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Transportation of coniferous bisaccate pollen from land to sea and deposition along the shelf off Erdemli (Turkey), NE-Mediterranean Sea

V. EDİGER[(1)], V. Ş. EDİGER[(2)] and M. ERGİN[(3)]

[(1)]*Institute of Marine Sciences-METU, Erdemli, İçel, Turkey*
[(2)]*Research Center Turkish Petroleum Corp., Ankara, Turkey*
[(3)]*University of Ankara, Department of Geological Engineering, Tandogan/Ankara, Turkey*

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Abstract. Transportation and deposition of coniferous bisaccate pollen grains from high in the coastal mountains to the Turkish coastal shelf waters in the northeastern Mediterranean Sea are investigated using seawater, atmospheric dust, river water, and core sediment samples. Bisaccate coniferous pollen grains are transported from the hinterland by the coastal land-breeze system and by coastal river-runoff into the Mediterranean Sea during the pollen dispersal period (April and May) each year. These pollen grains are also concentrated along the coastal zone by sea to land winds and dispersed over the sea surface by the land to sea winds. Pollen distribution patterns in core sediments along the shelf are dependent mainly on the recent climatic oscillations, the coastal urbanization density, and the energy level of the shelf water. Calculated recent bulk sedimentation rates in the region average 0.53 cm/year for the last 34 years along the Turkish shelf of the NE-Mediterranean Sea.

1. Introduction

1.1. Location and purpose

Off the rocky coasts between Erdemli and Kızkalesi (NE-Mediterranean, Turkey), it has commonly been observed that, during the heavy rainfall and stormy periods especially, an increased river plume changes the seawater colour from bluish-green to yellowish-green and extends as a surface film in the form of a narrow belt along the shore (Fig. 1). This natural pollution of the sea continues for about a month and has long been of interest to environmental scientists,

Corresponding author: V. Ediger; Institute of Marine Sciences-METU, P.O. Box 28, Erdemli, İçel 33731; e-mail: ediger@deniz.ims.metu.edu.tr

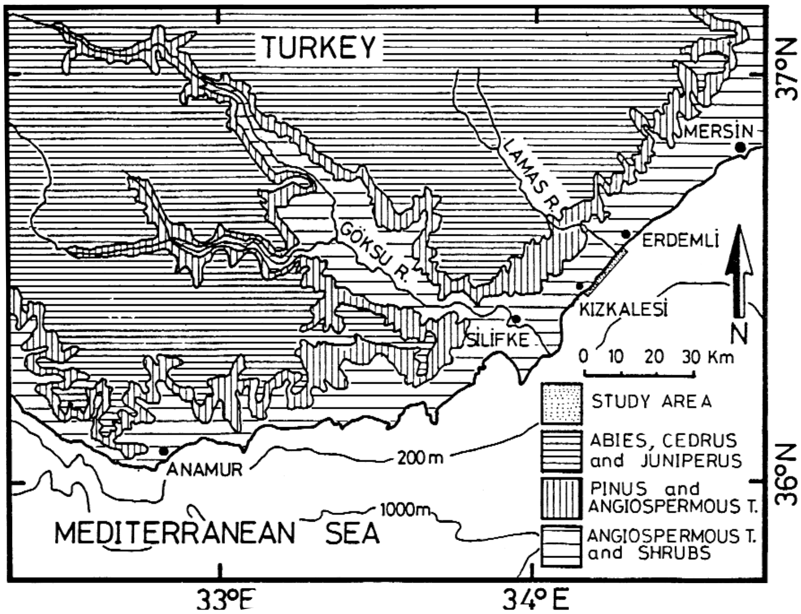

Fig. 1 - Location of the area of study with some information on coastal vegetation. *Abies, Cedrus* and *Juniperus*: >1000m; *Pinus* and Angiosperm trees: 600-1000 m; Angiosperm trees and Shrubs: 0-600 m.

since residents and tourists in the vicinity are scared of entering the sea. The sources and modes of transport of this yellowish-coloured water belt are poorly understood and, as yet, no detailed investigation is known to have been carried out. In this paper, we explain the origin of this seasonal yellowish plume off the Lamas River mouth, near Erdemli, and the factors controlling its dispersal along the coastal waters and bottom deposits in the region.

1.2. Hydrography, physiography, and vegetation

The general water circulation in the Eastern Mediterranean is unidirectional with a general cyclonic character (Fig. 2; Collins and Banner, 1979). The water circulation along the southeastern Turkish coast is controlled mostly by local winds and their corresponding waves and eddies in the coastal zones (Özsoy et al., 1989; Evans et al., 1995). From April to September, the sea-breezes (southerly winds) and land-breezes (northerly winds) are effective all along the coast, but from October to March, the sea-breeze system loses its importance and the region is affected by winter storms (Fig. 3). In the summer season, the sea-breeze system is in action together with the westerlies. The sea-breezes are generally from the SW near the study area (Ebren, 1982).

