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CHARACTERIZATION OF THE SEDIMENTARY ENVIRONMENT OF THE GILÃO RIVER MOUTH, BASED ON SEDIMENTOLOGICAL AND MINERALOGICAL ANALYSIS

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ABSTRACT

The main objective of this paper is to use the mineralogical composition of the fine and clay fractions of the sediments from the studied borehole to a better characterization of the Gilão Estuary sedimentary environment. For this study, 12 samples from G1 borehole were selected in order to represent the vertical heterogeneities, detected through previous sedimentological analysis. The mineralogical analysis of the <63 µm fraction shows the predominance of the detrital minerals quartz, feldspars and phyllosilicates, followed by a group of accessory minerals that includes calcite, dolomite, opal C/CT and pyrite. The mineralogical composition of the clay fraction reveals the presence of illite and kaolinite as the most abundant clay minerals; smectite, chlorite and random mixed-layers are the accessory clay minerals which are present. In both studied fractions, the distribution of the mineralogical assemblages identified along the sedimentary column is, in general terms, consistent with the previously defined units. The vertical evolution of both the mineralogical associations and the mineralogical *ratios*, as well as the Factor Scores, illustrated the oscillations of relative importance, intensity and hydrodynamics of the terrigenous supply as well as the dicothomy of marine versus continental influences.

INTRODUCTION

The studied estuary area is located east of Tavira village, southern Portugal (Fig. 1).

According to the literature and to ancient maps, Gilão and Almargem river mouths were draining into the same estuary until the sixteenth century. Until then, it seems that the estuary was open to the ocean, the sand barrier sytem forming the lagoon in front of Tavira appearing just later on (Veiga-Pires *et al.*, 2000).

This estuary, as well as three other estuaries from Algarve, have been choosen to study Sea Level variations during the Holocene. Accordingly, sedimentologic, mineralogic and micropaleontologic analysis have been undergone on several continuous boreholes.

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Among the three cores sampled from Gilão-Almargem estuary, the G1 sediment core (Fig. 1) revealed four biostratigraphic units (Fig. 2).

The main objective of this paper is therefore to use the mineralogical composition of the fine and clay fractions of the sediments from G1 borehole to identify mineralogical assemblages and relate them to changes in sedimentary sources (marine versus continental).

MATERIALS AND METHODS

Among the three cores sampled from Gilão-Almargem estuary, the G1 borehole, located west of Arraial Ferreira Neto (Fig. 1), was the only one reaching the Mesozoic limestones.

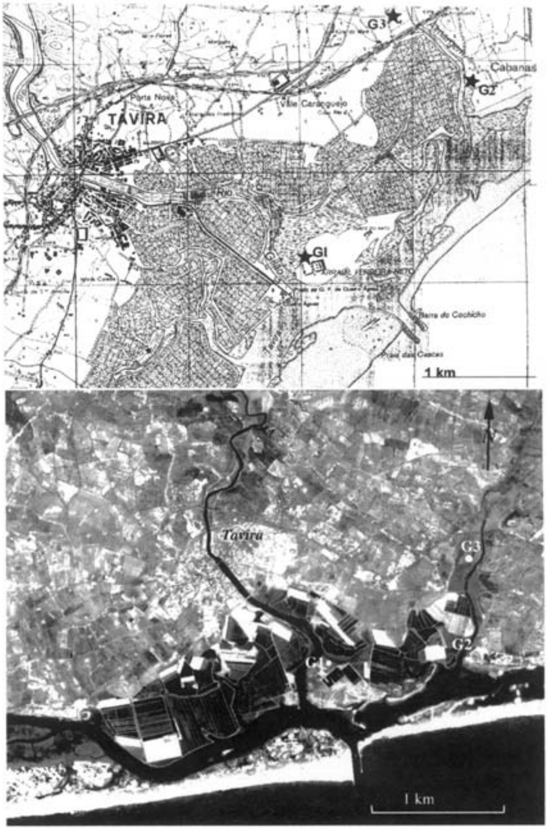

Figure 1.
Boreholes location.

For this study, 12 samples from G1 borehole were selected in order to represent the vertical heterogeneities, detected through previous sedimentological analysis.

Mineralogical studies were based on X-ray diffraction (XRD) determinations, carried out on the fine (<63µm) and clay (<2µm) grain size fractions of the sediments, using a Phillips PW 3040/60 diffractometer.

The clay fraction (<2 µm fraction) was separated by sedimentation, according to the Stokes law. Non-oriented powder (<63 µm fraction) and oriented sliced (<2 µm fraction) specimens for subsequent X-Ray diffraction analysis were then analysed, the later after drying, glycolation, and heating to 300ºC and 500ºC.

