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# Palynology as a Tool in Bathymetry

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## 1. Introduction

### 1.1 Rationale

Palynology is the science that studies the ontogeny, structure, dispersal mechanisms, deposition and preservation of spermatophyte pollen grains and spores of fern, mosses and liverworts in different environments (Erdtman, 1943). In a wider sense it involves the study of palynomorphs, a term created by Tschudy & Scott (1969) to define the organisms resistant to drastic chemical treatments used in Palinology as, e.g., some microscopic algae. This is because the composition of the palynomorphs external wall, constituted by sporepollenin, an organic polymer composed of carbon, oxygen and hydrogen, probably is the most resistant organic matter of all living beings, and has remained unaltered for millions of years, even after the death of the cell content. Due to its chemical and microbiological degradation resistance, palynomorphs have the potential to become microfossils in sediments (von Post 1916, Zetzsche 1932, Chaloner 1976, Brooks & Shaw 1978, Moore *et al.* 1991, Takahashi 1995).

The palynological analysis of the sediments is essentially based on plants reproductive strategy of abundantly release pollen grains during the flowering season, and spores during the sporophytic phase, in some cases in billions per m<sup>2</sup>. Apart from their different functions in plants, pollen and spores can be used in the reconstruction of recent and past vegetation, as they are easily carried by the wind due their minute size (ranging from a hundredth to a tenth of a millimeter in diameter) and be transported to high altitudes by vertical currents, remaining in the atmosphere for days, weeks or even months moving long distances to precipitate as “pollen rain” over land and water. After falling from the air to the soil or water, a number of factors affect their conversion into microfossils, before and during their sedimentation. Pollen grains and fern spores never accumulate in their original form when deposited in the sediments. This includes factors that can destroy spores and pollens in sedimentary deposits. Aware of these facts, researchers have developed several studies in order to observe the spore-pollen deposition in various current environments to serve as the basis for paleoecological studies.

As previously stated, current and past vegetation records can be preserved only where pollen and spores have accumulated as microfossils through time. As oxygen is the main destructor of organic matter, the deposition environment has to be free of this element (or present in small concentrations only) in order for pollen grains and spores be preserved after sedimentation, i.e. an anaerobic environment such as the subaquatic one. They are

integrated in the water as silt and clay size particles and get exposed to the same laws of particle movement in fluids, subject to water circulation dynamics that function as transport agent before their sedimentation in rivers, deltas, estuaries, lakes, bays, lagoons and open seas.

The accumulation of pollen and spores of recent and fossil deposits in sediments of aquatic ecosystems is a rich source of ecological information as the climatic evidence is indirectly contained in the biological data. The vegetational changes in the fossil record may have been caused by climate change. However, one should keep in mind that not all changes of pollen, spore and algae accumulation are necessarily caused by climatological factors. Sedimentary records can incorporate other kinds of evidence that can interfere in the palynological analysis of the vegetation changes. These interferences can mask the climatological data such as those caused by human activity in the vegetation or fire and insect infestations that require the analysis of other indicators, such as coal, which should be added to pollen spectra of anthropocoric plants.

The inherent characteristics of each palynomorph also affect the accumulation in subaquatic deposits, both in space and time, in number and quality of the sedimented material, causing under- or over-representation of specific types, depending on the sample local. Changes of the depositional processes that result in alterations in the accumulation and preservation of the palynomorphs and changes on the water level affecting the local flora succession, among others, are examples of interferences in pollen and spore frequency that can challenge the interpretation of regional flora and climate by means of Palynology. After sedimentation, the resuspension of previously deposited palynomorphs, and the convergence of these to other parts of the drainage basin due to currents and winds, also cause alterations in their frequencies, both in the central area and margins. In addition, the preservation of sedimentary deposits differs with each palynomorph type, which can result in its destruction before or during its incorporation in the sediment (Stommel 1949, Cushing 1966, Davis 1968, Davis *et al.* 1971, Davis & Brubaker 1973, Peck 1973, Bonny 1980, Delcourt & Delcourt 1980, Davis *et al.* 1984, Campbell 1991, Moore *et al.* 1991, Campbell 1999).

It is evident that defining the vegetation homogeneity or heterogeneity using pollen grains and spores is not a simple matter. As there is no constant between the release rate and the rate of spore and pollen grain accumulation it is not possible to make a direct correlation with the productivity of each parent plant. Even in underwater environments with stable sedimentation the inference regarding an aspect of certain vegetation based on palynological representation is inconsistent if the different processes that cause the possible spatial variations in the deposition of pollen, spores and algae aren't taken in consideration. Here bathymetry has a fundamental role. Any change in the frequencies and concentrations of pollen and spores may indicate changes in bathymetry and in the water volume.

This work aims to show the importance of an accurate spatial analysis of the deposition rate of pollen and spores in subaquatic sediments for a precise correlation with the source vegetation. In the preface is provided a brief description of the characteristics of pollen and spores, their different release mechanisms from the parent plants and possible factors that affect their conversion into microfossils. Details of the methods used for extracting palynological information in surface sediments and the criteria for data selection are defined in the next section. Finally, the results obtained from palynological analysis of surface sediments in some locals from the coast of Rio de Janeiro are compared and classified into

groups that represent the major influences in sedimentation of pollen and spores, i.e., the bathymetry, winds and currents.

## **1.2 Primary Differential Processes – production and release mechanisms of pollen grains and spores of fern, mosses, liverworts and algae**

The “Primary Differential Processes” are composed of different ways of production and release mechanisms of pollen grains, spores and algae that are peculiar to each parent plant added to the initial depositional influences unique to each sedimentary environment.

### **1.2.1 The pollen grains**

Pollen is the microgametophyte of Gymnosperms and Angiosperms. It is the fecundate element, the cell that contains the male reproductive nucleus. It is largely produced in flower anthers of monocots and dicots, and in male cones of Gymnosperms, both constituting the pollen grain contents of the pollen sack (= anther locules). The pollen grain is an essential element of the sexual reproduction of plants and it needs to reach the female part of the flower or cone to germinate and form the pollen tube that takes the male nucleus to the ovule (megagametophyte). The fusion of pollen and ovule nuclei originates the embryo and its involucres, constituting the seed which is the disperser agent of the species.

Until the 17<sup>th</sup> century nothing was known about pollen and its role as a fecundate source. It was only in the 18<sup>th</sup> century that the first successful observations and experiments had begun and proved that fruit development did not happen without pollen (Wodehouse 1935). In the 19<sup>th</sup> century, the microscope equipment was 500 times more efficient than magnifying glasses and made possible the visualization of the pollen external-wall (exine) which led to the discovery that it was ornamented and had apertures and other morphological characters, frequently similar within a species, allowing the identification of the plant that had produced it (Salgado-Labouriau 2007).

Pollen grains are produced after meiosis, when each pollen mother cell divides into four haploid cells. These frequently split and each pollen grain remains isolated from the other. However, pollen grains of some species remain attached in groups of two, four, more than four and in pollinium (Fig. 1). Pollen grains are involved by exine, a sporopollenin external-wall, composed by the sexine and nexine layers. Due to its resistance to chemical and microbiological attacks, pressure, and temperature changes, it is preserved for millions of years. In sedimentary rocks Gymnosperm pollen from the Paleozoic Era, more than 300 million years ago, can be found and Angiosperm pollen from the Upper Cretaceous, more than 100 million years ago (Traverse 1988).

The morphological analysis of pollen grains involves a series of descriptions (Barth & Melhem 1988, Punt *et al* 2007). The literature is rich, including catalogs and treatises on pollen morphology (Erdtman 1952, 1957, 1965, 1971, Faegri & Iversen 1950, Melhem *et al.* 1981, Roubik & Moreno 1991, Salgado-Labouriau 1973, among others). With this knowledge at hand it was possible to verify that unrelated plants can have similar pollen types and some plant families may have more than one morphological pollen type. There are monomorphic species, i.e., species with a basic morphological pollen type other than that are dimorphic, with two types, or polymorphic with several. That's why the identification of pollen grains remains in the “Pollen Type” category in microfossil studies. The pollen type represents an artificial grouping based on pollen morphological characteristics within or

between families. Frequently, similar species, varieties and subspecies within a species have the same pollen type (Salgado-Labouriau 1973).

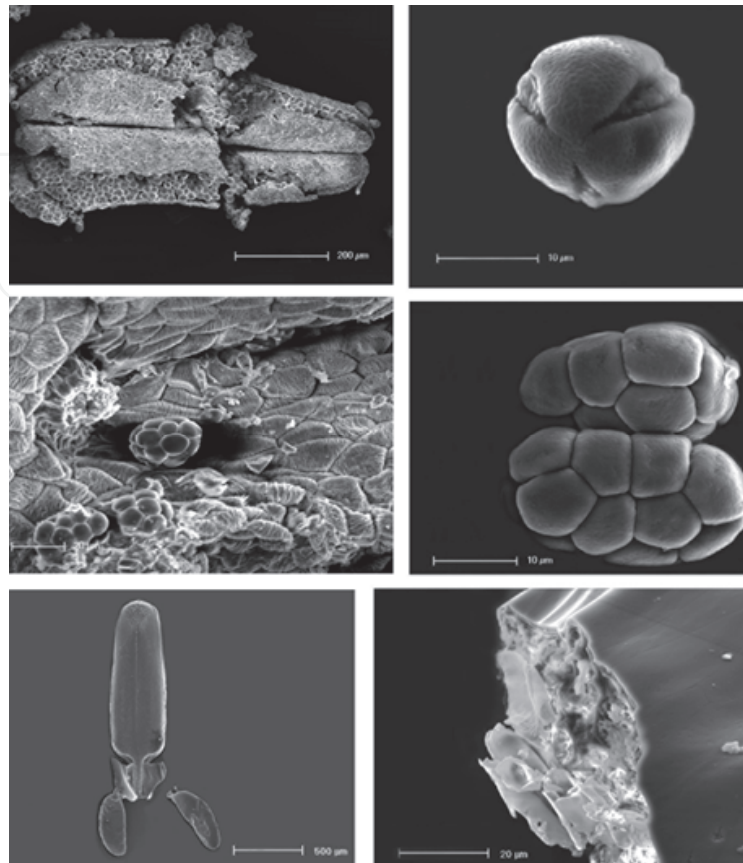


Fig. 1. Scanning electron microscope images of anthers, pollen grains and pollinarium.