Velocities and directions of the coastal currents show great variability in the study area. The mean southwesterly current off Erdemli was less than 4 cm/s (IMS-METU, 1984). The circulation of the plume of the Lamas River shows monthly variations and sometimes daily deflections from SW to NE and from NE to SW caused by the direction of the wind and the coastal current systems (Fig. 4) (Ediger, 1991). Tidal forces are so weak (maximum ±60 cm) that the tidal cir-

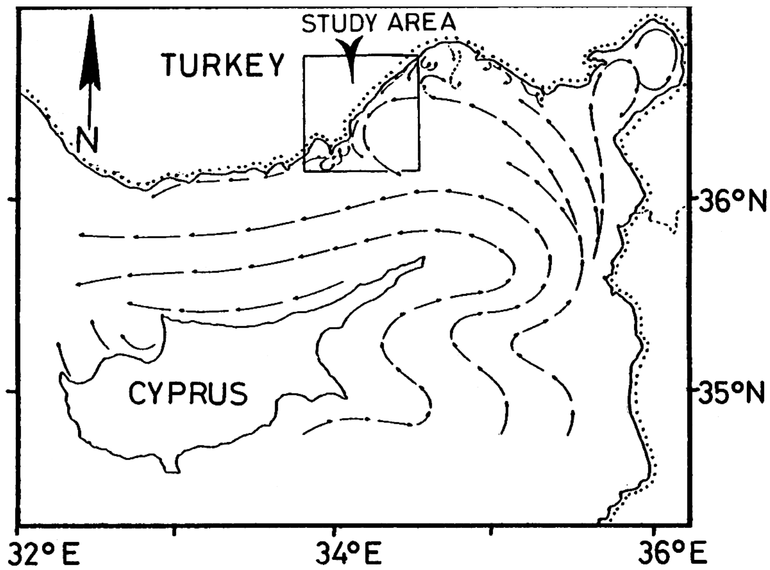

Fig. 2 - Postulated surface circulation in the NE-Mediterranean (from Collins and Banner, 1979).

culation is, in general, negligible on the shelf at the study area (Ediger, 1991). Wind generated currents, waves, and river inflow during the high rainfall season seem to act as the main source of turbulence in the nearshore areas (Evans et al., 1995).

In the study area, there are two principal rivers draining into the sea: the Göksu and Lamas Rivers (Fig. 1), with total annual discharges of about 4313×10^6 m^3 (between the years 1977-1978) and 220×10^6 m^3 (between the years 1977-1978) respectively (E.I.E., 1981). The highest rates of average discharge in both rivers occur during March and April (Fig. 5). Although the Göksu River drains an area (10065 km^2) which is about ten times bigger than that of the Lamas River (1055 km^2) (E.I.E., 1981), the latter seems to be more effective in pollen transportation in the study area.

The study area has a typically "Mediterranean climate" with hot and dry summers and mild wet winters (Mediterranean Pilot, 1961). The mean temperature ranges between 11 °C (in January) and 28 °C (in August) (mean 18.7 °C), and the mean humidity between 62-73 % (mean 68 %). The maximum monthly rainfall (153 mm) is observed in January, and the minimum values (0.1 mm) are in August (Meteorological Bulletin, 1970).

The vegetation cover of the study area is denser than the other southeastern parts of Turkey. Angiosperm trees and shrubs cover the foothills of the Taurus Mountains below 600 m elevation (Fig. 1). Above this level, an angiosperm-gymnosperm mixed forest is present between 600-1000 m (Fig. 1). The major element in this zone is *Pinus*, accompanied by several angiosperm species between 600-800 m, and by *Juniperus* trees between 800-1000 m. The hills higher than 1000 m are covered with *Abies, Cedrus*, and *Juniperus* (Fig. 1). Thus conifers belonging to the families Pinaceae *(Pinus, Abies*, and *Cedrus)* and Cupressaceae *(Juniperus)* are dominant in the area above 600 m (Walter, 1968; Mayer and Aksoy, 1986; Atalay, 1987).

