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## Modern organic-walled dinoflagellate cyst distribution offshore NW Iberia; tracing the upwelling system

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### Abstract

The northwest Iberian ocean margin experiences seasonal upwelling of nutrient-rich water resulting in enhanced primary productivity. The quantitative organic-walled dinoflagellate cyst distribution and that of other palynomorphs has been determined in 37 box core-tops along three transects to trace the upwelling signal. Oligotrophic *Impagidinium* spp. represent the dominant offshore elements. Cysts of heterotrophic *Protoperidinium* spp. mainly occur in sediments of the seasonal upwelling area on the shelf and slope and show a sharp decrease offshore. The eutrophic autotrophic taxon *Lingulodinium machaerophorum* is also abundant in sediments of the seasonal upwelling area on the shelf and slope, and also decreases more offshore. Both relative as well as absolute numbers of these taxa may be used to trace the upwelling system despite potential taphonomic problems. Considering the overall similar environmental conditions with respect to the other two transects, the elevated palynomorph concentrations in the shielded Nazaré Canyon samples may be seen to represent the actual fluxes of palynomorphs along the Iberian coast. If accepted, this would indicate a preservational and transport loss of cysts of an order of magnitude in other transects.

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**Keywords:** organic-walled dinoflagellate cysts; modern distribution; upwelling; Iberia; bioproductivity; transport

### 1. Introduction

The NW Iberian ocean margin experiences summer upwelling of nutrient-rich water resulting in enhanced primary productivity (e.g. [Boa et al., 1997](#); [Pérez et al., 1999](#)). Characterization, quantification and modeling of the physical, biochemical and sedimentological processes in this region is a major objective of the EC-funded Ocean Mar-

gin EXchange (OMEX) II project. Although the OMEX effort has resulted in important new information pertaining to transport processes in the water column, the apparently enhanced bioproductivity has so far not been clearly traced in the underlying sediments using conventional proxies such as diatom accumulation rates and sedimentation rates of particulate organic carbon ([Olli et al., 2001](#)). Current estimates of vertical fluxes of biogenic material lie within the range of published vertical flux rates at comparable depths from non-upwelling coastal and shelf areas and some open ocean sites ([Olli et al., 2001](#)). This

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apparent contradiction is as yet poorly understood.

Close relationships have been demonstrated between organic-walled dinoflagellate cyst (dinocyst) assemblages and sea-surface conditions, including temperature, salinity and nutrients (Rochon et al., 1999). Recent dinocyst distributions of the temperate and high latitudes of the North Atlantic Ocean and adjacent basins are relatively well documented (see overview in e.g. Rochon et al., 1999) and combined information indicates the strong potential of dinocyst analysis in tracing surface water conditions. Here, we aim to assess the potential of quantitative dinocyst analysis for tracing the Iberian upwelling system in bottom sediments. For this purpose we have selected 37 box core-tops from essentially three transects perpendicular to the Iberian coast (Fig. 1).

## 2. Setting

The research area is situated between 39–44°N and 9–12°W (Fig. 1). The oceanographic setting is rather complex (Fig. 2). The large-scale, slow circulating Portugal Current System (PCS) dominates the surface waters. It flows equatorward in late spring and summer, but flows poleward in autumn and winter (Peliz and Fiúza, 1999). The Eastern North Atlantic Central Water (ENACW, Fig. 2) consists of two water masses: a lighter, relatively warm and salty subtropical branch (ENACWst), and a less saline and colder subpolar branch (ENACWsp). In the northwest of the studied region the ENACWst is replaced by a southward extension of the North Atlantic Current, which is called West North Atlantic Central Water (WNACW). At the lower edge of the ENACW (500–600 m), which is marked by a salinity minimum, there is the highly saline and relatively warm Mediterranean Water (MW). At 1600 m, the lower-saline Labrador Sea Water (LSW), which also makes up part of the upper North Atlantic Deep Water (NADW), enters the northwest of the study area. The highly saline and cold NADW on the Iberian Abyssal Plain and the west Iberian margin mainly consists of Lower Deep Water (LDW), which is nutrient-rich and oxy-

gen-poor, LSW and Iceland–Scotland Overflow Water (ISOW) (Van Aken, 2000a,b).

