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Miocene sediments from Foz da Fonte and Penedo sections (Lower Tagus basin): clay minerals and isotopic data

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ABSTRACT

Key-words: Clay minerals; Isotopic data; Miocene; Lower Tagus Basin; Paleoenvironmental reconstruction.

Eight depositional sequences (DS) delimited by regional disconformities had been recognized in the Miocene of Lisbon and Setúbal Peninsula areas. In the case of the western coast of the Setúbal Peninsula, outcrops consisting of Lower Burdigalian to Lower Tortonian sediments were studied. The stratigraphic zonography and the environmental considerations are mainly supported on data concerning to foraminifera, ostracoda, vertebrates and palynomorphs.

The first mineralogical and geochemical data determined for Foz da Fonte, Penedo Sul and Penedo Norte sedimentary sequences are presented. These analytical data mainly correspond to the sediments' fine fractions. Mineralogical data are based on X-ray diffraction (XRD), carried out on both the less than 38 μm and 2 μm fractions. Qualitative and semi-quantitative determinations of clay and non-clay minerals were obtained for both fractions. The clay minerals assemblages complete the lithostratigraphic and paleoenvironmental data obtained by stratigraphic and palaeontological studies. Some palaeomagnetic and isotopic data are discussed and correlated with the mineralogical data. Multivariate data analysis (Principal Components Analysis) of the mineralogical data was carried out using both R-mode and Q-mode factor analysis.

RESUMO

Palavras-chave: minerais das argilas; dados isotópicos; Miocénico; Bacia do Baixo Tejo; reconstituição paleoambiental.

No Miocénico das regiões de Lisboa e da Península de Setúbal haviam sido reconhecidas oito sequências deposicionais (DS) limitadas por disconformidades. A zonação e as reconstituições paleoambientais foram obtidas, essencialmente, através do estudo de foraminíferos, ostracodos, vertebrados e palinomorfos.

No presente trabalho apresentam-se os primeiros resultados referentes à mineralogia e geoquímica das fracções finas dos depósitos miocénicos de Foz da Fonte, Penedo Sul e Penedo Norte. Os dados mineralógicos foram obtidos através de difracção de raios-X das fracções < 38μm e < 2 μm. Foram feitas determinações semi-quantitativas e qualitativas dos minerais argilosos e não argilosos. As associações de minerais argilosos foram utilizadas como complemento dos dados litostratigráficos e paleoambientais anteriormente definidos através de estudos de estratigrafia e paleontologia. Estabelecem-se correlações com dados paleomagnéticos e de isótopos estáveis (C, O) anteriormente obtidos de alguns dos níveis estudados. Foi levada a efeito análise multivariada (análise de componentes principais) dos dados mineralógicos recorrendo aos factores "R-mode" e "Q-mode".

INTRODUCTION

Detailed stratigraphic studies have been carried on in Lisbon and Setúbal Peninsula regions. Eight Miocene depositional sequences (DS) delimited by regional disconformities had been established. In the western coast of the Setúbal Peninsula, Lower Burdigalian to Lower Tortonian outcrops were studied. Environmental considerations that could be put forward were mainly supported by data on foraminifera, ostracoda, vertebrates and palynomorphs.

In the present work, the first mineralogical and geochemical data for Foz da Fonte, Penedo Sul and Penedo Norte sedimentary sequences are presented (< 38 μm and < 2 μm fractions) (Fig.1). The clay mineral assemblages were used as lithostratigraphic markers for correlation and paleoenvironmental reconstruction.

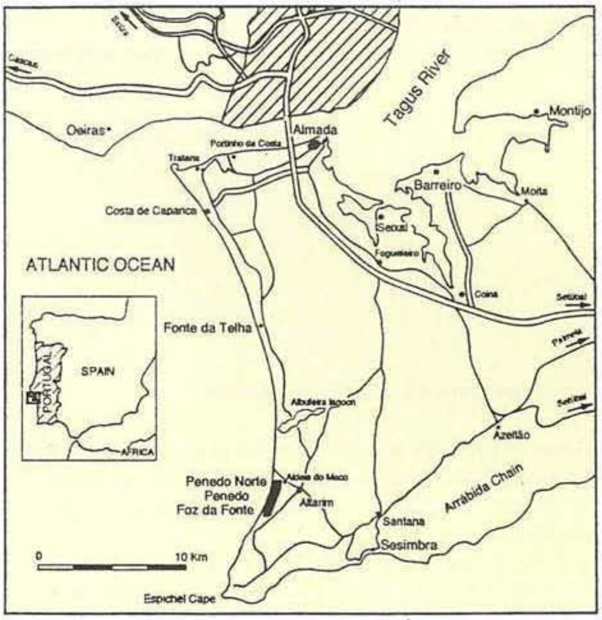

Fig.1 – Geographic setting of the area under study.

GEOLOGICAL SETTING

The oldest Miocene sediments outcrop on the cliffs at Foz da Fonte beach. Miocene sediments directly overlie Cretaceous limestones at a low angle unconformity. They consist essentialy of fossiliferous biocalcarenites and marls. The lowermost beds include cobbles and pebbles of Cretaceous volcanites and limestones. In the lower part of the section, a sandy bed corresponds to a regression event. The middle section presents detrital shallow facies and eroded surfaces. One of these is overlain by a remarkable concentration of oyster shells. The upper part of the section shows a marl/marly clay cyclic character.

Penedo Sul outcrop is exposed on the cliff at Bicas beach. Basal beds (fossiliferous biocalcarenites and sandstones with sedimentary discontinuities) are the same as in the intermediate part of Foz da Fonte section.

Penedo Norte outcrop is located about 1Km to the north of Penedo Sul. Zbyszewski (1967) correlates the Penedo Norte section with the classical units "Helvetian" VIa-b which occur in the Lisbon region. There is an erosion surface between beds 5 and 6, on which lies a conglomerate whose elements mainly consist of very abraded bivalve casts with a black, phosphate-rich patina (L. Gaspar, Marine Geology Lab., Portuguese Geological Survey). The conglomerate corresponding to bed 8 contains glauconite and fragments of phosphate crusts.

