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Paleoenvironmental Evolution of Estuarine Systems During the Last 14000 Years - the Case of Douro Estuary (NW Portugal)

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ABSTRACT

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The multidisciplinary study (sedimentology: texture, carbonates, organic matter, elemental composition, mineralogy of sand and clay; micropaleontology: foraminifera, calcareous nannoplankton and pollen - and radiocarbon dating) of three cores recovered from the Douro estuary infill has allowed to reconstruct the paleoenvironmental guidelines of this area for the last 14000 years. The major environmental changes recognized in the geological record of this area are principally associated with the Holocene transgression and the succession of different climatic types. The transgressive sequence is expressed through several environmental changes, related with a succession of different facies: a continental one till circa 9834 BP, followed by an alternated marine/continental facies with an intensification of marine signature till 5750BP; particularly after 6050BP, the environment is typically marine. After that and till present, it is followed by a regressive sequence (although within a still positive eustatic trend).

ADDITIONAL INDEX WORDS: *Environmental changes, estuarine systems, multi-proxies, sea-level rise.*

INTRODUCTION

Among depositional environments, estuarine systems are privileged locals to study the continental and marine influences that occurred in the recent past. The study of their sedimentary record can be a useful tool in the understanding of the environmental changes affecting the continental margin, particularly since the last deglaciation and following sea level rise. The present-day knowledge on the evolution pattern for the Portuguese continental margin since the last millennia is based on the work carried out by DIAS (1987) on the sedimentary dynamics and recent evolution of the shelf and paleoenvironmental reconstructions of southwestern coastal lagoons such as Santo André and Melides (BAO *et al.*, 1999; CRUCES *et al.*, 1999; FREITAS *et al.*, 2002). The aims of this paper are thus, to present the data resulting from multi-proxy studies of the Douro estuary sedimentary record, in order to propose a general evolutionary model for the last 14000 years and to provide additional information on the paleoenvironmental evolution of the NW Portuguese coast.

STUDY AREA

The Douro estuary is located in the northwestern Portuguese coast, south of Oporto. It is elongated almost W-E, funnel-shaped with 2,25km length, 1,25km maximum width and a mean depth of about 5m. The estuary is partially sheltered from the ocean by a sand spit, rooted in the southern margin, known as Cabedelo (Fig.1). This is a common feature of all northern Portuguese estuaries (Ave, Cávado, Lima, Minho), with the barrier differing in length (in the case of Douro, it can attain 1km long) and resulting from local reversal of littoral drift. Its morphology is quite variable, dependant on the marine and fluvial hydrodynamic conditions. In winter, during extreme floods, this barrier can be overtopped, breached or even drowned for short periods that can last some days or weeks.

Douro basin is located in the rainiest region of Portugal. It presents a climate varying from humid to semi-arid; the humid season occurs in October-March with 73% of total precipitation. The annual mean discharge is 710m^3/s, with a maximum of 3000m^3/s and a minimum of 50 m^3/s (LOUREIRO *et al.*, 1986).

METHODS

This work is based on the study of three cores, which were obtained by rotary drilling in the Douro estuary, one in the barrier (core 2), known as Cabedelo and two in the back-barrier (cores 1 and 1B, 50 cm apart), inside de S. Paio Bay (Fig. 1).

Cores 1 (+3.5/-4.4m height), 1B (-6.6/-16.2m height) and 2 (-15.16/-39.66m height) can be considered as representative of the complete sedimentary sequence present in the southern margin of Douro estuary. Cores 1B and 2 reached basement, consisting of weathered granite.

After visual description the cores were sub-sampled for several analyses, which included sedimentology (texture, mineralogy of fine-<63µm and coarse- >63µm- fractions, organic matter, carbonate and water content), geochemistry and micropaleontology (foraminifera, calcareous nannoplankton and pollen associations). Nine organic sediment samples were dated by ^{14}C AMS at Beta Analytic Inc., USA (Fig.2).