Top: anther with pollen grains of *Zornia diphylla* (L.) Pers. A single pollen grain of *Z. diphylla*. Middle: interior of the anther of *Stryphnodendron adstringens* (Mart.) Coville with polyads. Two polyads of *S. adstringens*. Bottom: general view of the pollinarium of *Oxypetalum insigne* (Decne.) Malme. Detail of the pollen grains inside the pollinium of *Oxypetalum capitatum* subsp. *capitatum* Mart.

There are different mechanisms by which plants release their pollen grains through biotic and abiotic agents in a wide range of specializations in order to avoid genetic losses due to environmental interference. The transport of pollen grains from the anther to the stigma is called pollination, and it can happen directly or not. In Angiosperms there are different pollination mechanisms. Direct pollination occurs in autogamous plants (pollination of the same flower) where biotic or abiotic agents can help in pollination, but they are not essential since pollen is received on the stigmatic surface of the same flower. This is the case of cleistogamous plants, where flowers are still closed when pollination happens. The pollen of cleistogamous plants is rarely seen in sedimentary records.

Indirect pollination occurs in allogamous plants (pollination between different flowers) where biotic and abiotic agents play an essential role. Abiotic agents can be water and wind, while biotic agents can be different groups of animals (Fig. 2). In hydrophilic plants pollen is taken to the stigma of another flower by water. A mass production of pollen is necessary,



however, pollen of this type of plant does not frequently show any sexine or nexine, thus not preserved in sediments.

Zoophilous plants use animals as pollinators. For the efficiency of this type of pollination the production of pollen of these plants is generally reduced. Zoophilous and ambophilous taxa (plants pollinated by both wind and animals) frequently occur in the pollen assemblage of sedimentary rocks, but they are consistently underrepresented (absence of pollen in the sediment while the parent plant does exist in the vegetation or by the abundance of pollen is much smaller in the sediment than the abundance of the parent plant in the vegetation). If no abiotic agent interferes, the pollen concentration of zoophilous taxa can be high in the ground next to the plant, and its presence in the fossil sediment can indicate proximity of the parent plant.

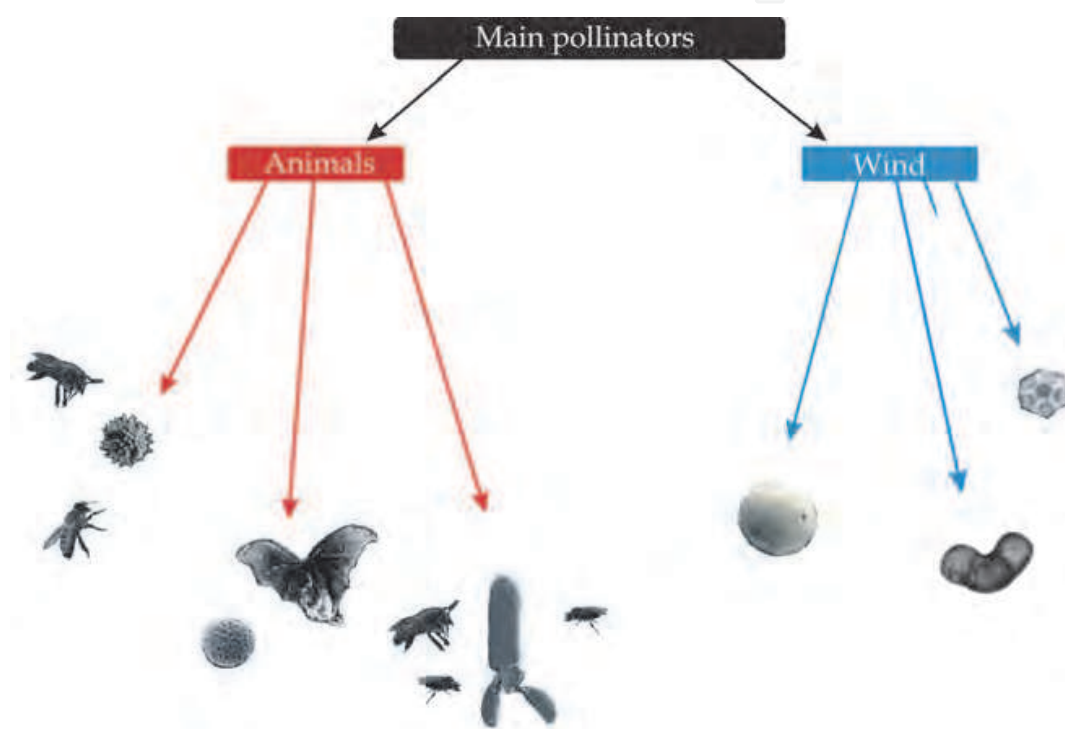


Fig. 2. Zoophilous pollen grains generally show complex sexine structures and use oils to stick to the body of the animal and may be a single grain or grouped into tetrad, polyad and pollinarium. The typical pollen grain pollinated by the wind has an aerodynamic shape with simple structures of sexine ornamentation and sometimes hollow spaces.

Anemophilous plants use wind to disperse pollen grains and include all the Gymnosperms and a substantial number of Angiosperms. With very few exceptions most palynomorphs accumulated in Quaternary lacustrine sediments consist of terrestrial plants pollinated by wind (Jackson 1994). Anemophilous pollen dominates even in tropical regions where the trees pollinated by insects are more abundant in the forest canopy (Kershaw & Hyland 1975, Colinvaux *et al.* 1988). As a large part of the anemophilous pollen don't fulfill their role in pollination, they are deposited in large amounts everywhere meanwhile zoophilous pollen enters the environment attached to animals that generally avoids landing in certain areas (for example, in water surfaces). Finally, anemophilous pollen is aerodynamic, light, with sizes between 5-100  $\mu\text{m}$ , and they are better suited for transport by the wind longer distances than zoophilous pollen, frequently big and dense, that tend to stick together with

other pollen grains (Whitehead 1969, 1983). This way, even if zoophilous pollen escapes from flowers to the air they will not travel long distances until deposition in the sediments.

### 1.2.2 The spores

Spores are the disperser cells of Cryptogams (mosses, liverworts, ferns, etc) which contain the genome and that asexually develops into a new gametophyte. In ferns (prothallus) the gametophyte is reduced, normally subterranean, and self-sufficient, while in mosses and liverworts the gametophyte represents the most developed generation, which we know as the “plant”.

The gametophytes of mosses and liverworts’ produce antherozoids and eggs that give origin to the sporophyte once fecundated, which grow from its own archegonium (like the ovary in plants) in the shape of a capsule – the sporangium – at the edge of a peduncle. The sporophyte attached to the parent plant produces haploid spores that gives origin to new plants after dispersion. In ferns, on the other hand, the sporophyte is independent, which is what we know as the “plant”. The spores are produced in structures on the abaxial side of the leaf, or frond, called sorus, where the sporangia are found.

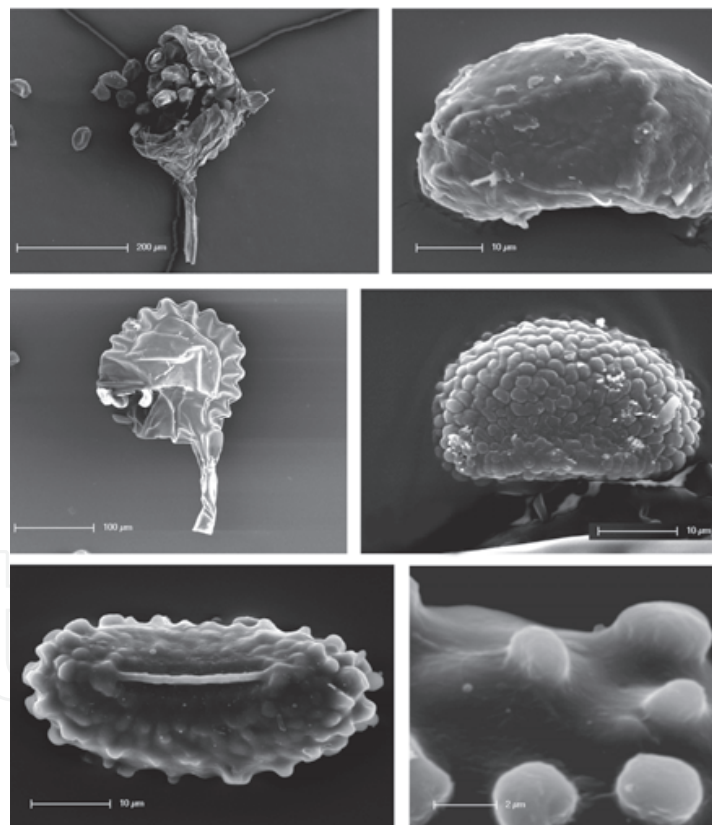


Fig. 3. Scanning electron microscope images of fern spores and sporangia. Top: sporangium of *Serpocaulon glandulosissimum* (Brade) Labiak & J. Prado. Monolet spore of *S. glandulosissimum* covered with the perine layer. Middle: sporangium of *Serpocaulon sehnemii* (Pic. Serm.) Labiak & J. Prado. Monolet spore of *S. sehnemii*. Bottom: detail of the monolet spore laesura of *Serpocaulon richardii* (Klotzsch) A. R. Sm. Detail of the verrucae ornamentation of the monolet spore of *S. richardii*. (Photos provided by Dr. Carolina Brandão Coelho and Dr. Luciano Mauricio Esteves, Instituto de Botânica, Brazil)

The spore, just like the pollen, has a resistant external wall composed by sporopollenin. Fern spores are found in sedimentary rocks from mid Silurian, more than 400 million years ago (Traverse 1988). The palynological analysis of Cryptogam spores is very similar to that from pollen grains, but there is less morphological variance and specific nomenclature (Barth 2004, Erdtman & Sorsa 1971, Tryon & Lugardon 1990, Lellinger 2002). The spore is usually a spherical, tetrahedral or reniform structure, frequently with elaborated ornamentation patterns (Fig. 3). Mature spores are always in isolated grains, and can have leasures on the proximal face. These leasures are important for its identification. Monolete spores have only one leasure, trilete spores show a leasure in a Y shape, and aletes do not have leasures and are commonly found in mosses (Cruz 2004).