MATERIALS AND METHODS

Fifty one samples, collected at the Foz da Fonte, Penedo Sul and Penedo Norte outcrops (Fig. 1), were studied.

The mineralogical composition of the sediments, particularly of their fine fractions, was determined through X-ray diffraction (XRD) patterns corresponding to less than 38 μm and 2 μm fractions. Qualitative and semi-quantitative determination of clay and non-clay minerals was carried out on both studied fractions.

Palaeomagnetic and isotopic previously obtained (Antunes *et al.,* 1996; 1998; 1999; 2000) are correlated with mineralogical data.

Multivariate data analyses (Principal Components Analysis) of the mineralogical data were carried out (R-mode and Q-mode factor analysis).

RESULTS AND DISCUSSION

Foz da Fonte Section (Figs. 2 - 5)

Fine fractions of Lower Miocene (lower Burdigalian, depositional sequence B0) sediments from Foz da Fonte section consists of non-clay minerals (quartz, phyllosilicates, calcite, plagioclase and K-feldspar), and clay minerals (illite, smectite, kaolinite and rare chlorite). The depositional sequence B1 mineral composition appears to be richer in carbonates and in opal C/CT. It shows sharp oscillations as far as smectite is concerned and slight oscillations in illite and kaolinite contents. Variations on the relative contents of the clay minerals (Fig. 3) allowed the definition of four mineralogical units in the Foz da Fonte section (the most represented clay minerals are underlined):

1. illite + smectite + kaolinite (ISK);
2. illite + kaolinite + smectite (IKS);
3. smectite + illite + kaolinite (SIK);
4. smectite + illite + kaolinite (SIK).

Antunes *et al.* (1999) point out a $^{87}Sr/^{86}Sr$ age of 20Ma approximately, for the lower beds. Disconformities can be observed in the intermediate part of the section. The isotopic data ($\delta^{18}O$ and $\delta^{13}C$ values) show clear changes between depositional sequences B0 and B1 (Fig. 4).

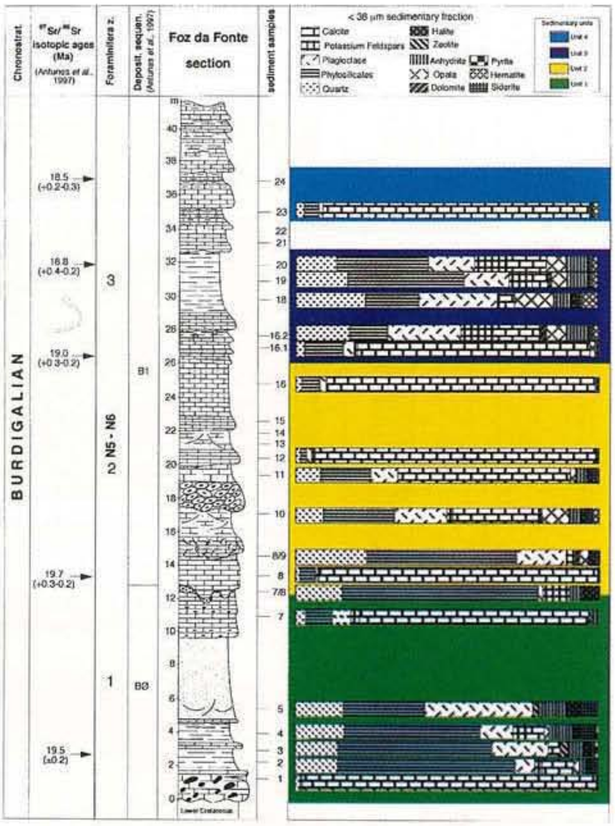

Fig. 2 - Foz da Fonte Section. Composition of the < 38μm sedimentary fraction.

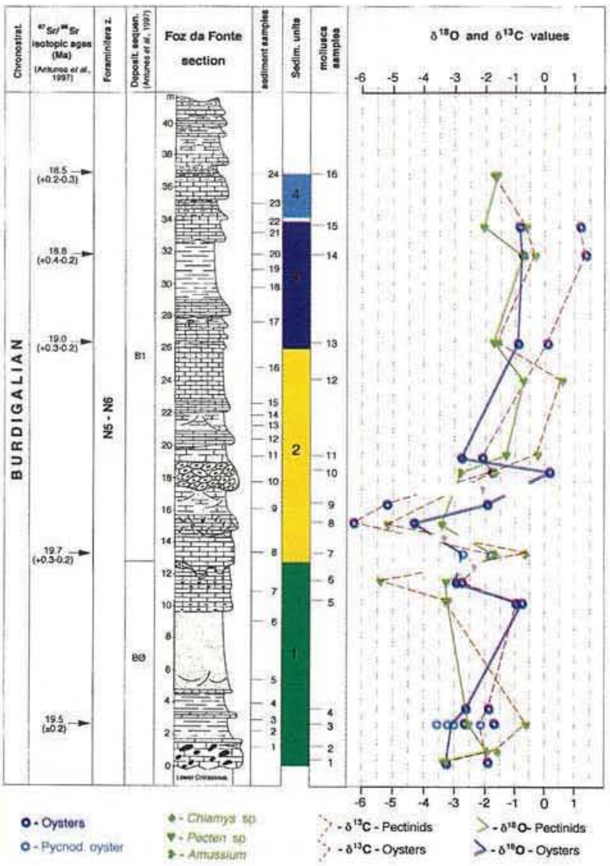

Fig. 4 - Foz da Fonte Section. C and O isotopic composition (Antunes *et al.*, 1997).

