

DO DARK/LIGHT LAMINAE IN CORE SEDIMENTS FROM THE PERUVIAN UPWELLING ECOSYSTEM REPRESENT ENSO EVENTS? A LOOK INTO DIATOM ASSEMBLAGES

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Marine laminated sediments are deposited under active upwelling cells along the Peruvian Current due to physical, chemical and biological processes incorporating to the ocean floor terrigenous sediments, organic debris, and carbonate and siliceous microorganisms. The decomposition of the organic carbon contributes to the development of an Oxygen Minimum Zone (OMZ) in the water column near the coast, preventing the development of burrowing fauna and favouring the preservation of the sediment structure (Helly & Levin, 2004).

To realize a sedimentological study at laminae (infra-centimetric) scale, we have to differentiate between the so-called dark and light laminations (or bands) which are referred to by many authors (Brodie & Kemp 1994, Skilbeck et al. 2004, Tapia et al. 2008). The identification of these laminae involves:

1. Visual observation and smear slides analysis of core sediments, using sediment color as the prominent feature (ODP core descriptions, Tapia et al. 2008).
2. Digital high-resolution color scanning over core sediments using red-color intensity data as a proxy for light and dark laminae (Fink et al. 2005, Skilbeck et al. 2006).
3. X-ray images, where negative films show light lines and bands of dense (terrigenous-rich) and dark layers of less-dense materials (Gutiérrez et al. 2006, Sifeddine et al. 2008).
4. BSEI technique in which backscattered and secondary electron emissions mapped resin impregnated sediments according to the atomic number of the material they collided, e.g. diatom-rich sequences with more porous space are darker in color than the lighter (and brighter) porous-compact terrigenous sequences (Kemp 1990, Brodie & Kemp 1994, 1995).

Detail surveys of these lamina types have served to better understand the composition, type, fabrics, origin, and lamina formation, as well as the application in paleoclimate studies to identify periods of higher terrigenous inputs or to reconstruct past ENSO variability.

It has been interpreted that dark laminations might represent El Niño events (Skilbeck et al. 2004) (ENSO's warm phase) in core sediments offshore north and central Peru, because ENSO-induced precipitation provides terrigenous material that is redistributed and deposited on the continental shelf. Accordingly, light laminations would represent normal or La Niña events (Fink et al. 2005). Oceanographically, during El Niño events, warm and nutrient-poor water intrusions and the deepening of the thermocline subdue the regular cold and nutrient-laden of the upwelling water regime altering the biota structure and primary productivity. Phytoplankton composition shifts from diatom-dominated to dinoflagellate-dominated assemblages, decreasing substantially the overall primary productivity (Ochoa et al. 1985, Rojas de Mendiola et al. 1985). Opposite conditions (intensified upwelling, increased primary productivity, and diatom dominance) characterize normal or La Niña conditions. Therefore, we might expect the formation of El Niño-related laminations containing warm-water siliceous microfossil assemblages with low organic matter (OM) concentration and high terrigenous content.

How ENSO events are registered in the sedimentary record? Did El Niño events leave a relatively high lithics/low bioproductivity record in the formation of dark laminae and/or leave a sedimentary imprint characterized by a low lithics/high bioproductivity in the formation of La Niña-like light laminae?

In order to elucidate whether dark and light laminae represent El Niño or La Niña episodes, we aim to assess the siliceous microphytoplankton composition in each lamina type and intent to group these remains according to their affinity to main water-mass types: coastal-neritic of cold temperatures or oceanic of warm temperatures. Secondly, we test the assumed ENSO-related laminae composition (high/low terrigenous –

low/high biogenic) through a comparison of the principal lithic and biogenic components for each lamina type.

METHODOLOGY

Diatom analyses were performed on 103 smear slides from individual laminae (60 dark, 43 light) samples from 5 boxcores in the Callao (B0405-13) and Pisco (B0405-6, B0506-9, B0506-13, B0506-14) areas. We identified and counted at least 100 individuals, although in certain levels we increased this number to overcome a bias effect due to the dominance of *Chaetoceros* resting spores. Smear slides were prepared by disaggregating small sediment splits in 22x40 mm coverslips and by fixing them over 25x75 mm slides with Norland™ Optical Adhesive 61 (NOA61, R.I.=1.56). The diatom analyses were made in a Transmitted Light Microscope, Olympus BX41 with a Plan N oil objective (N.A=1.25) at a final magnification of x1000. Diatom taxa with abundances greater than 10 % were plotted together with groups of affine ecology using the C2 analytical software (Juggins, 2007). Species in the ecological groups (Neritic-Littoral and Oceanic) were clustered following local, regional, and world-wide literature (Cupp 1943, Tomas 1997, Hustedt 1930, 1959, Ochoa et al. 1985, Rojas de Mendiola et al. 1985, Schuette & Schrader 1979, Zhuze 1972). Diatom abundances of all cores were plotted in a single graph for each lamina type as a function of their proper depth. The comparison of main lithic (quartz, feldspar) and biogenic (diatom, silicoflagellate) components was performed with selected data from a previous work (Tapia et al., 2008). Cores B0405-6 and B0405-13 covers about 600 years of deposition (Gutierrez et al., 2009), which is the expected time interval for the other cores.