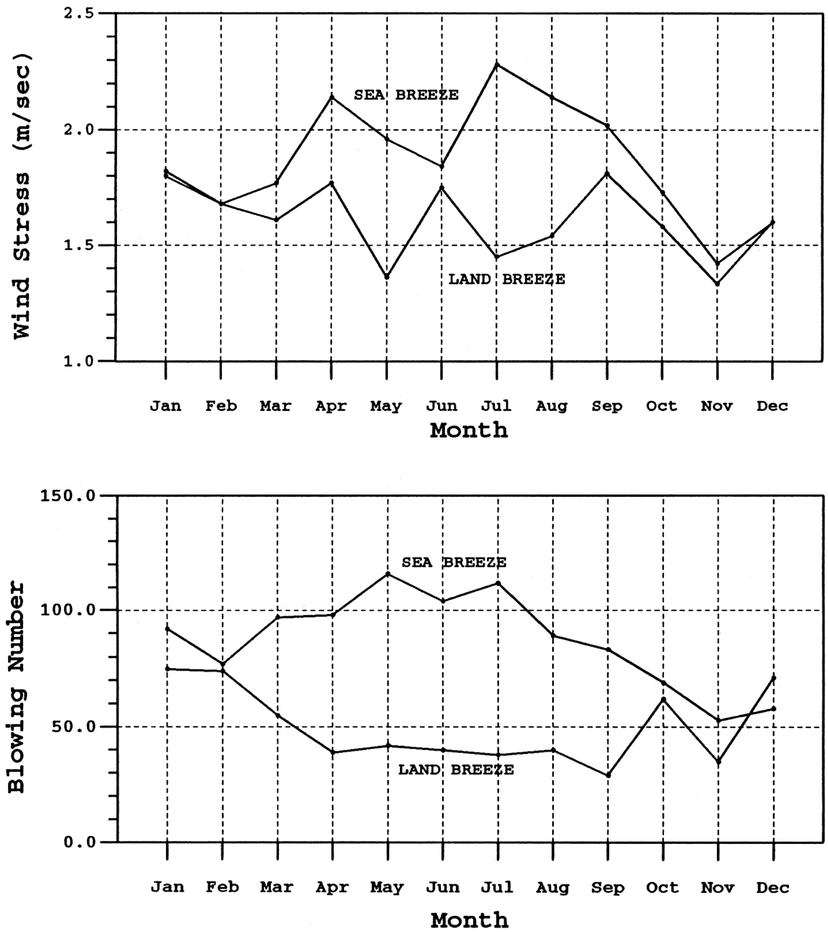

Fig. 3 - Monthly wind stress and blowing numbers of the sea and land-breezes (adapted from the Meteorological Bulletin, 1970).

2. Materials and methods

During the years 1988-1992, thin-layers (1 to 3 mm thick) of surface seawater film containing large amounts of yellowish coniferous bisaccate pollen grains were sampled in the study area. This area runs parallel to the shore, from the Lamas River mouth towards the SW and NE. The Town of Erdemli (Turkey, NE-Mediterranean), where the water depths are between 0 and 15 m. An area of about 20 km (1 km wide and 20 km long) was observed to be covered with these pollen grains (Fig. 1). In the laboratory, the water samples were centrifuged and the recovered suspended matter embedded in a mounting medium called "elvacite" for standard microscopical studies. Scanning Electron Microscope (SEM) studies were also carried out on air-dried and gold-covered suspended matter samples (Fig. 6).

Monthly representative atmospheric dust samples were collected using a net (Kubilay et al., 1997; Saydam, 1981) at the meteorological station IMS-METU (which is located 20 m above

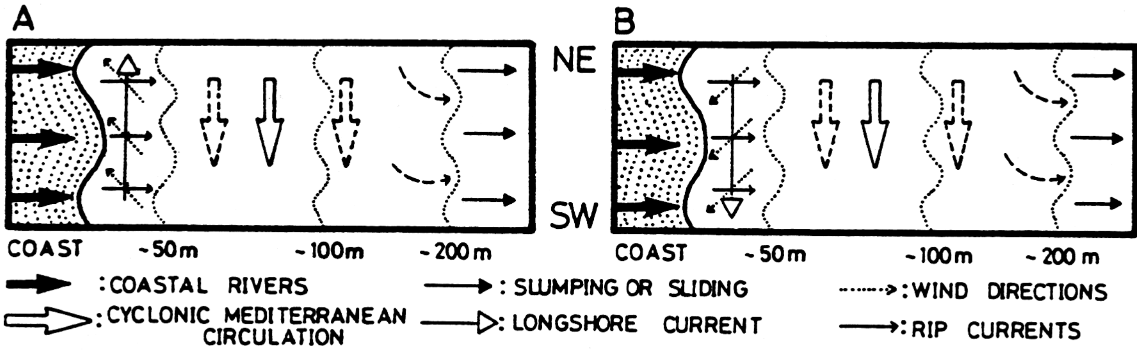

Fig. 4 - Current action along the northeastern shelf of the Mediterranean Sea. Dotted lines indicate depth contours in meter. Direction of the longshore currents are from SW to NE (A) and from NE to SW (B) (Ediger, 1991).

sea-level near the coast of Erdemli) in 1990 (Fig. 7), and examined under microscope to determine the presence of pollen grains (Fig. 8).

Three short sediment cores (Numbers 1, 3, and 129) were collected on the continental shelf, off Erdemli, in 1984 (Fig. 7), from water depths between 10-180 m. Nine subsamples were obtained from these three cores and analyzed palynologically. Standard laboratory techniques were used to isolate the palynomorphs as described in Ediger (1986). A minimum of two hundred grains/slide were counted under the microscope to determine the relative percentages of each palynomorph group (Table 1).