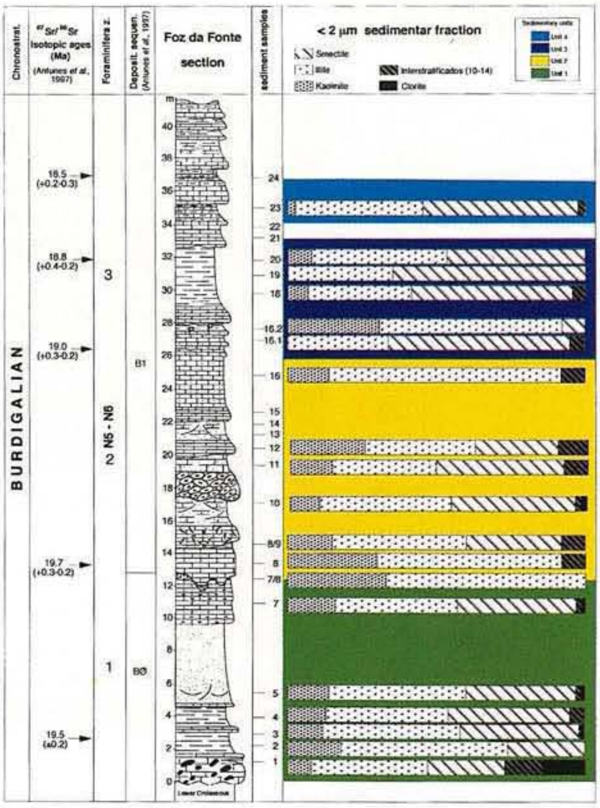

Fig. 3 - Foz da Fonte Section. Composition of the < 2 μm sedimentary fraction.

Penedo Sul Section (Figs. 6 - 9)

The mineral composition (fine fractions) of the Lower Miocene (Burdigalian) depositional sequence B0 at Penedo Sul consists in calcite, quartz, phyllosilicates, plagioclase and K-feldspar, and clay minerals such as smectite, illite, kaolinite and rare chlorite. Mineral composition, on the passage to depositional sequence B1, becomes richer in detrital minerals (quartz, phyllosilicates and plagioclase) and, in much less degree, in dolomite and opal C/CT. The calcite content diminishes; there are slight oscillations in smectite, illite and kaolinite contents. Variations of the relative contents of clay minerals (Fig. 8) were used to recognize four mineralogical zones:

1. illite + kaolinite (IK);
2. smectite + illite + kaolinite (SIK);
3. smectite + illite + kaolinite (SIK);
4. illite + smectite + kaolinite (ISK).

Once again, the isotopic curves ($\delta^{18}O$ and $\delta^{13}C$ values) show clear changes between depositional sequences B0 and B1 and between B1 and B2 (Fig. 7).

Penedo Norte Section (Figs. 10 -13)

The fine fractions of the lower beds of Penedo Norte depositional sequence B2 (Burdigalian) essentially consist

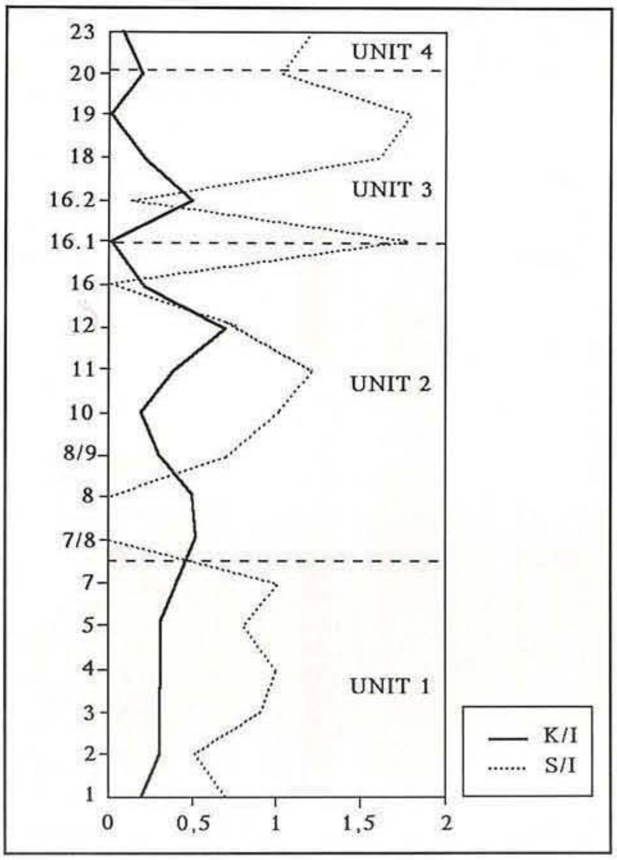

Fig. 5 - Foz da Fonte: variations on the relative contents of the main clay minerals K/I - Kaolinite/Illite; S/I - Smectite/Illite.

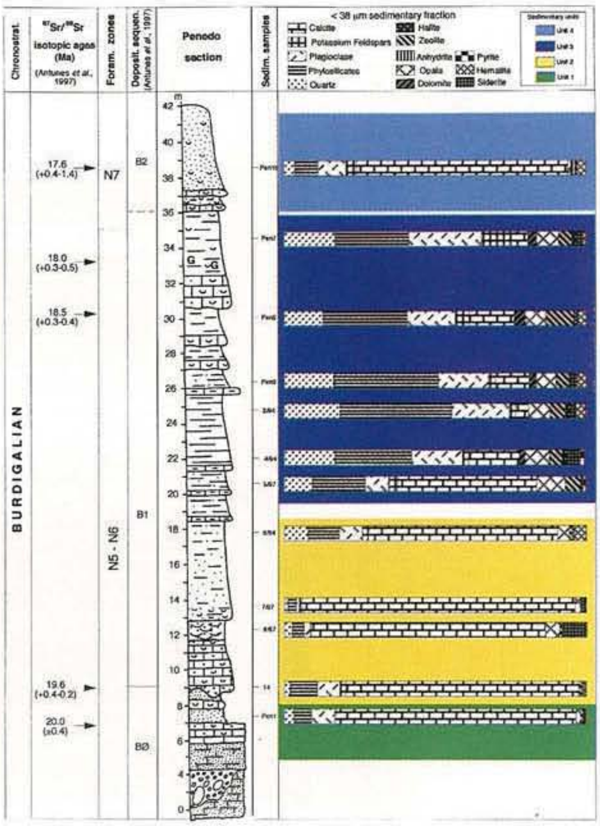

Fig. 6 - Penedo Sul Section, < 38µm sedimentary fraction.

