

Original article

Long-term upwelling evolution in tropical and equatorial Pacific during the last 800 kyr as revealed by coccolithophore assemblages[☆]

Évolution à long terme de l'upwelling du Pacifique tropical et équatorial durant les derniers 800 000 ans d'après les assemblages de coccolithophoridés

María Carmen Álvarez^{a,b,c,*}, José Abel Flores^b, Francisco Javier Sierro^b, Adolfo Molina-Cruz^c

^a Instituto de Medio Ambiente y Ciencia Marina, Universidad Católica de Valencia, 46003 Valencia, Spain

^b Departamento de Geología, Facultad de Ciencias, Universidad de Salamanca, 37008 Salamanca, Spain

^c Laboratorio de Ecología de Foraminíferos y Micropaleontología, Instituto de Ciencias del Mar y Limnología (ICMYL), UNAM, 04510 Mexico D.F., Mexico

Received 28 November 2008; accepted 20 July 2009

Available online 4 October 2009

Abstract

The coccolithophore assemblages in two ODP Sites (1237 and 1238) are studied in order to reconstruct the paleoenvironmental conditions in the tropical and equatorial Pacific during the last 800 kyr. Both ODP Sites are located in the two most significant upwelling zones of the tropical and equatorial Pacific: Peru and Equatorial upwelling, respectively. The two sites are considered to have had similar evolutions. The coccolith relative abundance, the nannofossil accumulation rate (NAR) and the *N* ratio (namely, the proportion of < 3 μm placoliths in relation to *Florisphaera profunda*) allow us to identify three different intervals. Interval I (0.86–0.45 Ma) and interval III (0.22–0 Ma) are related to weak upwelling and weak Trade Winds, as suggested by coccolithophore assemblages with low *N* ratios. Interval II (0.45–0.22 Ma), characterized by dominant *Gephyrocapsa caribbeanica* and very abundant “small” *Gephyrocapsa* and *Gephyrocapsa oceanica*, is conversely related to intense upwelling and enhanced Trade Winds.

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Keywords: Calcareous nanoplankton; Southeast Pacific; Upwelling; Nutricline; Thermocline; Trade Winds; El Niño-La Niña

Résumé

Les assemblages de coccolithophoridés de deux sites ODP (1237 et 1238) sont étudiés, dans le but de reconstruire les conditions paléoenvironnementales dans le Pacifique tropical et équatorial pendant les derniers 800 ka. Les deux sites ODP sont liés aux deux plus importantes zones d'upwelling, du Pacifique tropical et équatorial : les upwellings du Pérou et Équatorial. Les deux sites présentent une évolution similaire. L'abondance relative des coccolithes, le taux d'accumulation des nannofossiles calcaires et le rapport *N* (proportion des placolithes de taille inférieure à 3 μm par rapport à *Florisphaera profunda*) nous ont permis d'identifier trois intervalles différents. L'intervalle I (0,86–0,45 Ma) et l'intervalle III (0,22–0 Ma) correspondent à une faible intensité de l'upwelling ainsi que des Alizés. En effet, ces deux intervalles présentent des assemblages de coccolithophoridés similaires, à rapport *N* faible. L'intervalle II (0,45–0,22 Ma), caractérisé par la dominance de *Gephyrocapsa caribbeanica* et de très abondants « petits » *Gephyrocapsa* et *Gephyrocapsa oceanica*, est en revanche mis en relation avec des conditions d'upwelling et d'Alizés intenses.

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Mots clés : Nannoplancton calcaire ; Pacifique Sud ; Upwelling ; Nutricline ; Thermocline ; Alizés ; El Niño-La Niña

1. Introduction

Upwelling is an usual oceanic feature in the Subtropical Pacific. The Trade Winds system, together with the continental distribution and the Coriolis-Ekman effect, favour the

[☆] Corresponding editor: Emanuela Mattioli.

* Corresponding author.

E-mail address: a2741@usal.es (M.C. Álvarez).

development of coastal and equatorial upwellings. The development of high primary productivity is the result of the upwelling of this deep, cold and nutrient-rich water (Chavez and Barber, 1987; Fiedler et al., 1991; Thurman and Trujillo, 2002). Ocean surface circulation has sometimes been linked to changes in the atmosphere circulation, owing to the close relationship between the two systems (Kemp, 1994; Hovan, 1995; Lutgens and Tarbuck, 2001).