The shelf offshore Iberia is narrow (~50 km) and flat with steep slopes. It almost extends from the Nazaré Canyon in the south to the Spanish border at 42°N (Fiúza et al., 1982). The slope is indented by several canyons, such as the Nazaré Canyon centered at 39.6°N and the Arosa Canyon near 42.5°N. The Nazaré Canyon is a favorable site for the concentration and accumulation of fine-grained sediments (Schmidt et al., 2001).

The Iberian Peninsula is located in the northern part of the climatically subtropical high-pressure belt of the Northern Hemisphere. Due to pressure differences between land and water masses the front of this belt shifts northward during summer. The resulting changes in the winds, the northerly ‘Portuguese trades’, facilitate upwelling of cool, nutrient-rich water at the west coast (Fiúza et al., 1982). The upwelled water flows southward on the upper slope with meanders and filaments (Stevens et al., 2000). The upwelling filaments may extend as far as 200 km offshore (Fiúza et al., 1998). Sea-surface temperature (SST) and chlorophyll *a* imagery show upwelling to be active, with distinct offshore filaments that are cooler and of higher chlorophyll concentration than the surrounding oceanic water (Smyth et al., 2001). During the rest of the year, coastal convergence prevails and the surface water flow reverses from southward to poleward and is density-driven rather than wind-driven (Neves et al., 1999). According to Cotté-Krief et al. (2000), river run-off is an additional important source of nutrients to the surface waters.

## 3. Material and methods

The distribution of dinoflagellate cysts and that of other palynomorphs was determined in sediment samples from 37 box core-tops (0–1 cm) taken offshore northwest Iberia. Box cores were taken at water depths between 101 and 4939 m in five transects perpendicular to the coast (van Weering and de Stigter, 1999; see also Fig. 1). Due to the similar setting of transects 2–4, they were grouped together. These will be referred to