of quartz, phyllosilicates, plagioclase and K-feldspar, and opal C/CT and calcite as accessory minerals. Smectite, illite and kaolinite are the clay minerals. The Burdigalian section becomes enriched in calcite and (much less) in illite. The medium levels (Langhian, depositional sequence L1) are characterised by a strong increase in dolomite in the fine fractions, and by minor changes in the clay minerals associations (slight increase in illite and loss of smectite). The Serravallian part of the section (depositional sequences S1, S2 and T1) becomes much richer in calcite (almost monomineralic), with a strong increase of illite. The relative contents of clay minerals were used to characterize four mineralogical zones (Fig. 11) on Penedo Norte outcrop:

4. smectite + illite + kaolinite (SIK);
5. illite + smectite + kaolinite (ISK);
6. illite + kaolinite + smectite (IKS);
7. smectite + illite + kaolinite (SIK).

Pectinid shells from bed 8 were $^{87}Sr/^{86}Sr$ dated (H. Elderfield, Cambridge University) from 11.5 to 13Ma. Bed 9 is a medium grained, glauconite rich sandstone; K-Ar age (C. Regêncio Macedo, Coimbra University) is 10.97±0.25 Ma (Lower Tortonian). Isotopic data ($\delta^{18}O$ and $\delta^{13}C$ values) do not show so sharp disconformities between the depositional sequences as in the preceding outcrops.

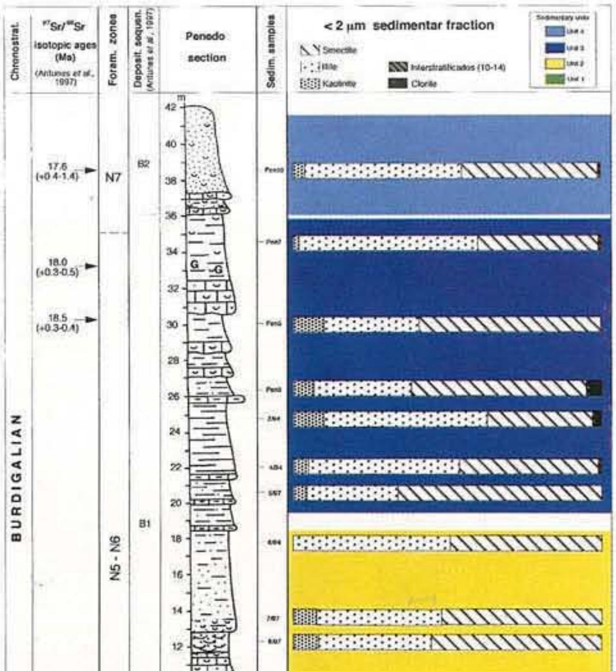

Fig. 7 - Penedo Sul Section. Composition of the <2µm sedimentary fraction.

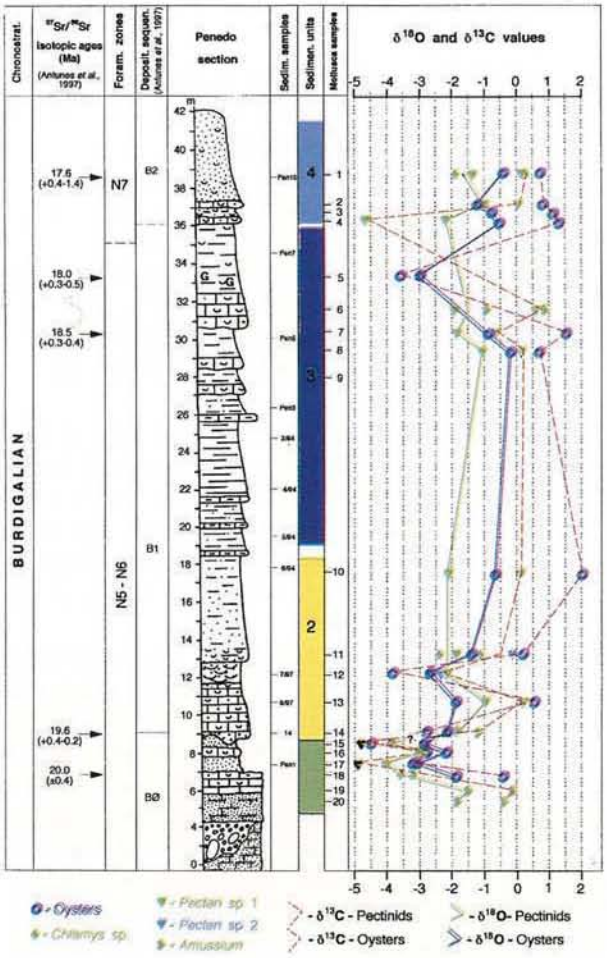

Fig. 8 - Penedo Sul Section, C and O isotopic composition (Antunes *et al.*, 1997).

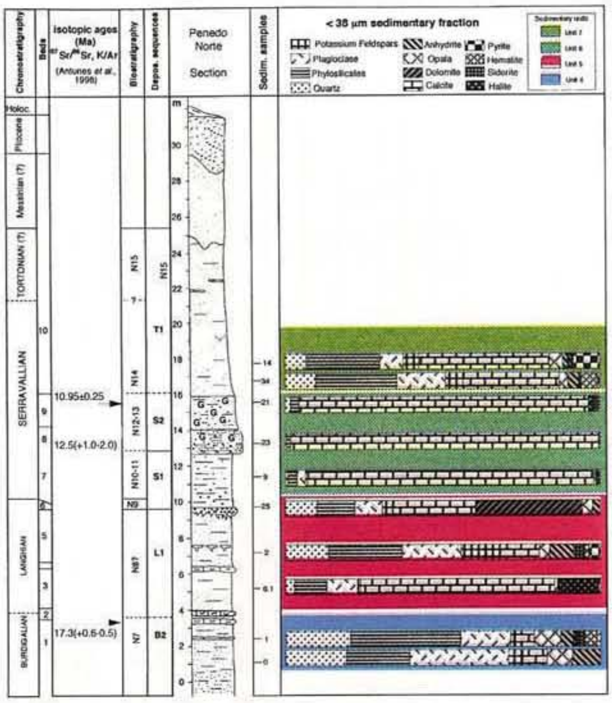

Fig. 10 - Penedo Norte Section, < 38µm sedimentary fraction.