In the case of the equatorial upwelling, the rising water comes from 100 metres depth, driven by the Equatorial undercurrent (EUC) from the south-western Pacific. The EUC rises eastward, near the Galapagos islands and feeds the Equatorial upwelling and also the Peru upwelling by means of the Peru countercurrent (PCC; Wyrcki, 1965; Molina-Cruz, 1984; Shipboard Scientific Party, 2003). In the case of the Peru upwelling, the thermocline rising varies between 50 and 350 m depth. There are some upwelling centres (3–4°S, 8–10°S, 11–12°S y 13–16°S) along the Peru current (Molina-Cruz, 1984). The south upwelling areas receive waters from Antarctic origin driven by the Chile current whereas the upwelling areas located northern from 12°S receive waters from Equatorial origin driven by the PPC (Molina-Cruz, 1984). These upwellings (Equatorial and Peru) occur under normal conditions of the atmospheric pressures (high pressures over Tahiti and lower over Darwin). When the atmospheric pressures are reversed, the Trade Winds are weakened or even substituted for the Western Winds. Frequently, the surface water currents are reversed and warm surface water arrives to the Eastern Pacific, giving rise to the “El Niño” phenomenon.

Coccolithophores are primary producers whose distribution in oceans is controlled by parameters such as latitude, ocean currents, water masses, nutrient contents, salinity, temperature, the available light, vitamins and minerals (Okada and Honjo, 1973; Giraudeau, 1992; Winter et al., 1994; Rost and Riebesell, 2004). Analysis of coccolithophore assemblages is therefore an excellent tool for the reconstruction of some of these features, allowing researchers to monitor their evolution in time and space (Roth, 1994; Winter et al., 1994; Baumann and Freitag, 2004). The present study analyzes the cores from two Ocean Drilling Project sites (ODP Site 1237 and 1238) situated in the two most significant upwelling zones in the tropical and equatorial Pacific: Peru and an equatorial upwelling close to the Ecuadorian coast. The coccolithophore assemblages studied in both cores allow us:

- to obtain data concerning productivity changes at each site;
- to compare their evolution and relationship with atmospheric and oceanic dynamics over the last 800 kyr.

2. Oceanographic setting

Both oceanic and atmospheric circulation patterns in the Subtropical Pacific are influenced by the Subtropical Pacific Gyre dynamics. Gyre formation is mainly due to the prevailing Trade Winds system. North of 20°S, the Trade Winds favour increased upwelling (coastal and equatorial upwellings), drive the South Equatorial Current (SEC) and, indirectly, influence

subsurface ocean circulation (Molina-Cruz, 1984, 1991; Pisias and Rea, 1988; Farrell et al., 1995). The Peru Current System, the SEC and the EUC or Cromwell Current are the most important oceanic currents in this Subtropical Pacific area (Fig. 1). The Peru Current System is composed of the Coastal Peru Current (CPC) or Humboldt Current and the Peru Oceanic Current (PC), both flowing northward. Between these two currents, the PCC flows southward as a subsurface current (Gunter, 1936). The SEC flows westward, while the EUC flows eastward. The EUC plays an important role because it is related to the Equatorial upwelling (Wyrcki, 1965; Molina-Cruz, 1984). The EUC rises eastward, near the Galapagos Islands and feeds both the SEC and the PCC. It also feeds the Peru upwelling (Wyrcki, 1965; Molina-Cruz, 1984; Shipboard Scientific Party, 2003).

The ODP Site 1237 location is under the influence of the productive upwelling of Peru, more precisely in the eastern edge of the pathway of the CPC; ODP Site 1238 lies in the eastern part of the equatorial cool tongue in an open-ocean upwelling system close to the equator, where the EUC attains the surface (Fig. 1).

3. Materials and methods

The first 22 and 50 m of ODP sites 1237 and 1238, respectively, were studied. ODP Site 1237 was recovered at 16°0.421'S, 76°22.685'W, 140 km off the Peru coast, at a water depth of 3212 m over the eastern flank of the Nazca Ridge. ODP Site 1238 was recovered at 1°52.310'S, 82°46.934'W, 200 km off the coast of Ecuador, at a water depth of 2203 m over the southern flank of the Carnegie Ridge (Fig. 1). Nannofossil ooze is the main sedimentary component of Site 1237, but gradually changes to a mixed nannofossil and clay sediment at the top of the core, due to a peak in terrigenous contribution. Light-olive nannofossil-rich and dark-olive diatom-rich meter interval alternations (about 1 m thick) characterize Site 1238 (Shipboard Scientific Party, 2003).

3.1. Sampling and sample preparations

Sampling was made every 10 cm in the core from site 1237 and every 20 cm in that from site 1238, providing a temporal resolution of about 3700 and 3300 years, respectively, according to average sedimentation rates of 27.15 m/Ma and 60.66 m/Ma, respectively (Shipboard Scientific Party, 2003). Smear slides were prepared at the Micropaleontology Laboratory of the University of Salamanca following the technique of Flores and Sierro (1997), which allows quantification of the coccolith absolute abundance of each sample. This technique consists of sediment decantation over the slide from a buffering solution into a Petri dish. The solution was homogeneously distributed in Petri dishes by pumping it in and out several times with a micropipette (in order to generate a slight circulation of water in the dish). The main goal of this procedure is to obtain a homogeneous distribution of coccoliths on the slide. This homogeneous distribution allows applying the calculation of Nannofossil Accumulation Rate (NAR) as