Textural analysis was performed by means of the traditional sieving methods and gravel-free sediments were classified according to FLEMMING (2000). The mineralogy of sand was determined by means of a stereomicroscope observation following DIAS (1987). Microscope counting of the heavy minerals species, separated using Na-polytungstate in the medium to very fine fractions, was made according to the line method (GALEHOUSE, 1969). The study of gravel followed the methodology suggested by DOBBKINS and FOLK (1970). The organic matter (OM) and carbonates contents have been determined following CRAFT *et al.* (1991) and HULSEMAN (1966), respectively. Mineralogical analysis of both the fine

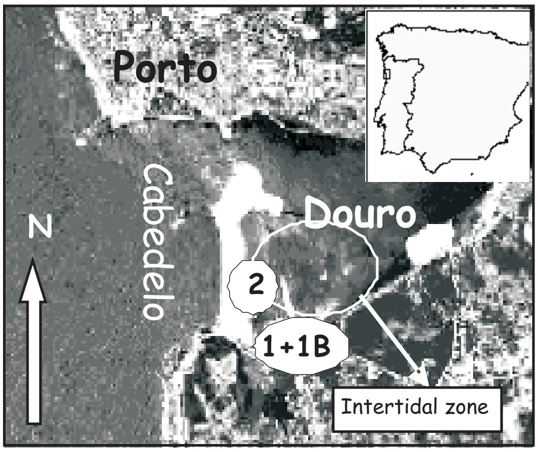

Figure 1: Location of Douro estuary and coring sites.

(<63 µm) and clay (<2 µm) fractions was carried out using X-Ray Diffraction (XRD) following ROCHA (1993). The semiquantitative determination of minerals by XRD, in disaggregated material (<63µm) and in oriented aggregates (<2µm), followed criteria recommended by BARAHONA (1974), SCHULTZ (1964), THOREZ (1976), MELLINGER (1979) and PEVEAR and MUMPTON (1989). For the fraction <63µm, a comparative analysis of quartz, feldspars and micas content, as well as some other ratios - FD/CD (fine detritals/coarse detritals) and C/D (carbonates/detritals) were carried out according to VIDINHA *et al*. (1998); for the clay fraction (<2µm), illite, chlorite, kaolinite and smectite contents and the kaolinite/illite ratio (K/I) were compared.

Elemental analyses were carried out for major, minor and trace elements by Energy-Dispersive X-Ray Fluorescence Spectrometry (EDXRF) in the fraction <63µm of forty samples of core 2. Sediment portions of about 1.5-2.5g of material were homogenised and dried at 110C for 24 hr. The homogenised material was mixed with an organic binder and pressed into pellets for analysis. Detailed sampling preparation techniques and analytical procedures have been published elsewhere by ARAÚ JO *et al.* (2002).

Foraminiferal analysis was undertaken in the coarse fraction and a minimum of 100 individuals were counted in each of the 105 studied samples. The ELLIS and MESSINA (1995) catalogue was used in the species recognition and the taxonomy followed LOEBLICH and TAPPAN (1988). The rippled smearslide technique was used for calcareous nannoplankton analyses based on the methodology described by CACHÃ O and MOITA (2000). A cococolith abundace index (CAI) was determined as a count of all coccoliths present in a 30mm row of the smearlide. Sample treatment for palynological analysis was based on the methodology reported by De VERNAL *et al*. (1996) partly modified by the "Département de Géologie et Oceanographie (DGO) - Université Bordeaux I". Pollen identification was based on REILLE (1992) Atla's as well as on pollen reference collection in the DGO. At least 350 pollen grains (excluding aquatic plants and spores) and 100 *Lycopodium* grains (exotic pollen introduced during the laboratory proceedings) where counted in each of the 77 samples analysed.

RESULTS

Sedimentological Analysis

According to the sedimentological characteristics, the sedimentary record of the Douro estuary may be divided in four main units (Fig.2):

SED1- from 13730 to 10310BP this unit is present only in core 2; it consists of slightly muddy sand with some muddy sand laminae at the bottom layers. It has low contents of fine sediment (usually less than 25%), OM (0.3-2.7%) and carbonates (0-0.35%).