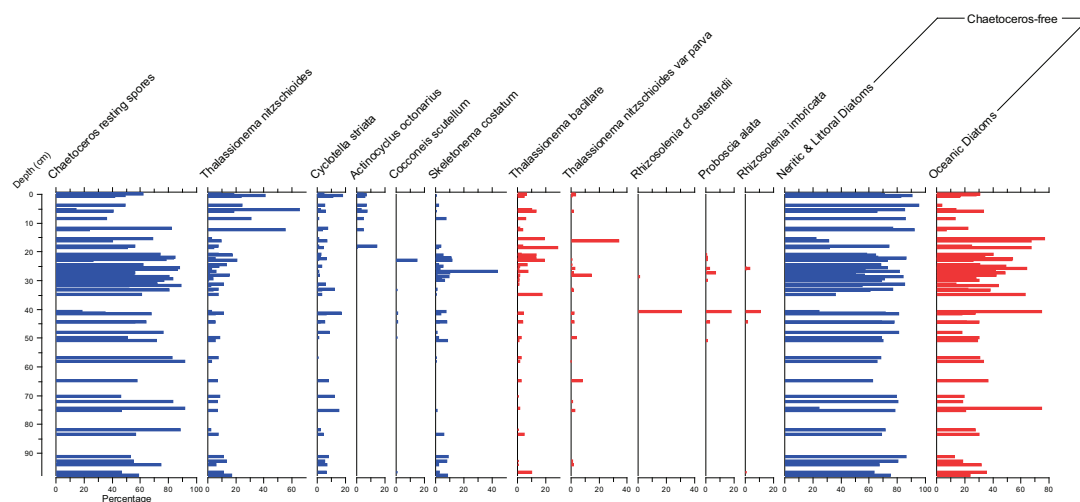


Figure 1. Combined stratigraphical distribution of selected diatom flora (>10%) from **dark laminae** samples at the Callao (B0405-13) and Pisco (B0405-06, B0506-9, B0506-13, B0506-14) cores. Percentages of ecologically related groups were recalculated excluding *Chaetoceros* resting spores.

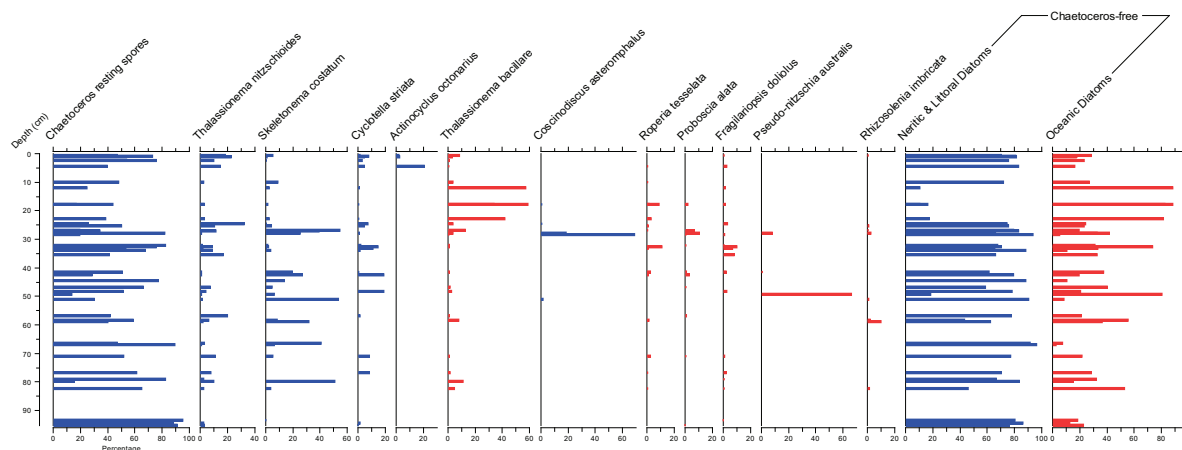


Figure 2. Combined stratigraphical distribution of selected diatom flora (>10%) from **light laminae** samples at the Callao (B0405-13) and Pisco (B0405-06, B0506-9, B0506-13, B0506-14) cores. Percentages of ecologically related groups were recalculated excluding *Chaetoceros* resting spores.