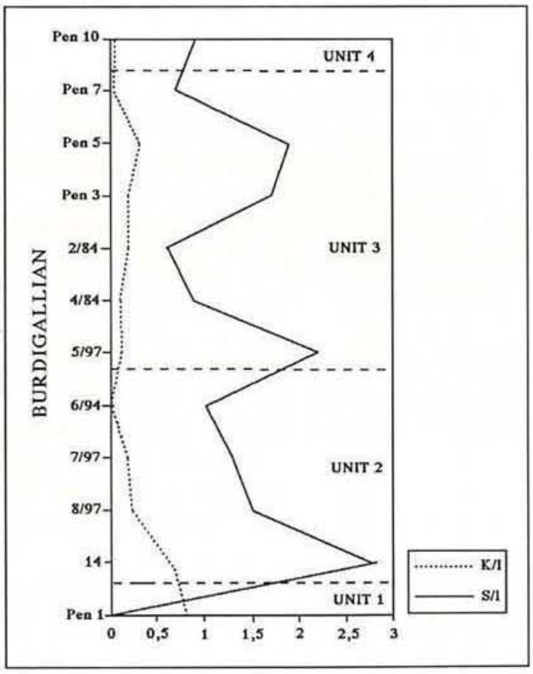

Fig. 9 - Penedo Sul: variations on the relative contents of the main clay minerals. K/I - Kaolinite/Illite; S/I - Smectite/Illite.

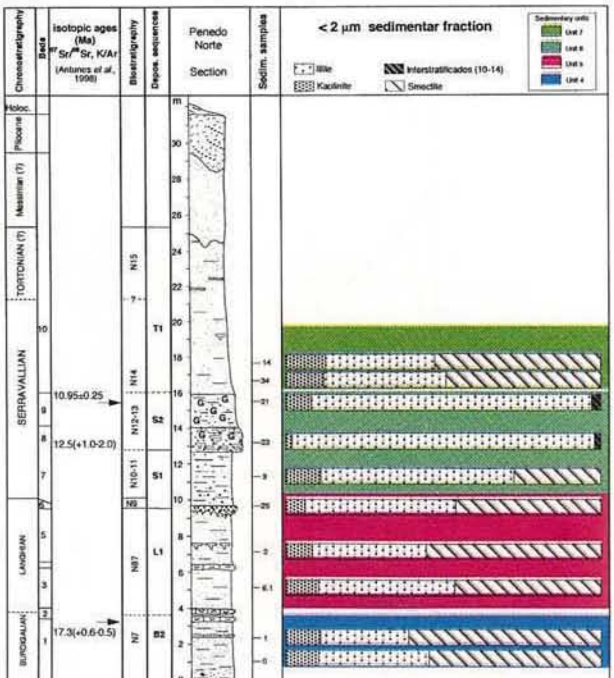

Fig. 11 - Penedo Norte Section, < 2 µm sedimentary fraction.

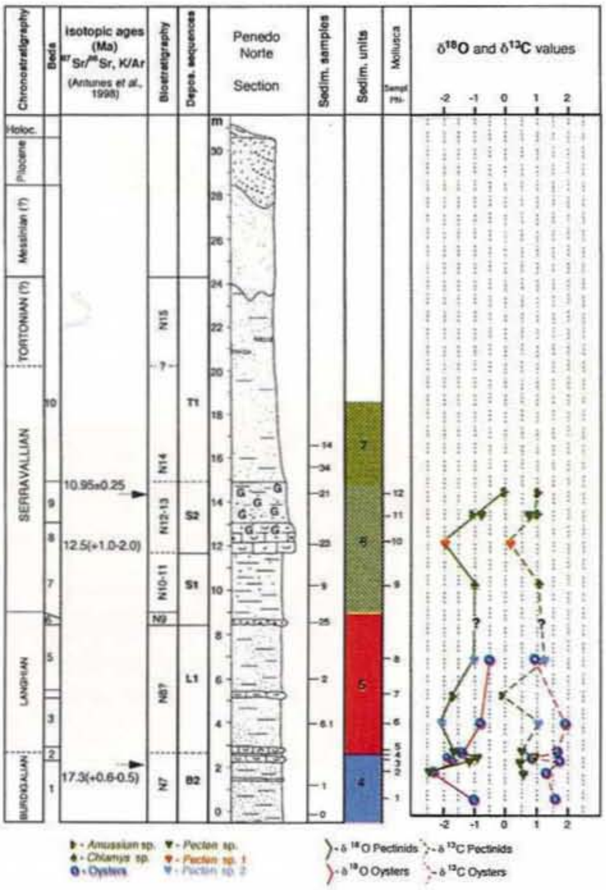

Fig. 12 - Penedo Norte section, C and O isotopic composition (Antunes *et al.*, 1996).

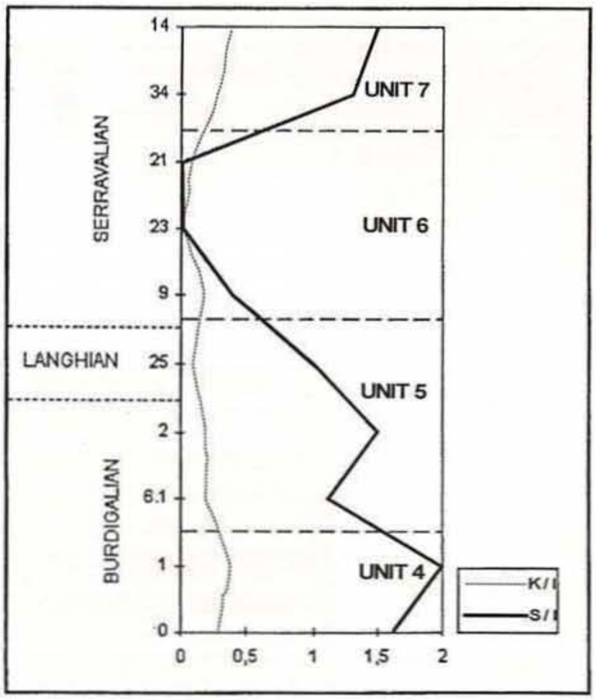

Fig. 13 - Penedo Norte: main clay minerals. K/I - Kaolinite/ Illite; S/I - Smectite/Illite.