SED2 - from 10310 till 5750BP- this unit is present in cores 2 and 1 B, although its topmost section has been preserved only in core 1B. In core 2, the base of this unit consists of thin interbedded layers of sandy mud and muddy sand, followed by slightly sandy mud and muddy sand sections; samples are in general characterized by high contents of fine fraction, reaching 91% of the total sample at the middle section and decreasing upwards. OM content, varying between 3 to 11%, mimics the variation found in the fine fraction. In core 1B, this unit is represented by alternated layers of sandy mud and muddy sand; fine fraction contents oscillates between low (1.4-23%) and high values (47-79%); once more OM matches the oscillations found in the mud content, varying in general between 2 and 6%, with extremes of 0.8 to 18%. Some peaks of carbonates can be observed in the upper part of core 2 and in core 1B, mostly related with biogenic sand.

SED3 - from post 5750BP and prior to 1580BP - this unit was found in all cores and is made of gravel and gravelly sand with a small contribution of mud (0.1-2.5%); OM (0.1-2.9%) and carbonate (0.2-5.3%) are consistently low.

SED4 - from 1580BP till present - this unit was retrieved in cores 2 and 1 and it corresponds to a sandy unit capping the gravel. In core 2, this unit is homogeneous and essentially made of clean minerogenic sand, while in core 1 there are some interbedded muddy sand layers, at the bottom and top of the unit; in these layers, both the fine fraction and OM, acquire significant importance varying between 40-89% and 5-8%, respectively.

Sand Composition

The terrigenous sand component is generally constituted by mica, quartz and in small amounts by heavy minerals.

The heavy mineral content in the medium to very fine sand is mainly composed by biotite, amphibole, andalusite, tourmaline, garnet and apatite among others (FRADIQUE *et al*., this issue). This mineral suite reveals a provenance signal related to the igneous and metamorphic Douro basin bedrock.

The basal levels of SED1show a heavy mineral suite resulting from the direct erosion of the bedrock being mainly composed by biotite (20%), andalusite (27%) and apatite (6%). The majority of the mineral grains have euhedral forms, reflecting an incipient transport. The medium and upper levels of this unit are basically composed by biotite (40%), amphibole (12%) andalusite (6%), tourmaline and garnet (both with 3%.).

In SED2 unit, the heavy mineral assemblage consists of biotite (45%), amphibole (10%), andalusite (4%), tourmaline and garnet (together with 3%). The levels with high (>50%) content of biotite match the muddy sand/sandy mud sequences in this unit.

In SED3, heavy minerals appear only in core 2 (less coarse), revealing the presence of biotite (49%), amphibole (7%) and rounded grains of garnet (3%), andalusite (4%) and tourmaline (2%).

The SED4 unit, has a heavy mineral suite composed by biotite (32%), amphibole (18%) and andalusite (5%). It should be referred the occurrence of a distinct heavy mineral suite that characterizes the upper layers of SED4 in cores 1 and 2. This distinct suite was used by FRADIQUE *et al*. (this issue) to define a sub-unit - SED 4A. It is composed of rounded grains of garnet (15%), andalusite (13%), tourmaline (8%) and staurolite (5%).

The vertical abundance of marine biogenic components (namely molluscs, foraminifera, equinoderms, etc.) and plant roots have opposite behaviour: the former are totally absent in SED1 and in the lower half of SED2 (in core 2) while the latter are abundant, reaching maxima of 34.5% (Fig. 2); further upcore in SED2, plant remains are virtually absent and marine biogenic components are abundant. The molluscs are the most represented biogenic marine group: they become more important when root content is less significant (in core 2). Higher values of molluscs usually associate with maxima in benthic foraminifera and "other biogenics" (e.g. between -28.11 and -27.45m and at -11.69m). A marked increase in biogenic component is verified from -8.69m till -8.20m (Fig.2).

SED3 and SED4 are virtually barren in these components: only a discreet presence of molluscs at -1.69m is verified (in core 1).