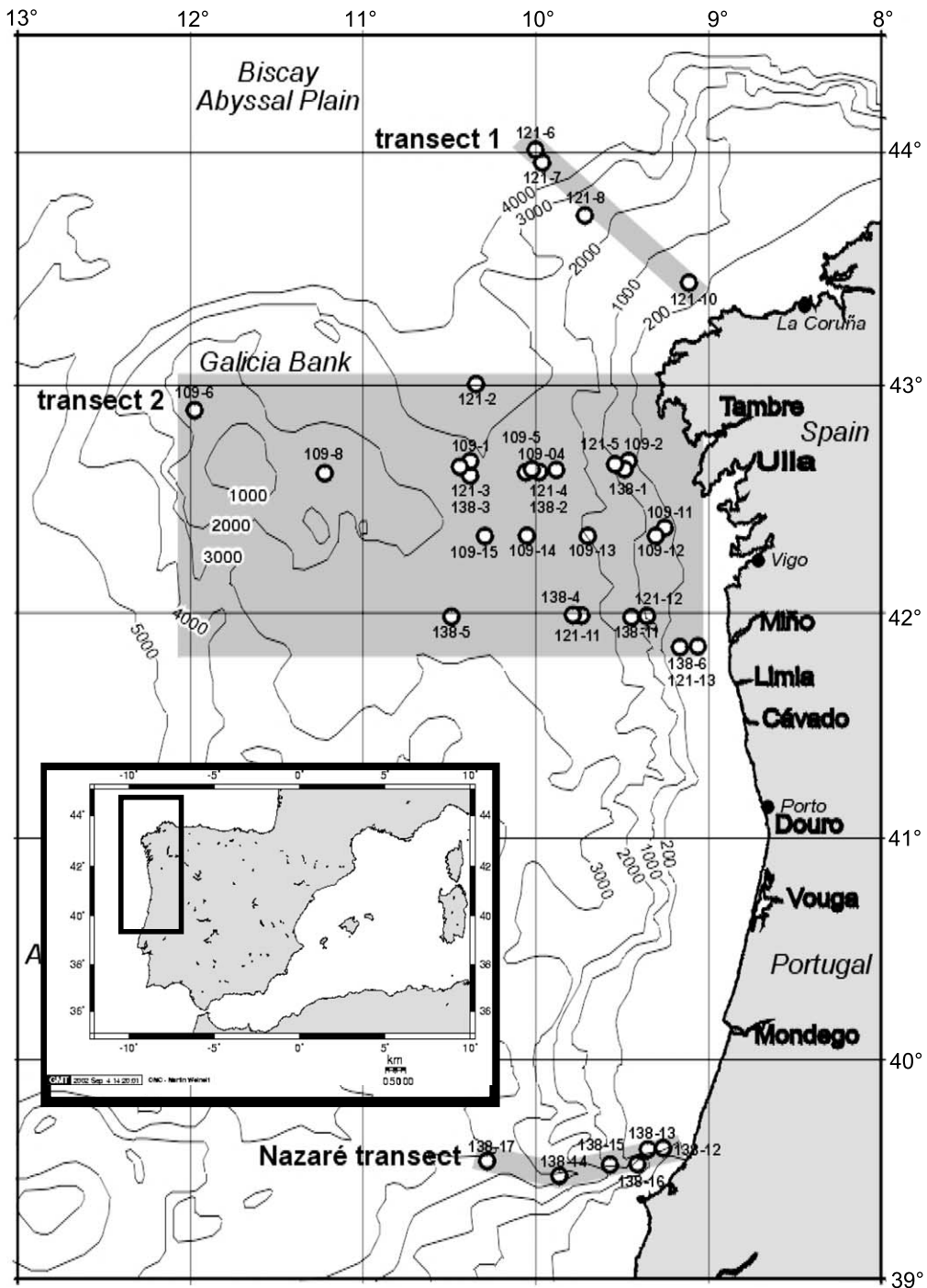


Fig. 1. Map of the sample points, transects, bathymetry (m) and rivers in the research area.

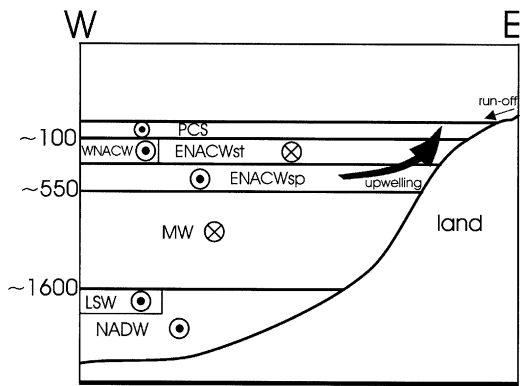


Fig. 2. Schematic west-to-east cross-section of the study area showing the different water masses. The numbers on the vertical axis show the water depth in m.

in this text as ‘transect 2’. This material was taken by the Netherlands Institute for Sea Research (NIOZ) on behalf of the OMEX II project. The first cm of box core 121-10 of transect 1 consists of a well-sorted, medium coarse quartz–glaucinite sand with fine gravel. The tops of the other, more offshore box cores are clayey–silty carbonate oozes. The shelf box core 109-11 of transect 2 consists of weakly layered clayey silt. The box cores between the 200 and 1000 m isobath are composed of homogeneous fine–medium silty quartz–lithic–bioclastic sand. Box cores 121-11, 109-4 and 109-13 consist of silty clay. The rest of the box core-tops of transect 2 are composed of clayey to silty carbonate oozes, except the most offshore box core 109-6, which is sandy. Schmidt et al. (2001) described the sediment of the upper and middle part of the Nazaré Canyon, the third transect, as very soft, silty clay. All samples are regarded to be Modern in age (Table 1).

### 3.1. Palynological processing

All samples were processed according to standard palynological preparation procedures. A known amount of 0.5–1.0 g of sediment is weighed and treated with 30% HCl for carbonate removal. Subsequently, 38% cold HF is added to remove silicates. Then the residue is treated with 30% cold HCl again, decanted and sieved through a 10 µm stainless metal sieve. An ultrasonic bath

is used to disintegrate lumps of organic matter. The residue is transferred into reaction vessels with a 0.5 ml scale interval. The vessels are standardized to 0.5 or 1.0 ml with water. A known amount between 10 and 50 µl is mounted on a slide and embedded in glycerin gel. Slides are sealed with paraffin wax.

