

Water column and recent sediment data on diatoms and coccolithophorids, off Portugal, confirm sediment record of upwelling events

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(Received 7 January 1997, revised 6 October 1997, accepted 22 October 1997)

Abstract – Diatom and coccolithophorid abundance and diatom assemblage composition found in the water column along the Portuguese margin, during upwelling and non-upwelling conditions, are compared to the distribution patterns observed in the recent sediments from the same area. The water column results indicate a one order of magnitude increase in phytoplankton biomass during upwelling conditions (summer), with diatoms being the most important contributors. Coccolithophorids, on the contrary, dominate the phytoplankton in winter (non-upwelling). The comparison of the upwelling and non-upwelling spatial distribution of these phytoplankton groups to their sedimentary record reveals the sediment record as a reflection of the upwelling situation, preserving most of its original spatial variability. The comparison between living and fossil diatom assemblages indicates that from the two genera which dominate the summer biological assemblage, *Pseudo-nitzschia* and *Chaetoceros*, *Pseudo-nitzschia* is not represented in the sediments, while *Chaetoceros* is the dominant form of the sediment. *Thalassiosira*, which occurs in the same abundance in both seasons, responding to both river and upwelling nutrient input, can not be a reliable indicator of any single process. However, this genus distribution in the sediments can be used as an indicator of continuous nutrient availability. Such results are of great importance for paleo-oceanographic reconstructions, since they constitute a good indication that the sediment record, even though somewhat altered with respect to assemblage composition, does reflect the water column characteristics. © Elsevier, Paris / Ifremer / Cnrs / Ird

upwelling / Portugal / diatom / water column / sediment

Résumé – Diatomées et coccolithophoridés dans la colonne d'eau et le sédiment et mémoire des *upwellings* au large du Portugal. L'abondance de diatomées et des coccolithophoridés et la composition des populations de diatomées ont été observées le long de la côte du Portugal dans la colonne d'eau et dans les sédiments récents. Pendant l'*upwelling* (été), la biomasse du phytoplancton dans la colonne d'eau augmente d'un ordre de grandeur avec les diatomées. En l'absence d'*upwelling* (hiver), les coccolithophoridés prédominent. La répartition de ces groupes dans le sédiment reflète la situation d'*upwelling* en conservant la variabilité spatiale originelle. La comparaison entre les populations de diatomées vivantes et les fossiles indique que l'un des deux genres dominants en été, *Pseudo-nitzschia*, n'est pas représenté dans le sédiment tandis que l'autre, *Chaetoceros*, y prédomine. Le genre *Thalassiosira*, présent avec la même abondance pendant les deux saisons, en raison de l'apport de nutriments par le fleuve et par l'*upwelling*, ne peut être l'indicateur fiable d'un processus unique, mais la présence de ce genre dans les sédiments indique la disponibilité permanente de nutriments. Ces résultats sont d'une grande importance en paléo-océanographie car ils montrent que le sédiment reflète les caractéristiques de la colonne d'eau, malgré les modifications observées dans la composition des populations. © Elsevier, Paris / Ifremer / Cnrs / Ird

upwelling / Portugal / diatomée / colonne d'eau / sédiment

1. INTRODUCTION

Reconstruction of the past productivity in the oceans has always been one of the most important issues for paleoceanographers, but since the discovery of a one-third decrease of the atmospheric CO₂ during the last glacial age [3] this theme has become a dominant one; given that oceanic productivity is a possible control on long-term changes in atmospheric carbon dioxide concentration.

In today's oceans, 50 % of oceanic productivity is estimated to be concentrated in 30 % of the oceanic area, in margins characterized by the occurrence of coastal upwelling [4]. The observed uncoupling between the primary and secondary producers that occurs in such areas results in significant export flux to the sediments [13]. So, these high sedimentation areas may preserve a great deal of information relative to the past productivity conditions. However, to estimate what biological and chemical characteristics determine the sediment record, we first need to try to relate the sediment record to modern conditions. Difficulties arise from the fact that the species generally preserved in the sediments may not be the ones that dominate the living community. Trap studies reveal a direct relation between the biogenic flux and productivity variations; however, the same type of data also shows that only a small fraction of the exported flux reaches the bottom, and confirms that different biogenic groups have different probabilities of becoming incorporated in the sediments [7, 14, 24, 28].

Even though a great amount of important information, obtained from trap studies, indicates maximum total organic carbon and biogenic opal, with diatoms being the main contributor to these opal fractions, occurring in association with upwelling conditions, [24, 28] that information is precise. A better understanding of the relations that exist between the sediment record and the water column processes may also be reached by the comparison of spatial and temporal plankton distributions on the water column to the spatial distribution of the same plankton groups in the surface sediments of several upwelling areas. Such a comparison has, to our knowledge, never been attempted before, but it is, in this paper, made for the Portuguese margin/upwelling system. Absolute diatom abundance patterns found in the surface sediments collected along this margin [1], which is characterized by the occurrence of seasonal upwelling, reflect the actual patterns of upwelling described for the area by Fiúza [9, 10] and revealed by the pigment content distribution during upwelling events [27]. Diatom assemblages were also

used by Abrantes [1] to describe the relationship between the hydrography and the diatom species and groups preserved in surface sediments off Portugal. According to this author, small species of the genus *Thalassiosira* characterize areas of persistent upwelling where availability of nutrients is more constant and/or higher; *Paralia sulcata* (Ehr.) Cleve appears as an abundant species with mean cell diameter increasing as nutrient availability decreases and the resting spores of *Chaetoceros* Ehrenberg, record the position of the inner upwelling front. More recently, Moita [17] presented integrated diatom data (abundance and assemblages composition) for the top 100 m of the water column for upwelling conditions. Her results show distribution and abundance patterns for diatoms, mostly represented by *Pseudo-nitzschia*, *Chaetoceros* and *Thalassiosira*, reflecting the direct area of influence of the newly upwelled waters.

Diatoms are abundant in the sediments along the Portuguese margin, but the biogenic component of these sediments is very rich in coccolithophorids. These phytoplankton, which are important bloom formers in low productive warm waters, are however, also consistent components of upwelling communities [28]. Off Portugal coccolithophorids mark the southern coast nutrient enriched summer upwelling waters [17].

In this study, we compare two of the published data sets [1, 17], with new water column data now available for a non-upwelling situation in order to introduce the possible effect of season into the sediment record as well as to define and/or check the validity of diatom taxa preserved in the sediments as indicators of paleoconditions. Another of the purposes of this paper is to evaluate the importance of coccolithophorids during upwelling versus non-upwelling conditions, as well as in the sediments.

2. MATERIAL AND METHODS

Water column sampling was performed off the Portuguese coast, along sixteen to eighteen sections perpendicular to the bathymetry, and up to the 1000 m isobath, during IPIMAR cruises CICLOS I and CICLOS III. These cruises were made aboard R.V. *Noruega*, from 20 August to 3 September 1985 and 20 January to 6 February 1986, respectively (figures 1a, b).

Salinity and temperature were determined at each station for the following depths: 0, 5, 10, 20, 30, 40, 50, 75, 100, 125, 150, 200 and 300 m (or near bottom in shallow areas). Samples for phytoplankton analysis and chloro-

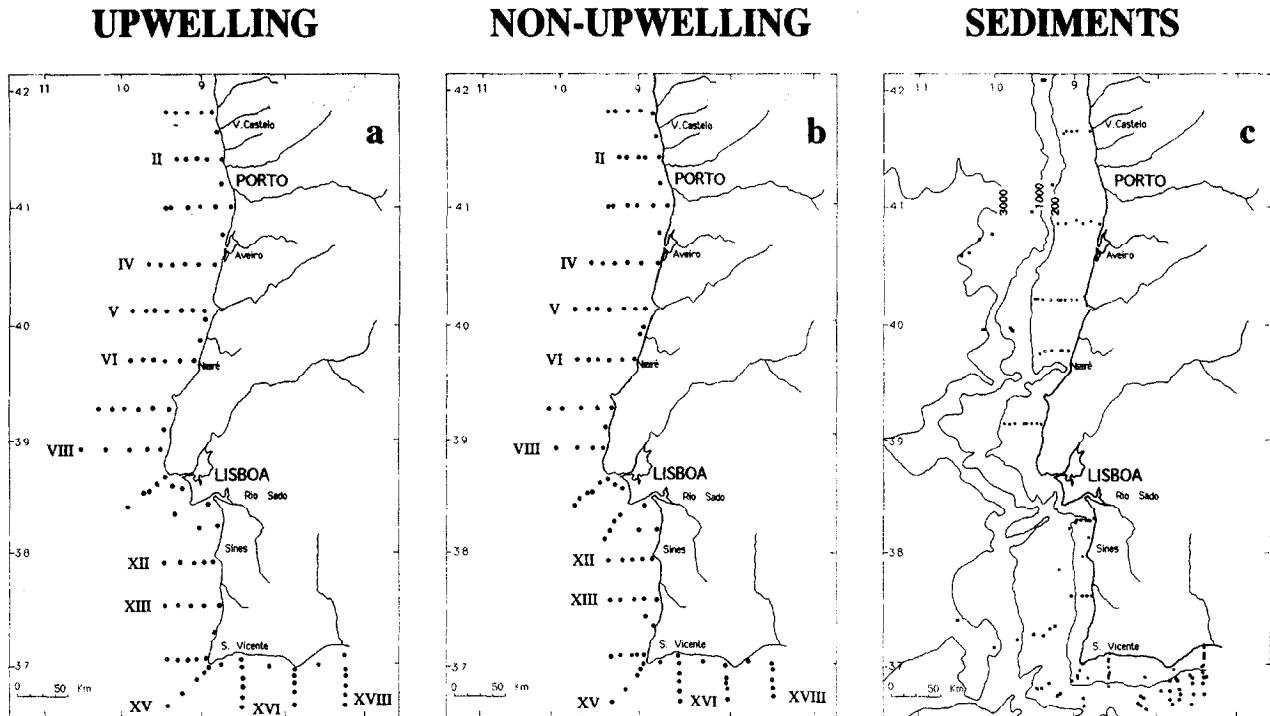


Figure 1. Sample location in relation to regional geographic features. a- Water column summer cruise of August 1985 - CICLOS I; b- Water column winter cruise of January 1986 - CICLOS III; c- Sediment samples: small circles - surficial samples; larger circles - Faegas IV core-tops.

phyll *a* determinations were collected at the same discrete levels down to 100 m. Temperature was determined from reversing thermometers coupled to Nansen bottles, and salinity (conductivity) was determined using a salinometer BECKMAN Mod. RS7-C. Phytoplankton samples were preserved with hexamethylenetetramine buffered formalin to a final concentration of 2% and counted under an inverted microscope, with phase contrast and brightfield illumination, using 100 mL composite settling chambers. Samples from each depth were integrated into one sample per station representing the water column (water samples from each depth were mixed in proportion to the extent of water column that they represented). Chlorophyll *a* was measured by fluorometry (Perkin-Elmer Mod. 204-A), after extraction in 90% acetone.