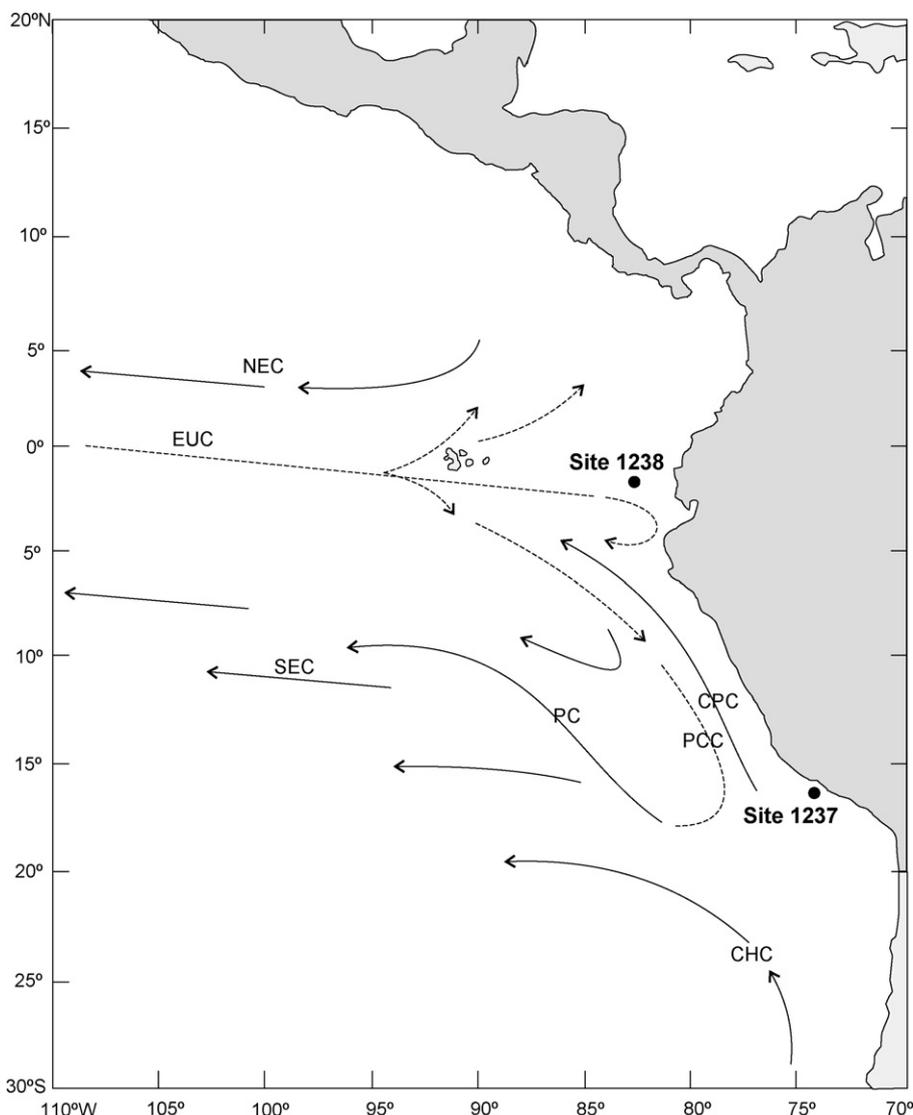


Fig. 1. Location of ODP Sites 1237 and 1238 and main ocean currents in the study area. Surface currents (→), counter and undercurrents (---→) are reported. NEC: North Equatorial Current; EUC: Equatorial Undercurrent; SEC: South Equatorial Current; PC: Peru Current; CPC: Coastal Peru Current; PCC: Peru countercurrent; CHC: Chile Current.

described in Flores and Sierro (1997). NAR relates directly the number of nannofossils per gram of dry sediment, the estimated density of dry sediment and the linear sedimentation rate.

Around 500 coccoliths per slide were counted using a light cross-polarizing microscope (1250 ×) in order to obtain both absolute (NAR) and relative abundance data.

3.2. Age model

In both cores, an age model was established through identification of calibrated biostratigraphic events and paleomagnetic data. The last occurrence (LO) of *Pseudoemiliana lacunosa* (0.46 Ma; Thierstein et al., 1977) was recorded at a depth of 13.48 m at site 1237 and 27.44 m at site 1238. The first occurrence (FO) of *Emiliana huxleyi* (0.26 Ma; Thierstein et al., 1977) was found at a depth of 5.29 m at site 1237 and

11.00 m at site 1238. The Matuyama-Brunhes reversal (0.78 Ma) was detected at a depth of 20.36 m at site 1237 (Shipboard Scientific Party, 2003). Taking all these data into account, it was observed that the sedimentation rate at site 1238 was two-fold higher than at site 1237 (Table 1).