Statistical analysis

The R-mode factor analysis of the Foz da Fonte Miocene profile fine fraction mineralogical data (Fig. 12) supports the following conclusions:

- Factor 1 shows zeolites (Zeol), pyrite (Pyr) and siderite (Sid) in front of K-feldspar (K-F);
- Factor 2 shows hematite (Hem), opal C/CT (Opal), plagioclase (Plag) and dolomite (Dol);
- Factor 3 shows calcite (Calc) in front of the quartz (Qz) and phyllosilicates (Kaol, Sm, Ill).

Factor 3 expresses the alternation of more or less marine environments (with events characterized by an intense detrital supply) with other ones marked by chemical sedimentation. Factor 1 stresses that there were transitions towards more proximal environments of lagoon type, under a more temperate climate; Factor 2 explains post-depositional parameters.

The vertical evolution of the Factor scores shows the impact of each Factor on the characterized zones and allows to recognize a paleoenvironmental evolution. Along Unit 1, the analysis of the evolution of the three Factors scores points out to a transition from a distal marine environment to a more proximal one, with some lagoon episodes. In Unit 2 oscillations of the relative impact of each Factor can be detected. This points out to an evolution towards more distal marine environments. The evolution of the Factors along Unit 3 reveals the occurrence of lagoon and fluvial episodes, alternating with marine ones. During the deposition of the sediments of the Unit 4, environment was again a more distal marine one.

The R-mode factor analysis of the mineralogical data of the Penedo Sul section fine fractions (Fig. 14) allows the following conclusions:

- Factor 1 shows calcite (Calc) in front of quartz (Qz), phyllosilicates (Kaol, Sm, Ill), K-feldspar (K-F), plagioclase (Plag), anhydrite (An), opal C/CT (Opal) and dolomite (Dol);
- Factor 2 shows siderite (Sid) in front of halite (Hal);
- Factor 3 shows pyrite (Pyr) in front of zeolites (Zeol).

Factor 1 expresses depositional environments of less marine influence, that are more proximal and more siliciclastic. Continental influence has been greater, with a few lagoon episodes, characterised by some chemical sedimentation. Factor 2 expresses an evolution towards lagoon environments; Factor 3 expresses a sharp evolution of the conditions expressed by Factor 2.

Once again, the vertical evolution of the Factor scores (Fig. 15) shows the role of each Factor on the distinctive zones being established; it allows the definition of their paleoenvironmental evolution. Along Unit 1 the evolution of the three Factor scores points out that sedimentation took place in a distal marine environment. In Unit 2 we can detect oscillations of the relative impact of each

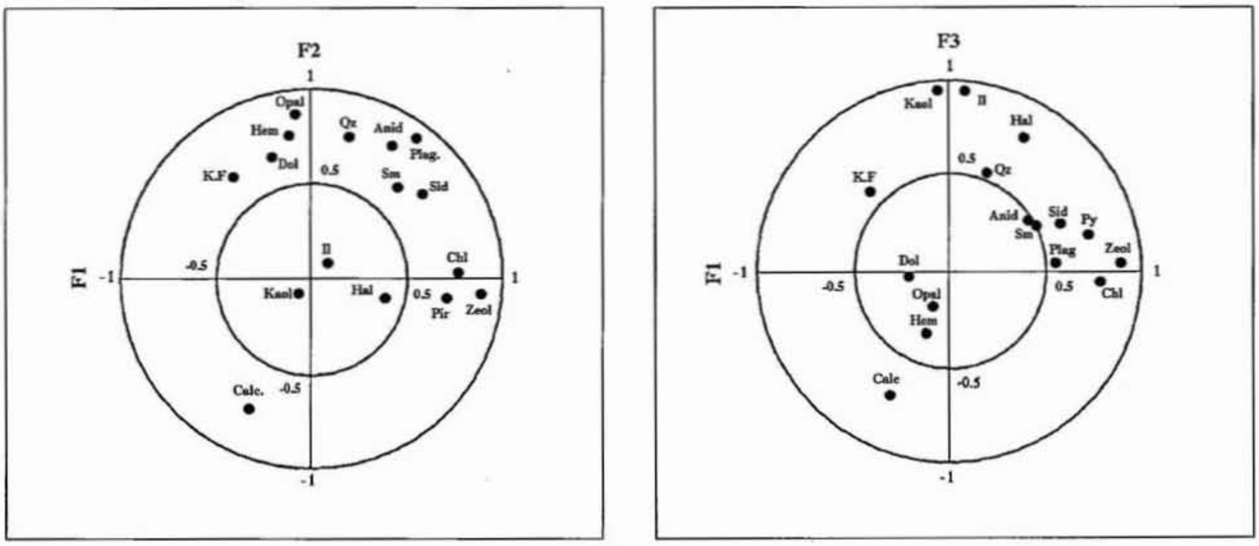

Fig. 14 - Foz da Fonte profile: R-mode factor analysis of the fine fraction mineralogical data .