The sediment samples were collected during cruises AC75/1, AC76/1 and AC77/2, conducted by the Department of Marine Geology of the Geological Survey of Portugal aboard R.V. *Almeida Carvalho*. Surficial shelf sediments were collected with a large Van Veen grab and the slope samples are core-top samples from piston cores collected in October 1982 (Faegas IV - Marine Geology

Group of the University of Bordeaux) (figure 1c). Procedures for the treatment of raw material, preparation of slides, diatom quantitative analysis and definition of counting units are described in Abrantes [2]. Specimens were identified and counted generally to the species level, and its abundance calculated as a percentage of total diatom assemblage.

Coccolithophorid abundance was determined in the < 20 μm sediment fraction, by evaluation of the percentage area of a smear-slide occupied by the group.

When defining the diatom assemblages, the genera *Chaetoceros* and *Thalassiosira* were treated as groups, even though species were counted separately as much as possible. *Chaetoceros* species are grouped because their presence in the sediments is mainly in the form of resting spores, most of which cannot be assigned to the vegetative form which generated them. On the other hand, *Thalassiosira* species are grouped due to the difficulty of properly identifying of the smaller specimens (< 12 μm) present in the water column using the inverted microscope.

3. HYDROGRAPHY

Upwelling takes place along the west coast of Portugal from April to September under the fairly strong and steady northerly "Portuguese trades" [9, 10, 11]. Based on the analysis of a series of thermal infrared images, Fiúza [9] considers the existence of three main areas, which are characterized by different upwelling patterns. In this respect the west coast, the area north of Nazaré is characterized by an homogenous upwelling along the shore. From Lisbon to Cape Sines, the upwelling structure is complicated both by the presence of coastal protrusions and the Lisbon and Setúbal Canyon. South of Cape Sines, the upwelling structure becomes more regular again, but the shelf water is strongly affected by the warmer and saltier offshore surface waters. On the Algarve coast, upwelling only takes place occasionally when westerly winds occur, but the west Algarve margin gets covered by western upwelled waters carried around Cape St. Vincent, along the shelf break, during upwelling events. This coastal upwelling brings to the surface waters which have slightly different characteristics from south to north, suggesting different sources [9, 10, 22].

According to Fiúza [10] the upwelling source water is the Eastern North Atlantic Central Water (ENACW), a subsurface water mass generally present below 100 m and composed of two branches of different origin and thermohaline characteristics. Rios et al. [22] designated these two branches by Subtropical Eastern North Atlantic Water (ENAWt; $\sigma_t < 27-27.1$) and Subpolar Eastern North Atlantic Water (ENAWp; $27.1 < \sigma_t < 27.3$), and consider that ENAWt overlays ENAWp. South of the Nazaré Canyon ENAWt is the upwelling source water, but decreases in importance towards the north where, depending on the wind strength, both branches can be upwelled.

In this paper, cruises CICLOS I (summer) and CICLOS III (winter) are considered to represent an upwelling and a non-upwelling season, and the hydrographic conditions found at each time are as follows:

CICLOS I . Patterns of sea surface temperature distribution in the area are presented in *figure 2a* and in the NOAA-9 satellite image (*figure 2b*). The isotherms, which run parallel to the west coastline, reveal a cross-shelf gradient of 5 °C and the presence of the coldest waters near the shore and south of the capes. In the Cape

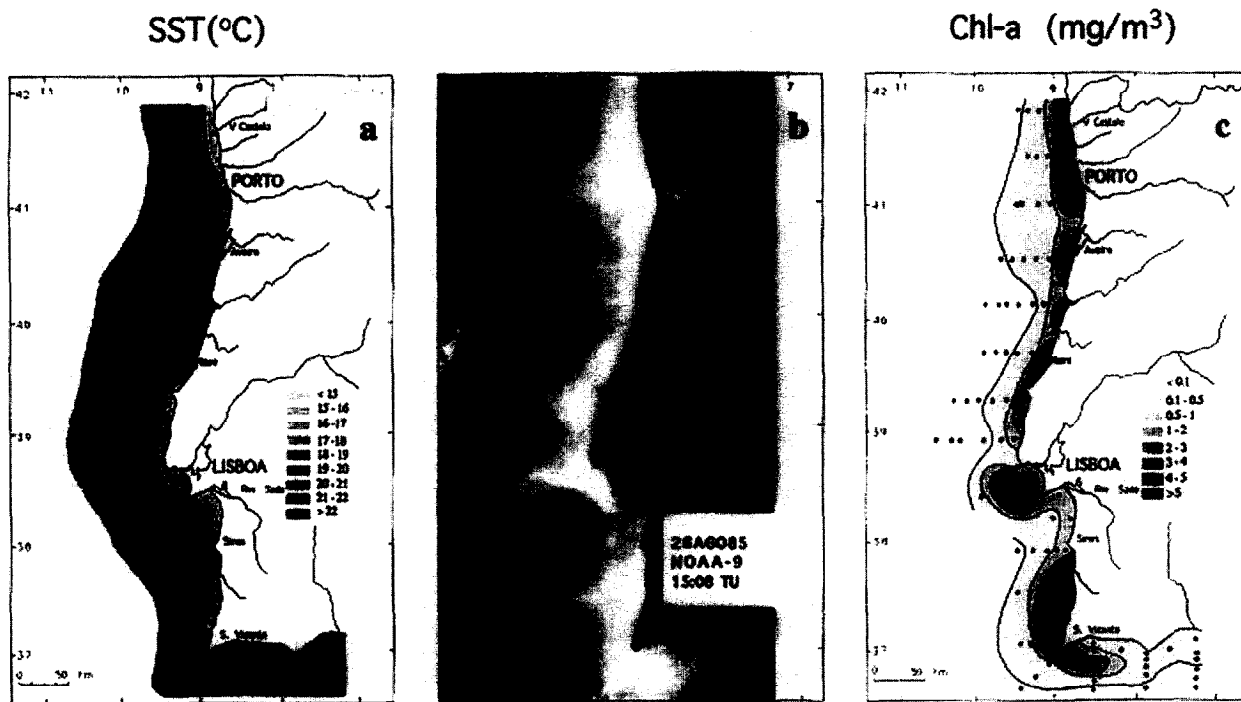


Figure 2. a- Sea surface temperature (°C) CICLOS I - August 1985; b- Tiros-N thermal infrared image obtained during the summer of 1985 (26 August 1985). (Courtesy of A. Fiúza, Institute of Oceanography - University of Lisbon); c- Chlorophyll-a surface distribution (mg m⁻³) CICLOS I - August 1985.

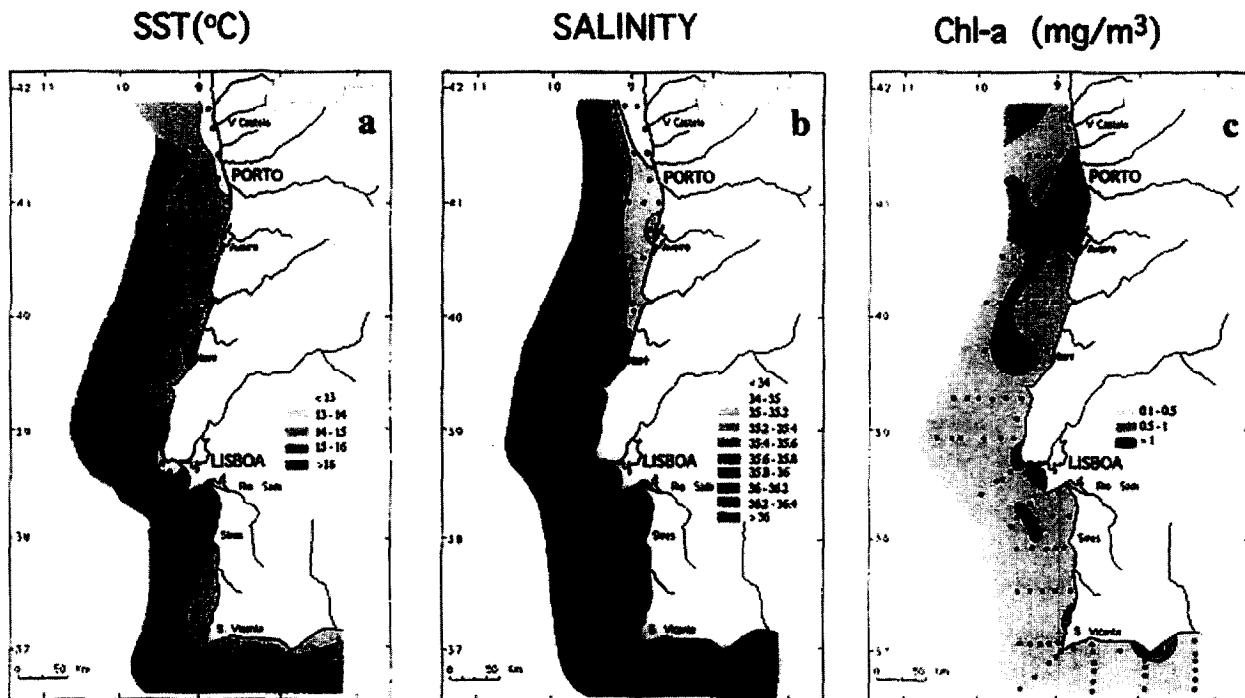


Figure 3. a- Sea surface temperature (°C) CICLOS III - January 1986. b- Salinity distribution CICLOS III - January 1986. c- Chlorophyll *a* surface distribution (mg·m⁻³) CICLOS III - January 1986.

S. Vincent area, the upwelling waters turn anticlockwise around the cape flowing eastward, following the pattern described by Fiúza [9]. North of the Nazaré canyon, the shelf was occupied by a shallow lens of reduced salinity water limited below by the seasonal pycnocline (figures 4, 5, 8 in [17]). The innermost 10 to 30 km are characterized by an uplifting of the upper 40 m isotherms and isopycnals, sometimes reaching the surface (figure 5, F. Foz in [17]). Along the southwestern coast, and specially at Cape S. Vincent, upwelling was particularly intense, with waters from 50 to 120 m rising to the surface (figure 6, Sagres in [17]), a situation which has also been observed even during moderate upwelling events (F. Sousa, pers. comm.).