Table 1

The sediment accumulation rates (SAR) in cm/yr of the sample points and their maximum sample depth in cm used in this report

Core	SAR Foram (cm/yr)	SAR <sup>210</sup> Pb (cm/yr)	Max. depth (cm)
<i>Transect 2</i>			
121-13	> 0.005	0.2103	0.5
138-6	n/a	0.0878	0.25
121-12	> 0.0029	0.1547	1
109-2	> 0.0043	0.1129	1
109-12	> 0.0036	0.1954	1
138-1	n/a	0.0249	0.25
121-5	> 0.005	0.1557	0.5
109-11	> 0.0043	0.1117	1
138-11	n/a	n/a	0.25
109-13	0.0119	n/a	0.5
138-2	n/a	n/a	0.25
109-4	0.0039	n/a	1
121-4	0.0061	n/a	0.5
121-11	0.0093	n/a	0.5
138-4	n/a	n/a	0.25
109-5	0.0043	n/a	0.5
109-14	0.0070	n/a	0.5
109-1	> 0.0429	n/a	0.5
138-3	n/a	n/a	0.25
121-3	> 0.0036	n/a	0.5
109-15	0.0039	n/a	0.5
138-5	n/a	n/a	0.25
109-8	0.0014	n/a	0.5
109-6	> 0.0029	n/a	1
<i>Transect 1</i>			
121-6	0.0157	n/a	0.5
121-7	> 0.0064	n/a	0.5
121-8	0.0054	n/a	0.5
121-10	> 0.0036	n/a	1
<i>Nazaré transect</i>			
138-17	n/a	n/a	0.25
138-14	n/a	1.4525	0.25
138-15	n/a	0.0573	0.25
138-16	n/a	1.0327	0.25
138-13	n/a	0.1106	0.25

The left SAR column is based on foram biostratigraphy, the right on <sup>210</sup>Pb measurements.

Table 2  
Palynomorph groups used in this study

Group	Consists of:
<i>Impagidinium</i> spp.	<i>I. aculeatum</i> , <i>I. paradoxum</i> , <i>I. sphaericum</i> , <i>I. striatum</i> , <i>I. patulum</i> and <i>Impagidinium</i> indet.
<i>Operculodinium</i> spp.	<i>O. centrocarpum</i> , <i>O. centrocarpum</i> var. short processes, <i>O. israelianum</i> , <i>O. centrocarpum</i> var. <i>truncatum</i> and <i>Operculodinium</i> indet.
<i>Spiniferites</i> spp.	<i>S. mirabilis</i> , <i>S. membranaceus</i> , <i>S. ramosus</i> , <i>S. hyperacanthus</i> , <i>S. lazus</i> and <i>Spiniferites</i> indet.
Cysts of <i>Protopteridinium</i> spp.	<i>Algasphaeridium minutum</i> , <i>Lejeunecysta</i> spp., <i>Selenopemphix</i> spp., <i>Brigantedinium</i> spp., <i>Trinovantedinium applanatum</i> , <i>Stelladinium stellatum</i> , <i>Echinidinium</i> spp., <i>Xandarodinium xanthum</i> , <i>Votadinium spinosum</i> and cysts of <i>Protopteridinium</i> indet.
Pollen and spores	Pollen grains, spores and fungal spores

### 3.2. Slide analysis

Slides were counted at 400× and 1000× magnification to a minimum of 200 dinocysts, where possible. The dinocyst taxonomy follows that cited in Williams et al. (1998) and Rochon et al. (1999). Besides dinocysts, pollen, spores, organic-walled linings of foraminifera, eggs and remains of copepods, remains of tintinnids and acritarchs are counted. In case of a similar ecology, dinoflagellate cysts are grouped together. Palynomorphs other than dinocysts are a separate group. The different groups are shown in Table 2.