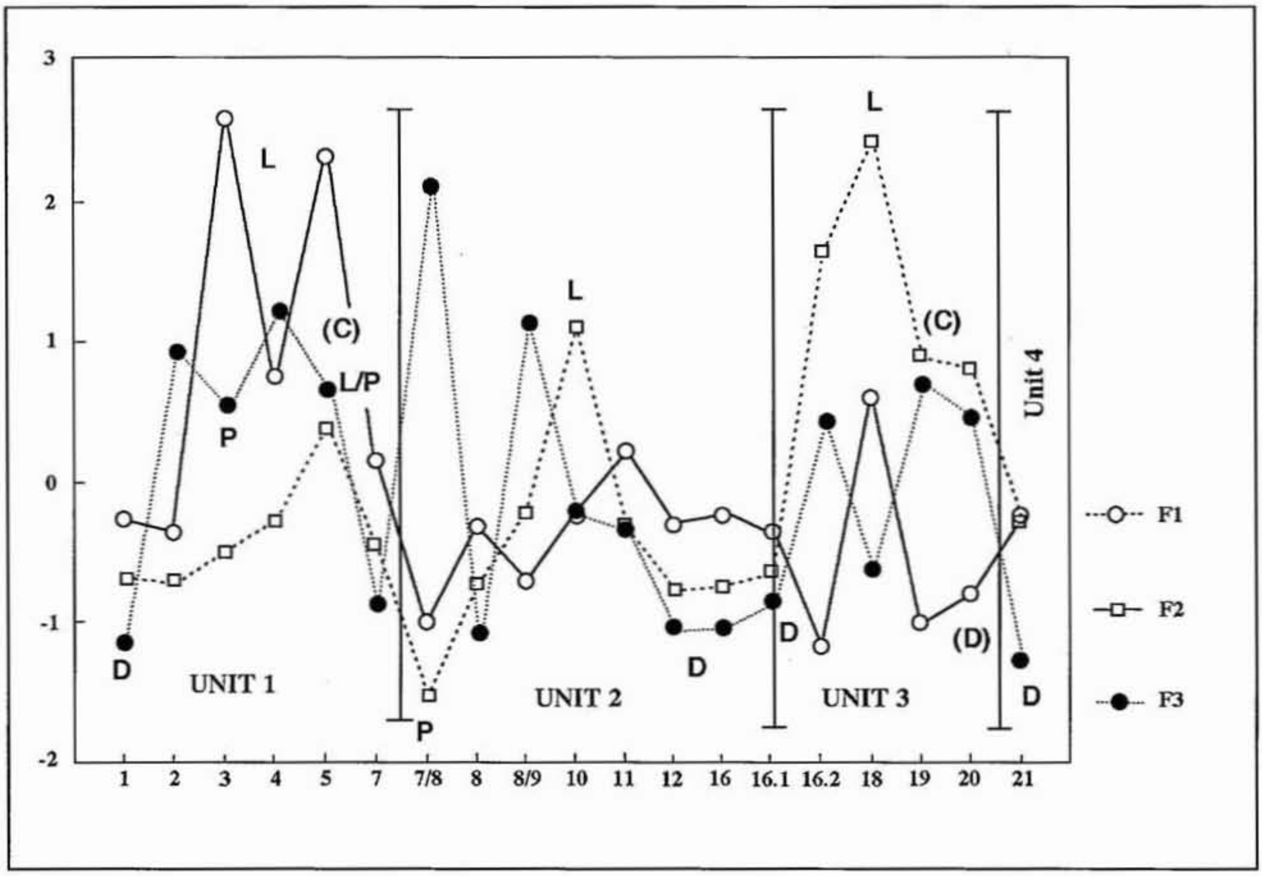

Fig. 15 - Foz da Fonte: vertical evolution of the Factor scores (). C - Continental; D – Marine, Distal; P – Marine, Proximal; L - Lagoon.

Factor, pointing out a gradual evolution towards a more proximal marine environment, with lagoon events. The evolution of the three Factors along Unit 3 reveals the persistency of alternating lagoon and marine events. During the deposition of Unit 4 environments became clearly marine.

The application of R-mode factor analysis to the fine fraction mineralogical data of Penedo Norte section (Fig. 17) allows us to recognize:

- Factor 1 shows calcite(Calc) in front of quartz (Qz), phyllosilicates (Kaol, Sm, Ill), plagioclase (Plag), opal C/CT (Opal), hematite (Hem) and anhydrite (An);
- Factor 2 shows siderite (Sid) in front of K-feldspar (K-F) and pyrite (Pyr);
- Factor 3 shows dolomite (Dol) in front of halite (Hal).

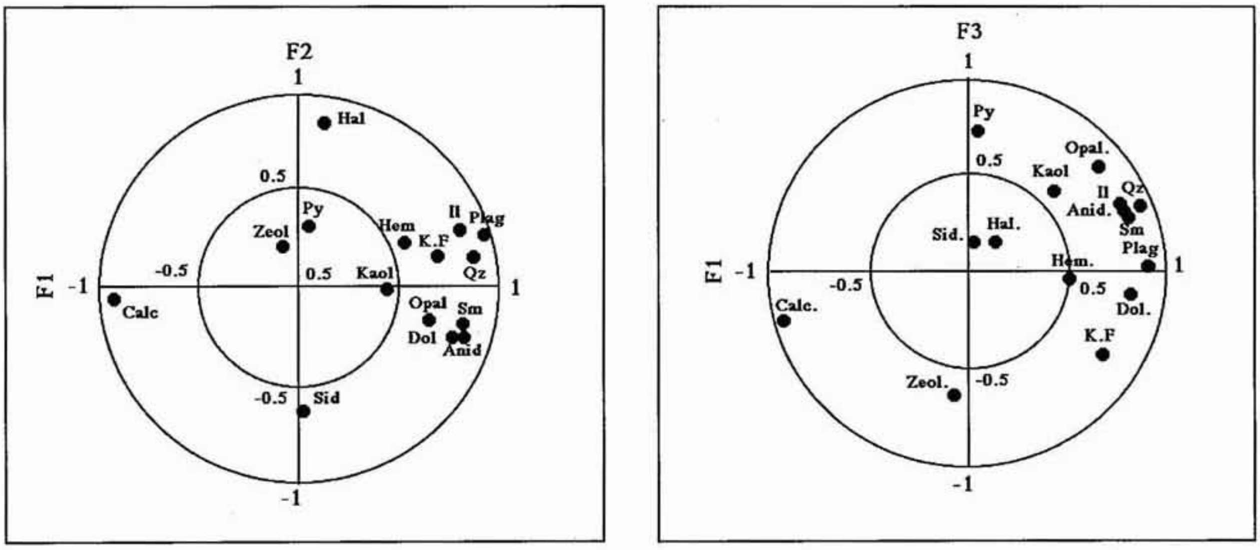

Fig. 16 - Penedo Sul profile: R-mode factor analysis of the fine fraction mineralogical data.