3.3. Nannofossil Accumulation Rate

The NAR (Fig. 2[a]) was determined based on coccolith total abundance (coccoliths per gram of sediment), sediment density (Gamma Ray Attenuation Porosity Evaluation [GRAPE]), and the values of the linear sedimentation rate. Total abundance was calculated using the method proposed by Flores and Sierro (1997) and GRAPE data were obtained from the Shipboard Scientific Party (2003). The linear sedimentation rate is shown in Table 1.

Table 1
Age models for ODP Sites 1237 (top) and 1238 (bottom), based on the first occurrence (FO) of *Emiliana huxleyi*, last occurrence (LO) of *Pseudoemiliana lacunosa* and LO of *Reticulofenestra assanoi*; mcd: meters compensation depth.

| Event | Age (Ma) | Flores and Wei (2003) Depth (mcd) | Site 1237, Depth (mcd) | 1237 Sedimentation rate (m/Ma) |
|-----------------------|----------|-----------------------------------|------------------------|--------------------------------|
| Core top | 0 | | 0.00 | |
| FO <i>E. huxleyi</i> | 0.26 | 5.39 | 5.29 | 20.35 |
| LO <i>P. lacunosa</i> | 0.46 | 12.76 | 13.48 | 40.95 |
| Matuyama/Brunhes | 0.78 | | 20.36 | 21.50 |
| Core base | | | 21.67 | |
| LO <i>R. asanoi</i> | 0.88 | 21.99 | | 16.30 |

| Event | Age (Ma) | Flores and Wei (2003) Depth (mcd) | Site 1238, Depth (mcd) | 1238 Sedimentation rate (m/Ma) |
|-----------------------|----------|-----------------------------------|------------------------|--------------------------------|
| Core top | 0 | | 0.00 | |
| FO <i>E. huxleyi</i> | 0.26 | 11.64 | 11.00 | 42.31 |
| LO <i>P. lacunosa</i> | 0.46 | 27.96 | 27.44 | 82.20 |
| Core base | | | 49.49 | |
| LO <i>R. asanoi</i> | 0.88 | 51.36 | | 56.95 |

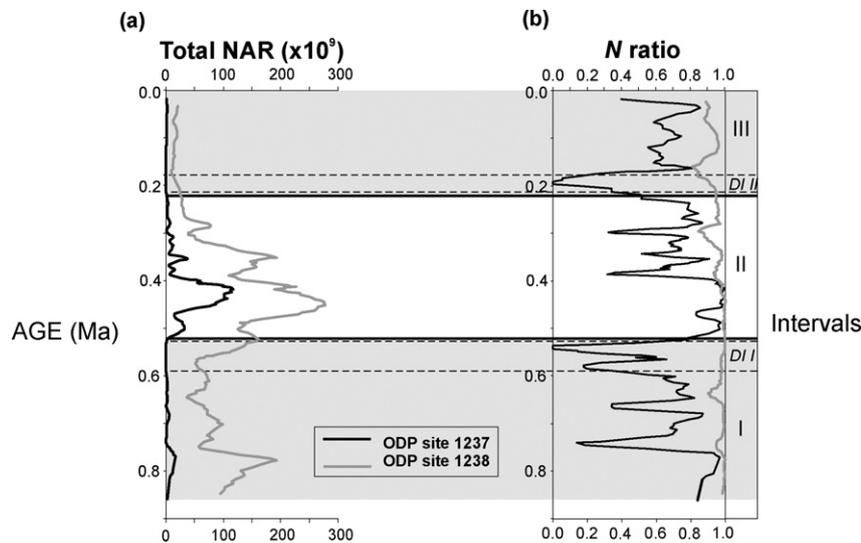


Fig. 2. (a) Total Nannofossil Accumulation Rate (NAR; nannofossils.cm⁻².kyr⁻¹) versus Age (Million years B.P.); (b) *N* ratio (quantitative paleoproductivity index) versus Age (Million years B.P). DI I and DI II: Dissolution Intervals in Site 1237.

3.4. Coccolith preservation

Coccolith preservation in the studied samples can be considered as good-to-moderate according to the methods of Roth and Thierstein (1972) and Flores and Marino (2002). However, two intervals (0.59–0.52 Ma and 0.22–0.18 Ma) at site 1237 show intense dissolution processes, coccoliths disappearing.