## 4. Results

Recovery of palynomorphs is consistent in all samples, although maximum concentrations are reached in the Nazaré transect. Quantitative data of palynomorphs and cysts are given in Fig. 4. The qualitative distribution of the most prominent taxa is depicted in Fig. 3A–D. Results are discussed per transect below. Raw data obtainable from the authors.

### 4.1. Transect 1

The highest concentrations of palynomorphs (up to 15 000 palynomorphs/g sediment) occur at sites 121-10 and 121-6. The concentration of pollen, spores, copepod eggs and foraminifera decreases more offshore, whereas dinocyst and tintinnid concentration increases slightly. A sharp decrease offshore can be seen for cysts of *Protopteridinium* spp. and *Lingulodinium machaerophorum*

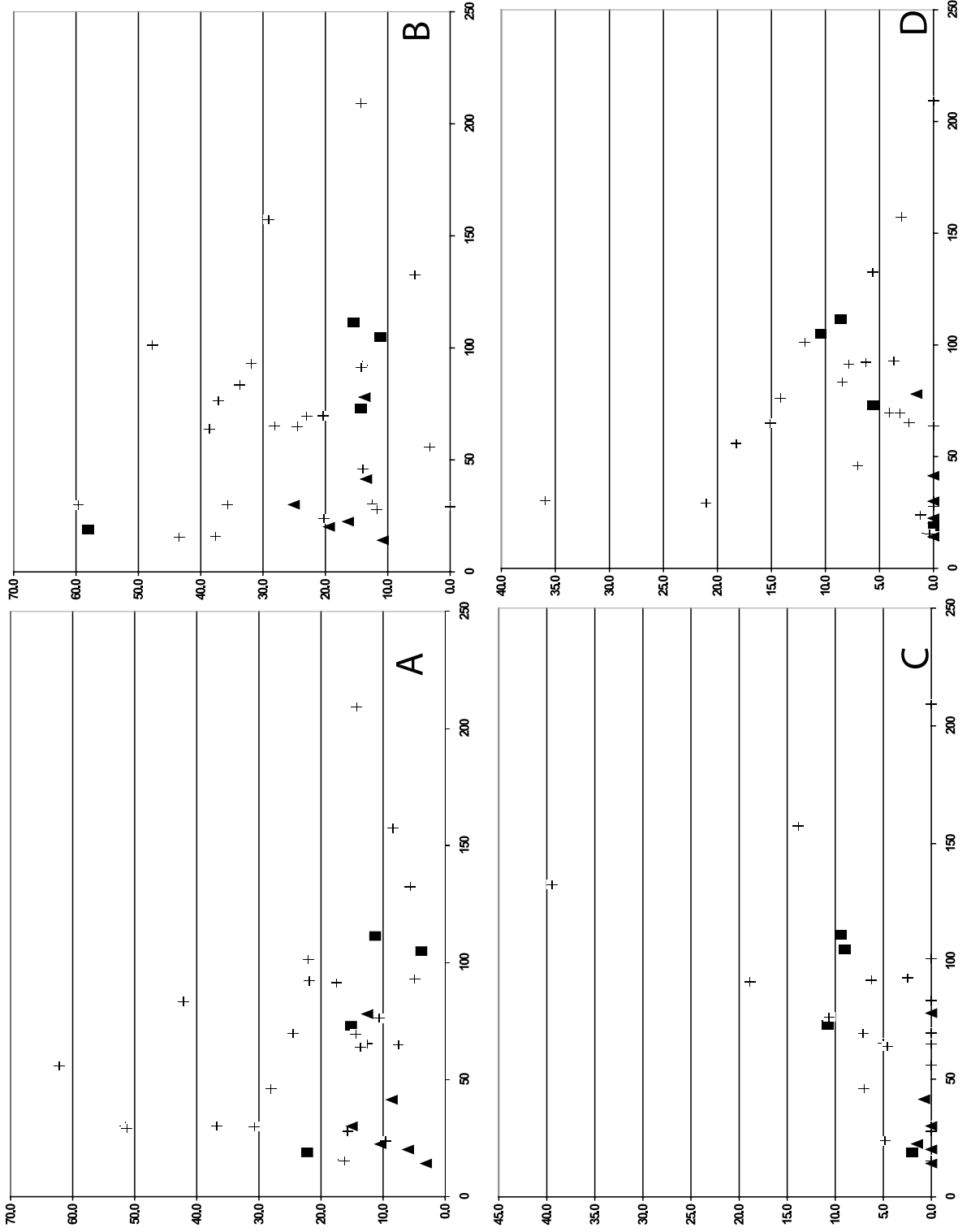
(Fig. 3A,B). *Operculodinium* spp. stay fairly constant throughout the transect, between 10 and 20% of the dinocyst assemblage. *Spiniferites* spp., *Nematosphaeropsis labyrinthus* (Fig. 3C) and *Impagidinium* spp. (Fig. 3D) show an offshore increase in relative abundance.

