PALAEOENVIRONMENTAL ANALYSIS OF DOURO ESTUARY
BASED ON MINERALOGICAL PARAMETERS

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Keywords: Palaeoenvironmental analysis; Douro estuary; Mineralogical parameters

ABSTRACT

Sedimentary studies in the Portuguese continental shelf have been mainly developed after the eighties, involving different interdisciplinary approaches, among them sedimentology, geochemistry and mineralogy. Most of those studies have been focused on the northwestern Portuguese shelf, particularly in sedimentary deposits extending at the adjacent shelf northwards of Douro river, but they have been essentially based on the study of superficial sediments or in recently deposited sediments. In this context, studies of stratigraphic succession of lagoonal and estuarine paleoenvironments may give helpful information. A study on the stratigraphic succession of the sedimentary record of Douro estuary is being carried out aiming at the recognition and distinction of the environmental changes, which have occurred during the Late Quaternary. Some results obtained on the sedimentology, carbonates, organic matter, mineralogy, foraminifera, nannoplankton and pollen assemblages have permitted to recognise the geological evolution of the area, including the shift of fluvial to marine facies. The aim of this work is therefore, to present the mineralogical evolution determined in the sedimentary record between 19.5 m and 44 m depth. Results are discussed in order to characterise the sediment distribution patterns and to recognise and evaluate some temporal changes.

INTRODUCTION

The terrigenous sedimentary particles contribute, for their characteristics, to the identification of alluvium deposits sources and of paleogeographic terms, assuming that they are not the result of successive reworking cycles, nor remarkably modified by diagenesis.

The utilization of clay as a stratigraphic marker constitutes one of the first essays of its application in the sedimentary basins and continues, actually, to be an important research area.

The clay associations' mineral analysis provides important information on paleoclimatic studies essentially concerning regional data. Paleoclimatic

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signal doesn't depend significantly of biotic factors and frequently survives the post-depositional modifications. The composition of detrital mineral associations is particularly useful in the way that they record the modifications that occur in source area, in what concerns the erosion conditions.

Clay and non-clay minerals assemblages of superficial sediments have been used in the recognition of sources since the sixties. Changes in sources or in current activity often determine modifications of the mineral assemblages. Therefore, these assemblages are useful indicators of detrital sources. On the other hand, these mineral associations, supplied from land to sea, often reflect the combined control of terrigenous supply and transportation agents and can be used to characterize recent estuarine environments.

Sedimentary studies in the Portuguese continental shelf have been mainly developed after the work by Dias (1987), involving different interdisciplinary approaches, among them sedimentology, geochemistry and mineralogy. Most of those studies have been focused on the northwestern Portuguese shelf, particularly in sedimentary deposits extending at the adjacent shelf northwards of Douro river, but they have been essentially based on the study of superficial sediments or in recently deposited sediments (Araújo et al., 2002; Drago et al., 1999; Oliveira et al., 2002). In this context, studies of stratigraphic succession of lagoonal and estuarine paleoenvironments may give helpful information (as shown by Freitas et al., 2002).

A study on the stratigraphic succession of the sedimentary record of Douro estuary is being carried out aiming at the recognition and distinction of the environmental changes, which have occurred during the Late Quaternary. Some results obtained on the sedimentology, carbonates, organic matter, mineralogy, foraminifera, nannoplankton and pollen assemblages have permitted to recognise the geological evolution of the area, including the shift of fluvial to marine facies (Drago et al., 2002).

The aim of this work is therefore, to present the mineralogical evolution determined in the sedimentary record between 19.5 m and 44 m depth. Results are discussed in order to characterise the sediment distribution patterns and to recognise and evaluate some temporal changes.

**MATERIALS AND METHODS**

The studied core was sampled by rotary drilling in the sand barrier of the Douro estuary (Figure 1) from -20 to -40 m depth. After being described, core was subsampled for multidisciplinary investigations, including grain-size, chemical and mineralogical analysis. Nine organic sediment samples were dated by 14C AMS.