CICLOS III. During the winter cruise, sea surface temperature distribution shows a one degree gradient between coastal and offshore waters all along the northwestern coast (figure 3a). Adjacent to the southwestern and Algarve coasts, SST distribution shows a zonal distribution of isotherms with a 2.5 °C gradient between inshore and offshore stations, a gradient also present in the salinity distribution. The existence of this colder water band is, however, not due to coastal upwelling (figure 3b). According to Fiúza [10] this is a general fea-

ture, which develops in these shallow coastal waters at the end of fall, when the whole water column begins to cool as a result of net heat loss from the surface; an idea corroborated by the presence of waters of subtropical origin ($\sigma_t < 27.0$) in the upper 200 m along most of the coast. An exception to this water column homogeneity was observed to the north of the Nazaré canyon where surface stratification probably caused by river runoff was detected in the upper 50 m (figure 3b).

4. RESULTS

4.1. Phytoplankton biomass

During the summer, phytoplankton biomass in the upper 100 m, measured as chlorophyll *a* (chl *a*) concentration, is distributed according to the patterns of sea surface temperature, with the coldest upwelled waters near the coast being phytoplankton enriched (figure 2c). During winter, chl *a* is low and constant along the entire coast, ranging between 0.1 and 1 mg·m⁻³ (figure 3c). Summer values, near the coast, are ten times higher than observed during the winter, reaching 5 mg·m⁻³ north of Porto and

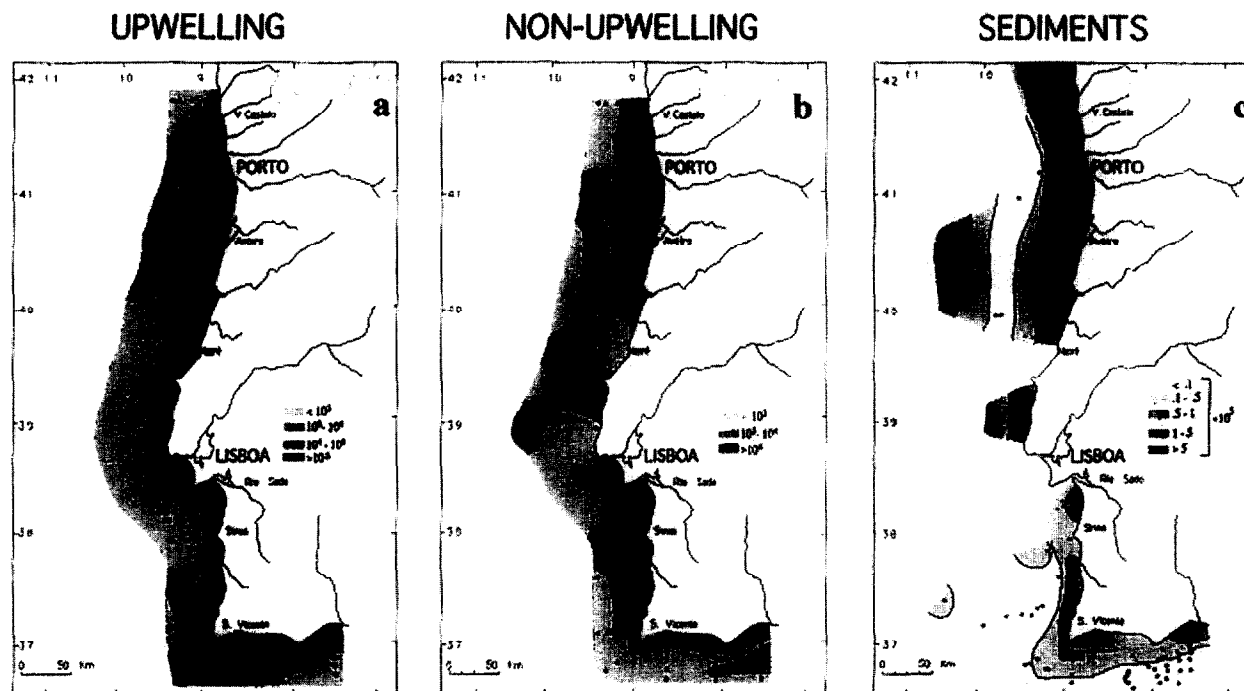


Figure 4. Distribution of the water column averaged abundance of diatoms (log cells/L); a- CICLOS I - August 1985; b- CICLOS III - January 1986; c- Distribution of the diatom abundance in the sediments (number valves/cc of fresh sediment).

3 mg m^{-3} at Cape S. Vincent. Offshore waters do not show a significant difference between the two seasons.

4.2. Diatoms

4.2.1. Water Column

The distribution of diatoms during the summer cruise follows the patterns of sea surface temperature and chl *a* being important contributors to the general productivity caused by the occurrence of coastal upwelling (figures 2a, c, and 4a). Water column abundances near-shore varied between 7×10^5 cells/L off Porto to 2×10^5 cells/L off Cape S. Vicente, in the range observed in other upwelling areas [6, 8, 15]. Offshore, the abundance of diatoms is similar in both seasons, ranging from 30 to 3×10^3 cells/L. Two distinct maxima are however detected north of the Nazaré Canyon during the winter cruise. One of the maxima, 4×10^4 cells/L occurs near-shore between surface salinities of 34 and 35, while the second maximum (2×10^4 cells/L) appears towards offshore, bordering the front of haline origin (figures 4b, 3b).

Figures 5a and b represent the relative abundance of diatoms within the total phytoplankton community during the

two sampled seasons, summer and winter respectively. From the observation of these figures, the indications given by the total abundance are confirmed with diatoms appearing as the major contributor to the summer phytoplankton community at the temperature defined upwelling centres; that is, in the inshore area north of Nazaré and around Cape S. Vicente. The poor contribution of this group to the winter phytoplankton is also clearly illustrated.

The diatom genera which dominate the water column during the summer period, showing maxima at the upwelling centres are *Pseudo-nitzschia* H. Peragallo and *Chaetoceros* Ehrenberg (10^5 cells/L) (figure 11 in [17]; Appendix 1a and figure 6a). *Thalassiosira* Cleve and *Thalassionema nitzschioides* (Grunow) Hustedt follow the major taxa distribution pattern, but have abundances one order of magnitude lower (10^4 cells/L) (figures 6d, g). In winter, when total diatom abundances are three orders of magnitude lower, *Pseudo-nitzschia* and *Chaetoceros* abundances decrease by three and two orders of magnitude respectively, while *Thalassiosira* and *Thalassionema nitzschioides* appear as the dominant forms maintaining the summer abundances (10^4 and 10^3 cells/L respectively) (Appendix 1b, figures 6b, e, h). However,

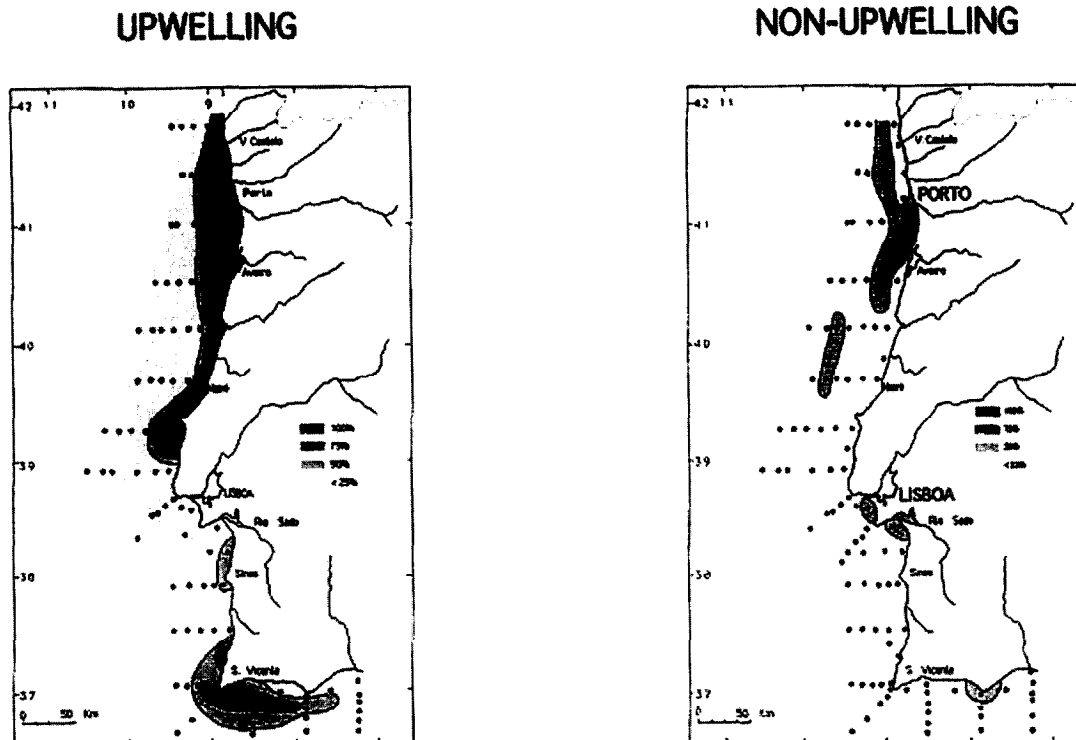


Figure 5. Distribution of the water column relative abundance of diatoms (% of total phytoplankton community); a- CICLOS I - August 1985; b- CICLOS III - January 1986.

these two taxa show quite different distribution patterns, while *Thalassionema nitzschioides* is homogeneously distributed all along the shelf, *Thalassiosira* is clearly more abundant north of Nazaré (figures 6h, e).

4.2.2. Sediments

The distribution pattern of diatom abundance (number/c.c) in the sediment samples of the Portuguese margin (Appendix 1c; figure 4c) shows generalised high abundance of diatoms on the northern part of the shelf (5×10^6 valves/c.c.) and a band of high values (10^6 valves/c.c.) that runs parallel to the southern coast and extends along the Algarve coast, immediately to the east of Cape S. Vicente.

In the sediments, the diatom taxa which appear as dominant are *Chaetoceros* resting spores and *Thalassiosira* spp. (figures 6c, f). Also present in lower abundance, but with a more homogenous distribution along the shelf, are *Thalassionema nitzschioides* and *Paralia sulcata* (Ehr.) Cleve (figures 6i, l).

4.3. Coccolithophorids

4.3.1. Water Column

Coccolithophorids are widely distributed, but more abundant to the south of the Nazaré canyon in both summer and winter sampling periods (figures 7a, b). During summer, the highest concentrations, more than 3×10^4 cells/L, are associated with upwelling and occur at Cape S. Vincent. North of Nazaré, this group is mainly distributed at mid and outershelf, with the lowest numbers (<10 cells/L) observed at the innershelf stations. In winter, concentrations of the same order of magnitude of the summer maxima (10^4 cells/L) are only present in some minor dispersed patches, on the southwestern and southern coasts.