### 4.2. Transect 2

The two shelf samples 121-11 and 109-13 have the highest palynomorph concentrations (up to 50 000 palynomorphs/g sediment), as can be seen in Fig. 4, left. The two most offshore samples have the lowest palynomorph concentrations (< 10 000 palynomorphs/g sediment). Absolute numbers of pollen, spores and foraminifera show an offshore decrease. A similar pattern can be seen for the remains of tintinnids, copepod eggs and dinocysts. The concentrations of the palynomorphs are in general lower in the more northern part of the transect.

Percentages of pollen and spores show an offshore decrease. Foraminifera are dominant in this transect, values over 40% of the total palynomorph assemblage can be seen. The relative cyst distribution has widely varying values, ranging from < 20 to > 40% of the assemblage.

Cysts of *Protopteridinium* spp. (Fig. 3A) and *Lingulodinium machaerophorum* (Fig. 3B) occur in high percentages in the shelf/slope area and decrease more offshore. *Operculodinium* spp. is present in about the same percentages throughout the transect, although it shows slightly higher percentages in the rise area (data not shown). *Spiniferites* spp. has high percentages throughout the entire transect, but percentages > 30% can be



found from the rise till more offshore (data not shown). *Nematosphaeropsis labyrinthus* (Fig. 3C) and *Impagidinium* spp. (Fig. 3D) start their relative increase even more offshore than *Spiniferites* spp.

#### 4.3. Nazaré transect

This transect has by far the highest palynomorph concentrations (>75 000 palynomorphs/g sediment) (Fig. 4, left). Cysts (>20 to >40% of the palynomorph assemblage) and pollen and spores are abundant in this transect. Cysts of *Protoperidinium* spp. (Fig. 3A) have a maximum relative abundance of 20% of the dinocyst assemblage in this transect. *Lingulodinium machaerophorum* (Fig. 3B) reaches percentages up to 30% of the assemblage. *Operculodinium* spp. dominates the dinocyst assemblage with values of over 50% (data not shown). The relative abundance of *Spiniferites* spp. ranges from about 10 to 30% of the dinocyst assemblage, with one point in the highest category from 30 to 40% (data not shown). *Nematosphaeropsis labyrinthus* does not reach percentages higher than 5% in this transect (Fig. 3C). The percentages of *Impagidinium* spp. are even lower: 2.5% is the maximum (Fig. 3D).

## 5. Discussion

In modern sediments high relative and absolute numbers of cysts of heterotrophic *Protoperidinium* are found in areas with high nutrient content and high productivity in surface waters, such as upwelling areas (e.g. Wall et al., 1977; Rochon et al., 1999). The autotrophic gonyaulacoid taxon *Lingulodinium machaerophorum* is a nutrient indicator that occurs in particular in coastal areas (Targarona et al., 1999). Boessenkool et al. (2001) suggested that *L. machaerophorum* is associated with (summer) upwelling in the Iberian region. Both total numbers of dinocysts and

the distribution patterns of these taxa indicate eutrophic conditions close to the coast, and more specifically in the upwelling area. It thus appears that these taxa can be used as indicators of nutrient-rich waters, linked to upwelling, in this study.