In the mosses and liverworts where the sporophyte production is high, spores are produced and released over many months (e.g. *Anthoceros*). Generally in terrestrial plants, spores are dispersed by the wind and capable of resisting long period of drought. However, it is only when they fall over humid and suitable surfaces that they will absorb water and germinates.

According to Tuomisto & Poulsen 1994 (*apud* Graçano *et al.* 1998) edaphic specializations in some fern species justify its use as soil fertility indicators, where patterns of geographical distribution should be considered in ecological studies.

### 1.2.3 Chlorococcales algae

There are relatively few algae *taxa* with spores, cysts or other resistant forms that are preserved in sediments, that stands out in the geological history, from 500 million years ago (Brenner & Foster 1994, Jansonius & McGregor 1996). Algae are relatively recently used in paleoecological interpretations (van Geel 1976, van Geel & van Der Hammen 1978, Salgado-Labouriau & Schubert 1977, Luz *et al.* 2002). Algae from the Chlorococcales order are the most abundant microfossils found in lake and swamp sediments, due their resistant external wall of sporopollenin. It is an order of green algae that includes both unicellular and colonial species (Fig. 4).

All Chlorococcales have an endogenous asexual reproduction (vegetative), where the number of daughter cells or colonial cells is determined by the number of cleavages of the mother cell. Some have solitary cells isolated inside the colony (Botryococcaceae for example), while others have directly united cells that form a *coenobium* (Coelastraceae, Hydrodictyaceae and Scenedesmaceae, for example).

The life period of unicellular algae is probably measured in hours or days. Asexual reproduction in algae usually occurs under favorable conditions, while sexual reproduction occurs when conditions are less favorable. If the algae doesn't reproduce the protoplast dies and the remaining cell wall sinks and deposits in the sediment. In some species there is also a type of vegetative reproduction where somatic cells can change by adding a thick wall, and these cells can function as resistance spores (cysts), dormant during hostile periods, while all other somatic cells die. The dimensions of individual cells and the *coenobium* depend on the growth rate which in turn depends on environmental factors (Brenner & Foster 1994, Jansonius & McGregor 1996).



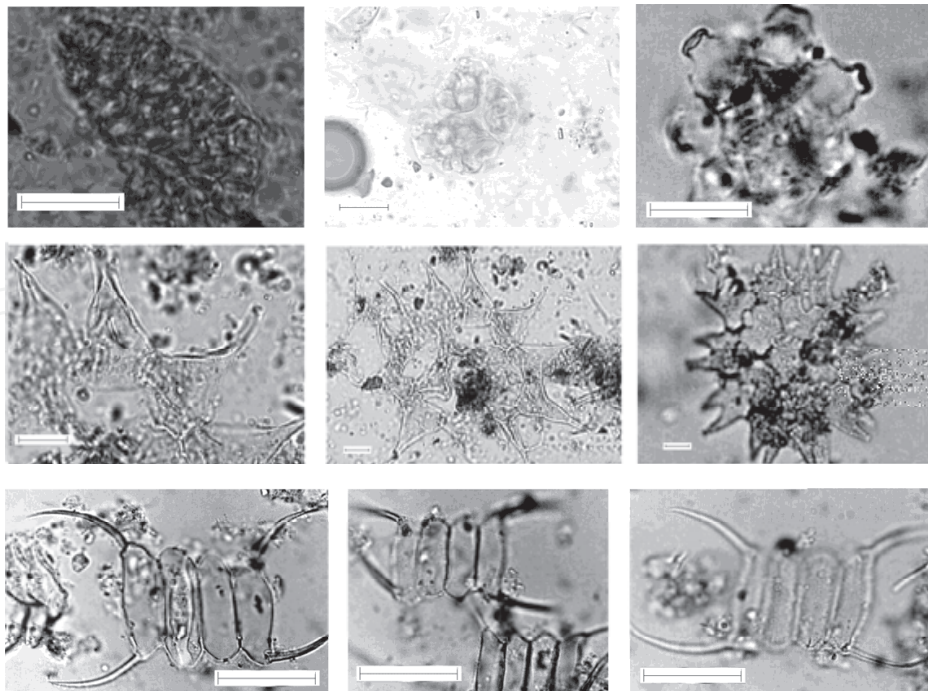


Fig. 4. Light photomicrographs of Chlorococcales algae. Top: colonies of *Botryococcus* sp1, *Botryococcus* sp2 and *Coelastrum proboscideum* Bohlin. Middle: detail of the coenocytes of *Pediastrum* sp, coenobium of *Pediastrum* sp and *Pediastrum duplex* var. *subgranulatum*. Bottom: colonies of *Scenedesmus protuberans*, *S. magnus* and *S. ohauensis*. Scale = 10  $\mu$ m.

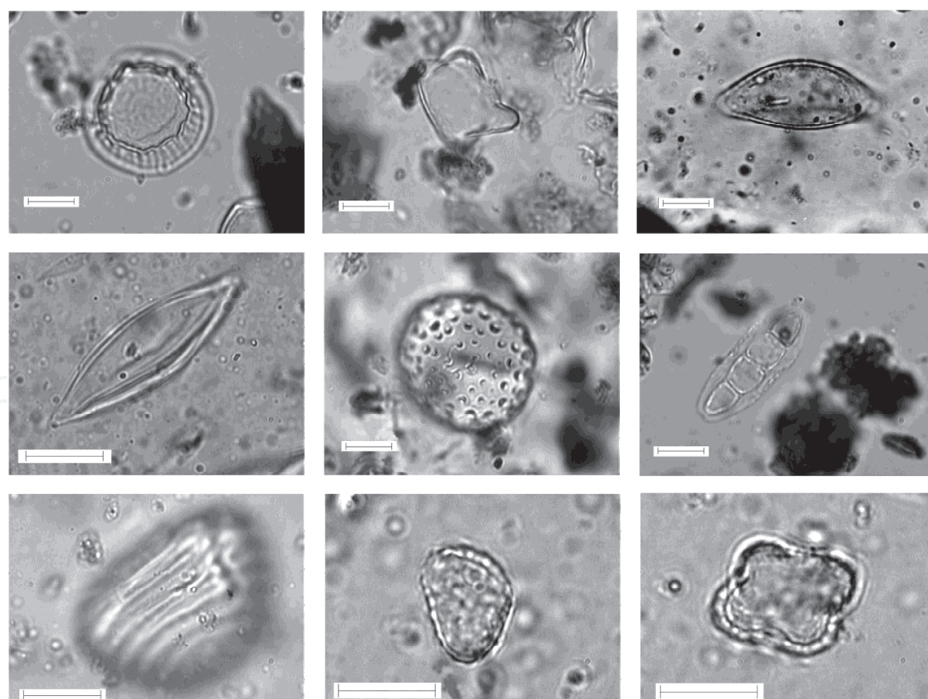


Fig. 5. Light photomicrographs of Zygnematales and others algae. Top: zygospores of *Debarya* (De Bary) Wittrock, *Mougeotia* C. A. Agardh and *Spirogyra* Link sp1. Middle: zygospores of *Spirogyra* Link sp2, *Zygnema* C. A. Agardh and a not identified algae. Bottom: Other forms of algae. Grain of *Incertae sedis* (*Pseudoschizaea rubina* Rossignol ex Christopher) and two forms of *Tetraedriella jovetti* (Bourelly) Bourelly (Xanthophyceae). Scale: 10  $\mu$ m.

### 1.2.4 Zygnematales algae

Just like the Chlorococcales, many zygospores from the Zygnemataceae family have a resistant external wall, composed of sporopollenin (Fig. 5). This family unites the algae formed by cylindrical cells associated to filaments, floating and free-living, although *Mougeotia*, *Spirogyra* and *Zygnema* may also grow adhered to substrates (Smith 1955, Kadlubowska 1984 *apud* Dias 1997). They are inhabitants of shallow waters of freshwater lakes and ponds. However, they have also been found in brackish and saline environments. They easily grow in lentic environments (shallow and stagnant waters or in higher waterbodies, permanent or temporally), lotic, phytotelmic, terrestrial bromeliadous and subaerials (wet soil and peat) (Dias 1997).