If, instead of the total abundance of cells, the relative importance of coccolithophorids in the phytoplankton community [% Coccolithophorids = (number cells of coccolithophorids/l) / (total number of phytoplankton cells / L)] is considered (figure 8a, b), we find that during the

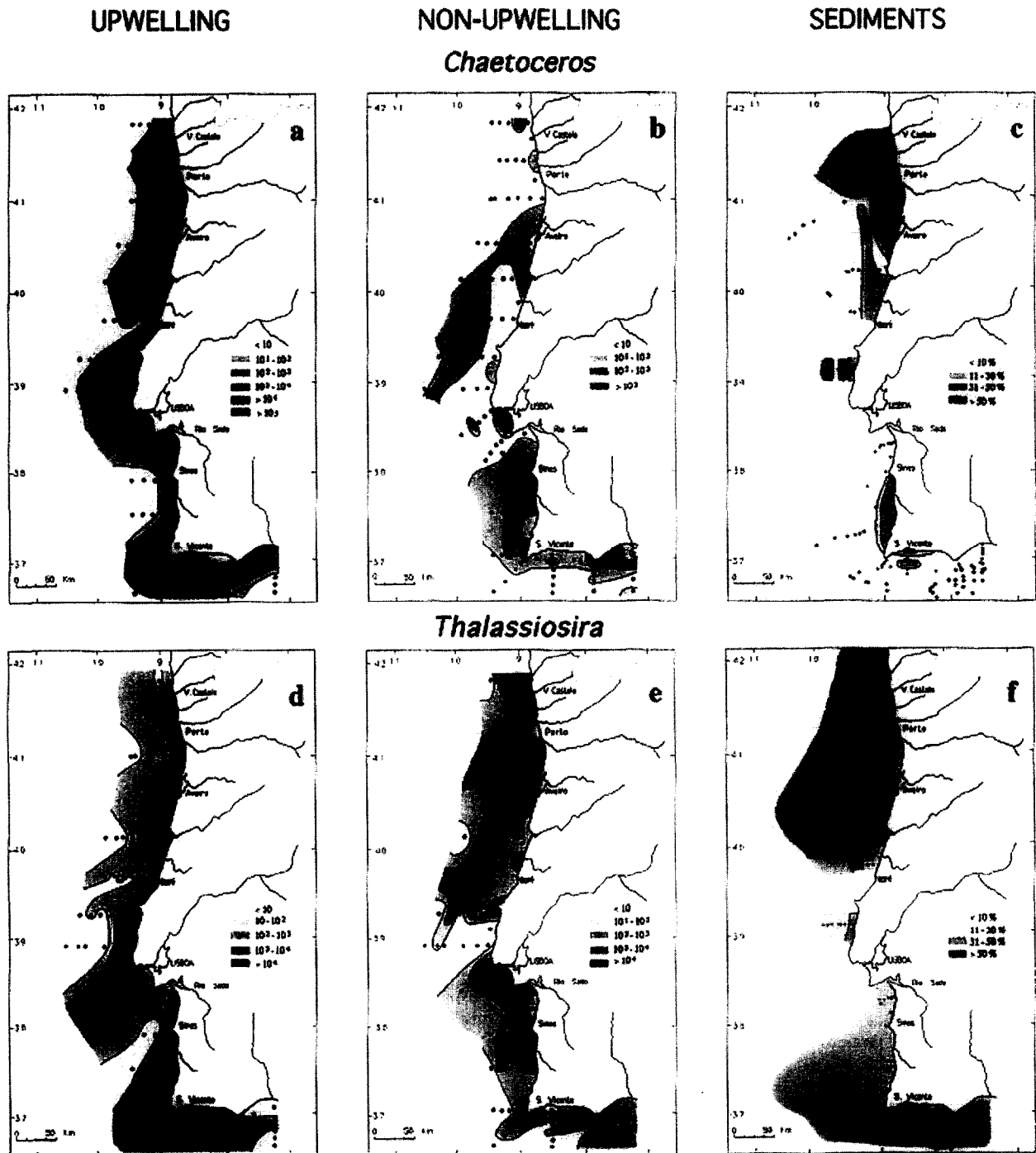


Figure 6. Distribution of the water column abundance (log cells/L) of *Chaetoceros*.
 a- CICLOS I - August 1985; b- CICLOS III - January 1986; c- Distribution of the percent abundance in the sediments.

Distribution of the water column abundance (log cells/L) of *Thalassiosira*.
 d- CICLOS I - August 1985; e- CICLOS III - January 1986; f- Distribution of the percent abundance in the sediments.

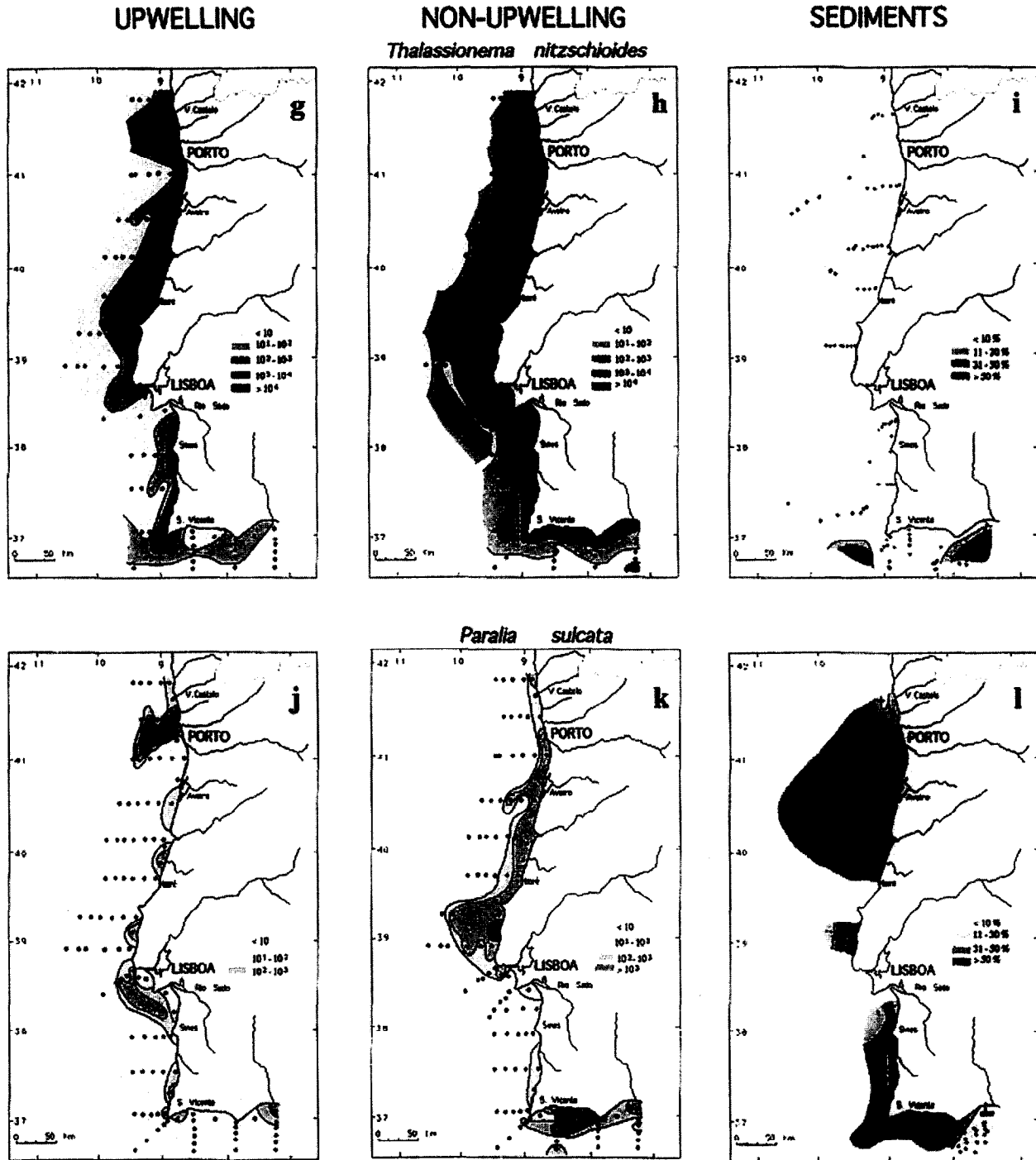


Figure 6 (continued). Distribution of the water column abundance (log cells/L) of *Thalassionema nitzschioides*.
 g- CICLOS I - August 1985; h- CICLOS III - January 1986; i- Distribution of the percent abundance in the sediments.

Distribution of the water column abundance (log cells/L) of *Paralia sulcata*.
 j- CICLOS I - August 1985; k- CICLOS III - January 1986; l- Distribution of the percent abundance in the sediments.

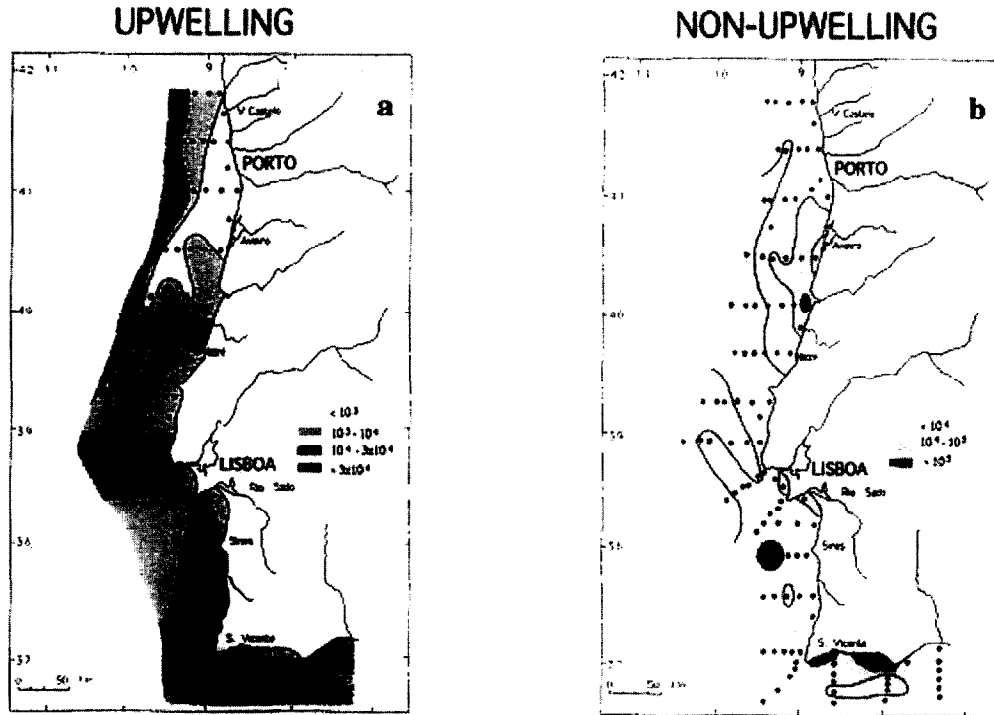


Figure 7. Distribution of the water column averaged abundance of coccolithophorids (log cells/L). a- CICLOS I - August 1985; b- CICLOS III - January 1986.

upwelling period, their importance is significantly reduced in the areas influenced by the upwelling phenomena. Higher relative abundances occur associated with warmer waters (figures 2a and 8a). During the non-upwelling situation, this group composes up to 90 % of the total phytoplankton community all along the south and western coasts, except for the north inshore area (Figueira da Foz to Caminha and up to the 100 m bathymetric), which corresponds to the area of lower salinity (figure 3b).