Textural analyses have been performed by means of the traditional sieving method. Gravel free sediments follow the Flemming (2000) classification (considering only the < 63µm and > 63µm fractions percentages). For sediments with variable gravel percentage, the Hydrographic Institute classification was adopted (Moita, 1986).

For mineralogical analysis of both fine (<63 µm, 90 samples) and clay (<2 µm, 43 selected samples) fractions, each sample was dried, washed with distilled water and wet sieved to separate the clay/silt size fraction. Sediment fractions <63 m were dried in an oven at 60°C and gently disaggregated with a porcelain mortar. X- Ray Diffraction (XRD) was used following the methodology proposed by Rocha (1993). For the semiquantitative determination of minerals by XRD, in random-oriented powders (<63 m) and in oriented aggregates (<2 m), criteria recommended by Barahona (1974), Schultz (1964), Thorez (1976), Mellinger (1979) and Pevear and Mumpton (1989) were followed.
Two mineralogical indexes were computed (according to Vidinha et al., 1998 a, b, 2000): phyllosilicates/(quartz+feldspars) - DF/DG and carbonates/detrital minerals - C/D for each sample. Phy/Qz+Feld ratio is related with the transport of detrital materials from the hydrographic basins of the nearby continental region (the higher values indicating the lower hydrodynamism of the transportation agent). C/D ratio expresses the dichotomy between the detrital transport and the biogenic component, the higher values indicating the lower contribution of detrital materials and the higher contribution of biogenic materials.

RESULTS AND DISCUSSION

Sedimentary, geochemistry and palaeoecological studies of this corer reveal the existence of four sedimentary units referred by (Drago et al., 2002) as SED1, SED2, SED3 and SED4 (Figure 2a).

Results from the mineralogical studies allowed the characterization, along the studied core, of the vertical evolution of the mineral composition of the fine fractions (Figure 2a) and clay fractions (Figure 3) of the sediments as well as of the mineralogical ratios phyllosilicates/(quartz+feldspars) - DF/DG, and carbonates/detrital minerals - C/D (Figure 2b).

This characterization allowed to assess a zonography of the core's sedimentary column, similar to the informal units defined by Drago et al. (2002) - SED1, SED2, SED3 and SED4, as well as to attempt a morphoclimatic reconstruction.

Therefore, it was possible to distinguish, from base to top, the following units (upper and/or lower limits reported to sea-level):

SED 1 is the lower unit (13730-10310 BP) and consists of slightly muddy sand with some gravelly
sand and muddy sand layers at the bottom; the vertical evolution of the studied mineralogical parameters allowed its subdivision into two sub-units, SED 1a and 1b. SED 1a, from the core's base until -37.66 m, consisting of slightly muddy sand with gravelly sand and muddy sand layer, is characterized by a mineralogical suite composed essentially by relatively coarse-grained siliciclastic minerals (quartz and feldspars), with a very discrete presence of phyllosilicates and carbonates; clay minerals' suites are composed by kaolinite (Kt) and illite (Ill), with some smectite (Sm) and chlorite (Chl), these two clay minerals alternating as the third more abundant clay mineral of this sub-unit; these mineralogical associations point out to a continental environment with temperate to subtropical climatic conditions, with milder periods (concerning both temperature and pluvioscity), favorable to heavy detrital supply (intense fluvial input). SED 1b, overlying SED 1a until -34.07 m, consisting mainly of slightly muddy sand, is characterized by a clear increase of quartz (and, much more discrete of the phyllosilicates) and decrease of feldspars, as well as, in the clay fractions, by a decrease of kaolinite, illite becoming clearly the predominant clay mineral whereas chlorite becomes the third clay mineral, Smectite being always very discrete; these mineralogical changes point out to a morphoclimatic evolution towards milder conditions, although still continental ones.