Cysts of *Protoperidinium* spp. show a sharp decrease offshore. The recorded distribution may be reflecting its actual occurrence in the water column, implying that cysts of *Protoperidinium* spp. actually do not occur outside the upwelling region. *Lingulodinium machaerophorum* is abundant below the upwelling area on the shelf and slope and also decreases offshore, although not as sharply as *Protoperidinium* spp. If the distribution of cysts of *Protoperidinium* spp. and *L. machaerophorum* is controlled by seasonal eutrophic conditions, their distribution should be similar. Differences may be explained by preferential preservation of *L. machaerophorum* over cysts of *Protoperidinium* spp., as indicated by e.g. the studies of Zonneveld (Zonneveld, 1996; Zonneveld et al., 1997, 2001).

*Operculodinium* spp. have their highest relative and absolute numbers throughout the 200 and 1000 m isobath, the slope area, although the cysts occur throughout the entire transects.

A similar pattern was found by Wall et al. (1977), who describe *Operculodinium* spp. as ‘cosmopolitan’. The low accumulation rates on the abyssal plain may be caused by oxidation of the cysts, since *Operculodinium centrocarpum*, the dominant *Operculodinium* cyst in this study, is moderately sensitive to oxidation (Zonneveld, 1996). The high abundance of *Operculodinium* spp. in the Nazaré transect, with high sedimentation rates and fine-grained sediments, which favors the preservation of cysts, suggests that these cysts are destroyed offshore.

*Spiniferites* spp. represent the dominant cyst type in the oxygen-rich offshore area, especially in the relative abundance data. The fact that *Spiniferites* spp. are moderately sensitive to oxygen

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Fig. 3. Relative abundance of cysts as percentages of the dinocyst assemblage of (A) *Protoperidinium* spp; (B) *Lingulodinium machaerophorum*; (C) *Nematosphaeropsis labyrinthus*; (D) *Impagidinium* spp. X-axis shows distance from coast in km; rectangle is transect 1, cross is transect 2, triangle is Nazaré transect.