### 1.2.5 Vegetational representation in surface sediments

Knowing that the assemblage of pollen and spores recovered from the sedimentary record cannot be directly interpreted as an accurate reflection of parental vegetation, researchers recognized the need to know in detail the source area of pollen and spores (the vegetation area from which most pollen and spores derives) to interpret the patterns observed in the palynological diagram curves. The concept of source area originated from considerations of von Post (1967) from a transect in Sweden regarding location and spacing of the depositional site in relation to long-distance pollen transport. Differences in the efficiency of the dispersion of pollen grains and spores mean that many of them found in the depositional site may have originated in plants located in a wide geographical area, transported by winds or rivers. Therefore, the percentage analysis of the pollen grains record requires knowledge of the abundance of plants found at the depositional site, both locally and regionally, helping to better understand issues regarding overrepresentation (abundance of pollen in the sediment is much higher than the abundance of the plant at vicinity) and underrepresentation of certain spore and pollen types. The abundance of the parent plant in the landscape can be perceived and described in a variety of ways. The ecologist expresses abundance of plants per unit area in terms of stem density, total biomass, coverage area projected vertically, etc. The intensity of pollen and spores of the source area is another way of describing the abundance of the plant. Intensity of spore-pollen in the source area depends on many factors, however, in many cases, it is inversely measured by the distance of the depositional site to the vegetation where the *taxon* in question is located. Several authors have developed studies on the source area (Tauber 1965, Janssen 1966, Andersen 1970, Janssen 1973, Tauber 1977, Bradshaw 1981, Jacobson & Bradshaw 1981, Parsons & Prentice 1981, Prentice 1985, Prentice 1988, Calcote & Davis 1989, Jackson 1990, Jackson 1991). Since these studies used “pollen and spores traps” to relate to the sedimentary basins, which offer a “sedimentary environment” very different from reality, quantification is limited. Comparative studies of pollen deposited today and existing vegetation in the vicinity highlighted the importance of certain choices of parameters for the calibration of the relationship pollen/vegetation and for the interpretation of spore-pollen records as a whole (Webb *et al.* 1978, Parsons *et al.* 1980, Bradshaw & Webb 1985, Prentice *et al.* 1987, Jackson 1990). The selection of the size of the depositional site and the choice of Spore-pollen Sum (i.e. which *taxon* to be included in the diagrams) are very important for the analysis of the sedimentary record of the vegetation. The variations between the spore-pollen assemblages can, in many cases, be related to vegetation patterns in the spatial scale from  $10^2$  to  $10^3$ m, however, the size of the drainage basin affects the pollen representation of

this vegetation. The results of simulations on the vegetation spatial scale represented by pollen grains and spores deposited in lake sediments indicated that this scale may seem homogenous in palynological records even when its actual pattern is heterogeneous and uneven. This will depend on the size of the depositional site in relation to the size of the vegetation patches existing in the surroundings. The larger the lake, the more the pollen assemblage will be influenced by the extra-local and regional components (Janssen 1966, 1984; Andersen 1970; Calcote & Davis 1989; Jackson 1994). The data obtained corroborate the empirical knowledge that smaller lakes are especially suitable for the reconstruction of local vegetation, while larger lakes are more appropriate for the reconstruction of regional vegetation and climate.

Sugita (1993) points out the importance of recognizing the differences between the areas of pollen source in the central part of the depositional site and the pollen deposited over the entire surface. The author constructed a differential deposition model based on the model of pollen transport to depositional basins suggested by Prentice (1985, 1988). Several assumptions and mathematical equations suggest that the local distribution of plants around the lake has great influence on the pollen assemblage found throughout the lake basin, and that pollen deposition decreases slowly from the margin to the center of the basin, and the center tends to present a lower deposition, since it is farther from the closer area of pollen source. In this model, the mean of pollen input of the entire basin would involve the effect of higher accumulation of pollen near the margins. However, for the author, even in locations without significant pollen input from aqueous streams and tributaries entering the basin, the re-suspensions and redirection of the sediment to the deepest part can generate high rates of pollen deposition in the deeper areas increasing differences in pollen deposition in the entire basin.

Regarding local components, it is assumed that much of the pollen deposited in aquatic plants derives from plants that grow in the lake. As pollen and spores of local plants are usually overrepresented in the depositional site, any change in their frequencies and concentrations may indicate changes in bathymetry and in the water volume. Still, the representation of aquatic plants in spore-pollen assemblage is highly variable, depending on its abundance, lake extent as well as if the sample was obtained from benthic or coastal sediments (Janssen 1966). The pollen analysis of coastal sediments can indicate changes in aquatic vegetation resulting from disturbances in the ecological succession and in the water level, because their percentage in the assemblage is reduced when horizontal dimension of the water body decreases (Janssen 1967, Birks *et al.* 1976, Jackson *et al.* 1988). According to Jackson (1994), many submerged and floating aquatic plants are pollinated by insects or have their pollen dispersed by water. Although many important *taxa* are anemophilous (Cook 1988), the pollen production of these plants is low and dispersal is often limited. In other emerging aquatic plants, pollination is anemophilous and they are high-pollen producers (e.g., *Typha*, Poaceae and Cyperaceae) and, thus, high amounts of pollen are observed where these plants grow. The challenge is to determine how much pollen of these *taxa* represents local aquatic plants or how much originates from regional terrestrial plants.

The phytoplanktonic community in watersheds is conditioned to dynamic processes related to the physical and chemical instability of their waterbodies, among which salinity fluctuations and variations in the concentration of nutrients stand out. These factors will regulate populations and interfere with the phytoplankton succession. These fluctuations



are related to the water circulation which is a reflex of the hydrography and the concentration of the suspended material, besides being conditioned to the annual cycle of entry and exit of water in the system (evaporation relation/precipitation). The succession of Algae usually begins with green algae, and then by blue algae in eutrophication processes. In large scale, fluctuations in phytoplankton populations in coastal lakes and lagoons were linked to variations in the sea level from its origins to the present. If in any moment there was a water entry with a higher salinity than the lacustrine environment, it would have caused a total change of the richness, diversity and density of certain algae genera. The characteristics of phytoplankton in these environments, when under direct marine influence, show high values of biomass, a high productivity and low diversity (Margalef 1969(Comin 1984, Margalef 1969 and Odebrecht 1988, *apud* Huszar & Silva 1992).

### **1.3 Secondary Differential Processes – differential sedimentation, preservation and reworked palynomorphs in rivers, lakes, estuaries and deltas**

The “Secondary Differential Processes” are the various depositional influences after sedimentation of pollen and spores, each one unique to a specific sedimentary environment.

The interest in palynological sequences that record the dynamics of vegetation in the Quaternary period has led palynologists to seek depositional environments of good preservation for pollen and spores with stable, continuous and datable deposition. Overall, it is assumed that in these environments, variations of palynological records attributed to depositional processes are small compared with changes in the abundance of plant species and in the production and release of pollen and spores. However, even in environments with stable sedimentation, palynological studies show that in the horizontal gradient (transect) the deposition of palynomorphs display different patterns of location. The spatial differences in the abundance of sedimented pollen grains, fern spores and algae are striking, even in lakes without tributaries and located nearby each other. Moreover, in certain basins, depositional processes are the main causes of interference in the palynological records. In aquatic environments, depositional processes occur because spatial variations in rates of fern spores and pollen grains accumulation over time (“influx” = amount of pollen that falls each year in cm<sup>2</sup> of soil) are influenced, among other factors, by the seasonal differences in the “input” of pollen and spores and the hydraulic selectivity (“sorting”) the various types of palynomorphs suspended in water, according to their different morphologies and densities, which cause differences in the sinking speed. In addition, there are physical and chemical characteristics inherent to each aquatic environment such as the intensity of water currents and vertical movements of water (seasonal and daily) caused by variations in temperature and density. Types of sediments deposited at the bottom and their movements to another part of the basin as well as the bathymetry and the intensity/direction of dominant winds that can cause resuspension of previously deposited material, also influence the pollen and spores sedimentation. Thus, the hydrodynamic distribution of pollen grains and fern spores, as well as other particles, produces differences in the quality and in the total of accumulation rates of these particles in different locations of the basin. Therefore, the spatial analysis of fern spores, pollen grains and algae deposition in the surface sediments of the bottom of water bodies show different patterns from place to place and can help in sedimentological studies (Davis 1968, Davis *et al.* 1971, Peck 1973, Lehman 1975, Bonny 1980, Davis *et al.* 1984, Moore *et al.* 1991, Sugita 1993).

Jackson (1994) highlighted the care to be taken in interpreting the temporal changes observed in the recent and fossil spore-pollen assemblages in sediments, because to directly correspond to the respective changes in the intensity of the spore-pollen *taxon* involved (number of pollen grains or fern spores produced by a *taxon*, per unit of land area, per unit time) all other aspects should remain constant (e.g. spore-pollen dispersion and spore-pollen deposition), which never occurs.

Stommel (1949) studied the behavior of particles affected by the action of water currents produced by winds and demonstrated that the number of long-axis vertices in parallel formed at the water surface and the direction of dominant winds cause different types of distribution of these particles. This distribution occurs according to the sinking speeds of each, and the particles can only sink if the sinking speed is close to the maximum upward speed of the water. Potter (1967) found that even with the influence of dominant winds in a single direction, the pollen grains deposition in the sediment of the bottom of water reservoirs varies among the *taxa*, at the banks as well as in the center of the reservoir. Contrary to the expectation that dominant winds could cause higher pollen concentration at the opposite margin, results show a complex differentiation of pollen accumulation in bottom sediments.

Hopkins (1950) investigated the spatial differential sedimentation in lakes regarding the sinking speed of certain pollen grains and found that the *Pinus* pollen sinks less quickly than the *Quercus* pollen suggesting that this is due to differences in the size of pollen grains. Bradley (1965) pointed out that the sinking speed of many particles in a lake, such as the diatoms, is too slow to allow them to reach the bottom of deep lakes in the same year that they were formed and are, thus, subject to various transport mechanisms. Davis (1968) observed that the pollen types with low sinking speed (smaller sizes) are preferentially deposited in shallow areas of the coast of a lake. The author also showed that in the bottom sediment, more than 80% of the pollen was derived from sediments that had previously been deposited elsewhere in the lake (redeposition). Davis & Brubaker (1973) based on the Stommel theory to affirm that water circulation in a lake affects pollen sedimentation according to the different morphological types, and even small differences in sinking speed of each pollen type would cause great effects on the distribution of these in aquatic environments and, therefore, the total accumulated pollen grains are different, for example, in several parts of a lake.