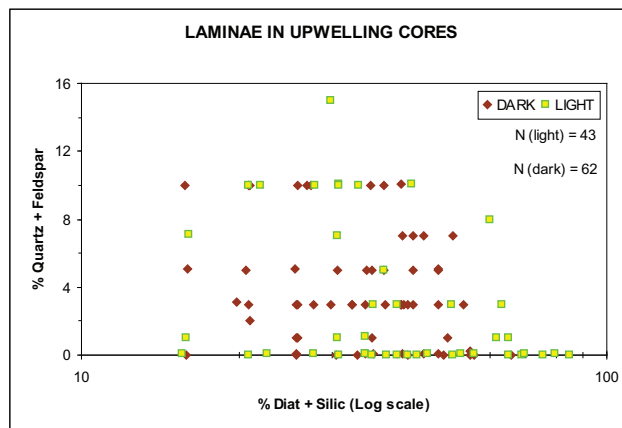


Figure 3. Distribution of terrigenous and siliceous microfossil components in dark and light laminae sampled in Callao and Pisco sedimentary cores, Central Peru.

RESULTS AND CONCLUDING REMARKS

Samples from the dark lamination facies are dominated by three diatom taxa throughout the combined core: the *Chaetoceros* resting spore group, *Thalassionema nitzschioides*, and *Skeletonema costatum* (Fig. 1). In modern samples, these taxa are indicative of cold, coastal upwelling water mass together with the subdominant species *Cyclotella striata*, *Actinocyclus octonarius*, as well as the tycho planktic *Cocconeis scutellum*. Co-occurring within this upwelling diatom association, we found a warm-water assemblage composed of the species *Thalassionema bacillare*, *Thalassionema nitzschioides* var. *parva*, *Rhizosolenia* cf. *R. oestensfeldii*, *Proboscia alata*, and *Rhizosolenia imbricata*. It is worth noting the dominance of warm water species in a couple of samples collected at depths centered at 40 and 15-cm.

The species composition for the light laminae is very similar to that of the dark layers. Five out of the six diatom taxa from the upwelling association are present here: the *Chaetoceros* resting spore group and *S. costatum* are still dominant, whereas *Coscinodiscus asteromphalus* replace *C. scutellum* due to its larger relative abundance (Fig. 2). More differences are found in the oceanic assemblage. Only 2 out of the 5 dominant taxa from the dark-laminae warm-water diatom association are encountered here: the dominant *T. bacillare* and the subordinated *P. alata*. The others are replaced by *Pseudo-nitzschia australis*, *Roperia tessellata*, and *Fragilariopsis doliolus*. Moreover, almost monospecific diatom ooze occurred in these light laminae facies made up by the warm-water *P. australis* and the cold-water *C. asteromphalus* in samples collected at depths of 50 and 30-cm, respectively.

To enhance the relative contribution of both upwelling and oceanic diatom associations, we took away the dominant *Chaetoceros* resting spore counts and recalculate their relative abundances. Even though, the coastal upwelling assemblage dominates both laminae facies. We may expect to encounter some warm-water diatom taxa that tolerate cold-water environments, thus if we consider 40% as a background level, larger percentages may indicate warm-water anomalies indicator of El Niño events. We can observe at least 11 episodes of warm-water intrusions in the dark layers against 7 episodes from the light one throughout the combined core. Even though, applying this crude and simplistic exercise, we may have an El Niño-related signal left in both type of laminae.

In order to assess the validity of the assumed ENSO-related laminae composition, we took a different approach comparing the relative abundance of terrigenous material (quartz, feldspar) against the relative abundance of biogenic components (diatom, silicoflagellates) for both lamina type (Fig. 3). The results indicate a significant, higher frequency of light laminae having greater biogenic than terrigenous component. Nevertheless, both lamina types have similar distribution and relative abundances for both the biogenic and terrigenous components in the 30-40% range of the siliceous microfossils. Few samples of almost pure diatom oozes with small amounts of terrigenous materials are forming the end-member of this distribution. We cannot asseverate that light laminae represent normal or La Niña-related episodes because of the low OM concentration opposite to the high bioproductivity we would expect in this case.

In conclusion, the diatom species composition related to its ecologically-derived water mass preference and the composition of the main lithic and siliceous microfossil relative abundances do not support the

assumption of El Niño-related dark laminae or La Niña-related light laminae formation in the hypoxic sediments deposited under the Peruvian upwelling ecosystem.

We want to acknowledge at IRD, IMARPE, LOCEAN, PALEOTRACES, and MIXPALEO for their constant support along this project.

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