Mineralogical Composition of Fine and Clay Fractions

Mineralogical characteristics of fine and clay fractions are quite different in the several sedimentary units.

SED1 unit may be divided in three subzones:

- from the base until -37.66m, the fine fraction mineralogy is characterized by an almost silicilastic association, constituted by quartz and feldspars (and therefore, denoting a low mineralogical maturity), and by a discrete presence of phyllosilicates and rare carbonates. The clay minerals association is rich in kaolinite and illite (but showing high K/I ratio), although with a relatively high expression of smectite or chlorite (Fig.2);
- between -37.66m and -34.07m, quartz increases simultaneously with feldspars decrease (and a discrete increment in phyllosilicates) whereas clay fraction is characterized by a decrease of kaolinite (which leads to the predominance of illite) and by a much higher increase of chlorite in relation to smectite;
- between -34.07m and -31.16m, a relative increase in quartz related to the decrease of phylosilicates and feldspars can be observed. In clay fraction, kaolinite drastically decrease, illite (very degraded) becomes much more important and smectite acquire higher importance than chlorite (rare and even absent in some samples).

This last subzone continues through the lowest layers of SED2 (core2). This unit is mainly characterized (from -31.16m to -20.66m) by the gradual increase of feldspars and the presence of micas (and more discreetly, carbonates) in the fine fraction, and by the decrease of illite (now more ordered) in relation to kaolinite, whereas smectite decrease comparatively to chlorite. After -22.74m, C/D ratio increases and K/I decreases. In core 1B, SED2 is characterized by the presence of some detrital minerals such as quartz, feldspars and phyllossilicates, while the predominant mineral in the clay fraction is illite, followed by kaolinite discretely accompanied by chlorite. Smectite gradually increases in relation to the progressive decrease of chlorite.

SED3 is characterized by a large increase in quartz (particularly evident for core 2) and a very discrete decrease of chlorite in clay fraction (core 2); kaolinite increases and smectite decreases, relatively to SED2 unit, more clearly at the bottom of this unit (particularly for core 1) but these tendencies reverse topwards (core 1) (Fig.2).

SED4 contains the lowest values (almost null) of C/D ratio and the highest values of FD/CD ratio. In the clay fractions, kaolinite decreases in relation to illite whereas smectite increases in relation to chlorite. Illite is once again predominant in a relatively complex assemblage, illite *plus* kaolinite *plus* chlorite *plus* vermiculite *plus* smectite; topwards (core 1), smectite decreases very significantly, at the same time that other clay minerals increase - such as vermiculite, mixed-layers and chlorite.

Geochemical Analysis

The elemental analysis of core 2 shows that SED1 is characterized by higher values of Al, K, Si, Ti and Zr, comparable to the continental crust composition, which can be attributed to continental input (Fig.2). The systematically low Ca (~0.2-0.5%) and Sr contents are due to the widespread occurrence of weathered granitic rocks in the region. However, a significant and unexpected increase in Ca, Sr (non-common in sediments with a granitic origin) and Zr was observed at the base of SED1, which is probably related to some local enrichment in specific minerals (e.g apatite) in non-weathered basement rock. In particularly, Al, K, Rb contents should be related to the existence of feldspars and/or micas of granitic rocks. Besides, the gradually decrease of these elements till the middle of SED2, negatively correlated with Si (that increases upwards -32.56m) can be associated with the decrease in terrigenous input (in agreement with other proxies). It is worth noting the "anomalous" increasing concentrations in Ca and Sr found in the upper sections of core 2 (from -25.36m upwards), probably due to the presence of biogenic marine organisms.

Micropaleontological Analysis

Foraminiferal assemblages mainly record estuarine/brackish, estuary mouth/marine and outer shelf/slope environments (Fig.2).