Merilainen (1969) suggested that the epilimnion current (top-most warmer and less dense layer in a thermally stratified lake) affect the deposition patterns of diatoms in sediments.

Davis *et al.* (1984) demonstrated that there is a tendency for deeper areas of a lake to accumulate sediments faster than the shallower ones, thus resulting in large variations in accumulation rates of pollen among samples. Faegri *et al.* (1989) reported that the differential spatial distribution is due to bathymetric differences and the effective capacity of pollen grains and spores to accumulate in accordance to their sinking speeds. Sugita (1993) suggested that the pollen "input" proportion of a total area in a lake basin is higher than the pollen deposition at the center. The author also noted that the diameter radius of the spore-pollen deposition is often longer in lighter pollen grains and spores than in the heavier ones, which may have more pronounced differences in the deposition percentages in relation to the total area of a lake basin.



Pollen reworking is generally an indicator of an unstable environment, and instabilities can always occur on a time scale. Several authors (Davis 1968; Davis *et al.* 1971; Peck 1973; Bonny 1980; Davis *et al.* 1984), concerned with palynological analyses of lake cores based on estimates of pollen deposition from a single central point of the sedimentary basin, highlighted that the internal processes of a lake redistribute the pollen originally deposited on the bottom surface. These may cause mixtures through the resuspension of previously deposited pollen and the pollen existing in the water prior sedimentation through the "sediment focusing" to the deeper area of the basin. These processes of secondary importance generate the differential deposition and an assembly of palynomorphs in which each type has a differential preservation (Campbell 1999). Dupont (1985) suggested that a differential removal of pollen in aquatic environments would be solely due to the water movement as surrounding areas have different incidences of pollen grains and spores, as in the case of a canal bed and its margin. However, Campbell (1999) explained in detail the reworking process of pollen grains and spores, and the removal of the oldest ones from the deposit would operate in four ways:

- a complete removal of the deposit and total redeposition.
- a partial removal and total deposition of the reworked fraction.
- a complete removal of the deposit and partial deposition (in this case, a fraction of pollen grains and spores could be destroyed by transport as suggested by Fall (1987) in the case of a fluvial transport).
- a partial removal and partial deposition.

The author suggested four fundamental processes that could occur in the differential reworking:

- differential resuspension of the original deposit.
- differential transport.
- differential capture in the receiving area.
- differential preservation during transport.

As an example, the passage of water or wind over a surface could resuspend the pollen grains and spores in a different way, leaving the heavier ones in relation to hydrodynamic (or aerodynamic) behind and moving the lighter ones to a new deposit. This type of resuspended pollen assemblage presumably occurs constantly in the environment. In cases where redeposited palynomorphs are not obviously older than those of the original deposit, their presence becomes very difficult to detect.

For Chmura *et al.* (1999) the fluvial transport of palynomorphs provides a more inclusive vision of the vegetation than the aerial transport alone, corresponding to a palynological assemblage of the vegetation found in the drainage basin, including high amounts of pollen and spores that would not be readily available to the anemophilous transport (such as herbaceous plants). The author noted that, on the contrary, deposits of pollen and spores in lakes without tributaries and located far from estuaries are much more influenced by anemophilous plants, particularly wind-pollinated tree species. The author suggested that in the fluvial transport, the deposits of banks, sand and bars existing in the way, can also introduce spores and pollen of local plants (local component) to the pollen assemblage, as well as lead to the resuspension of these deposits. Obviously, this supply of pollen and spores directly from rivers is dependent on its geomorphology. A sinuous

river will be much more exposed and receive more pollen and spores from the banks than a straight course river.

Muller (1959), Cross *et al.* (1966), Traverse & Ginsburg (1966), Heusser & Balsam (1977), Heusser (1978) and Traverse (1988) when studying the ocean transport of pollen and spores found that they are transported by currents and deposited together with silt preferably at the river mouths. The contribution of plants growing on the river banks dominates the spore-pollen assemblage, since most of it is introduced into the ocean by fluvial transport. In the absence of ocean currents, abundance of pollen and spores decreases with the distance from the coast, but the turbulence of the sea water and waves are important factors in the redistribution of palynomorphs. Those that settle far from the coast are those able to float longer, such as the bisaccate pollen grain of conifers that have hollow cavities formed by an expansion of the exine. But Wang *et al.* (1982) observed that the surface sediments of the Yangtze River mouth (China) showed a low concentration of palynomorphs, while high concentrations were found far from the coast. Traverse (1988) suggested that this pattern could be explained by the local hydraulic turbulence, since the pollen deposition at river mouths is primarily controlled by currents and hydraulic sorting according to the sizes of pollen grains and, therefore, the ordering of the pollen assemblage should follow a distance gradient from the delta (Fig. 6).

Another point that deserves attention is the pollen and spores destruction before or even during sedimentation. Pollen grains and spores are subject to various weathering and decay processes, from the time of anther dehiscence and sporangia until the deposition time (Campbell 1999). During periods of soil erosion, pollen and spores can become incorporated into river and lake sediments. As a result, the contemporary vegetation may be poorly represented by the palynomorphs in the sediments because of the reworked component of in washed pollen and spores. This assemblage of reworked palynomorphs generally presents itself with several levels of exine deterioration. The differential preservation is often recognized by the tendency that the assemblage of pollen grains and spores shows in terms of their poorly preserved condition and abundance. Analysis of the level and type of deterioration is very important in assessing the sedimentation conditions to which pollen and spores have been exposed because changes in taphonomic process can influence the composition of the palynological assemblage, producing variations independent from changes in vegetation (Pennington 1996). Differences in the preservation of pollen grains and spores during transport have been reported in many studies, particularly those related to damage caused by collisions of the pollen grains and spores in fluvial transport (Catto 1985, Fall 1987). However, Campbell (1991) showed that this type of damage is minimal, because the greater damages occurred during fluvial transport are likely to be originated from oxidation and dryness in temporal deposition areas along the time.

It is known that the endexine is more resistant to oxidation than the exine (Rowley 2001). The type of deposit, to which pollen grains and spores are eventually incorporated, will affect the assemblage of palynomorphs, meaning that the differential degradation may continue after the deposition. The oxidative-reduction potential (Eh) of the depositional environment is affected when the sediments with low Eh are more favorable for the pollen preservation. The adverse effect of soil pH on the pollen and spores preservation occurs in soils with pH above 6.0 (alkaline) where the pollen is not usually preserved and when preserved the identification to the taxonomic level becomes impossible due to the poor

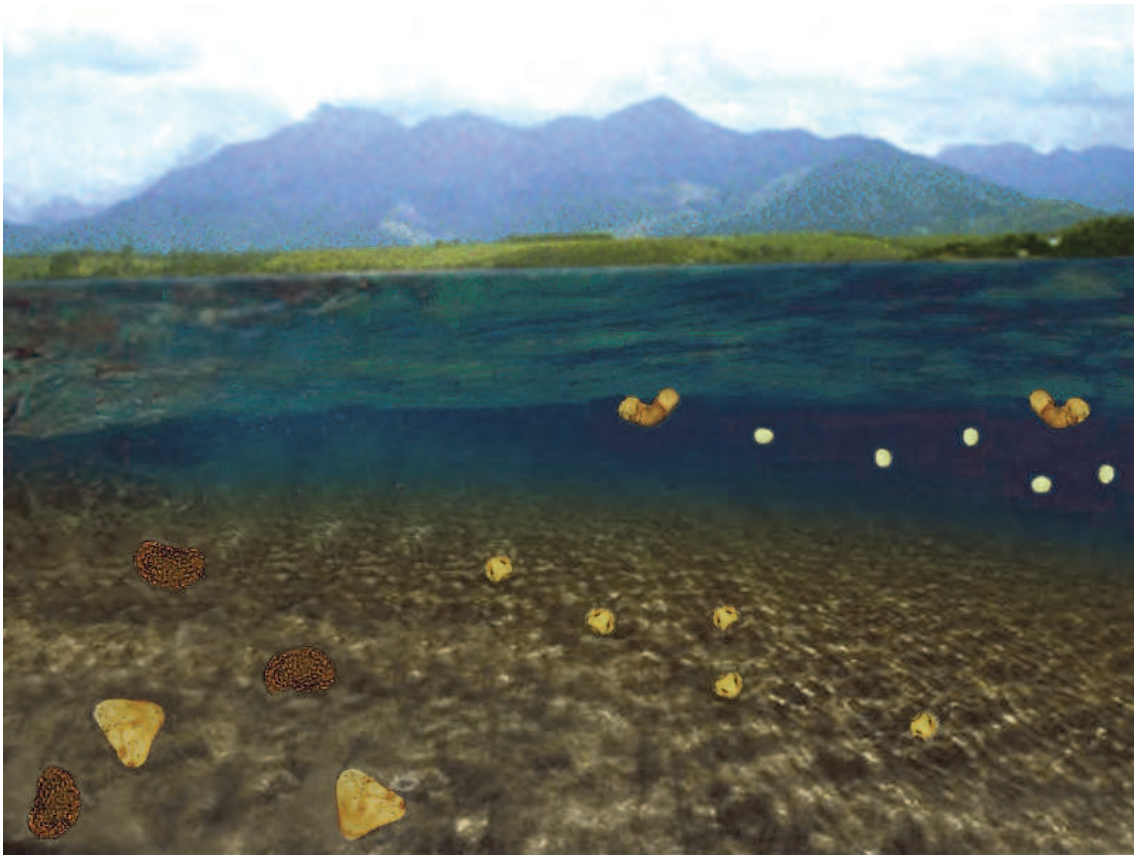


Fig. 6. General representation of differential deposition of palynomorphs in a river mouth: large size grains are deposited in the delta, near to the river mouth; medium size grains are deposited at sites of transitional depths of the delta and the smallest ones or those with hollow cavities such as bisaccate pollen grains of *Pinus* and *Podocarpus* continue to float longer, placing it farther away with the currents or, in the case of shallow lakes, on the opposite side of the dominant direction of the wind.

visualization of the exine (Pennington 1996). In the destruction process of pollen grains and spores, the biochemical attack of bacteria and fungi also plays a very important role (Elsik 1971). The speed and damage extent caused by all these factors are in many cases related to the genetics of pollen and spores such as the low amount of sporopollenin of the exine that generates greater instability in their preservation in the sediment (Havinga 1964). The sculpturing elements of the exine may also provide greater or lesser resistance to the attacks, as in psilate pollen grains (usually with thin exine) that are less resistant to oxidation.