3. Results and discussion

3.1. Pollen distribution in sea and river waters and in the air

Palynological analysis showed that the riverine plume of floating material in coastal waters along the shore consisted primarily of coniferous bisaccate pollen grains (Figs. 6 and 9). The pre-

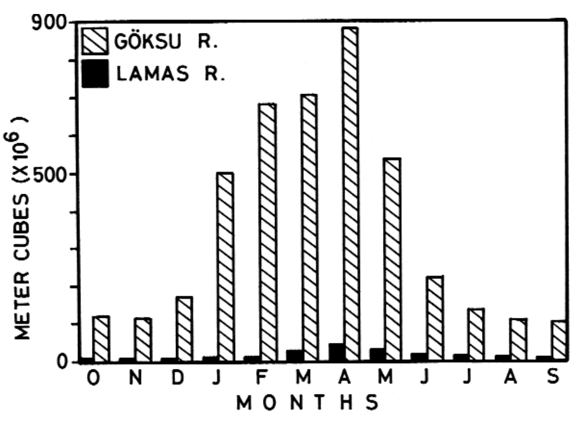

Fig. 5 - Monthly river discharges of the Göksu and Lamas Rivers.

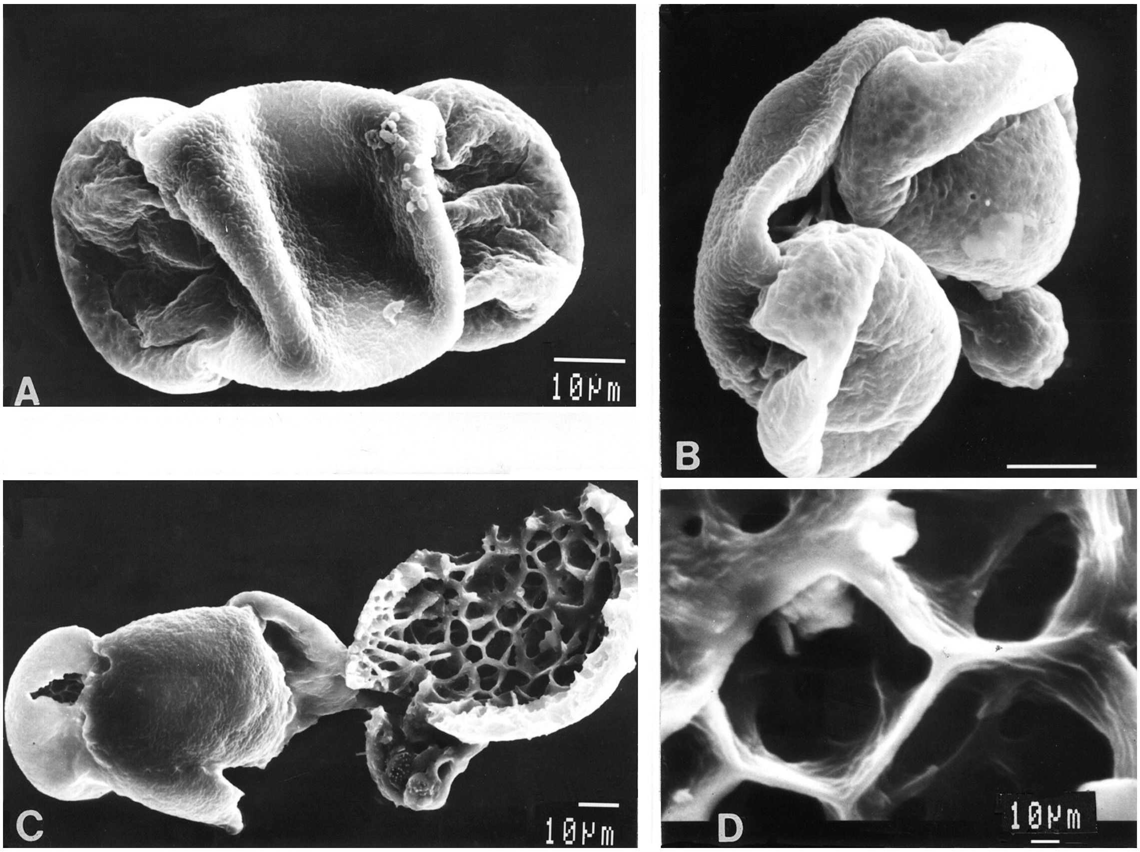

Fig. 6 - Morphology of bisaccate pollen grains. A-D; SEM photomicrographs of pollen grains (in sea water).

servation of the pollen grains is good, since only a slight degradation was observed. The exine of pollen grains is smooth and thin (Fig. 9), and a alveolar structure is present, probably to help wind dispersal.

Pollen production by the coniferous trees is usually very high at the time of dispersal. For instance, a *Pinus silvestris* forest produces nearly 30,000-280,000 grains per square cm in a season (Koski, 1970; Faegri and Iversen, 1975). It has also been noted that certain anemophilous gymnosperms such as *Pinus* produce nearly $1x10^6$ pollen grains per ovule (Erdtman, 1969; Niklas and Paw, 1983). The production of more pollen than Angiosperms (gymnosperms produce about 166 times more pollen grains per ovule than angiosperms; Faegri and Iversen, 1975) may mean that pollination in gymnosperms is less efficient. In fact, only a negligible fraction of the pollen settles on stigmata, the bulk of it being lost on the ground (Faegri and Iversen, 1975).