The earliest foraminifera occurrence is noticed at -27.77/-27.66m, with abundant *Haynesina germanica, followed by Elphidium gunteri, Cibicides lobatulus and Amonia spp*., which suggest a brackish environment. After a barren interval of circa 2.5m, foraminifera reappear in the fossil record with *H.germanica* (with lower abundance than the levels cited above) or *E.gunteri*, followed by *A. tepida* and some species typical of estuary mouth and of major depths, suggesting a brackish intertidal, low salinity estuarine environment. The facies then changes to a subtidal environment with normal to moderate (-22.39 and -21.48m), or moderate to low salinity (-21.26 and -20.53m), typical of an estuarine mouth under marine influence as it is suggested by the presence of *H. germanica, E. gunteri* and *A. tepida* occurring conjointly with *Cassidulina laevigata*, *C. lobalutus* and *Gavelinopsis praegeri*.

Between -12.7 and -9.38m, a dominance of *H. germanica*, followed by *E. gunteri*, *A.tepida*, *C.praegeri* and *C. lobatulus,* indicates a brackish intertidal estuarine environment, of low, and punctually, moderate salinity; between -9.26 and -8.85m, *C. lobalutus* and *G.praegeri* become dominant, probably in relation with an intertidal-subtidal estuarine mouth environment with normal to moderate salinity and clear marine influence (Fig.2).

It is only upwards -8.35m and till the end of SED2 that some middle continental shelf species as *Cassidulina crassarossencis Globocassidulina subglobosa and Bolivina difformis* become more important. On the other hand, the dominance of *C. lobalutus*, *G.praegeri* and *B.pseudoplicata*, together with the low abundance of *H. germanica* (<5%) and the absence of *A. tepida* and *E. gunteri* indicate maximum marine influence in the estuarine mouth.

SED3 is barren in foraminifera, and SED4 of core 1 has only one layer (-1.69m) with foraminifera content.

In general, the estuary mouth/marine and outer shelf associations increase in SED2 unit (core 2 and 1B). However, this increase is not uniform, but characterized by some peaks and interruptions, the former being synchronous with cocoliths peaks, indicating an increase of marine influence.

In fact, the variations in cocoliths in the SED2 topmost layers are congruent with the environmental changes deduced from estuary mouth/marine and outer shelf/slope foraminifera associations. The earliest occurrence of calcareous nannoplankton is at -22.74m (which corresponds an age of circa 9320BP). In the lowermost layers of SED2 in core 1B, a discreet and initially interrupted presence of coccoliths, dominated by *Gephyrocapsa oceanica and Emiliana huxleyi*, suggests an environment with ephemeral marine influence. Only in the top levels of this unit (after -8.34m and 6050 BP), the coccolith abundance (>5,000 CAI) and diversity, is compatible with a clear marine environment in which *Helicosphaera carteri, E. huxleyi, Gephyrocapsa ericsonii, G. oceanica* and *G. muellerae* dominate together with *Coccolithus pelagicus* in lesser degree (Fig.2). *H. carteri can exceed 1,000 CAI, equivalent to more than 80% of the assemblage.*

Pollen Analysis

Pollen analysis from core 1B, shows the presence of a *Pinus-Quercus*-forest with *Alnus* and some Poaceae-Ericacea open communities, in the Douro basin, between 9490 BP and 5750 BP. This forest reflects a temperate and humid climate in the first part of the Holocene. Pollen preserved in this unit was transported by the river (NAUGHTON, 2002; NAUGHTON *et al*., 2002 and NAUGHTON *et al*., submitted).

In core 1, the pollen grains are only present in the muddy sand layers of SED4. These layers are dominated by pollen of Ericaceae, Poaceae and Asteraceae. This pollen assemblage represents the signature of the local vegetation characterising nowadays the surroundings of the coring point.