4. Results

4.1. ODP Site 1237

The coccolithophore assemblage was dominated in Site 1237 by three taxa: “small” *Gephyrocapsa* (*Gephyrocapsa ericsonii* and *Gephyrocapsa aperta*), *Gephyrocapsa caribbeanica* and *Florisphaera profunda* (39.60, 31.58 and 13.56%, respectively). In minor proportions, *Calcidiscus leptoporus* (7.58%), *Emiliana huxleyi* (2.75%), *Gephyrocapsa oceanica*

(1.51%) and *Helicosphaera carteri* (1.38%) are also recorded (Fig. 3[a]). Other species such as *Pseudoemiliana lacunosa*, *Coccolithus pelagicus*, *Rhaphdosphaera clavigera*, *Umbilicosphaera sibogae*, *Oolitothus fragilis*, *Pontosphaera multiphora*, *Discoaster* spp. and *Reticulofenestra* spp. are recorded in percentages lower than 1%. Changes in the relative abundances of different species (Fig. 3[a]) and the distribution of NAR (Fig. 2[a]) allow us to define three different intervals along the core:

- interval I (0.86–0.45 Ma) is dominated by “small” *Gephyrocapsa*, with percentages fluctuating between 10 and 90%, *F. profunda* percentages ranging from 0 to 40%. The NAR is very low;
- interval II (0.45–0.22 Ma) is dominated by *G. caribbeanica*, reaching percentages about 90%, while “small” *Gephyrocapsa* and *F. profunda* are scarce, especially “small” *Gephyrocapsa* since these species seem to have been replaced by *G. caribbeanica* in the coccolithophore assemblage

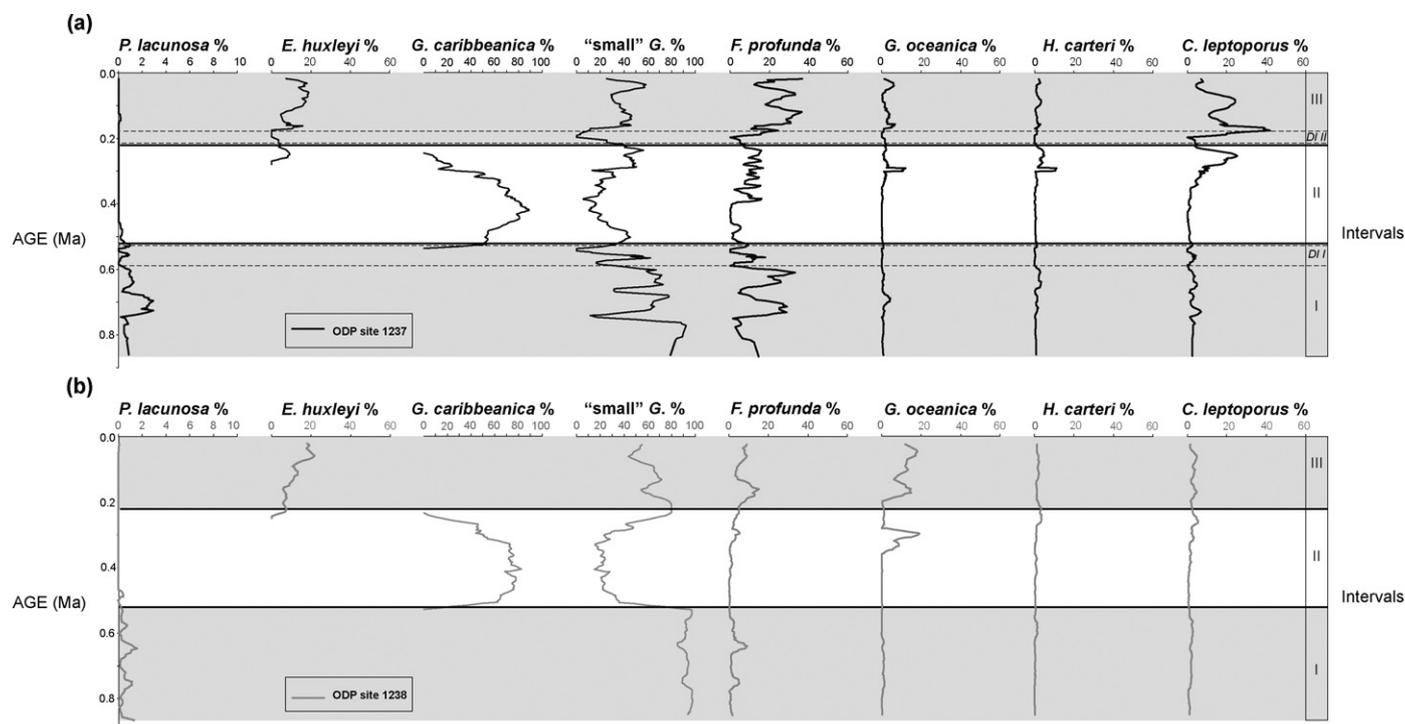


Fig. 3. (a): Relative abundance (%) of single taxa versus Age (Million years B.P) and Dissolution Intervals (DI I and DI II) in Site 1237; (b): Relative abundance (%) of single taxa versus Age (Million years B.P) in Site 1238.

(Fig. 3[a]). A rare species, *G. oceanica*, shows an abundance peak of 10% in the upper part of this interval (0.30 Ma). *H. carteri* shows a similar trend, with a peak of 10%. *C. leptopus* shows an increase in abundance (20%) at the upper limit of the interval. The NAR in this interval is very high, attaining values of 120×10^9 nannofossils.cm⁻².kyr⁻¹;

- Interval III (0.22–0 Ma) is characterized by the high abundance of "small" *Gephyrocapsa* (0–60%) and *F. profunda* (10–40%). *C. leptopus* shows an abundance peak in this interval (40%) occurring around 0.16 Ma, and then, it decreases in abundance up to the top of the core. NAR is very low.

