozoa, are large (50-2000 microns in length) flask shaped palynomorphs which appear dark and almost opaque when viewed using a light microscope. They are important Palaeozoic microfossils.

Scolecodonts are the mouth parts of annelid worms they are composed of chitin and silica, the chitin being carbonised to jet black during fossilisation; they are of limited stratigraphic use.

Biostratigraphy and geochronology

Palynological studies can be used in biostratigraphy to correlate strata and determine the relative age of a given bed, horizon, formation or stratigraphical sequence. In other words, stratigraphic palynology is typically applying geological and evolutionary principals to the understanding of sedimentary sequences and the geological record. In general, stratigraphic palynology is applied to pre-Quaternary sediments and is, therefore, a part of Paleopalynology. However, stratigraphic principals apply to sediments of all ages, so stratigraphic palynology is also a part of Quaternary Palynology. There is a high degree of similarity amongst palynofloras from different continents of Gondwanaland. However, the latitudinal disparity and land-sea interface have also played an effective role in shaping regional differences (Tiwari, 1999). Palynomorphs (dinoflagellates, acritarchs and tasmanites) can be used in Permian (approx. 260 myrs) to recent sediments and in most sediments types (though they tend to be rare in chalky limestone). Palynological evidence unravels the broad structure of terrestrial flora which was greatly modified in a relatively short time near the end of the Carboniferous or beginning of the Permian period (Balme, 1980). The palynological succession in different basins of India during the Permian has been studied in detail and reviewed from time to time (Bharadwaj, 1970, 1975; Lele and Karim, 1971; Srivastava, 1974, 1992; Lele and Srivastava, 1980; Tiwari and Ram Awatar, 1989; Srivastava *et al.*, 1989; Tiwari, 1974; Tiwari *et al.*, 1991; Tiwari and Tripathi, 1992; Tripathi, 1993; Srivastava and Jha, 1989, 1990, 1992a and b; Jha and Srivastava, 1996). Even a comparison of Permian palynoflora of India and Africa has been attempted to interpret phytogeographic provincialism in Gondwana (Jha, 2006). Bibliography of Gondwana Palynology by R. H. Weiss (1995) deals with 3214 literature citations concerning the palaeopalynology of all former parts of the ancient Gondwanan supercontinent, as well as those related to mixed microfloral assemblages containing typical Gondwanan elements from the areas surrounding Gondwana. Stratigraphic Palynology played a prominent role in petroleum exploration during the mid-twentieth century.

Palaeoecology and climate change

Palynology can be used to reconstruct past vegetation (land plants) and in turn infer past environmental (palaeoenvironmental) and palaeoclimatic conditions. Palynological records hold the key to understanding past changes in the climate system as well as the sensitivity of tropical regions to present and future climate change. Lake sediments can provide continuous records of past climate variability and human activities making lakes excellent sensors of environmental change. Since pollen cannot be destroyed easily and can be retrieved in large quantities allow statistical inference from the data. These Quantitative analyses of fossil pollen, fungal spores, and microscopic charcoal assemblages in lake sediments provides an excellent basis for investigating the timing and nature of shifts in an area brought about by climate and/or human impact. Palaeoenvironmental reconstruction based on the pollen is highly reliable for number of reasons including the fact that pollen from lake sediments unravels a record of past vegetation, and vegetation is gives rise to what type of climate in which it was thrived in the given area (Birks and Birks, 1985).

Reconstruction of past vegetation patterns was initiated as early as 1916 by von Post. He developed the technique of using pollen grains to build stratigraphies that could be used to correlate peat layers locally. He opined that it is possible to understand the past vegetational dynamics by analyzing the present vegetation and their pollen signatures from the modern surface soil samples. Moreover, there is no significant change in the plant morphology in the quaternary period (Jarzen and Nichols, 1996; MacDonald, 1996; Mudie and Harland, 1996). The present climatic condition was set during the Pleistocene period and the anthropogenic changes modified them during the course of the present period called Holocene (Hope, 1994). This clearly suggests that the present pollen signature can be used as an analogue for reconstructing past vegetation and climate change. Way back in 1968, Terasmae discussed about Quaternary Palynology’s scope, problems and its potential use in stratigraphic applications (Terasmae, 1968).

Organic palynofacies studies

This examines the preservation of the particulate organic matter (POM) and palynomorphs provides information on the depositional environment of sediments and depositional palaeoenvironments of sedimentary rocks. Palynofacies a term that was first introduced by the French geologist Combaz in 1964 (Combaz, 1964). It is defined as the assemblage of palynomorph taxa in a portion of sediment, representing local environmental conditions and not typical of the regional palynoflora or other words the assemblage of phytoclasts found in a certain kind of sediment, as palynomorphs, wood fragments and cuticles (Traverse, 1988). Palynofacies studies are often linked to investigations of the palynology and organic geochemistry of sedimentary rocks.

Organic palynofacies considers the entire acid insoluble POM, including kerogen and palynomorphs in sediments and palynological preparations of sedimentary rocks. Their abundance, composition and preservation of the various components, together with the thermal alteration of the organic matter are considered. The ratio of marine fossil phytoplankton (acritarchs and dinoflagellate cysts), together with chitinozoans, to terrestrial palymomorphs (pollen and spores) can be used to derive a terrestrial input index in marine sediments. Both types of palynofacies studies are used for geological interpretation of sedimentary basins in exploration geology, often in conjunction with palynological analysis and vitrinite reflectance.

Geothermal alteration studies

This examines the colour of palynomorphs extracted from rocks to give the thermal alteration and maturation of sedimentary sequences, which provides estimates of maximum palaeotemperatures. This is closely related with organic petrology, a branch of the earth science that studies organic matter in sedimentary sequences including coal and the finely dispersed organic matter in rocks (DOM) (Isabel, 2012). In transmitted light microscopy the organic matter is characterized by means of palynofacies analysis (Combaz, 1980; Tyson, 1993, 1995). The palynofacies analysis combined with studies of organic petrography, geochemical investigations, stratigraphy and paleontology, is a tool in the interdisciplinary analysis of organic matter providing accurate information in the investigation of organic facies and depositional paleoenvironments, paleoclimate reconstructions, origin and transfer studies of fossil organic matter in recent environments, hydrocarbon source rock potential and petroleum exploration (Isabel, 2012).

Archaeological palynology

This examines human uses of plants in the past. This can help determine seasonality of site occupation, presence or absence of agricultural practices or products and plant-related activity areas within an archaeological context. In other words, it refers to the palynological study of human impact on the environment (Faegri and Iversen, 1989). When identified to species, archaeological pollen can be used to identify clues to prehistoric climate (what kind of plants grew in the neighborhood of a given site) and diet (what kind of plants were consumed at a given site). In the early 1940s, Iverson (1941) expanded the utility of palynology to include the problems specifically related to archaeology by successfully dating the start of the Neolithic period in Denmark. A detailed account on the role of palynology in archaeology can be found in Bryant and Holloway (1983).

Conclusion

This paper provides a general picture of microscopic world called Palynology. Palynology is a subject of broad scope that started when microscope was invented. The two basic divisions, such as basic and applied palynology have been explained in this paper. It is noted that palynology encompasses many different disciplines and has potential to apply many more. Palynology has been increasingly branching out into other fields of studies like pollination ecology, pollen biotechnology, embryology and many more. It is obvious that only a tip of the ice berg is shown in this paper, since each sub-discipline is developed manifold individually, it can't be possible to put everything in one single paper.

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