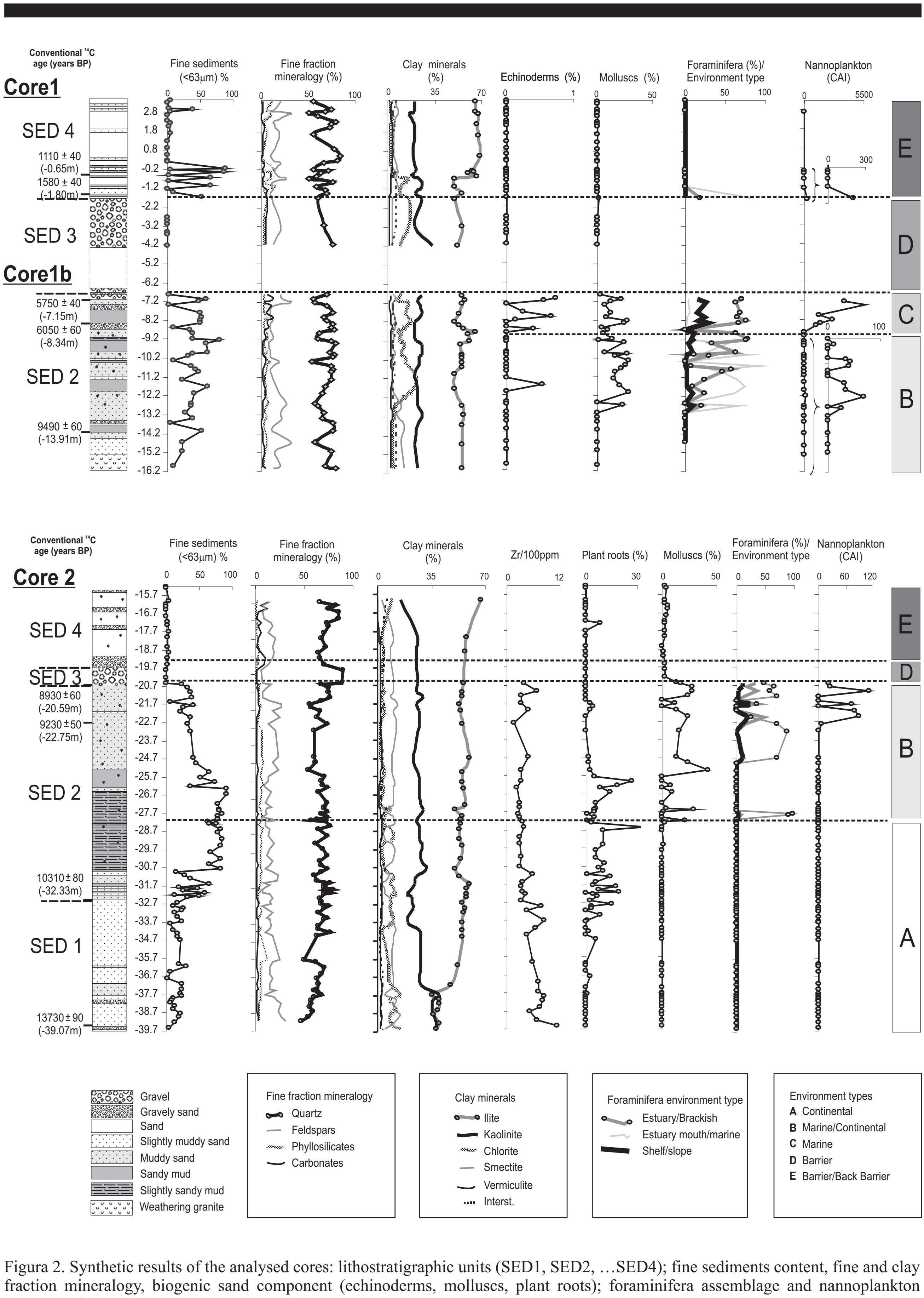

Figura 2. Synthetic results of the analysed cores: lithostratigraphic units (SED1, SED2, …SED4); fine sediments content, fine and clay fraction mineralogy, biogenic sand component (echinoderms, molluscs, plant roots); foraminifera assemblage and nannoplankton "Content Abundance Index" (CAI). A, B,..,E correspond to the defined environmental types.

DISCUSSION - EVOLUTION MODEL

Overall results from this study allowed to distinguish several environmental changes related with sea-level rise (in particularly, with the Holocene transgression), regional climate changes occurred since the Lateglacial and some local forcing factors.