All samples were analysed in the range from 2º to 40º 2θ, at 1° 2 θ /min, with Cu-Ka radiation. The XRD reflections were evaluated with the Phillips X'Pert 1.2 and Profit softwares.

For the semi-quantitative determination of clay and non-clay minerals, the relative content of each identified mineral was estimated on the basis of its characteristic peak area corrected by the corresponding reflective power (Rocha, 1993), as recommended by Barahona (1974), Schultz (1964), Thorez (1976), Mellinger (1979) and Pevear & Mumpton (1989).

Three mineralogical indexes (Vidinha *et al.*, 1997, 1998, 2000) were computed:

- Fine Detrital Minerals / Coarse Detrital Minerals = phyllosilicates/(quartz + K-feldspars + plagioclases);
- Feldspars / Quartz = (K-feldspars + plagioclases) / quartz;
- Carbonate minerals / Detrital minerals = (calcite + dolomite) / (phyllosilicates + quartz + K-feldspars + plagioclases).

These mineralogical *ratios* express the relative importance, intensity and hydrodynamics of the terrigenous supply as well as the marine versus continental influences.

Fine Detrital Minerals / Coarse Detrital Minerals [Phy/(Qz+Feld)] and Feldspars / Quartz [(K-feldspars + plagioclases) / quartz] *ratios* are 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).

The variation of quartz (a chemically and physically stable mineral) in relation with feldspars permits to considerer it as an index of mineralogical maturity of sediments, in terms of quartz contents in relation to K feldspars and plagioclases. The higher values of this Feldspars / Quartz *ratio* indicate lower maturity.

Carbonate minerals / Detrital minerals (C/D) *ratio* expresses the dichotomy between the marine versus continental influences as well as between the detrital transport and the biogenic component, the higher values indicating higher marine influence, lower contribution of detrital materials and higher contribution of biogenic materials.

Multivariate analysis (Principal Component Analysis) of the mineralogical data (from both fractions) has been carried out.

The use of these statistical methods, as outlined by Imbrie & Van Andel (1964), Jöreskob *et al*. (1976), Davis (1986) and Reyment & Jöreskob (1993), allows a convenient characterisation of the data, through the reduction of the complexity of the model and classification of the variables and samples into natural groups (Mezzadri & Saccani, 1989).

Therefore, statistical analysis of mineralogical parameters can be used as a tool to reinforce the usefulness of these parameters as lithostratigraphic and environmental markers (Rocha, 1998).

RESULTS AND DISCUSSION

The vertical heterogeneities, detected through previous sedimentological analysis of the G1 sediment core (Fig. 2) revealed four biostratigraphic units:

1) at the bottom of the studied column (from 17 m to 13.8 m depth), occur carbonated detrital Upper Miocene formations; this section shows some silty levels interbedded in the gravel and coarse sand deposits;

2) From 13.8 m to 9.1 m depth, occur a positive granulometric sequence, whose coarser fraction corresponds to medium sand; in this section, bioclasts are rare and badly preserved; at the top of the section, occur sedimentary structures corresponding to sand injections to the lower part of the overlaying silty bed;

3) Next unit, from 9.1 m to 2.9 m depth, is composed by alternated beds of sands and sandy silts, showing significant bioclastic fraction, characteristic of confined environments (probably a estuarine lagoon);

4) The upper 2.9 meters of sediments, composed by a mixture of sands, silts and clays seemed to be the result of remobilisation through anthropic action

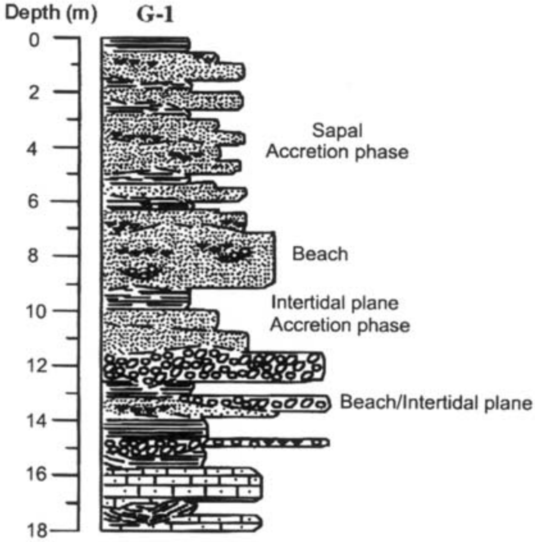

Figure 2.
Sedimentary column of G1 borehole.