The pollen-producing microsporangia dehisce only under active climatic (wind, temperature and humidity) conditions (Faegri and Van Der Pijl, 1979; Traverse, 1974). This usually happens in the spring. In the studied area, the temperature (mean 18.7 °C) and the humidity (mean 68 %) in spring are probably the best for pollen dispersal. The velocity and frequency of winds play a very important role in pollen dispersal. The most effective winds are from the SSW, SSE, and SW (sea-breezes) in the region. In springtime, the prevailing wind direction is mainly SSW.

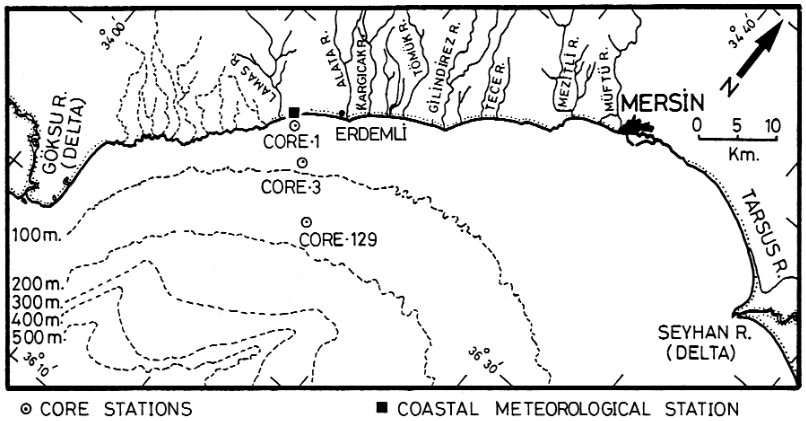

Fig. 7 - Location map of the cores across the shelf and the meteorological station at the coast of Erdemli.

From this direction the wind velocity is 3.0 cm/s and the number of major winds in spring is 100. This means that about one-third of the winds blow from this direction with a velocity of about 3.0 cm/s during spring. However, northerly winds (land-breezes) are needed for wind-transportation of the bisaccate pollen from land to the Mediterranean Sea. Thus some other transportation agent in addition to the wind must occur in the area (Fig. 3).

River water, which is known to be a very powerful dispersal agent (Muller, 1959; Traverse and Ginsburg, 1966; Erdtman, 1969; Faegri and Iversen, 1975) is another possibility. Rivers flowing through different types of vegetation cover are known to bring pollen loads of a different composition into the basin (McAndrews and Power, 1973). Therefore, the coniferous pollen grains found in our samples might have been mostly carried by rivers (Roman, 1974; Koreneva, 1966) flowing from high in the mountains down to the Mediterranean coast. This would also explain why the surface film of the Lamas River appears to be yellowish during this period.

Saccate pollen are known to have remained on the surface for a long time, and pollen grains are reported months after the flowering season and hundreds of kilometers from the nearest forest, because of their buoyancy (Faegri and Van Der Pijl, 1979; Koreneva, 1966). Drifting masses of pollen grains are frequently observed closer to the shore. Here the wettability plays an important role (Davis et al., 1969). Strong currents prevailing in shallow-marine environments greatly influence the deposition of pollen (Faegri and Iversen, 1975). The prevailing direction of longshore currents is SW to NE in the coastal zone of the Cilician Basin during spring, although it is NE to SW during the rest of the year (Fig. 4) (Ediger, 1991).

Light microscope and SEM studies showed that the bulk of the surface floating solids consists primarily of the bisaccate pollen grains produced by conifers in April and May (Figs. 6, 8, and 9). These pollen grains were probably transported mostly by the Göksu and Lamas Rivers, but also by the winds blowing from the mountains down to the coast. During the period 1988-1992, the sea was covered extensively with pollen for about one mouth in spring in the vicinity of the Lamas River mouth by the action of the sea-breeze system (Fig. 8). Thus means that the pollen grains did not sink immediately after settling on the sea surface at the inner-shelf. The

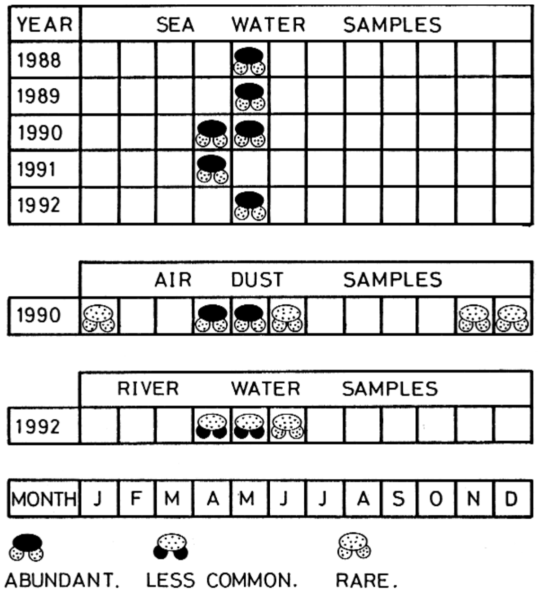

Fig. 8 - The abundance of Coniferous Bisaccate Pollen in sea water, air dust, and Lamas River water samples.

strong currents prevailing in shallow-marine environments have a great influence on the deposition of pollen.