A striking observation is the occurrence of two intense dissolution intervals: DI I, between 0.59 to 0.52 Ma, and DI II, between 0.22 to 0.18 Ma (Fig. 3(a)).

4.2. ODP Site 1238

The most abundant species at site 1238 were "small" *Gephyrocapsa*, *G. caribbeanica*, *G. oceanica* and *F. profunda*, (60.80, 26.77, 3.18 and 2.81%, respectively). *E. huxleyi* and *C. leptopus* reached 2.45 and 1.86%, whereas *H. carteri*, *U. sibogae*, *P. lacunosa*, *O. fragilis*, *Syracosphaera* spp., *C. pelagicus*, *R. claviger*, *P. multipora* and *Reticulofenestra* spp. did not represent more than 1%.

As in the case of site 1237, relative abundance (Fig. 3[b]) and the NAR (Fig. 2[a]) allow us to divide the core into three intervals:

- interval I (0.86–0.45 Ma) is characterized by a very high abundance of "small" *Gephyrocapsa* with stable percentages

comprised between 80 and 100%, a relatively high abundance of *F. profunda* from 0 to 10%, and *C. leptopus* from 0 to 3%. NAR, which was higher in the lower part of the interval (up to 200×10^9 nannofossils.cm⁻².kyr⁻¹ between 0.86 and 0.75 Ma) attains lower values ranging between 50 and 100×10^9 nannofossils.cm⁻².kyr⁻¹ in the upper part of the interval;

- interval II (0.45–0.22 Ma) is characterized by a high abundance of *G. caribbeanica* (up to 90%) and a high NAR of nearly 300×10^9 nannofossils.cm⁻².kyr⁻¹. Both parameters decline near the upper part of the interval (0.33 Ma). The abundances of "small" *Gephyrocapsa* and *F. profunda* are low, and a peak is observed in the abundance of *G. oceanica* (20%), *H. carteri* (5%) and *C. leptopus* (6%) in the upper part of the interval (0.33–0.22 Ma);
- interval III (0.22–0 Ma): "Small" *Gephyrocapsa* show percentages of 40 to 80%, but the increase in *F. profunda* (5–15%) and mainly in *G. oceanica* abundances (5–20%) is the most significant feature of this interval. NAR is very low.

5. Discussion

5.1. Paleoceanographic interpretations

After comparison of the evolution of the two sites presented above over the last 800 kyr, the most significant feature seems to be the similar trend in the assemblage composition, which is dominated by small placoliths at both sites. The NAR at equatorial upwelling Site 1238 is higher than in coastal upwelling Site 1237, although a very similar trend is recorded (Fig. 2[a]). This pattern suggests a similar behaviour of

coccolithophore assemblages from the two upwelling systems of the Southeast Pacific Ocean, but there is an important difference in species relative abundances.

In order to understand the paleoproductivity patterns at each site during the last 800 kyr, we used the *N* ratio (Flores et al., 2000), i.e., the ratio between < 3 µm placoliths (inhabiting the upper photic zone; Okada and Honjo, 1973; Young, 1994) and *F. profunda*, thriving in the lower photic zone (Okada and Honjo, 1973; Young, 1994; Wells and Okada, 1997; Fig. 2[b]). The *N* ratio at site 1238 is relatively stable and high all along the studied interval, fluctuating between 0.8 and 1.0. Conversely, at site 1237, *N* ratio is much more fluctuating, ranging between 0.0 and 1.0. Thus, the *N* ratio shows a higher, approximately stable average paleoproductivity in the equatorial upwelling area (Site 1238) than in Peru coastal upwelling (Site 1237), where paleoproductivity varies from very low to high.

The general parallel pattern described by the assemblages of the most abundant coccolithophores in both cores reflects the response to variations in the Trade Winds regime, affecting both sites synchronously. The differences in the absolute value of paleoproductivity, which appears more intense at the equatorial site, can be linked to the important role of the EUC (Cromwell Current), close to the Galapagos Islands (Wyrki, 1965; Molina-Cruz, 1984; Shipboard Scientific Party, 2003), thereby providing extranutrients for the equatorial upwelling. This region is highly productive but departs from all other oceanic regions in that production does not consume all nutrients at sea surface level (Levitus et al., 1993).