4.3.2. Sediments

Higher abundances of Coccolithophorid are found on the southwestern and Algarve coasts, while low abundances characterize the northern part of the shelf (figure 8c).

5. DISCUSSION

5.1. Diatom and Coccolithophorid abundances - water column versus sediments

If we compare the diatom abundance distribution patterns in the water column for a typical upwelling period and a

non-upwelling situation (figure 4b, a) to the diatom abundances distribution in the surface sediments (figure 4c), the main observation is that the sediment distribution pattern is closely related to the water column upwelling situation, but does not show any relation to the winter water column distribution.

When the same type of comparison is made for the coccolithophorids (upwelling, non-upwelling and sediments, figure 8), the low abundances in the north and the highest values in the zone immediately to the north of Cape S. Vincent, observed in the sediments, reflect not only the general N-S difference observed in the water column for both upwelling and non-upwelling situations, but also the summer water column distribution (figure 8c).

Our water column data are reduced to two discrete periods of specific seasons, not representative of the interannual variability and certainly not of the same range of scale of the sediment record. However, assuming their representativeness of the biological interseasonal variability, one can say that the diatom and coccolithophorid abundance distributions observed in the sediments is mainly a reflection of the water column distribution observed during an upwelling situation. Moreover, both

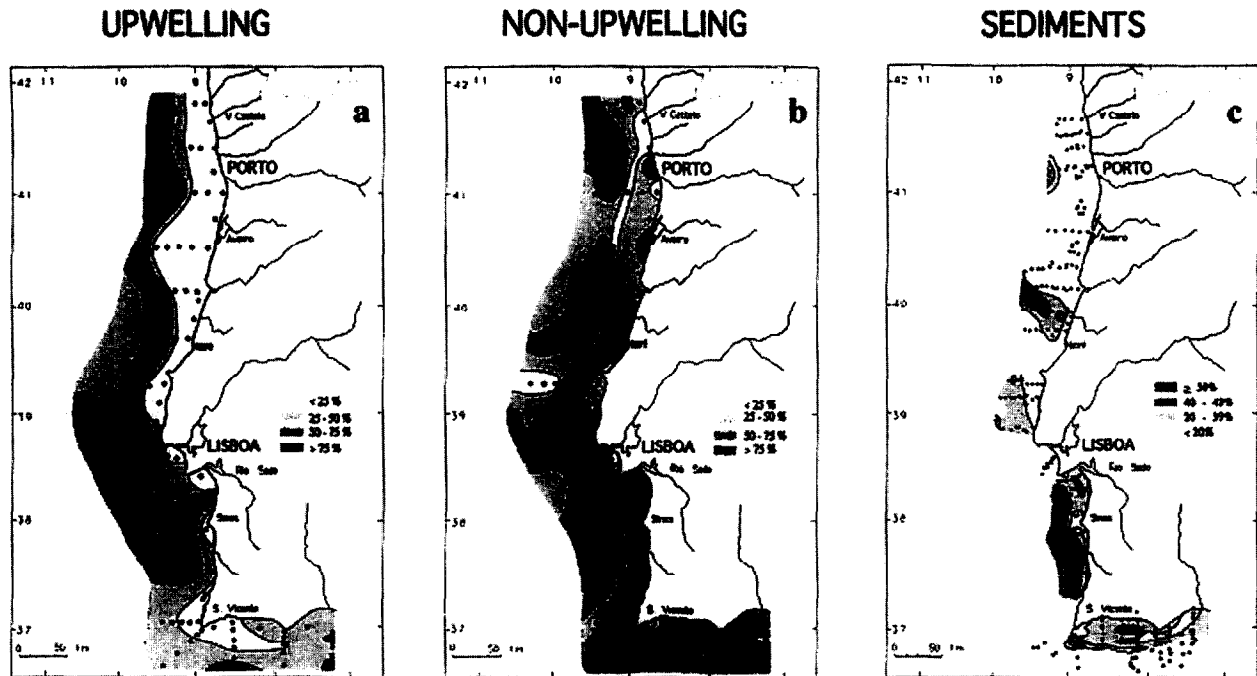


Figure 8. Distribution of the water column relative abundance of coccolithophorids (% of total phytoplankton community). a- CICLOS I - August 1985; b- CICLOS III - January 1986; c- Distribution of the coccolithophorids abundance in the sediments (% slide area covered by coccolithophorids).

groups' distribution patterns in the sediments preserve most of their original biological spatial variability, independently of the sediment lithology and/or the relative importance of the several geological processes known to act on the Portuguese shelf [18]. This indication, that both diatom and coccolithophorids produced during blooms are preserved with greater efficiency than those produced during non-bloom periods, has also been shown in the work of Nelson et al. [19]. Such a conclusion favours Margalef's idea which maintains that the high inputs of energy followed by a gradual decay of that same energy create discontinuity, and allow life to make history which becomes recorded in the sediments [16]. In the same way it contradicts the inference of Sancetta [23], who considers, based on the study of trap material and top box-cores material from British Columbian Fjords, that homogenisation by the geological processes, which act within the sediment mixed zone (such as bioturbation and erosion), obscures the original biological spatial variability.

Diatom abundances in the sediments of the Portuguese margin are thus confirmed as reflecting the original "proportions" of production generated by the occurrence of upwelling. Therefore, one can assume that the taxa pro-

duced during this highly productive but relatively short time interval are the ones that dominate the fossil record. However, it is also well known that the sediment record is incomplete, lacking many of the diatom species present in the water column. The relatively extensive water column data, now available for this region of strong seasonal variation in productivity, appears to be an excellent opportunity to assess the relative importance of the different seasons/species to the sedimentary record, and to check the interpretations put forward by Abrantes [1].

5.2. Diatom assemblages - water column versus sediments

Clear differences and similarities are evident from the comparison of the most important water column taxa in both seasons and the taxa found in the sediments. The differences are the absence in the sediments of one of the most abundant summer genus, *Pseudo-nitzschia*, and the persistent presence in the sediments of *Paralia sulcata*, a species present in the plankton of both seasons but in small numbers and mainly at the more coastal stations ([17]; figure 6). The similarities are the co-occurrence and high abundances both in the water column and the

sediments of the genus *Chaetoceros* and *Thalassiosira*, and the persistent presence of *T. nitzschioides* (figure 6).

Can we explain these differences and similarities?

The summer dominant genus *Pseudo-nitzschia* is a genus characteristic of the upwelling centres where primary production is maximal [5, 6, 14, 15, 20, 24]. *Pseudo-nitzschia* species are, however, small and lightly silicified, and therefore very prone to dissolution and rarely preserved in the sediment record [14, 23, 24]. On the contrary, *Paralia sulcata* is a fairly rare species in the plankton, but often reported as important in the sediments. This dense taxon is also reported to increase in relative abundance at the deepest traps of the British Columbia Fjords [23]. This increase is attributed to lateral advection from shallower sites, which can also be invoked to explain the sedimentary record reported here, given the persistent presence of the species in the innermost part of the Portuguese shelf (figures 6j, k). Nevertheless the coastal presence of the species, a situation also recorded along the NW African coast, is known to extend its domain over the shelf during periods of strong upwelling [5, 6]. This fact, concurrently with the inverse relationship observed in the Portuguese margin sediments between this species size and the upwelling intensity (figure 6d in [1]), points to upwelling as a determining factor for its presence throughout the shelf sediments, a factor certainly enhanced by the robustness of the species.

The second most important genus in the summer water column is *Chaetoceros*, the genus which also dominates the sediment assemblage (figures 6a, c). The species of this genus are, like *Pseudo-nitzschia*, fragile forms, however the genus is characterized by its ability to form resting spores when nutrients are nearly exhausted in the euphotic zone [5, 6, 15]. According to Smith et al. [26] and Pitcher [21], diatom spores form a major component of phytoplankton settling from the upper mixed layer. The fact that *Chaetoceros* is one of the dominant diatoms during upwelling events, associated with its ability to form spores, may well increase its chances of becoming incorporated in the sedimentary record of coastal upwelling areas, such as Portugal, SW Africa and California [1, 24, 25].

Thalassiosira represents another major contributor to the diatom assemblage in summer. A genus which has been reported in other upwelling zones but is also found in other areas of fertilisation and flow [5, 15]. According to Margalef [15], in an upwelling system this genus is represented by different species, with the mucilage produc-

ing species related to the place and intensity of upwelling, while cells of *Thalassiosira* devoid of mucilage become more frequent away from the upwelling centres. Off Portugal, the genus is present in the water column with maxima of the same order of magnitude in both winter and summer conditions. Its distribution in the two seasons is, however, quite different. In summer maximum abundances occur at the upwelling centres associated with chl *a* and diatoms maxima (figures 6d, 2c, 4a). In winter, maximum abundances occur off the Tagus and Sado estuaries and north of Nazaré, within the low salinity area clearly visible in the salinity distribution (figures 6e, 3b). A pattern probably related to the increased fertilisation generated by the higher river runoff and nutrient input that is likely to occur in those areas [1, 10]. *Thalassiosira* was, in both seasons, mainly represented by the species *T. anguste-lineata* (A. Schmi.) Fryxell and Hasle and *T. eccentrica* (Ehr.) Cleve, non mucilage producers, which together reached 60 to 100 % of the total of *Thalassiosira*.

The distribution of *Thalassiosira* spp. in the sediments shows a clear N/S contrast with a higher abundance (30–50 %), especially of very small forms north of Nazaré (figure 6f). The species present are: *T. binata* Fryxell, *T. decipiens* (Grunow ex Van Heurck) Jorgensen, *T. delicatula* (Ostenfeld) Hasle and *T. dyporocyclus* Hasle, forms not identified in the biological samples, certainly due to their small size and non-existence of SEM observations. Regions of high abundance are also noticeable off the Algarve coast, where the most abundant form is *T. eccentrica*.

Given that the genus *Thalassiosira* is common in the area and represented by the same species in both seasons, neither the genus nor any of the species can be a reliable indicator of a single process. However, the similarity observed between the non-upwelling water column and sediment distribution (figures 6e, f) points to continuous (all year long) production conditions/nutrient input, as the determining factor of this genus, sedimentary record.