Moore *et al.* (1991) noted the importance of observing the level and type of pollen deterioration of any palynological sample.

They summarized the work of Cushing (1967) and Delcourt & Delcourt (1980) on four deterioration types of pollen grains and spores (Fig. 7):

- **Corrosion** is characterized by the completely perforated exine, as a network of circular holes or all the tectum (layer of the sexine) is removed, leaving an exposed surface of scabrate appearance. Sometimes only the outermost layer of the sexine is affected and may be slightly excavated. This type of deterioration is more intense in peat bogs

deposits. The most usual cause for it is the microbial activity. Provided that the growth of bacteria and fungi activity occurs in conditions of, at least, periodical aeration, the implication of such deterioration in aquatic environments is that before or after the deposition the pollen grains and spores were exposed to oxygen. The microbial attack, particularly by anaerobic bacteria, can remain in humid and flooded sediments, but with a lower rate.

- A general reduction in exine thickness characterizes **degradation**. This type of deterioration occurs more frequently in pollen grains and spores with thinner exine. In its extreme form, this can result in a condition where the sculpturing elements of exine become undefined, or apparently become a uniform mass, without structures. The degradation involves exposure of pollen grains and spores to the air, resulting in chemical oxidation. In peat bogs and lakes, pollen grains can undergo this type of decay due to dry periods.
- **Mechanical damages** cause ruptures breaks or creases in the exine, but they do not necessarily show reductions, thinning and perforations. The cause of this type of deterioration is usually the physical stress to which the pollen grains and spores were exposed in the course of their depositional process such as collisions due to fluvial transport; as the result of digestion observed in invertebrate coprolites whose pollen grains and spores are extremely wrinkled or even because of the compaction of sediments that may have occurred after their deposition.
- **Obscured pollen** grains and spores may be infiltrated with crystallized minerals *in situ*, or opaque debris may occur in the microscope slides affecting the visualization of palynomorphs.

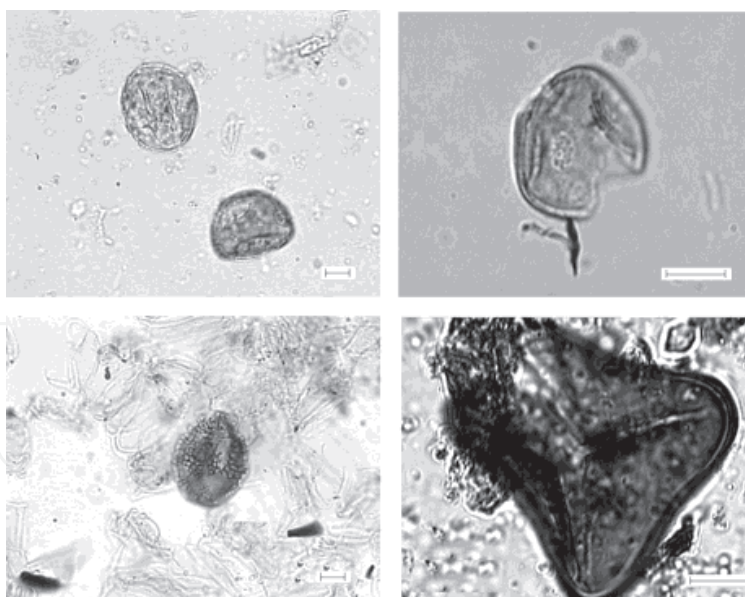


Fig. 7. Light photomicrographs of pollen and spore types of deterioration. Top: two examples of pollen corrosion. Bottom: examples of pollen degradation and of mechanical damage in a trilete fern spore. Scales in the figures= 10 µm.

Therefore, the pollen transport is different in different aquatic environments which will influence the overrepresentation or underrepresentation of certain pollen and spore *taxa* in the assemblage of the sediments. In general, there are:



- In **rivers** and **streams** a large amounts of pollen and spore can be transported by the currents and generally correspond to the vegetation of large surface areas where these currents flowed. Studies have shown that the sediments collected from within the main channel have a pollen assemblage representative of the distant mountains (regional elements) where the river passed by. Instead, the sediments adjacent to the main channel represent the vegetation near the sampling site (local elements).
- In **lakes**, during fluctuation, pollen and spores are subjected to the action of the winds along the water. Types of low sinking speed (smaller sizes) are preferentially deposited in the shallow areas of the coast. The sediment containing pollen, spores and algae can move to the deep parts of the lake ("sediment focusing"), below the region of wave action.
- In **deltas** and **estuaries** pollen and spores are transported by ocean currents and deposited together with the silt sediment. The pollen grains and spores carried by perennial rivers are deposited usually near the river mouth, in deltas. From the river mouth to the deeper parts of the ocean, the pollen grains and spores are deposited in decreasing gradients in relation of the grain size and concentration. In the spore-pollen assemblage, there can be high percentage of corroded, degraded and mechanically damaged pollen grains and spores. In estuaries, the mixing and reworking of sediments caused by the turbulence of the waves makes it almost impossible to pollen analysis. In general, you should be very careful when searching in marine environments because of the distortions in the palynomorphs spectra due to the complexity of the depositional patterns.

## 2. Sampling methods and analyses

Recent underwater deposition of pollen and spores can be studied by collecting surface sediment (first 2 cm) performed by equipment such as dredges, bottles, plastic tubes or with a modified free-fall valve corer (Davis *et al.* 1971). In collecting short cores, if there have not been rework or material loss, the top sediment corresponds to deposition of the last decades. It is important that collections of the surface sediments be carried out in a horizontal gradient ("transect") and along the direction of dominant winds, taking into account the direction of prevailing currents, including material at the margins as well as at the center of the depositional site. The number of samples is determined by the extent of the site. The chemical preparation employs a series of reagents in order to remove organic and inorganic residues in order to concentrate the palynomorphs in microscope slides (Faegri & Iversen 1950, Ybert *et al* 1992, among others). In order to assess the relative and absolute frequency of palynomorphs, pollen are counted, either by volume measurements (Cour 1974) or by introduction of exotic spores or pollen (Stockmarr 1971, Salgado-Labouriau & Rull 1986), making sure to perform observations in more than one slide, seeing both at the edges as at the center. It is common to count 300 grains of pollen per sample, but at the tropics, in general, this number needs to be larger in order to be noticed, even the rare grains (pollen types underrepresented in the sediment). The diagrams show the curves of Relative Frequency and Concentration of each palynomorph for each category and according to established Pollen-spore Sum, separating the regional elements from local elements which are indicators of humid environments. These diagrams may be plotted in different software programs (Polldata, Tilia, Coniss, C2, among others).



### **3. The influence of bathymetry associated with prevailing wind and fluvial currents - case study: Palynological depositional patterns in coastal lakes of the northern region of the Rio de Janeiro state, Brazil**

The coastal plain of Campos dos Goytacazes municipality, northern coastal region of the Rio de Janeiro State, is an important area for palaeoenvironmental studies. This region presents several shallow lakes, which are relict bays of a large palaeolagoon system that was isolated from the sea during the Quaternary by sediments from the Paraíba do Sul River (e.g., Lagoa de Cima lake), by sand barriers or beach ridges (e.g., Lagoa Salgada lake), or by alluvial fans of the Barreiras Formation (e.g., Lagoa do Campelo lake).

The Lagoa de Cima Lake is embedded in a valley (Imbé River basin) located between the Barreiras Formation (Tertiary sediments) and the Precambrian crystalline basement, 50 km west from the coastal line and with about 30 m high. This lake may have been formed by an obstruction of a palaeolagoon called Ururaí Bay, and, therefore, represents the oldest lake in this region. The water is fresh and presents diatomite deposits at its margins. It is conditioned by the inflow of the Urubu and Imbé Rivers and presents an outlet called Ururaí that flows towards the Lagoa Feia Lake that is connected to the sea by a narrow passage. Nowadays, the Lagoa de Cima Lake drainage basin occupies an area of circa 986 km<sup>2</sup> and does not present industrial activities but intense sugar-cane agriculture, pastureland, and a small remnant fragment of the Atlantic forest bordering the lake. The evergreen rainfall forest covers the high mountains of the drainage basin, especially inside the Parque Estadual do Desengano, a governmental area for the protection of the forest that is located 5 km west from the Lagoa de Cima Lake.