Regarding the three intervals defined here, the coccolithophore assemblages can be interpreted as following:

- the dominance of “small” *Gephyrocapsa* during interval I (0.86–0.45 Ma; Fig. 3) suggests an active upwelling system (Okada and Honjo, 1973; Kleijne et al., 1989), although the low NAR (Fig. 2[a]), the low *N* ratio values (Fig. 2[b]), and the high abundance of *F. profunda* (Fig. 3), which is usually abundant when nutricline/thermocline are relative deep (Okada and Honjo, 1973; Young, 1994; Wells and Okada, 1997; Flores et al., 2000; Álvarez et al., 2005b), suggest a moderate intensity of productivity. Additionally, the low abundance values of *C. leptoporus*, which is interpreted as a typical oligotrophic taxon (Giraudeau and Rogers, 1994; Brand, 1994), and of *H. carteri* (Fig. 3), abundant under surface water stratification (Colmenero-Hidalgo et al., 2004; Álvarez et al., 2005a), support the interpretation of relatively high fertility of surface waters. We interpret the upwelling intensity as weak during interval I. This situation could have favoured a deepening of the nutricline/thermocline, causing moderate paleoproductivity at both site 1237 and site 1238, correlated with a prevailing but weak Trade Winds system close to an “El Niño” condition (Beaufort et al., 2001; Lamy et al., 2001; Fig. 4[a]). Despite this moderate productivity, the paleoproductivity was always higher in site 1238 than in site 1237. The higher paleoproductivity at site 1238 may be linked to the proximity of the EUC, providing extra nutrients for primary production. So, when the upwelling is weakened, low productivity is more evident in the area of Perú;
- interval II (0.45–0.22 Ma). Although the ecological interpretation of *G. caribbeanica*, which is the dominant species in this interval (Fig. 3), seems controversial, as abundance may be linked to an evolutionary trend rather than to a response to paleoenvironmental conditions (Flores et al., 1999, 2003), this species has been assimilated to the placoliths developing in the upper photic zone (Okada and Honjo, 1973; Okada, 1983). The development of *G. caribbeanica*, a heavily calcified species, is a global event in the World Ocean (Flores et al., 2003; Bollmann et al., 1998) that likely represent a change in the ocean environment that was likely warmer than today, and changes in the depth of the thermocline (Bollmann et al., 1998). Eutrophic conditions in this interval are supported by the abundance of *G. oceanica* (Brand, 1994), which reaches percentages of 10 and 40% of the assemblage at Sites 1237 and 1238, respectively, in the middle part of interval II (Fig. 3), indicating an enhanced nutrient supply to the surface waters of the euphotic zone. The highest values of NAR in the core (Fig. 2[a]) and the high *N* ratio, although this value is fluctuating at Site 1237 (Fig. 2[b]), reveal an important production and a relatively shallow nutricline/thermocline (Flores et al., 2000, 2003; Álvarez et al., 2005b), probably due to intense upwelling driven by the intensification of the Trade Winds. These conditions are very similar to those observed today during “La Niña” events (Beaufort et al., 2001; Lamy et al., 2001; Fig. 4[b]), which are common in the Equatorial Pacific from MIS 10 to 9. This time interval, MIS 10 to 9, is isochronous with the Mid-Brunhes event characterized by global high carbonate production (Howard, 1997; Flores et al., 1999, 2003; Hodell et al., 2000) and by a general intensification of the oceanic and atmospheric circulation in the Southern Hemisphere (Jansen et al., 1986);
- interval III (0.22–0 Ma) shows a situation close to that of interval I. An active upwelling may be considered to have occurred during this interval, as revealed by the high relative abundances of “small” *Gephyrocapsa* (Fig. 3). Nevertheless, the high percentages of *F. profunda* (Fig. 3) with respect to “small” *Gephyrocapsa* suggest a deepening of the nutricline/thermocline (Álvarez et al., 2005b). Weaker Trade Winds were responsible for this pattern, leading to a dominant “El Niño” condition (Beaufort et al., 2001; Lamy et al., 2001; Fig. 4[a]).

5.2. Dissolution intervals at Site 1237

Two intense dissolution intervals (Figs. 2 and 3[a]) are recorded before and after the most productive interval in this core, and are interpreted as induced by conditions when “La Niña” was dominant (interval II). These intervals are linked to the highest dissolution intervals defined by Farrell and Prell (1989) in the equatorial Pacific, and by Flores et al. (2003) in the South Atlantic Ocean, both related to changes in the lysocline during interglacial periods. At present, the position of the lysocline is located at an average depth of 4000 m in the Pacific (Farrell and Prell, 1989) and Site 1237 is located at a water depth of 3212 m. A lysocline rising during the dissolution