Another species, which is present at the same level of abundance in both sampled seasons, is *Thalassionema nitzschioides*. This species is a diatom common in and around upwelling centres [12, 15], which seems to increase in importance during periods of long and weak upwelling [5]. Off Portugal (figures 6g, h), although a secondary form during upwelling, the species is present in the upwelling centres. In winter, its level of abundance (10^3 cells/L) is the same as during summer, and it has an homogeneous distribution all along the shelf. This

situation seems to be reflected in the low numbers and homogeneous distribution found in the western shelf sedimentary cover.

6. CONCLUSIONS

Upwelling determines the production patterns observed off Portugal. At the temperature-defined upwelling centres, phytoplankton biomass at the surface is ten times higher during an upwelling situation than during a non-upwelling period. Diatoms are the major phytoplankton group during upwelling, while coccolithophorids dominate during winter.

The comparison of the total phytoplankton biomass, diatoms and coccolithophorids abundance (# cells/L and % abundance) distribution in the water column, during a non-upwelling and an upwelling situation, and the same groups' distribution in the sediments reveals total diatom distribution pattern in the sediments as a clear record of the diatom dominance of the phytoplankton during upwelling. The same is true for the coccolithophorids, even though it is clearly more important in winter phytoplankton. The distribution of this group in the sediments also shows a visible connection to the distribution of the same group during upwelling periods.

Water column diatom assemblages during upwelling are mainly composed of *Pseudo-nitzschia* and *Chaetoceros* followed by *Thalassiosira* and *Thalassionema nitzschioides*, while in winter *Thalassiosira* and *Thalassionema nitzschioides* are the most important taxa. In the sedi-

ments, *Chaetoceros* dominance appears to reflect the importance of the short but high production associated with upwelling, while *Thalassiosira* appears to mark more persistent fertility conditions, which are likely to occur in the northern area.

Aside from the disparity between biological and geological scales used in this study, the recurrence of the upwelling phenomena on the Portuguese margin was shown to leave a clear imprint in the sediments, where the original hydrological and biological variability is actually preserved. Even though some plankton species, such as *Pseudo-nitzschia*, never make it to the sediments, this does not appear impeditive of correct paleoecological inferences from the coastal upwelling sedimentary record. In fact, the dominant taxa of each season were also shown to be dominant in the sediments, and to have distribution patterns similar to their plankton distribution.

Acknowledgements

This work was supported by JNICT ICDE contract n° 572.83.92, the Instituto Geológico e Mineiro and Instituto de Investigação das Pescas e do Mar. The authors wish to thank the phytoplankton and marine geology laboratory technicians for their support with sample preparation. Thanks are also due to the masters and crews of research vessels *Almeida Carvalho* and *Noruega* for their efficient help at sea. Criticism by two anonymous reviewers contributed to improving this paper.

REFERENCES

- [1] Abrantes F., Diatom assemblages as upwelling indicators in surface sediments off Portugal, *Mar. Geol.* 85 (1988a) 15–39.
- [2] Abrantes F., Diatom productivity peak and increased circulation during latest Quaternary deglaciation: Western Mediterranean, *Mar. Micropaleontol.* 13 (1988b) 76–96.
- [3] Barnola J.M., Raynaud D., Korotkevich Y.S., Lorius C., Vostok ice core provides 160,000-year record of atmospheric CO₂, *Nature* 329 (1987) 408–414.
- [4] Berger W.H., Global Maps of Ocean Productivity, in: *Productivity of the Ocean: Present and Past.*, Berger W.H., Smetacek V.S., Wefer G., (Eds), John Wiley and Sons, New York, 1989, 429–455.
- [5] Blasco, D., Estrada M., Jones B., Short time variability of phytoplankton populations in upwelling regions – The example of Northwest Africa, *Proceedings of the International Symposium on Coastal Upwelling*, Los Angeles (1981) 339–347.
- [6] Blasco D., Estrada M., Jones B., Relationship between the phytoplankton distribution and composition and the hydrography in the northwest African upwelling region near Cabo Corbeiro, *Deep-Sea Res.* 27 A (1980) 799–821.
- [7] Boltovskoy D., Alder V., Abelman A., Radiolarian Sedimentary Imprint in Atlantic Equatorial Sediments: Comparison with the Early Flux at 853 m, *Mar. Micropaleontol.* 23 (1993) 1–12.
- [8] Estrada M., Blasco D., Two phases of the phytoplankton community in the Baja California upwelling, *Limnol. Oceanogr.* 24 (1979) 1065–1080.

- [9] Fiúza A., Upwelling patterns off Portugal, in: Suess E., Thiede J., (Eds.) Coastal Upwelling its sediment record, Plenum, New York, 1983, pp. 85–98.
- [10] Fiúza A., Hidrologia e Dinamica das Aguas Costeiras de Portugal, Universidade de Lisboa (1984).
- [11] Fiúza A., Macedo M.E., Climatological space and time variation of the Portuguese coastal upwelling, *Oceanol. Acta* 5 (1982) 31–40.
- [12] Hasle G.R., Mendiola B.R., The Fine Structure of Some *Thalassionema* and *Thalassiothrix* Species, *Phycologia* 6 (1967) 107–125.
- [13] Hutchings L., Pitcher G., Probyn T., Bailey G., The Chemical and Biological Consequences of Coastal Upwelling, Proceedings of the Upwelling in the Ocean. Modern Processes and Ancient Records, Berlin, 1994, 65–83.
- [14] Lange C.B., Treppke U.F., Fisher G., Seasonal diatom fluxes in the Guinea Basin and their relationships to trade winds, hydrography and upwelling events, *Deep-Sea Res.* 41 (1994) 859–878.
- [15] Margalef R., Phytoplankton communities in upwelling areas, The example of NW Africa, *Oecol. Aquat.* 3 (1978) 97–132.
- [16] Margalef R., Asimetrías introducidas por la operación de la energía externa en secuencias de sedimentos y de poblaciones, *Acta Geológica Hispánica* 16 (1981) 35–38.
- [17] Moita T., Spatial Variability of Phytoplankton Communities in the Upwelling Region off Portugal, Proceedings of the International Council for the Exploration of the Sea, L64 (1993) 1–20.
- [18] Monteiro J.H., Dias J.A., Gaspar L., Possolo A., Recent marine sediments of the Portuguese continental shelf, Proceedings of the Present Problems of Oceanography in Portugal (1980) Lisbon.
- [19] Nelson D., Tréguer P., Brzezinski M., Leynaert A., Quéguiner B., Production and dissolution of biogenic silica in the ocean: Revised global estimates, comparison with regional data and relationship to biogenic sedimentation, *Global Biogeochemical Cycle* 9 (1995) 359–372.
- [20] Olivieri E., A Description of the Hydrography and Phytoplankton Communities in the Upwelled Waters of the Cape Peninsula, South Africa, September 1972–February 1973, *S. Afr. J. mar. Sci.* 1 (1983) 199–229.
- [21] Pitcher G., Phytoplankton seed populations of the Cape Peninsula upwelling plume, with particular reference to resting spores of *Chaetoceros* (Bacillariophyceae) and their role in seeding upwelling waters, *Est. Coast. Shelf Sci.* 31 (1990) 283–301.
- [22] Rios A.F., Pérez F.F., Fraga F., Water masses in the upper and middle North Atlantic Ocean east of the Azores, *Deep-Sea Res.* 39 (1992) 645–658.
- [23] Sancetta C., Processes controlling the accumulation of diatoms in sediments: a model derived from British Columbian fjords, *Paleoceanography* 4 (1989) 235–251.
- [24] Sancetta C., Diatoms in the Gulf of California: Seasonal flux patterns and the sediment record for the last 15,000 years, *Paleoceanography* 10 (1995) 67–84.
- [25] Schuette C., Recent marine diatom taphocoenoses off Peru and off Southwest Africa. Reflection of coastal upwelling, Oregon State University (1980).
- [26] Smith W., Heburn G., Barber R., O'Brien J., Regulation of phytoplankton communities by physical processes in upwelling ecosystems, *J. Mar. Res.* 41 (1983) 539–556.
- [27] Sousa F., Bricaud A., Satellite-derived phytoplankton pigment structures in the Portuguese upwelling area, *J. Geophys. Res.* 97 (1992) 11,343–11,356.
- [28] Wefer G., Fisher G., Seasonal Patterns of Vertical Flux in Equatorial and Coastal Upwelling Areas of the Eastern Atlantic, *Deep-Sea Res.* 40 (1993) 1613–1645.

SEDIMENT RECORD OF UPWELLINGS

Appendix 1a. CICLOS I (August, 1985).