The Lagoa do Campelo Lake is located at 17 km away from the coastal line, with about 8 m high, bordering the Barreiras Formation and reaching the flattened sediments of the coastal plain, which cover the Cretaceous layers of the Campos Basin. Its drainage basin is not well limited and occupies an area of circa 98 km<sup>2</sup>. Without a tributary and an affluent, the lake receives fresh water and sediments from several swamps and bogs connected to the Paraíba do Sul River. The water of the lake was not naturally drained into the Atlantic Ocean because in 1950 the government carried out several changes in the Campos dos Goytacazes municipality in order to control the natural floods in this region. The building of a channel connecting this lake to the Paraíba do Sul River and another channel towards the sea was not good to its hydrological balance. A small remnant of the seasonal semideciduous forest can be observed at 5 km southwest of the lake, and a small swampy forest fragment of “restinga” vegetation in the northeastern margin of the lake. Pastureland, sugar-cane agriculture and subsistence plantations constitute the regional landscape of the drainage basin. The marsh vegetation at the lake borders presents Cyperaceae, Poaceae, some additional plant taxa, and a characteristic large belt of cattail (*Typha*).

Aiming to support the reconstruction of the temporal dynamics of the vegetation during the last 7,000 years (Luz *et al.* 2011), palynological studies of surface sediment samples were performed to elucidate the current dynamics that have influenced the sedimentation of palynomorphs inside these lakes. Fifteen surface samples were collected with a hand dredger in the top five centimeters of the Lagoa de Cima Lake sediments and four of the Lagoa do Campelo Lake, in a transect of 500 m steps from one to the opposite side, in the NE/SW direction, which is the same direction of the dominant wind (Luz *et al.* 2002, 2005, 2010).

Pollen grains occurring in samples obtained in the surface sediments from the transect across the Lagoa de Cima Lake reflect the extant vegetation around the lake and along the Imbé and Urubu Rivers, with an expressive contribution of arboreal regional taxa, as well as an important contribution of hydrophyllous/swampy plant species and ruderal plants from the wide-ranging pasturelands in this region. In the Lagoa de Cima Lake, the resuspended sediments (with corroded pollen and fern spores) take a preferential direction of deposition caused by water currents that generate high pollen rates in less deep and decentralized areas.

The smaller pollen grains and spores (5-25  $\mu\text{m}$ ) showed preferential deposition in the region of the water outlet of the lake (the Ururaí River) while the larger size grains, near the entrance of rivers Imbé and Urubu. The central region did not show a consistent pattern of deposition by grain size and presented also sand deposition at the most central point (sample 7) which prevented the preservation of palynomorphs in the sediment, making it sterile (Fig. 8).

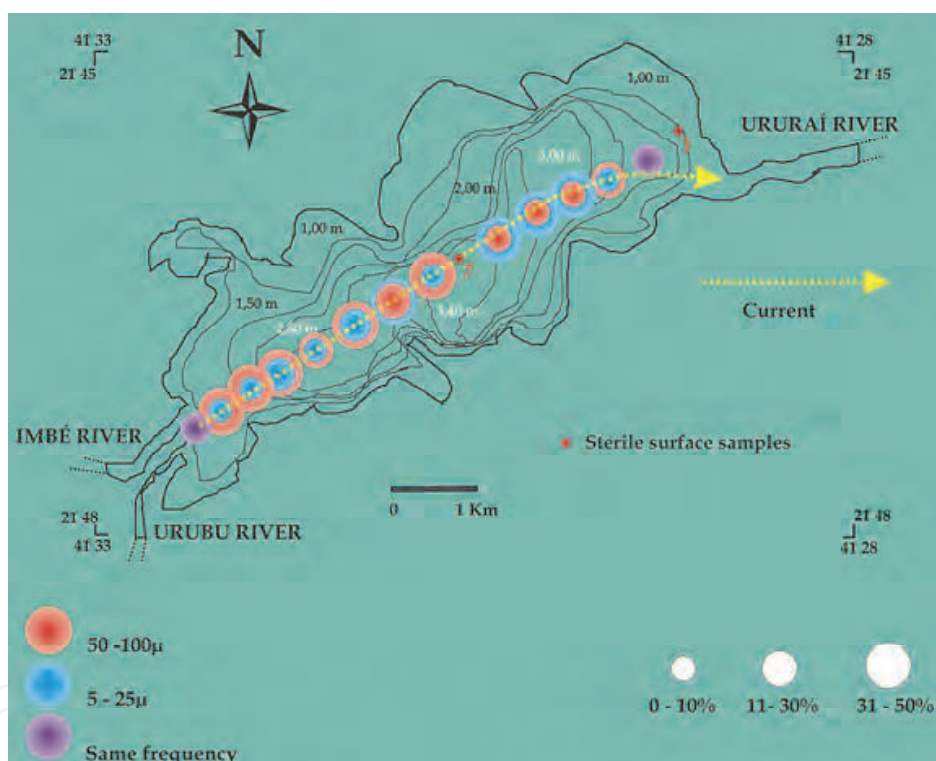


Fig. 8. Differential deposition of pollen and ferns spores in Lagoa de Cima lake, Rio de Janeiro, Brazil, through the frequency analysis of grain size.

Pollen and spores preservation was sometimes poor in the superficial sediments of the Lagoa do Campelo Lake, evidencing their exposition to the air during the partial drying of the lake and corrosion by microorganisms. The pollen spectra indicate a major performance of the local vegetation and the preferential deposition of regional pollen types at the southwest margin of the lake, reflecting the action of a dominant NE wind. The smaller pollen grains and spores (5-25  $\mu\text{m}$ ) showed preferential deposition in the central and deepest area of the transect, while the larger size grains were deposited preferentially near to the cattail belt at the north east margin of the lake (Fig. 9).

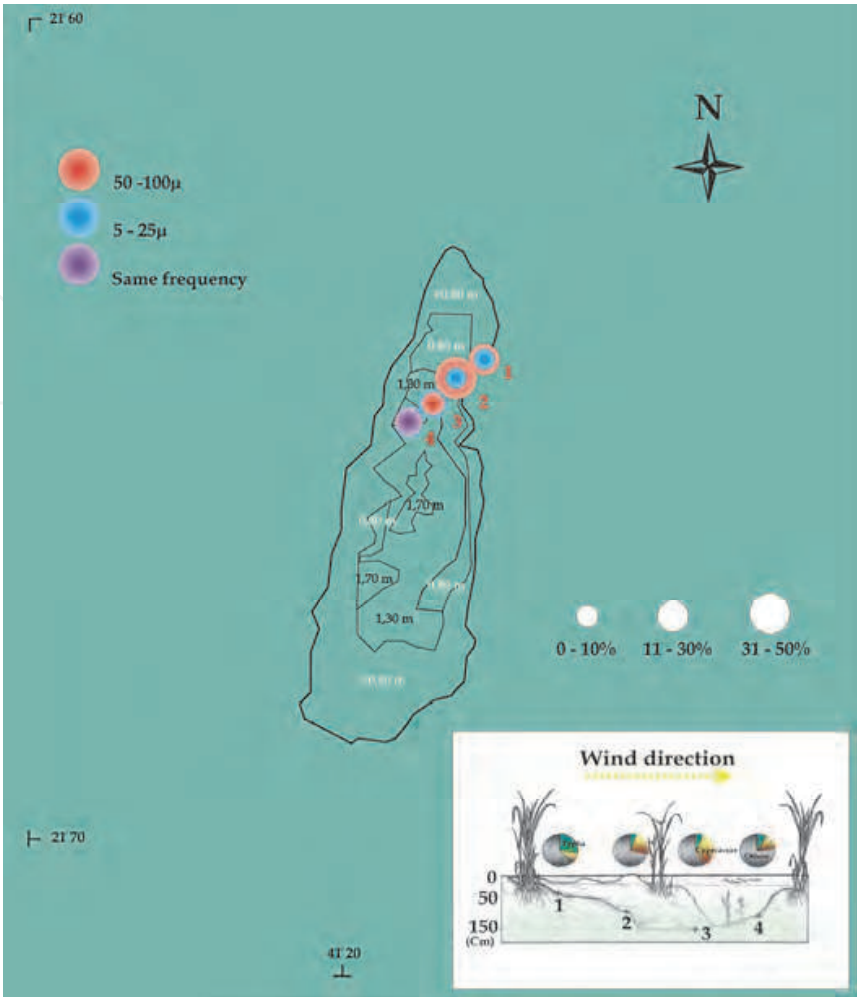


Fig. 9. Differential deposition of pollen and ferns spores in Lagoa do Campelo lake, Rio de Janeiro, Brazil, through the frequency analysis of grain size. In the right side image below: the pollen grains of autochthonous *Typha* (cattail) and Cyperaceae were deposited preferentially on the side of the source-plant, according to the direction of the prevailing wind.

The dynamic of deposition was different in the areas of the two studied lakes. At Lagoa de Cima Lake, it reflects the response to the sea level, always presenting a strong grouped influence of regional and local forest, grassland and swampy vegetation. Nevertheless, the dynamic of deposition in the Lagoa do Campelo Lake is in innermost dependence of the dominant wind and bathymetry. The high number of pollen types is attributed to the local plants.

**4. The influence of bathymetry associated with tidal currents - case study: Palynological depositional patterns in Baia de Guanabara bay, Rio de Janeiro state, Brazil**

The Guanabara Bay has a narrow entrance, approximately 1.6 km wide, which stretches towards S-N to its bottom, reaching a maximum diameter of 28 km, with a perimeter of 131 km. The water surface measures 373 km<sup>2</sup>, excluding its islands and considering only its outer limits. Its basin covers approximately 4,600 km<sup>2</sup>, including almost all the metropolitan

areas of the municipalities of Rio de Janeiro and Niterói, among others. Around 35 rivers culminate into the bay and the longest ones (The Macacu and the Caceribu rivers) are born in the “Serra do Mar” mountain range. In the narrow entrance, there is a large sand bank, located at 22°56'48 "S/43°07'54" W, which rises from a depth of 20 m to 11 m. This feature promotes the canalling of the currents and acts as an obstacle to free movement of tidal currents. In the bottom topography of the bay, a feature that deserves mention is the center canal, general N-S orientation, stretching from the entrance neighborhood to near Ilha do Governador island. The most common depths of this canal are around 30 and 40 m, and near the Ilha Lage island, there is a depression which reaches 58 m of depth. The tides of the Guanabara Bay are classified as semi-daytime, with a period of about 12.5 h and differences in the high and low tides, whose amplitudes range from 0.20 to 1.40 m and with an average syzygy amplitude of about 1.20 m. The propagation of the tidal wave into its interior undergoes changes in phase and amplitude depending on the geometry of the Guanabara Bay.