Large amounts of gymnosperm bisaccate pollen content in the air dust samples were observed in these samples only in April and May (Fig. 8). Between November and January a small amount of gymnosperm bisaccate pollen was observed in the dust samples. The presence of a few pollen grains is probably the result of resuspension of deposited pollen grains by the local northerly winds.

3.2. Pollen distribution in core sediments

Among the palynomorphs, spores, angiosperm pollen, gymnosperm bisaccate pollen, fungal spores, fungal mycelia, algal remains, ovoidites, dinoflagellate, and microforaminiferal linings were identified in the nine studied samples from the three different cores (Table 1).

The spores and mycelia of fungal origin appeared to be the most common palynomorph group in the sediment samples. Their relative abundances ranged between 16.2-85.4 % (Table 1). It was difficult to determine which fungal palynomorphs were transported from land and which were formed *in situ*. However, most of them are probably principally transported on the angiosperm leaves from land. The distribution of mycelia among the samples seems to be as expected. The samples from Core 129 contained the least amount of mycelia, whereas in the samples of Core 1 it was highly abundant (Table 1). A gradual increase was observed in the abundances of mycelia from bottom to top of two of the cores, which might suggest an increased input/transportation from the land and/or increased decomposition with time in the sediment column.

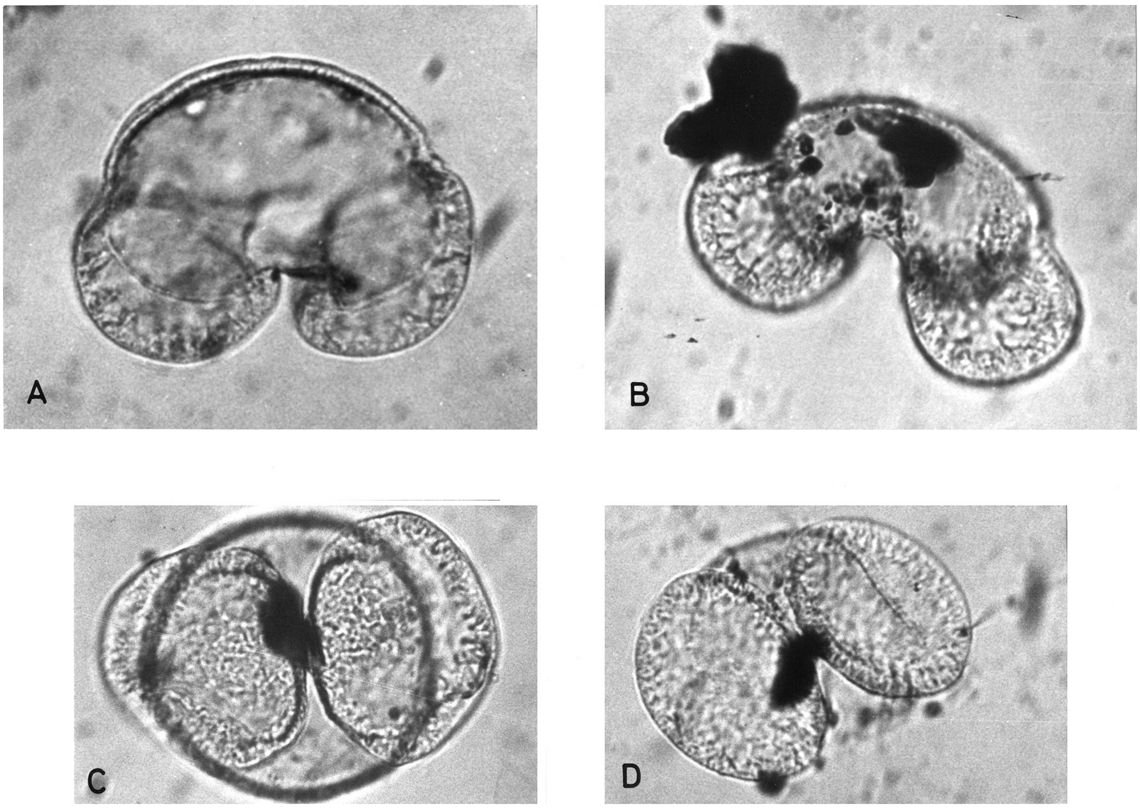

Fig. 9 - Morphology of bisaccate pollen grains. A-D; Binocular photomicrographs of pollen grains (in sediments). Ax1200, Bx1200, Cx1200, and Dx1200.

Spores and pollen grains were the second and third most abundant palynomorph groups in the sediment samples. The relative percentages of spores vary between 0.6-4.2 %, of angiosperm pollen between 4.2-32.8 %, and of gymnosperm bisaccate pollen between 4.3-46.6 % (Table 1). These palynomorphs almost always belong to the lower and higher vascular terrestrial plants, although some of them were produced by non-vascular and aqueous vascular plants. These spores and angiosperm pollen were mostly transported from land, together with suspended solids, mainly by rivers (Groot, 1971; Koreneva, 1966). Larger amounts of spores and angiosperm pollen are, therefore, to be expected in Core 1 than Core 129 (Fig. 7). However, this was not always the case in the studied samples, which may have been due to fluctuations in the intensity of atmospheric, oceanic, and sedimentologic conditions.