Sections	Stations	Lat. (N)	Long. (W)	Depth (m)	Dist. offsh. (Km)	Diatoms (n° cells/l)	Diatoms (%)	Coccolith. (n° cells/l)	Coccolith. (%)	<i>Pseudonitzschia</i> (n° cells/l)	<i>Chaetoceros</i> (n° cells/l)	<i>Thalassiosira</i> spp. (n° cells/l)	<i>T. nitzschoides</i> (n° cells/l)	<i>P. sulcata</i> (n° cells/l)
S II	8	41°25'	8°49'	35	2.8	717,950	94.3	0	0.0	631,150	61,320	420	680	660
	9	41°25'	8°58'	77	15.3	51,840	88.9	20	0.0	25,540	15,760	160	1,940	180
	10	41°25'	9°05'	100	25.0	28,180	68.8	6,040	14.7	23,300	300	160	1,100	0
	11	41°25'	9°12.5'	200	35.4	1,860	9.2	6,180	30.4	90	0	60	420	270
	12	41°25'	9°17'	>1000	41.7	1,860	10.1	9,150	49.7	540	60	60	240	0
S IV	20	40°30'	8°50'	16	2.8	532,310	90.1	40	0.0	13,000	6,640	6,640	11,220	60
	21	40°30'	9°01'	68	18.3	29,960	70.1	3,100	7.2	5,380	620	660	40	0
	22	40°30'	9°11.5'	107	33.1	6,060	20.7	6,060	20.7	780	360	520	0	0
	23	40°30'	9°21'	128	46.5	2,256	21.0	96	0.9	72	216	72	96	0
	24	40°30'	9°30'	273	59.2	780	13.4	180	3.1	30	0	30	0	0
	25	40°30'	9°37'	971	69.0	1,140	1.9	39,270	66.6	60	0	30	0	0
S V	26	40°05'	9°48.5'	>1000	80.1	1,200	4.7	12,000	47.3	0	0	0	0	0
	27	40°05'	9°40'	510	68.0	8,40	58.3	0	0.0	120	240	0	0	0
	28	40°05'	9°34'	198	59.5	450	8.4	3,000	56.2	60	0	0	0	0
	29	40°05'	9°25'	135	46.8	1,320	10.0	10,824	81.7	144	48	48	0	0
	30	40°05'	9°15.5'	101	33.3	4,900	20.5	60	0.3	1,880	0	440	60	0
	31	40°05'	9°06.5'	77	20.6	9,940	24.8	7,040	17.6	3,040	500	240	760	0
	32	40°05'	8°58'	23	8.5	84,000	57.9	1,000	0.7	14,040	37,120	1,540	2,960	0
S VI	34	39°40'	9°06'	20	4.3	54,920	52.8	21,000	20.2	160	3,400	180	2,640	0
	35	39°40'	9°15'	125	17.1	2,520	10.9	6,000	25.9	216	0	48	888	0
	36	39°40'	9°25'	141	31.4	625	3.3	15,000	78.6	0	0	0	500	0
	37	39°39.5'	9°33'	180	42.8	810	1.9	27,000	63.4	60	90	60	90	0
	38	39°40'	9°39'	>1000	51.3	120	0.7	6,000	35.3	0	0	0	60	0
	39	39°40'	9°47'	>1000	62.7	120	0.6	7,500	36.0	30	0	30	0	0
S VIII	47	38°55'	9°27.5'	42	2.2	6,580	11.9	13,000	23.5	60	1,640	520	100	0
	48	38°55'	9°37'	115	15.9	3,920	10.9	27,000	75.1	60	1,240	300	0	0
	49	38°55'	9°48'	120	31.7	132	1.9	6,600	93.5	0	0	0	0	0
	50	38°55'	10°04'	200	54.8	240	1.0	12,000	51.1	0	90	0	0	0
	51	-	-	-	-	-	-	-	-	-	-	-	-	-
	52	38°55'	10°21'	>1000	79.3	30	0.1	19,500	62.1	0	0	0	0	0
S XII	70	38°00'	8°52.5'	34	2.2	50,790	43.9	21,440	18.5	5,180	33,720	1,000	340	20
	71	38°00'	8°58'	129	10.2	2,213	3.8	15,875	27.4	275	150	225	75	0
	72	38°00'	9°05'	289	20.4	30	0.1	22,890	86.7	0	0	0	0	0
	73	38°00'	9°13'	525	32.1	180	0.7	15,210	60.9	0	0	0	0	0
	74	38°00'	9°24'	>1000	48.2	180	1.1	6,540	39.5	0	0	30	0	0
S XIII	75	37°35'	9°29'	950	58.7	1,770	10.7	8,340	50.6	0	0	0	0	0
	76	37°35'	9°15'	566	38.2	1,830	1.9	53,550	54.9	0	0	120	0	0
	77	37°35'	9°06'	300	25.0	420	0.9	43,740	96.7	0	0	210	30	0
	78	37°35'	8°58'	142	13.2	1,863	3.1	31,374	52.2	108	0	27	0	0
	79	37°35'	8°50'	52	1.5	15,690	14.5	42,340	39.2	1,140	5,280	5,770	220	20
S XV	86	36°40'	9°24'	>1000	53.5	25,170	47.4	11,730	22.1	1,020	60	210	0	0
	87	36°47'	9°15'	810	34.8	10,200	16.0	28,410	44.5	600	60	30	120	0
	88	36°54.5'	9°06'	550	15.6	25,680	28.7	36,600	40.9	3,180	300	180	120	0
	89	36°57.5'	9°03'	92	8.7	190,640	80.7	34,100	14.4	103,580	8,640	8,660	220	0
	90	37°00'	9°00'	34	3.0	195,760	83.4	32,320	13.8	82,780	9,620	14,340	220	0
S XVI	92	37°05.5'	8°35'	26	1.5	51,020	30.1	24,440	14.4	4,060	1,040	440	0	0
	93	37°00'	8°35'	52	9.3	35,100	58.0	8,660	14.3	5,140	4,780	2,060	0	0
	94	36°54'	8°35'	98	20.4	64,380	64.3	18,200	18.2	24,760	6,020	3,280	0	0
	95	36°51.5'	8°35'	205	26.9	118,950	59.1	37,590	18.7	56,430	1,530	1,530	60	0
	96	36°45'	8°35'	741	38.9	9,210	31.1	12,390	41.8	2,940	30	270	0	0
	97	36°39'	8°35'	>1000	50.0	2,970	8.2	29,760	82.2	240	180	60	0	0
S XVIII	104	-	-	-	-	-	-	-	-	-	-	-	-	-
	105	36°58.5'	7°25'	100	23.2	5,240	13.0	16,600	41.1	0	120	100	0	680
	106	36°56'	7°25'	200	29.6	3,330	6.0	39,720	71.3	30	270	210	0	0
	107	36°50'	7°25'	497	40.8	120	0.5	8,430	35.0	0	0	0	0	0
	108	36°45'	7°25'	530	50.0	240	0.9	7,560	27.0	0	0	0	0	0
	109	36°39'	7°25'	535	61.1	300	1.1	14,430	54.5	60	0	0	0	0

Appendix 1b. CICLOS III (January, 1986).

Sections	Stations	Lat. (N)	Long. (W)	Depth (m)	Dist. offsh. (Km)	Diatoms (n° cells/l)	Diatoms (%)	Coccolith. (n° cells/l)	Coccolith. (%)	<i>Pseudonitzschia</i> (n° cells/l)	<i>Chaetoceros</i> (n° cells/l)	<i>Thalassiosira</i> spp. (n° cells/l)	<i>T. nitzschoides</i> (n° cells/l)	<i>P. sulcata</i> (n° cells/l)
S II	8	41°25'	8°49'	33	2.8	6,170	18.2	7,120	21.0	0	40	5,660	80	30
	9	41°25'	8°58'	75	15.3	6,240	48.4	5,320	41.3	0	0	5,100	760	0
	10	41°25'	9°04.5'	100	24.3	3,840	37.6	5,420	53.1	0	0	3,220	240	0
	11	41°25'	9°12'	200	34.7	1,050	4.4	16,500	69.1	300	0	100	50	0
	12	41°25'	9°17'	1000	41.7	540	6.7	6,750	83.3	0	0	45	30	0
S IV	20	40°30'	8°50'	22	2.8	980	11.7	5,040	60.1	0	0	180	120	540
	21	40°30'	9°01'	61	18.3	42,800	73.00	15,020	25.6	100	260	37,760	0	0
	22	40°30'	9°11.5'	100	33.1	4,660	17.9	5,060	19.4	60	40	2,640	1,220	300
	23	40°30'	9°21'	126	46.5	336	2.4	12,000	85.0	0	0	144	48	0
	24	40°29.8'	9°29.7'	195	58.8	1,890	41.7	2,010	44.4	90	0	90	780	0
	25	40°30'	9°37'	1000	69.0	300	1.1	9,900	37.8	0	0	90	120	0
S V	26	40°05'	9°48.6'	1000	80.2	420	0.5	21,090	26.1	150	0	0	0	0
	27	40°05'	9°40'	470	68.0	705	5.2	12,480	92.3	0	150	120	180	0
	28	40°05'	9°34.5'	200	60.3	17,790	36.4	26,100	53.4	150	1,350	12,780	570	0
	29	40°05'	9°25'	132	46.8	432	4.0	9,600	89.9	0	0	216	48	0
	30	40°05'	9°15.5'	104	33.3	620	8.5	6,120	84.3	0	0	140	260	0
	31	40°05'	9°06.5'	75	20.6	1,300	12.3	9,120	86.5	0	0	20	360	460
	32	40°05'	8°58'	28	8.5	17,920	17.4	36,640	35.6	240	7,280	80	4,640	1040
S VI	34	39°40'	9°06'	32	4.3	470	7.0	6,020	89.7	0	0	30	100	210
	35	39°40'	9°15'	123	17.1	820	13.0	5,140	81.3	320	0	20	40	40
	36	39°40'	9°25'	140	31.4	575	1.8	10,200	32.6	25	0	50	250	0
	37	39°40'	9°33'	170	42.8	7,020	22.6	19,590	63.0	60	150	5,610	210	0
	38	39°40'	9°38.7'	1000	50.9	17,010	31.6	22,770	42.3	150	30	15,150	990	0
	39	39°40'	9°47'	> 1000	62.7	2,010	9.5	13,470	63.9	180	60	210	360	0
S VIII	47	38°55'	9°27.5'	36	2.2	620	4.1	9,060	59.8	0	0	0	120	240
	48	38°55'	9°37'	117	15.9	220	1.7	4,400	34.4	0	0	0	44	88
	49	38°55'	9°48'	131	31.7	420	5.3	7,160	90.2	0	0	0	80	200
	50	38°55'	10°04'	190	54.8	270	1.7	15,450	94.8	0	0	0	0	0
	51	38°55'	10°21'	527	63.4	3,360	11.7	13,890	48.4	60	3,000	30	60	0
	52	38°55'	10°21'	1000	79.3	1,020	9.7	7,710	73.0	90	0	0	150	0
S XII	70	37°56'	8°54.5'	75	9.5	3,100	17.1	13,500	74.7	160	380	140	460	0
	71	37°56'	9°00'	135	17.5	3,050	11.7	21,300	81.8	0	600	150	300	0
	72	37°56'	9°07'	290	27.8	3,810	7.8	23,130	47.2	0	660	60	330	0
	73	37°56'	9°16'	545	40.9	10,350	14.2	46,770	64.1	0	2,880	450	540	0
	74	37°56'	9°26'	1000	55.5	1,920	5.2	32,880	89.5	60	90	120	0	0
S XIII	75	37°34'	9°25'	1000	52.9	510	2.2	21,330	94.0	120	60	0	120	0
	76	37°34'	9°17'	656	41.1	1,080	4.4	22,230	91.1	0	120	210	60	0
	77	37°34'	9°08'	342	27.9	2,610	18.8	5,160	37.2	0	540	120	120	0
	78	37°34'	9°00'	160	16.2	5,325	17.6	21,060	69.5	150	570	510	300	0
	79	37°34'	8°50'	55	1.5	4,340	19.8	17,220	78.7	200	420	340	200	180
S XV	86	36°40'	9°24'	1000	53.5	90	0.5	16,650	98.1	0	0	0	0	0
	87	36°47.5'	9°15'	770	34.2	360	1.8	18,870	93.2	210	0	30	0	0
	88	36°54.5'	9°06'	527	15.6	330	1.7	16,950	87.5	30	30	60	60	0
	89	36°57.5'	9°03'	50	8.7	630	3.4	16,100	86.9	0	60	20	80	80
	90	37°00'	9°00'	40	.0	1,960	9.4	15,080	72.4	0	140	20	200	0
S XVI	92	37°05.5'	8°35'	31	1.5	980	7.7	11,320	89.0	40	40	0	160	380
	93	37°00'	8°35'	53	9.3	2,540	11.7	17,660	81.2	0	180	40	500	0
	94	36°54'	8°35'	100	20.4	700	3.3	20,100	95.0	0	0	0	0	180
	95	36°51.5'	8°35'	210	26.9	540	2.1	18,600	73.2	0	0	30	60	210
	96	36°45'	8°35'	700	38.9	140	1.1	8,460	67.7	0	0	0	0	0
	97	36°39'	8°35'	1000	50.0	570	2.8	12,870	62.9	90	0	0	0	90
S XVIII	104	37°06'	7°25'	20	9.3	940	2.8	19,220	57.3	0	40	80	120	300
	105	36°58.5'	7°25'	100	23.2	540	1.3	27,520	69.2	0	0	20	40	0
	106	36°56'	7°25'	220	29.6	2,520	2.8	33,630	37.8	30	750	0	120	60
	107	36°50'	7°25'	490	40.8	1,140	4.3	25,080	94.1	30	180	30	0	0
	108	36°45'	7°25'	550	50.0	1,560	6.7	20,670	89.0	510	0	30	0	0
	109	36°39'	7°25'	528	61.1	510	1.9	25,590	96.9	30	90	30	90	0

SEDIMENT RECORD OF UPWELLINGS

Appendix 1c. Sediments.