The main mineralogical results obtained so far are presented on Figures 3 (fine fractions), 4 (mineralogical *ratios*) and 5 (clay fractions).

Figure 3 shows the vertical evolution of the mineralogical composition of the fine fractions

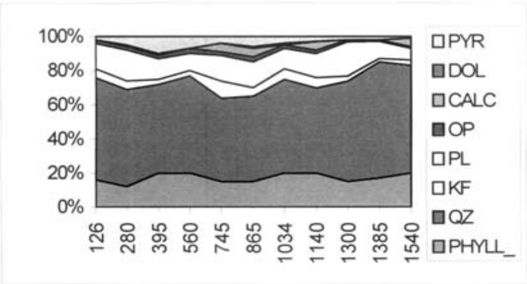

Figure 3.
Vertical evolution of the mineralogical composition of the fine fractions.
(X-axis: depth in cm; Y-axis: cumulative %)
PHYLL - phyllosilicates; QZ - quartz; KF - potassium feldspars; PL - plagioclases; OP - opal C/CT; CALC - calcite; DOL - dolomite; PYR - pyrite.

At the bottom of the core, occurs a clear predominance of quartz, decreasing along the intermediate section (≈1300 cm to ≈395 cm), increasing again to the top. Along the intermediate section, an increase of feldspars do occur relatively to quartz, pointing out to a sediment maturity lower on top than on the bottom. Concerning the accessory minerals of the fine fractions (<63 µm), occurs, from base to top, an increase of pyrite and, more discretely, of opal C/CT.

Figure 4 shows the vertical evolution of the computed mineralogical *ratios*.

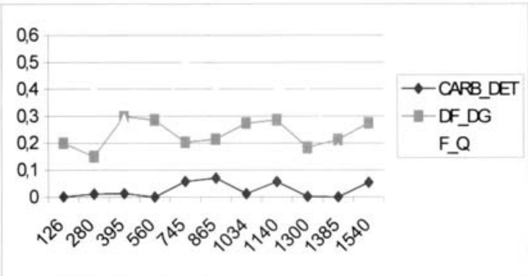

Figure 4.
Vertical evolution of the Carbonate minerals / Detrital minerals (CARB_DET), Fine Detrital Minerals / Coarse Detrital Minerals (DF_DG) and Feldspars / Quartz (F_Q) ratios.
(X-axis: depth in cm; Y-axis: ratios numerical values).

Fine Detrital Minerals / Coarse Detrital Minerals *ratio* presents a decreasing trend, from base to top, pointing out to a continuous, although relatively discrete, impoverishment in phyllosilicates. Feldspars / Quartz *ratio* shows an opposite trend, but on an irregular basis. On the other hand, Carbonate minerals / Detrital minerals *ratio* shows significant values only along the intermediate section (from ≈1300 cm to ≈745 cm) of the studied sedimentary column.

Figure 5 shows the vertical evolution of the clay fractions mineralogical composition .

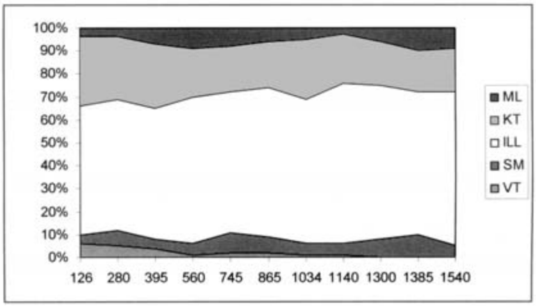

Figure 5.
Vertical evolution of the clay fractions mineralogical composition.
(X-axis: depth in cm; Y-axis: cumulative %)
ML - random mixed-layers;KT - kaolinite; ILL - illite; SM - smectite; VT - vermiculite.

Illite is clearly the predominant clay mineral, but decreasing from base to top, kaolinite showing an opposite trend. Similar behaviour occurs between the other two identified clay minerals, smectite (and random mixed-layers, essentially illite-smectite) and vermiculite; smectite (and the random mixed-layers) decreasing from base to top, whereas vermiculite (absent at the base) increasing to top.

Taking into account the previously defined subdivision of the sedimentary column in four informal units:

1) at the base of the core (from 17m to 13.8 m depth) occurs abundant quartz, accompanied by small amounts of phyllosilicates (mainly mica/illite and kaolinite), plagioclases and calcite.

2) Overlaying this unit, up to 9.1 m depth, there is a discrete increase of the phyllosilicates (in particular, of kaolinite) and of the feldspars, whereas the carbonates became little more than vestigial, pointing out to an increase of the detrital supply, immature and more energetic.