Continental Environment (A): *Circa* 13730-9834 BP

The basal sedimentary record indicates a continental environment with terrestrial facies that includes SED1 and the lower half of SED2 (Fig.2). This terrestrial signature is supported by the total absence of biogenic sand components (namely molluscs), the significant abundance of plant remains and the total absence of foraminifera and calcareous nannoplankton. The suite of heavy minerals, together with the high contents of Al, Ca, Sr and Zr and the clay mineral association corroborates this interpretation suggesting evidences of direct erosion of outcroping basement. This section seems to have been deposited in a changing climate: it evolved from temperate to subtropical conditions (from base to -37.66m) to milder ones (-37.66m/-34.07m) and finally to temperate conditions (but with colder periods) with an increase of precipitation (-34.07/-31.16m).

SED1 sequence probably corresponds to a typical fluvial environment, in the dependence of the Douro river. It was deposited when the shoreline was far away from the coring sites: circa 13km (between 13-11ka; sea level at -30m) and 20km (between 11-10ka; sea level at -60m) according to DIAS (1987). The sedimentation becomes finer in the lower part of SED2 unit, probably in response to the approximation of the base level.

Marine/Continental Environment (B): 9834-6050 BP

The following facies is characterized by alternating marine/continental influences and corresponds to the upper half of SED 2 (in core 2) and SED2 (in core 1B) (Fig.2). This facies is characterized by increasing marine influence, as suggested by the general increase of estuary mouth/marine and continental shelf foraminifera (especially expressed in core 1B). However, drastic decrease in abundance or even interruption in the foraminiferal record, molluscs and nannoplankton can be observed at specific levels (Fig.2). These perturbations, are simultaneous with augmentation in terrigenous indicators, especially plant remains. Thus, these intervals were attributed to continental inputs, which seem to have been short-lived (some of them may correspond to intervals as short as 130-200 years, considering the radiocarbon dates and a uniform sedimentation rate) and disturbed the transgressive trend. They can represent either regressive periods or, more probably, episodes of important fluvial sediment input.

The earliest marine signal is represented by a single ephemeral episode, with brackish foraminifera assemblage and some peaks of molluscs and "other biogenics", noticed between -28.11m and -27.45m and corresponding to an interpolated time period between circa 9834 and 9756 BP. However, it is after a threshold circa -25m that the signal of sea level incursions persists, as shown by the abundance and associations of molluscs and foraminifera.

The marine signature is also supported by the increase in C/D ratio and decrease in K/I, particularly after -22.74m, when augmentations in Ca and Sr are also observed.

Besides, the presence of nannoplankton at this specific level (corresponding to circa 9230 BP) indicate that sea level had already exceeded this elevation by this time. According to DIAS (1987), after 11-10ka, when sea level was circa -60m, a rapid rise took place, reaching approximately -20m at 8ka. However, this new data seem to indicate that this level was reached at an earlier stage (circa 9ka), which may imply a higher sea level rise rate than previously proposed.

The pollen assemblages are in agreement with the climatic amelioration that characterizes the Holocene as it was deduced by pollen analysis. In particular, XRD data of core 2 put in evidence a climate evolution towards more temperate conditions, with less precipitation and, therefore, less favorable to hydrolysis development in source areas. In core 1B, hydrolysis seems to increase progressively, towards a warmer and more humid climate, with seasonal contrast, simultaneously with less hydrodinamism.

Marine Environment (C): 6050-5750 BP

A clear marine environment upwards -8.35m is very well expressed (and corresponds to the topmost layers of core 1B), through the foraminifera assemblage (effective presence of continental shelf species and minor importance of brackish environment species), nannoplankton diversity and abundance (Fig.2) and by the evident increase of C/D ratio. These data confirms that the coastline stood landward of the core location, when sea level was circa 7m below present day level, representing thus the maximum of the Holocene transgression. However, core 1B site was probably related to a partially confined environment, probably by the precocious development of a sandy bar as it seems to be suggested by the observed abnormal opportunistic development of *H.carteri* which denote some ecological particularities (CACHÃO *et al.*, 2002).

This environment can be considered an extension of the preceding one, and some of its characteristics, as the climatic ones, remained unchanged from the B to the C environment.