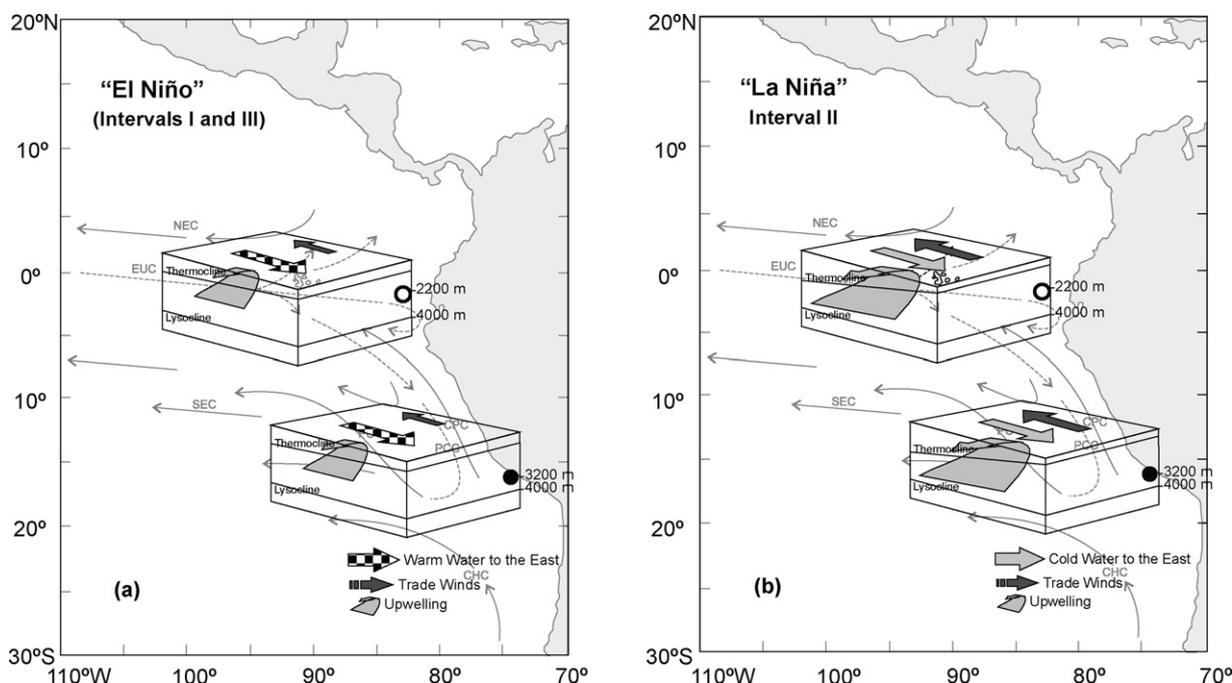


Fig. 4. Proposed paleoceanographic conditions during “El Niño” (a) and “La Niña” (b) events in the Southeastern Pacific Ocean. The size of the arrows is proportional to the intensity of the event; ● Site 1237; ○ Site 1238.

intervals (Id I: 0.59–0.52 Ma and Id II: 0.22–0.16 Ma), due to an increase in the surface water productivity (Berger et al., 1982; Farrell and Prell, 1989), could explain the coccolith-barren samples in Site 1237.

6. Synthesis and conclusions

Some peculiar patterns are recorded in coccolith assemblages and abundances in two ODP Sites from the tropical Pacific Ocean:

- the parallel evolution of the coccolithophore assemblages at Sites 1237 and 1238 during the last 800 kyr was the response to contemporaneous changes in intensity of the upwelling in the Peru Coastal area and the Equatorial Pacific driven by variations in the Trade Wind system;
- the total abundance of coccoliths and the NAR were higher at site 1238 than at site 1237 probably because of the higher nutrient supply of the EUC to the sea surface, resulting in higher phytoplankton paleoproductivity;
- the continuous presence of “small” *Gephyrocapsa* in the samples studied suggests that upwelling was active during the considered time interval, but fluctuations in the upwelling intensity resulted in changes of the coccolithophore assemblages that allowed us to differentiate three intervals;
- during interval I (0.86–0.45 Ma) and interval III (0.22–0 Ma), the abundance of *F. profunda* reveals a relatively deep nutricline/thermocline probably associated with weak upwelling and weak Trade Winds. This scenario is similar to extant conditions during “El Niño” events;
- during interval II (0.45–0.22 Ma), the abundance of the species of *Gephyrocapsa* suggests that the upwelling was intense in the tropical Pacific. The intensification of the Trade

Wind system could have favoured these paleoceanographic conditions that are similar to extant situation during “La Niña” events;

- two intense dissolution intervals (*DI I*: 0.59–0.52 Ma and *DI II*: 0.22–0.18 Ma) were observed in site 1237, linked to changes in the lysocline depth related to increase in the surface water productivity.

Acknowledgements

The authors wish to express their gratitude to ODP for making the samples available, and the scientific and technique crew of the Leg 202. We also appreciate the comments and suggestions by Mário Cachão, Karl-Heinz Baumann, and Emanuela Mattioli, who contributed to improve the original manuscript. This research was financially supported by a post-degree grant from the Universidad Nacional Autónoma de México and the Universidad de Salamanca agreement/covenant to M.C. Álvarez and by the projects BTE2002-04670 and REN2003-08642-C02/CLI from the Ministerio de Educación y Ciencia, and SA088/04 from the Consejería de Educación de la Junta de Castilla y León.

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