3) Next unit, from 9.1 m to 2.9 m depth, shows at the base a notorious increase of feldspars and carbonates, followed, along the next section, by an increase of phyllosilicates (appearing, by the first time, vermiculite, generally very discrete and in relation to a decrease of smectite).

4) At the top, along the last 2.9 meters of sediments, there is no clear trend detected, concerning either the fine fractions or the clay fractions.

The multivariate factorial analysis (Principal Components Analysis) of the obtained mineralogical data (concerning the fine fractions) - Table 1 and Figure 6 - extracted 3 Factors, explaining 78% of the total variance and allowing to put forward some considerations:

•Factor 1 shows quartz in opposition to K-feldspars, opal C/CT, dolomite, and, less clearly, plagioclases and pyrite.

•Factor 2 explains the phyllosilicates (in a relative opposition to the plagioclases).

•Factor 3 explains calcite.

Table 1. *Factor Loadings (fine fractions).*

	FACTOR_1	FACTOR_2	FACTOR_3
PHYLL	-0.270972	-0.851805	-0.200130
QZ	-0.924127	0.173939	0.148292
KF	0.711646	0.240974	-0.479848
PL	0.438214	0.771091	0.265936
OP	0.745653	-0.394438	0.300250
CALC	0.397876	-0.129744	-0.811924
DOL	0.585708	0.064180	0.236373
PYR	0.503109	-0.539286	0.533628
Expl.Var	2.936384	1.875841	1.453020
Prp.Totl	0.367048	0.234480	0.181627

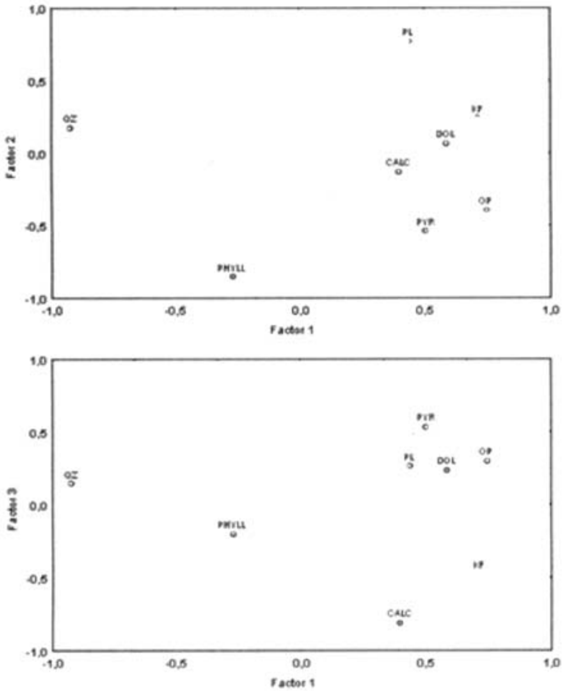

Figure 6.
Projection of the mineralogical parameters (fine fractions) on the factorial planes.

The transit "Factor 1 negative (quartz) - Factor 1 positive (K-feldspars, opal C/CT, dolomite) - Factor 2 negative (phyllosilicates) - Factor 3 negative (calcite)" illustrates a classical sedimentological and mineralogical evolution pointing out to a decrease of relative importance, intensity and hydrodynamics of the terrigenous supply as well as the increase of marine *versus* continental influences, thought an evolution from fluvial to transition (lagoon) to marine environments.

Table 2. *Factor Loadings (clay fractions).*

	FACTOR_1	FACTOR_2
VT	0.938275	0.221690
SM	-0.590911	0.589999
ILL	-0.757831	-0.646136
KT	0.979243	-0.005047
ML	-0.614715	0.559755
Expl.Var	3.140634	1.128088
Prp.Totl	0.628127	0.225618

The multivariate factorial analysis (Principal Components Analysis) of the clay fractions mineralogical data - Table 2 and Figure 7 - extracted 2 Factors, explaining 85% of the total variance and allowing the following considerations:

- Factor 1 shows kaolinite and vermiculite in opposition to the other three clay minerals (illite, smectite and random mixed-layers).

- Factor 2 shows illite in opposition to smectite and the random mixed-layers.

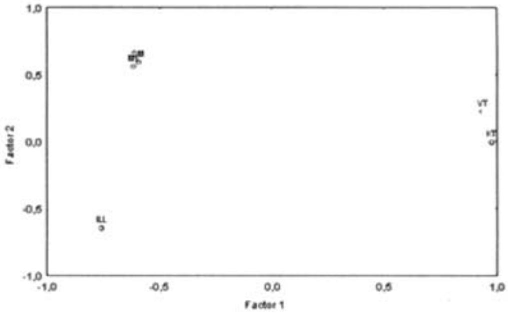

Figure 7.
Projection of the mineralogical parameters (clay fractions) on the factorial planes.