Mineralogical unit SED 2 begins a little earlier (-34.07 m) than sedimentological SED2 unit (-32.33 m). It consists mainly of thin interbedded layers of sandy mud and muddy sand, followed by a slightly sandy mud section and muddy sand sections; like SED 1, it can be subdivided into two sub-units. SED 2a, until -31.16 m, consisting mainly of muddy sand and sandy mud thin layers, is characterized by a higher relative increase of quartz caused by the decrease of phyllosilicates and feldspars, whereas in the clay...
fractions, kaolinite decreases again in relation to illite (in general, very degraded), and smectite becomes the third clay mineral, chlorite being rare and even absent in some samples; climatic conditions should be temperate (but with colder periods), relatively more wet and, from the morphologic point of view, more plane, presenting also the first periods of marine influence. SED 2b, until -20.66 m, consisting of slightly sandy mud, sandy mud and muddy sand is marked by a gradual increase of feldspars and, in the clay fractions, of kaolinite relatively to illite (now more ordered), smectite decreasing relatively to chlorite; therefore, climate should have changed to less wet conditions, less favourable to hydrolysis development in the source-areas, implying that the deposition environment would be more marine. This upper half of SED2 although showing no significant textural contrast with the lower part of the same unit, presents compositional proxies indicating an alternation of marine/continental facies until 6050BP. The terrestrial facies may represent regressive episodes, which are more probably due to large fluvial sediment input than to eustatic sea level fall. A discrete increase in carbonates indicates a first marine incursion episode between 9834 and 9756BP. The gradual increase of the C/D (carbonate/detrital) ratio in the fine fraction points out to an increase in marine influence noticed after 9230BP and becoming more pronounced between 6050 BP and 5750 BP, when the transgressive maximum occurred.

SED 3 is a gravel unit, deposited after 5750 BP. Overlying SED 2b until -19.4 m is characterized by notorious increase of quartz (up to 100%), whereas in the clay fractions only a discrete decrease of chlorite is detected; morphoclimatic conditions changed, becoming more continental and wet favourable to heavy detrital supply (very intense fluvial input).

SED 4 is the upper unit of the studied sedimentary sequence; it is composed by sand with few interbedded gravelly sand. It shows an increase of feldspars and carbonates and a decrease of phyllosilicates; concerning the clay fractions, kaolinite decreases relatively to illite whereas smectite increases in relation to chlorite; climate should be season-contrasting with periods less wet, tempered, alternating with others more hot and wet, erosive, clearly continental.

CONCLUSIONS

The results obtained so far allowed to perform the mineralogical characterization of the fine and clay fractions of the sediments from the studied core as well as the morphoclimatic reconstruction of the Douro Estuary.

Climatic conditions should have changed from temperate/subtropical, pluvious, to milder ones, more tempered, whereas, from the morphologic point of view, the evolution should have been similar, mainly continental, changing from more to less hydrodynamic fluvial conditions, with a few periods showing some marine influence. Evidences of hotter period followed by a cold one were found and it may correspond to the Bölling-Alleröd interstadial and the Younger Dryas stadial. The transition to the Holocene is well represented by the climatic amelioration (circa 10310BP) and the appearance of the marine influence (9834BP).

SED 3 probably represents an ancient coarser barrier, established in relation to the deceleration of sea level rise, coupled with favourable climate conditions. This unit may have constituted the foundation for the development of the present-day sandy barrier (SED 4) after 1580 BP. In the sheltered back-barrier area alternating sandy and muddy layers have been deposited in this time interval and the presence of sparse foraminifera and coccoliths (only at -1.69m), together with other paleoenvironmental indicators suggest a brackish environment with low salinity, that rapidly acquired fluvial and/or subaereal characteristics towards the top.

On top of the studied column we found evidences of less wet conditions, still temperate, but with some hotter and wet periods, season-contrasted, within an environment becoming again continental.

ACKNOWLEDGEMENTS

This work is being funded by FCT under the research project PLE/12/00 "Late Quaternary ENVIronmental CHANGES from Estuarine and Continental Shelf Sedimentary Record" (ENVI-CHANGES).
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(Received: January, xx, 200x. Accepted: July, xx, 2005)