Barrier Environment (D): Post 5750 - Before 1580 BP

After 5750 BP, a clear change in the environment is expressed by the deposition of a gravel layer - SED3 (Fig.2). This unit seems to have had a fluvial origin and subsequently a littoral reworking (NAUGHTON, 2002; NAUGHTON *et al.*, *submitted*), which seems to be supported by the rounded, spherical and ellipsoidal grains of garnet, andalusite and tourmaline in this unit of core 2. This gravel layer may represent a gravel barrier, which formed post 5750 and before 1580 BP (NAUGHTON, 2002, NAUGHTON *et al.*, *submitted*) and thus, contemporaneous of similar features (though sandy) found in the SW Portuguese coastal lagoons of Albufeira, Melides and Santo André (FREITAS and ANDRADE, 2001).

The extension of this gravel barrier allowed the northward relocation of the Douro channel (NAUGHTON, 2002, NAUGHTON *et al.*, *submitted*), leaving its former position fossilized as a paleovalley located south of the present-day talweg (CARVALHO and ROSA, 1988). This could be responsible for the observed change in the pollen signature from regional to local before 5750 and post 1580BP, respectively.

Climatic proxies seem to indicate an increase in temperature and precipitation, favouring a strong hydrolysis in source areas and an intense fluvial transport as it was deduced from mineralogical data.

Barrier/Back-barrier Environment (E): 1580BP - Present Day

A barrier/back-barrier environment is evident in SED 4, with a brackish signal suggested by micropaleontological data and a small percentage (<1% molluscs) found in muddy layers at its bottom (-1.69m) (Fig.2). With the exception of this episode, no biogenic sand components have been detected further upcore. This facies includes a significative percentage of amphibole in the heavy mineral suite of the top of the unit, which is probably related with the amphibolitic outcrops in the southern area of Douro basin.

The accumulation of the estuarine spit and sedimentation in the estuarine domain sheltered by the barrier, progressed at a high rate, allowing the marine signal to fade away in the topmost section of the sedimentary record of this place. Therefore, a forced regressive facies was constructed here in spite of a persistent eustatic positive trend.

XRD data seems to show the existence of hydrolysis conditions with seasonal contrast and a loss of fluvial hydrodinamism.

The conceptual model out coming from these results follows in the essential the one accepted for the southwestern Portuguese lagoons of Santo André and Melides (FREITAS *et al*., 2003). Since the Lateglacial until the Early Holocene, the sedimentary record of these lowlands shows a pronounced terrestrial character (FREITAS *et al*., 2003). Sediments are generally coarse-grained characterizing detrital fluvial input, and bearing a strong provenance signal from the watershed. In contrast, the overlying deposits show a dominant marine influence, the sediment being in general finer, enriched in OM bioclastic particles (FREITAS *op. cit*.). This influence reached a maximum circa 5000-5500 BP, when the deceleration of sea-level rise rate allowed the emplacement of detrital barriers and the establishment of restricted environments, which evolved as such until present.

CONCLUSIONS

The sediments of the Douro estuary were deposited through a succession of different environments, mostly related with changes in sea-level rise, specially, with the Holocene transgression, regional climate and local forcing factors that occurred since the Late glacial. The proposed evolution model agrees with the existing one for the southwestern Portuguese lagoons of Santo André and Melides (FREITAS *et al*., 2003), reinforcing some original aspects that seem to have a regional meaning.

In fact, since 13730 and till 10310 BP, the sedimentary record shows a terrestrial character followed by a marine environment, characterized by an alternating marine/continental facies (10310-6050BP). However, a clear marine influence expressing the maximum transgression event is possible to observe only after 6050 and till 5750BP. After 5750 BP, the establishment of a gravel barrier followed by a sandy barrier development allowed partial sheltering of the estuary. Thus, the post-Late glacial evolution of the Douro estuary includes a transgressive facies followed by a regressive one. It represents therefore, a complete sedimentary cycle in spite of a positive eustatic signal that persisted throughout almost this entire period.

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