The relative percentage of gymnosperm bisaccate pollen increase from bottom to the center of the inner, mid, and outer-shelf Cores 1, 3 and 129, and reaches a maximum at around 18-22 cm depth in these cores (Fig. 10). The relative percentage then decreases to the top of these cores. Since bisaccate pollen are transported from a source on land to the sea by rivers and wind, their absolute percentages should be less in the near-shore samples and higher in the outer-shelf sediments (Figs. 7, 10 and 11). The increasing relative percentages of bisaccate coniferous pollen from the bottom to center of the cores (Fig. 10) possibly indicates that the density of the vegeta-

Table 1 - Relative percentages of palynomorphs in Cores 1, 3, and 129. Locations of the stations are shown in Fig. 6.

	CORE-1			CORE-3			CORE-129		
CORE INTERVALS:	0-4	18-20	28-30	0-2	20-22	30-32	0-3	20-22	30-32
	(cm)			(cm)			(cm)		
PALYNOMORPHS:	RELATIVE PERCENTAGES:								
SPORES	0.6	2.7	2.7	1.4	1.2	1.1	1.0	3.0	4.2
ANGIOSPERMOUS POLLEN	4.2	12.6	16.2	32.8	24.0	30.5	25.6	22.7	23.0
GYMNOSPERMOUS BISACCATE POLLEN	4.3	22.8	19.6	27.8	29.9	28.0	41.9	46.6	38.3
FUNGAL SPORES	5.1	9.8	9.5	14.8	29.9	29.4	18.7	15.9	23.0
FUNGAL MYCELIA	80.3	44.2	43.9	7.4	0.0	0.0	0.0	0.3	0.0
ALGAL REMAINS	0.9	0.7	0.3	9.7	2.7	1.8	3.4	3.8	5.1
OVOIDITES	0.8	1.7	0.7	1.0	0.8	0.0	0.0	0.0	0.0
DINOFLAGELLATE	0.6	3.1	0.7	0.0	0.0	0.7	1.0	0.6	1.3
MICROFORAMINIFERAL LININGS	0.2	0.0	2.4	0.0	3.2	2.1	0.5	1.8	0.0
UNKNOWN	3.0	2.4	4.0	5.1	8.3	6.4	7.9	5.3	5.1

tion increased during the time interval from the last cool to warm periods along the coastal zone (A.C.1400-A.C.1850) (Table 2). The maximum coniferous bisaccate pollen are deposited at around 18-22 cm depth in the cores which corresponds to the last warm and wet period (A.C.1900-A.C.1950) (Table 2). From those depths to the top of the cores maximum values gradually decrease which depend on the drying period.

These results are thought to be a response to the recent climatic oscillations and/or the changing urbanization density (DHKD, 1992, 1993) around this part of the Mediterranean coastal zone. If we use the previously known sediment accumulation rate in the Mersin Bay (0.08-0.35 cm/year) inferred from radiometric dating (Tadjiki, 1992) and seismostratigraphic correlation (Ergin et al., 1992), between A.C.1900-A.C.1950, climate of this coastal region was relatively warmer and wetter than recent conditions (Table 2) (Erinç, 1969) and coastal vegetation density was probably relatively high during this period (Atalay, 1987). The maximum in bisaccate pollen deposition at the 18-22 cm depth in the cores is probably related to the recent past warm climatic conditions (A.C.1900-A.C.1950) (Table 2) (Roman, 1974). After A.C.1950, the percentages of coniferous bisaccate pollens gradually decreased from the 18 cm depth to the surface of the cores (Fig. 10), because, the vegetation density and the amount of riverine input gradually decreased from the year A.C.1950 to A.C.1984 (sampling time of cores) due to the climatic change. Bulk sedimentation rates are known to be 0.53 cm/year (18cm/34years); hence, the period A.C.1950-A.C.1984 (34 years) corresponds to the depth of maximum relative percentages of coniferous bisaccate pollen in the cores and the time between the recent (A.C.1984) and the end of the last warm period (A.C.1950).