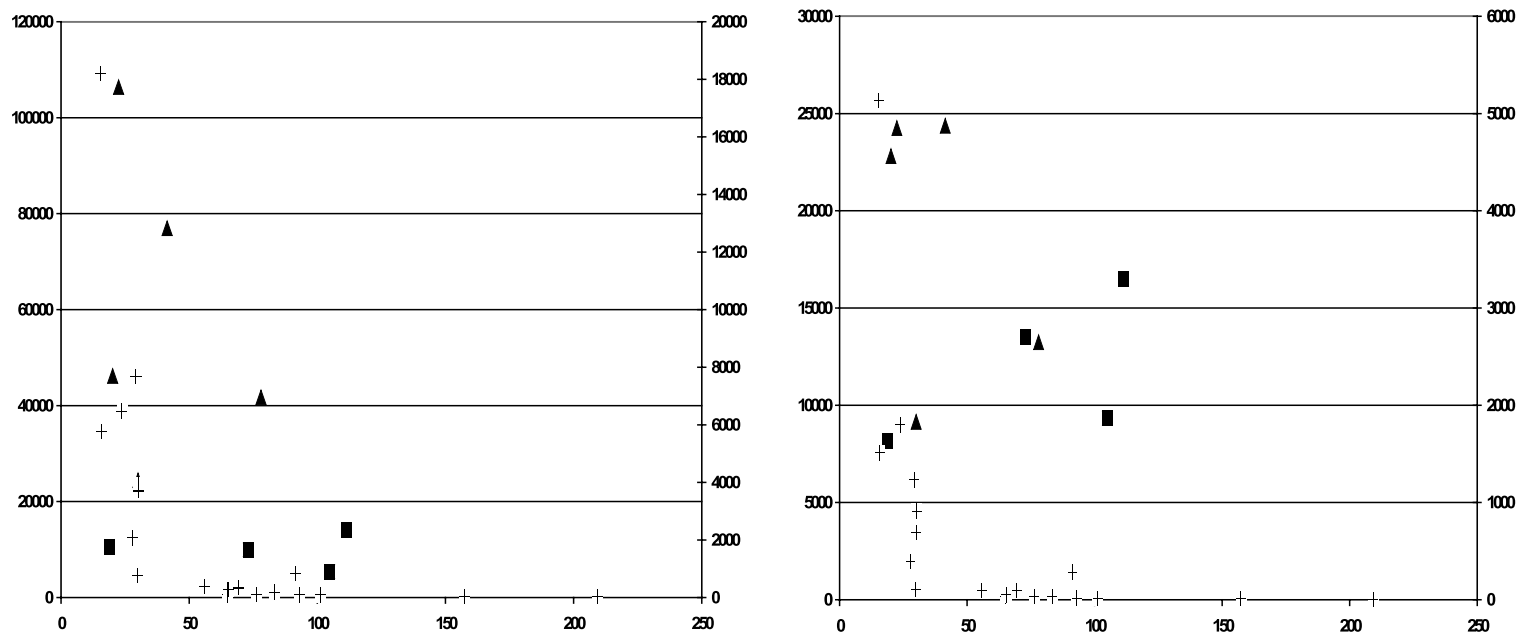


Fig. 4. (Left) Total palynomorph concentration in palynomorphs per gram dry sediment;  $x$ -axis shows distance from coast in km; rectangle is transect 1, cross is transect 2, triangle is Nazaré transect; transect 2 on right  $y$ -axis. (Right) Total concentration of organic-walled dinoflagellate cyst in cysts per gram dry sediment;  $x$ -axis shows distance from coast in km; rectangle is transect 1, cross is transect 2, triangle is Nazaré transect; transect 2 on right  $y$ -axis.



(Zonneveld et al., 1997) suggests that these cyst types, despite their dominance, may be underrepresented in the offshore samples.

*Nematosphaeropsis labyrinthus* occurs in the offshore section of the research area. It is considered to be a neritic/oceanic species (e.g. Dale, 1996).

The *Impagidinium* spp. group, which mainly consists of *I. paradoxum* and *I. aculeatum*, increases offshore, both in absolute and relative numbers. *Impagidinium* is a typical oceanic, oligotrophic taxon (e.g. Wall et al., 1977; Edwards and Andrieu, 1992; Rochon et al., 1999; Boessenkool et al., 2001).

Concerning transport and preservation of the palynomorphs in the seasonal upwelling area, the shelf and slope samples in transects 1 and 2 are not as favorable a site for preservation as the Nazaré transect. Palynomorph numbers are remarkably lower in transects 1 and 2, which are apparently influenced by transport. The shielded Nazaré transect may represent the actual fluxes of palynomorphs in the Iberian area, since palynomorph numbers are highest in the fast-accumulating sediments of this canyon. Between the 200 and 1000 m isobath, winnowing may have occurred on the slope where the sediment contained generally less than 25% grains smaller than 63 µm. The dynamic hydrographic situation on the slope keeps fine-grained sediment particles, including dinocysts, which behave as silt (Traverse, 1988), in suspension and transports them.

In the Nazaré transect, winnowing is less important due to the shielding from bottom currents, leading to an essentially fine-grained succession. The sediment is mainly derived from the shelf/slope area, since the oceanic *Impagidinium* spp. barely occur in the transect. Schmidt et al. (2001) suggest capturing of the alongshore sediment transport.

Since the winds during the main flowering season blow from the northwest, the pollen and spores, which show an offshore decrease in overall abundance, are likely to be transported by water.

The Nazaré Canyon, with its high sedimentation rates and small grain sizes, is a favorable site for the preservation of cysts, even though in the most offshore part of the transect the oxygen concentration in the sediment is higher. The shielded

situation may in effect record the actual fluxes of palynomorphs in the NW Iberian area.

Despite the presumably large influence of transport and preservation in transects 1 and 2, relative abundances of cysts of *Protoperidinium* spp. and *Lingulodinium machaerophorum* are still reliable tracers of upwelling.

## 6. Concluding remarks

In all three transects cysts of *Lingulodinium machaerophorum* and cysts of *Protoperidinium* spp. are clearly associated with upwelling on the Iberian margin, despite winnowing, transport and possible preservation problems in transects 1 and 2. While previous studies using conventional proxies failed to trace the seasonal upwelling in the bottom sediments in this area, this study indicates that dinocysts are useful tracers of upwelling on the Iberian margin.

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