Sample number	Lat. (N)	Long. (W)	Depth (m)	Dist. (Km)	TDiat/cc (*10 ³)	Coccoliths (%)	Chaetoceros resting spores (%)	P. sulcata (%)	Thalassiora (%)	T. nitzschioides (%)		
116	41	35.00	8	52.30	40	0.6	4778	13	33	22	31	0
120	41	34.90	9	0.90	85	1.7	4160	10	64	8	19	1
122	41	35.00	9	5.90	100	2.5	100	10	9	11	12	0
123	41	35.30	9	9.80	100	3.0	1100	10	57	18	16	0
124	41	34.50	9	11.50	105	3.3	174	10	44	37	15	0
165	40	48.50	9	12.20	140	4.2	543	1	25	34	19	0
167	40	48.60	9	4.90	95	3.2	1000	15	7	52	8	0
168	40	48.50	9	1.40	85	2.7	2500	20	69	10	13	0
170	40	48.50	8	55.50	50	1.8	19500	7	75	10	11	0
172	40	48.50	8	48.90	35	0.9	6000	5	39	31	9	0
174	40	48.50	8	43.90	10	0.3	500	3	15	56	6	0
696	40	11.50	9	35.80	220	6.0	60	50	-	-	-	-
698	40	11.50	9	31.60	158	5.3	63	45	4	39	29	0
700	60	11.50	9	24.20	135	4.2	113	15	6	42	19	1
702	40	12.30	9	11.30	100	2.5	950	-	8	54	20	0
703	40	12.20	9	6.50	85	1.8	3797	2	28	34	20	1
704	40	11.70	9	3.90	65	1.4	3100	P	23	26	25	2
706	40	11.30	8	59.30	45	0.7	1000	-	4	29	22	0
708	40	11.10	8	56.00	18	0.3	2000	-	4	58	12	0
709	40	8.60	8	53.40	10	0.2	1027	-	24	17	13	1
215	39	43.10	9	4.20	20	0.1	529	-	13	45	6	0
217	39	43.20	9	8.00	53	0.7	600	1	26	52	4	0
218	39	43.00	9	10.70	70	1.1	941	10	28	48	7	1
219	39	43.10	9	13.60	100	1.5	794	20	15	50	14	0
221	39	43.00	9	20.00	130	2.4	162	15	4	41	19	0
224	39	43.00	9	25.50	130	3.1	175	25	7	58	11	0
226	39	42.90	9	30.00	145	3.8	211	10	4	54	8	0
242	39	5.20	9	26.70	30	0.3	950	-	2	45	11	0
244	39	5.00	9	31.70	52	1.0	1600	1	0	68	0	0
246	39	5.00	9	34.90	62	1.5	300	-	59	28	1	0
248	39	5.00	9	39.90	94	2.2	391	10	7	57	7	0
249	39	5.00	9	42.00	94	2.5	600	20	4	71	1	0
252	39	5.00	9	46.00	116	3.1	678	25	3	58	4	0
254	39	5.00	9	50.00	144	3.6	138	30	79	10	3	0
256	39	5.10	9	56.50	154	4.5	214	30	31	22	7	0
449	38	12.30	9	2.10	160	2.2	300	-	-	-	-	-
451	38	13.10	8	58.10	140	1.9	180	30	3	30	3	2
453	38	13.90	8	54.50	120	1.4	333	40	3	31	10	0
455	38	14.40	8	52.10	105	1.0	278	50	1	30	8	0
457	38	14.80	8	50.00	60	0.7	1400	10	1	11	5	0
458	38	15.00	8	48.50	35	0.3	30500	-	0	1	2	0
445	37	48.80	9	11.80	450	10.0	851	30	1	26	4	0
426	38	5.00	8	53.90	112	0.7	221	25	4	42	2	0
415	37	55.00	8	56.50	105	1.2	300	35	6	40	5	0
386	37	34.90	8	52.00	95	0.6	200	25	40	27	2	0
387	37	34.80	8	52.90	110	0.8	300	30	28	30	3	2
388	37	34.90	8	54.00	118	0.9	958	50	71	13	1	0
389	37	35.10	8	55.00	129	1.0	1144	50	75	8	3	2
393	37	35.10	8	59.00	160	1.6	125	45	38	28	6	0
395	37	34.90	9	1.10	190	2.0	250	37	16	40	5	1
397	37	35.00	9	3.20	245	2.3	307	50	36	30	9	1
362	37	0.60	8	58.00	17	0.1	1000	P	-	-	-	-
366	36	58.20	8	59.00	80	0.9	80	35	-	-	-	-
369	36	55.00	9	2.70	93	1.5	700	P	0	52	3	1
371	36	53.00	9	3.80	157	1.9	67	45	-	-	-	-
338	37	3.50	8	40.00	33	0.3	200	25	11	44	2	2
339	37	2.90	8	40.00	36	0.4	1064	30	6	50	2	1

F. ABRANTES, M.T. MOITA

Appendix Ic. Sediments (continued).

Sample number	Lat. (N)	Long. (W)	Depth (m)	Dist. (Km)	TDiat/cc (*10 ³)	Coccoliths (%)	<i>Chaetoceros</i> resting spores (%)	<i>P. sulcata</i> (%)	<i>Thalassiora</i> (%)	<i>T. nitzschioides</i> (%)		
341	37	1.60	8	40.00	38	0.7	1800	20	5	54	0	1
343	37	0.00	8	40.00	63	1.0	150	20	11	42	4	1
345	36	58.10	8	40.00	80	1.4	63	30	4	62	0	1
347	36	56.00	8	40.00	98	1.7	369	35	8	45	6	1
349	36	53.80	8	40.00	105	2.1	116	20	5	38	13	1
351	35	52.50	8	40.00	110	2.4	325	20	2	41	11	2
273	37	8.50	7	30.00	8	0.3	12000	3	1	1	0	0
275	37	6.00	7	30.10	19	0.8	67	20	-	-	-	-
276	37	3.90	7	30.10	47	1.2	266	25	2	23	8	3
277	37	2.30	7	30.10	74	1.4	181	20	1	5	15	47
278	37	2.20	7	30.10	95	1.8	286	25	4	3	13	50
280	36	57.00	7	29.90	180	2.4	96	30	3	3	12	52
282	36	54.60	7	30.00	405	2.8	139	30	2	2	8	64
287	36	54.50	7	48.00	235	1.1	526	30	0	9	8	20
317	36	50.30	8	10.20	95	2.8	112	15	0	17	12	3
326	36	53.40	8	52.00	110	1.8	150	25	3	45	4	1
1316	41	44.41	12	24.77	5035	37.9	43	-	-	-	-	-
1318	42	14.34	9	40.17	2080	34.4	161	-	-	-	-	-
1324	40	56.85	9	34.23	2010	60.3	23	-	-	-	-	-
1325	40	43.41	10	1.85	1880	86.2	176	-	-	-	-	-
1326	40	41.30	10	12.20	3590	95.0	160	-	20	30	4	10
1327	40	34.43	10	20.54	3380	153.5	685	-	9	30	21	7
1331	39	54.80	9	46.60	1045	53.4	77	-	-	-	-	-
1333	39	53.00	10	49.00	4950	91.0	634	-	8	72	7	2
1335	37	22.08	10	30.23	4145	95.0	74	-	-	-	-	-
1337	37	12.50	9	42.70	2507	51.7	0	-	-	-	-	-
1338	37	14.15	9	31.01	1285	39.7	0	-	-	-	-	-
1339	37	15.44	9	24.03	900	36.2	0	-	-	-	-	-
1340	37	17.08	9	19.97	853	31.0	60	-	-	-	-	-
1341	36	43.63	9	30.12	1518	41.4	26	-	-	-	-	-
1343	36	50.00	9	25.11	787	31.0	65	-	1	8	3	53
1344	36	43.70	9	12.40	880	60.3	59	-	-	-	-	-
1348	36	41.10	8	55.90	720	27.6	28	-	-	-	-	-
1354	36	53.37	7	30.88	448	25.9	0	-	-	-	-	-
1355	36	52.17	7	30.01	502	27.6	0	-	-	-	-	-
1356	36	50.00	7	30.60	510	29.3	26	-	-	-	-	-
1358	36	37.28	7	39.75	850	34.5	0	-	-	-	-	-
1360	36	40.12	7	49.81	765	25.9	0	-	-	-	-	-
1361	36	44.50	7	48.60	645	22.4	24	-	-	-	-	-
1362	36	47.50	7	48.80	585	13.8	0	-	-	-	-	-
1363	36	51.00	7	49.00	619	12.1	258	-	7	7	7	36
1365	36	53.70	7	49.20	300	10.3	208	-	-	-	-	-
1366	36	46.31	8	0.86	735	19.0	19	-	-	-	-	-
1367	36	45.20	7	57.20	675	20.7	0	-	-	-	-	-
1368	36	41.10	7	55.80	725	25.9	36	-	-	-	-	-
1369	36	37.80	7	52.70	745	32.8	155	-	-	-	-	-
1370	36	44.14	8	14.54	710	29.3	0	-	-	-	-	-
1371	36	43.92	8	15.28	695	31.0	0	-	-	-	-	-
1373	36	34.59	8	14.00	1002	43.1	0	-	-	-	-	-
1374	36	41.70	8	15.40	740	34.5	77	-	-	-	-	-
1377	37	18.00	9	17.60	835	27.6	0	-	-	-	-	-