The type of remaining vegetation in the region of the Guanabara bay is represented by the Rainforest (Atlantic forest domain), currently located in rugged topography (mountain slopes), mainly, and in a few forestry reserves. The areas of mangrove vegetation that, in the past, covered almost all of its edge, are currently limited to a continuous patch on the bottom of the bay and very sparse occurrences on its east coast.

A total of 27 surface samples were collected with a hand dredger in the top centimeters of the Guanabara Bay sediments (Barreto *et al.* 2006). The palynological results obtained showed a high percentage of herbaceous vegetation and a high richness of pollen grains from the mixed rainforest. The differential distribution of palynomorphs followed a pattern that was influenced by the bathymetry associated to the guidance of tidal currents, which originated the highest concentration of palynomorphs in the deeper and topographical obstructed areas (e.g., the islands) (Fig. 10).

Despite the complexity of currents that create resuspensions in the unconsolidated sediment surface in the entire Guanabara Bay and on the coast with an individualized morphology, differential deposition of palynomorphs followed a pattern of higher percentage of accumulation of small sizes at greater depths in the main canal, while the larger sizes preferably deposited in protected areas along the islands, laterally in lower depths and at the bottom of the bay after the discharge of major rivers. In the middle sector near Ilha do Governador island and at the bottom of the bay, concentrations of total palynomorphs were the highest in all samples analyzed. As the currents in the main canal near the mouth of the Baía de Guanabara Bay has a higher speed, it is assumed that in this area, the resuspended palynomorphs are constantly taken by the tides making their sedimentation difficult, which was observed in the analysis as a low total concentration of palynomorphs. This also explains the higher percentages of smaller sizes found there, once they are easier to be carried because they float longer. The islands with their points, coves and areas of less bathymetry favored the “capture” of palynomorphs in transit, resulting in a higher deposition there. The higher deposition of larger palynomorphs at the bottom of the bay, region of the culmination of several major rivers corroborates the idea of differential deposition in a gradient due to the grain size as postulated by several authors.



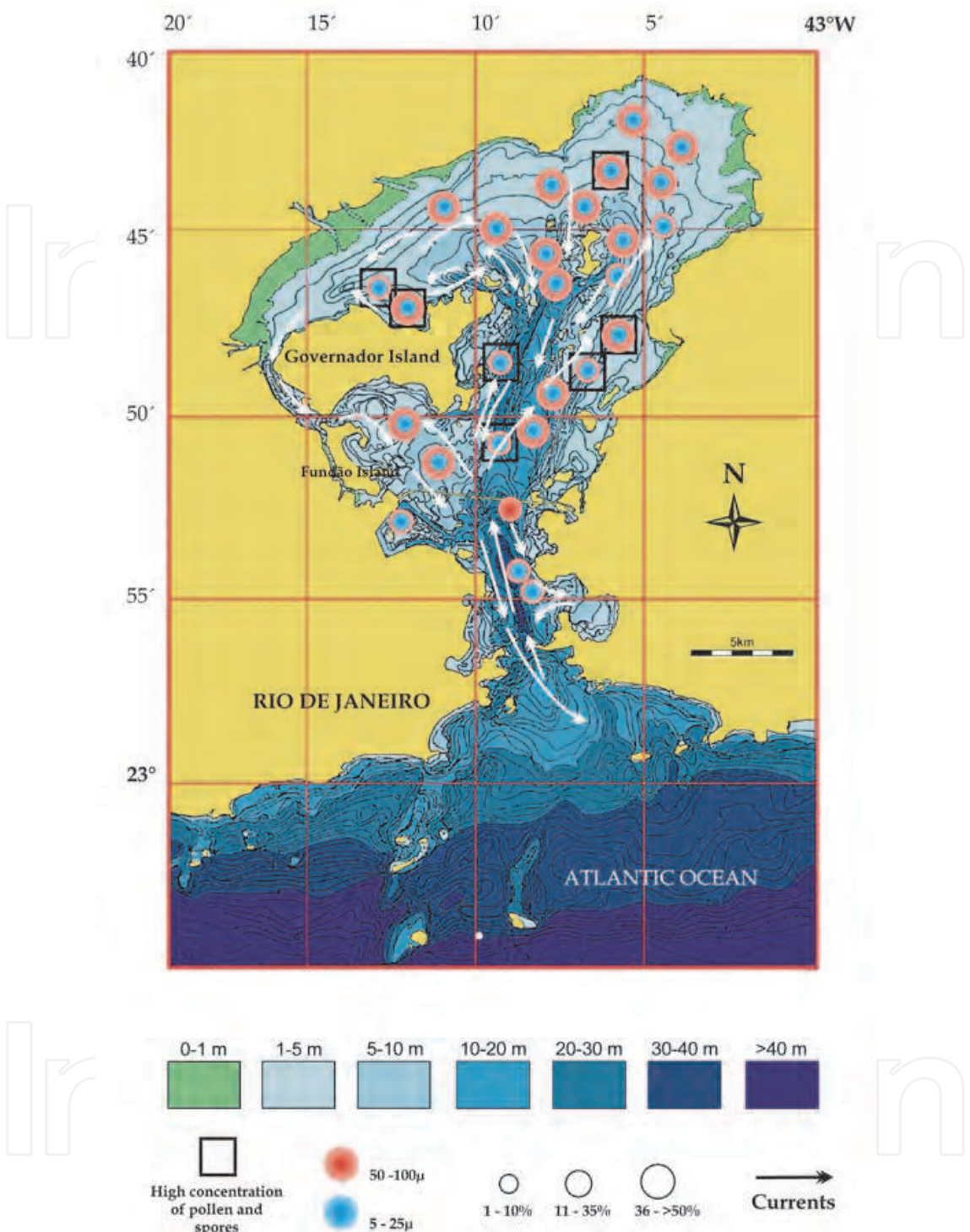


Fig. 10. Differential deposition of pollen and ferns spores in Baía de Guanabara bay, Rio de Janeiro, Brazil, through the frequency analysis of grain size.

5. Conclusions

The foundations of differential sedimentation in aquatic environments have been long investigated by palynologists, but their exact implications for the preservation of spore-pollen records are usually not fully taken into account in interpretations of changes in



vegetation and climate through cores. The approach on the variable “space” in palynological research of the Quaternary is still neglected, both because there is a greater concern with the temporal dimension of vegetation obtained by the analysis of samples obtained at one single place and because there is usually no preliminary assessment of horizontal space of spore-pollen deposition in the study area. The lack of knowledge on this variable often leads to a poor choice of place for probing sample collection causing interpretation problems due to reversals of sedimentary layers and absence of palynomorphs deposition (Luz *et al.* 1996, Barth *et al.* 2001, Luz *et al.* 2011). Even between areas very close to each other or in two samplings obtained from the same site on a time-scale, disparate climate interpretations are seen through Palynology. The effects of this relation to local sedimentation problems of palynomorphs are often not explicitly addressed in the literature. However, in the last ten years, spatial analysis has been identified as a breakthrough in making ecology (hence, paleoecology) a more robust science (Pinto *et al.* 2003). Of course, factors such as differences in the pollen and spores productivity by the parent plant, modes of pollination and release of spores from each of them and their locations in the landscape with respect to the depositional site, present as significant problems to climate and paleoclimate reconstruction. However, one of the key points to understand is that in water transport, there is no uniform and continuous dispersion of palynomorphs, and they may suffer resuspensions or temporary deposition beyond the sampling site, and may also go through various stages of wear and tear. This worn and broken material is an important environmental indicator and should be analyzed for its proportion in perfect and whole grains, because they provide important paleoecological information regarding temporal variations of the energy of water flows and possible droughts, exposing them to air. The disturbances in the sedimentation caused by hydrological and climatic changes alter both the quantity and the quality of the material deposited over time, such as interbedded sands amid packs of silt and clay, horizontal redistribution of previously deposited material causing reversals in the chronology of layers, higher occurrence of palynomorphs of large or small size at certain areas, etc., and should be taken into account especially where the compaction of the material is not yet big. An undisturbed laminar sedimentation is very rare in the tropics where there are no demarcated four seasons and where torrential rains are constant. Therefore, even if the Quaternary palynologist has a remarkable knowledge and is able to identify the family, genus or even the species to which the pollen and spore fossils belong, correct identification is only one side of the coin. Climate reconstruction over an image of the primitive vegetation that flourished in a given region through the palynology of sediments is a very difficult problem and, equally important is to know the possible causes of spatial variations in deposition of pollen grains, fern spores and algae, including undoubtedly the influence of bathymetry.

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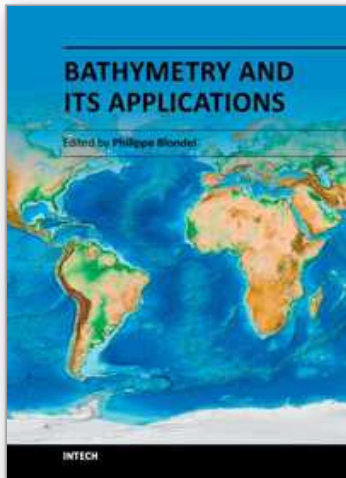


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