The transit "Factor 1 (kaolinite and vermiculite) - Factor 2 negative (illite) - Factor 2 positive (smectite and random mixed-layers, mainly illite-smectite)" illustrates either the decrease of soil dismantling and a topographic smoothness or, once again, the decrease of relative importance, intensity and hydrodynamics of the terrigenous supply as well as the increase of marine *versus* continental influences.

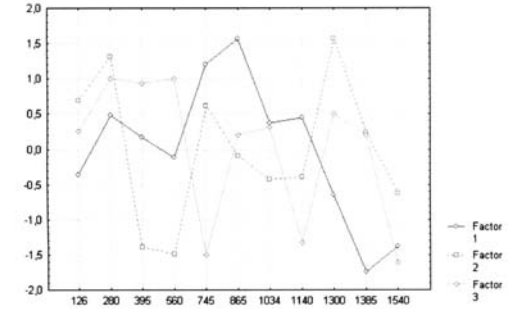

Figure 8. *Factor Scores vertical evolution (fine fractions).*

The vertical evolution (Figure 8) of the Factor Scores (fine fractions), along the previously defined four informal units, put in evidence very significant values of Factor 1 negative for the lower unit (from 17 m. to 13.8 m depth), pointing out to a very important terrigenous supply, quartz-rich, although associated, at the bottom, to small amounts of calcite (Factor 3 negative).

Along the overlaying unit (from 13.8 m to 9.1 m depth), Factor 1 values loose significance, pointing out to a decrease of relative importance, intensity and hydrodynamics of the terrigenous supply, occurring some carbonated episodes.

The third unit (from 9.1 m to 2.9 m depth) can be subdivided into two sections; its lower section shows values highly positive for Factor 1, pointing out to a finer terrigenous supply, richer in feldspars; in what regards its upper section, it shows significant negative values for Factor 2, pointing out to an increase in phyllosilicates, within a carbonated episode.

Finally, the fourth unit does not show any peculiar behaviour of the 3 extracted factors, coherently with its complex sedimentological composition, a mixture of sand, silt and clay, most probably due to anthropic remobilization, as previously stated.

Concerning the clay fractions, the vertical evolution of their Factor Scores (Figure 9) shows the occurence, in the lower unit (from 17 m to 13.8 m depth), of an illite-kaolinite-smectite association, in accordance with the environmental conditions putted in evidence by the fine fractions analysis: very important terrigenous supply, quartz-rich and (now possibly to say) kaolinitic, having, at the bottom, calmer episodes, carbonated and with some smectite content.

The following unit (from 13.8 m to 9.1 m depth), shows values highly negative of Factor 2, together with a relative increase of Factor 1, meaning an evolution towards an illite+kaolinite association.

The third unit (from 9.1 m to 2.9 m depth) can be, as previously stated, subdivided into two sections; its lower section shows values highly positive for Factor 2, pointing out to a decrease in intensity of the terrigenous supply, becoming finer and relatively richer in smectite, probably indicating some episodic marine influence; in what regards its upper section, it shows again a very significant increase of Factor 1 values, meaning an increase in kaolinite, accompanied by some vermiculite, pointing out to a relative recover of intensity of the detritical supply.

This trend follows up along the fourth unit, the richer in kaolinite and vermiculite.

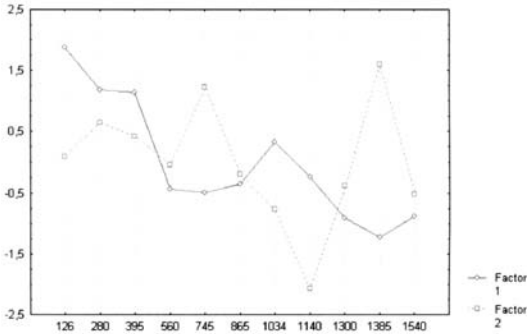

Figure 9.
Factor Scores vertical evolution (clay fractions).

CONCLUSIONS

In both studied fractions, the distribution of the mineralogical assemblages identified along the sedimentary column is, in general terms, consistent with the previously defined units. The mineralogical data allowed the characterization of each one of these informal units.

The vertical evolution of both the mineralogical associations and the mineralogical *ratios*, as well as the Factor Scores, illustrated the oscillations of relative importance, intensity and hydrodynamics of the terrigenous supply (more important along unit 1, upper section of unit 3, and all unit 4) as well as the dichotomy of marine *versus* continental influences (general predominance of continental influences but with unit 2 and lower section of unit 3 showing evidences of some marine influences).

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