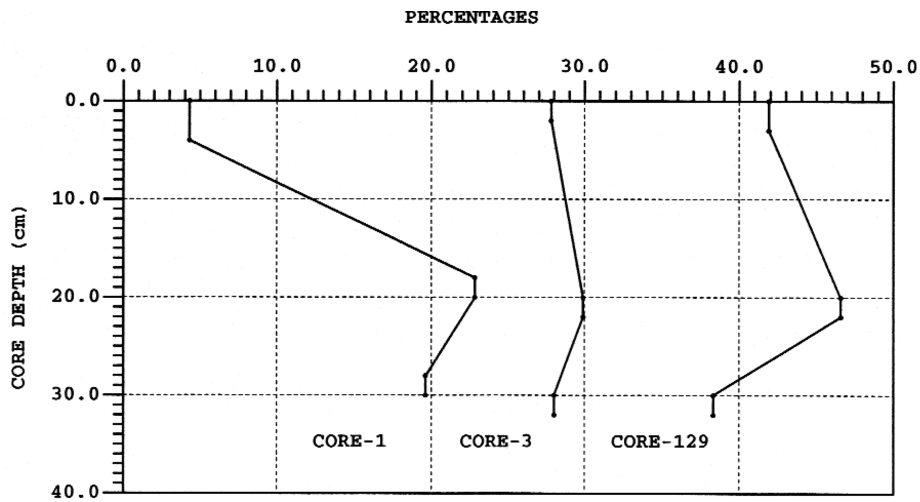

Fig. 10 - Relative percentages of the bisaccate pollen along Cores 1, 3 and 129. Locations of the stations are given in Fig. 7.

The increasing relative percentages of these pollen at the surface, center and bottom of the cores from shore to offshore shows that they are generally transported across the shelf, and the majority deposited in the deeper zones (Figs. 10 and 11) (Roman, 1974). Generally, the dynamics of the inner and mid shelf zones control the deposition of gymnosperm bisaccate pollen in shallow water.

The dinoflagellates, Ovoidites spp., microforaminiferal linings, and other algal remains are mostly the organic remains of *in situ* marine organisms. Their relative percentages vary between 2.5-10.7 % (Table 1). This clearly shows that the algal productivity of the seawater is very low, as is also confirmed by the works of Göçmen (1988) and Salihoğlu et al. (1990).

Table 2 - Recent climatic oscillations after the Last Glacial Maxima (Erinç, 1969).

TIME INTERVALS	CLIMATE	YEARS BEFORE 1984	DURATION (years)
B.C.5000-B.C.3000	WARM	6984-4984	2000
B.C.3000-B.C.2890	WARM-COOL	4984-4874	110
B.C.2890-B.C.2440	COOL	4874-4424	450
B.C.2440-A.C. 800	COOL-WARM	4424-1184	3240
A.C. 800-A.C.1200	WARM	1184-784	400
A.C.1200-A.C.1400	WARM-COOL	784-584	200
A.C.1400-A.C.1850	COOL	584-134	450
A.C.1850-A.C.1900	COOL-WARM	134-84	50
A.C.1900-A.C.1950	WARM	84-34	50
A.C.1950-A.C.1984	WARM-COOL	34-0	34

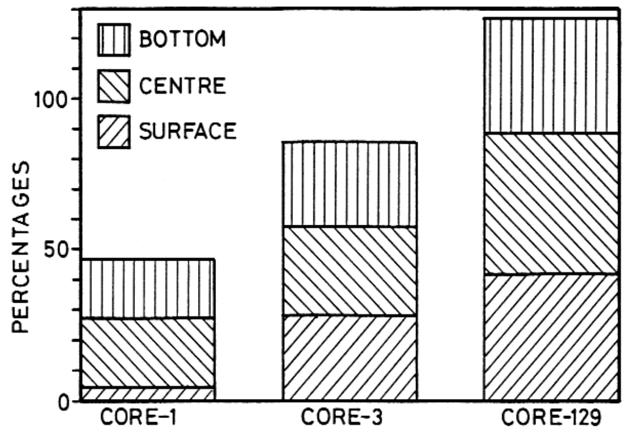

Fig. 11 - Bar diagram showing the relative percentages of bisaccate pollen in surface, center, and bottom sections of

4. Conclusions

On the basis of the results presented here, it can be concluded that the occurrence of a river plume off the southeastern Turkish Mediterranean coast, which changes the colour of the surface film of the seawater from blue to yellow is a narrow belt along the coast, is caused by bisaccate pollen grains from the Taurus Mountains. The Lamas River together with the wind systems are obviously important mechanisms for transportation of these pollen from their source in the high coastal hinterland to the coastal lowlands. In particular, the land-breeze system around the coastal area spreads the yellowish bisaccate pollens offshore, and the sea-breeze system traps and concentrates bisaccate pollen along the coastal zone.

The amount of bisaccate pollen was found to be generally low in nearshore, and high in offshore sediment samples, due to riverine and eolian transportation from the land, and increased deposition in the sea. On the other hand, the relatively increasing percentages of bisaccate coniferous pollen from the bottom to the centers of the cores indicates that the density of the coastal vegetation has increased in time. This might have been a response to the recent climatic changes along the Eastern Mediterranean coastal zone. The percentages of coniferous bisaccate pollen decreased from 18 cm depth to the surface of the cores during the years 1950 to 1984. A 0.53 cm/year bulk sedimentation rate has been calculated for the last 34 years.

The spores and mycelia of fungal origin appeared to be the most common palynomorph group in the analyzed samples, but it was difficult to determine which fungal palynomorphs were transported from land and which formed *in situ*. A gradual increase in abundance of mycelia from the bottom to the top of the cores might mean increased sediment transportation from the land.

The relative percentages of dinoflagellates, Ovoidites spp., microforaminiferal linings, and other algal remains clearly show that the productivity of the seawater is very low, as has also been noted by many authors.

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