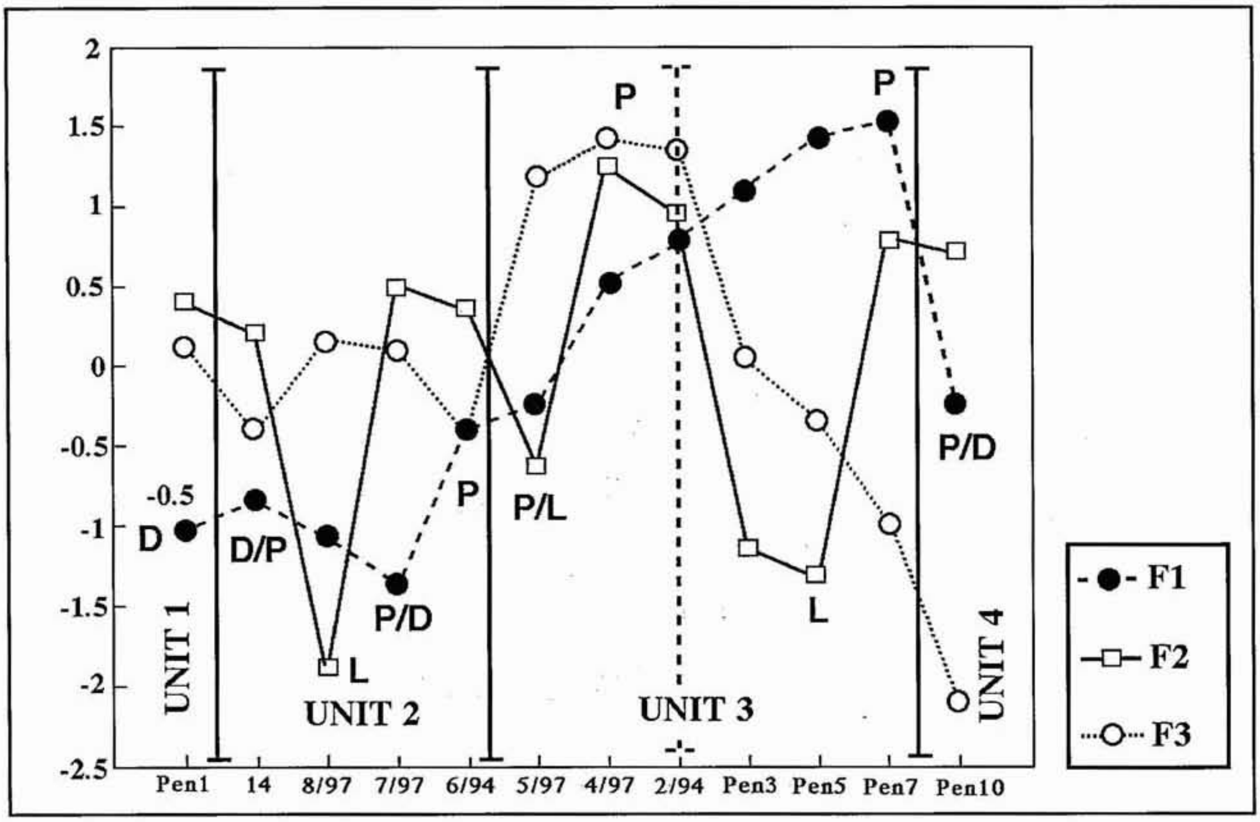

Fig. 17 - Penedo Sul: vertical evolution of the Factor scores. D – Marine, Distal; P – Marine, Proximal; L - Lagoon.

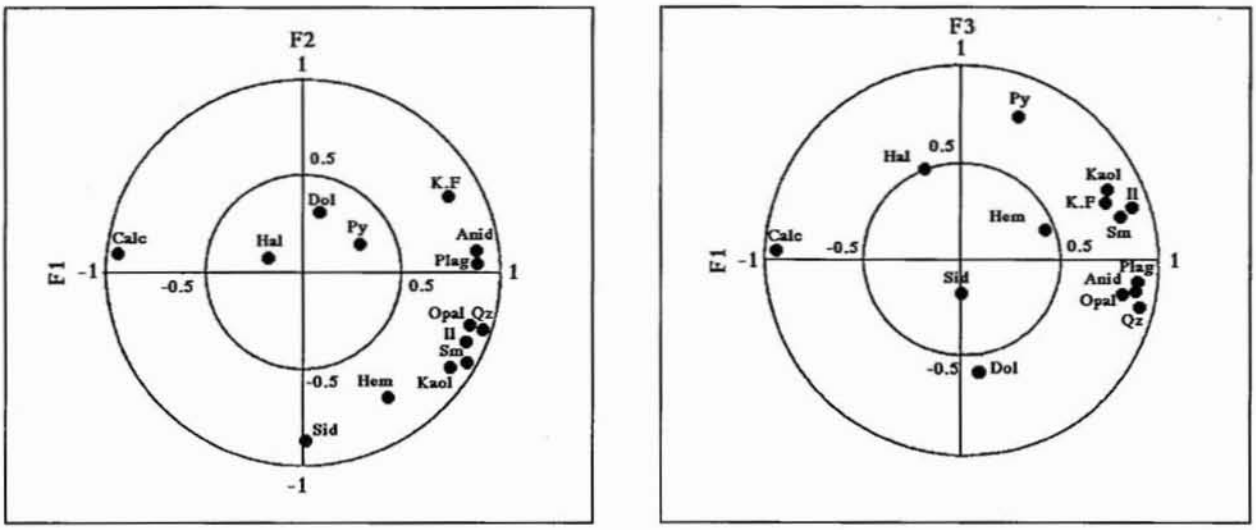

Fig. 18 - Penedo Norte profile: R-mode factor analysis of the fine fraction mineralogical data.

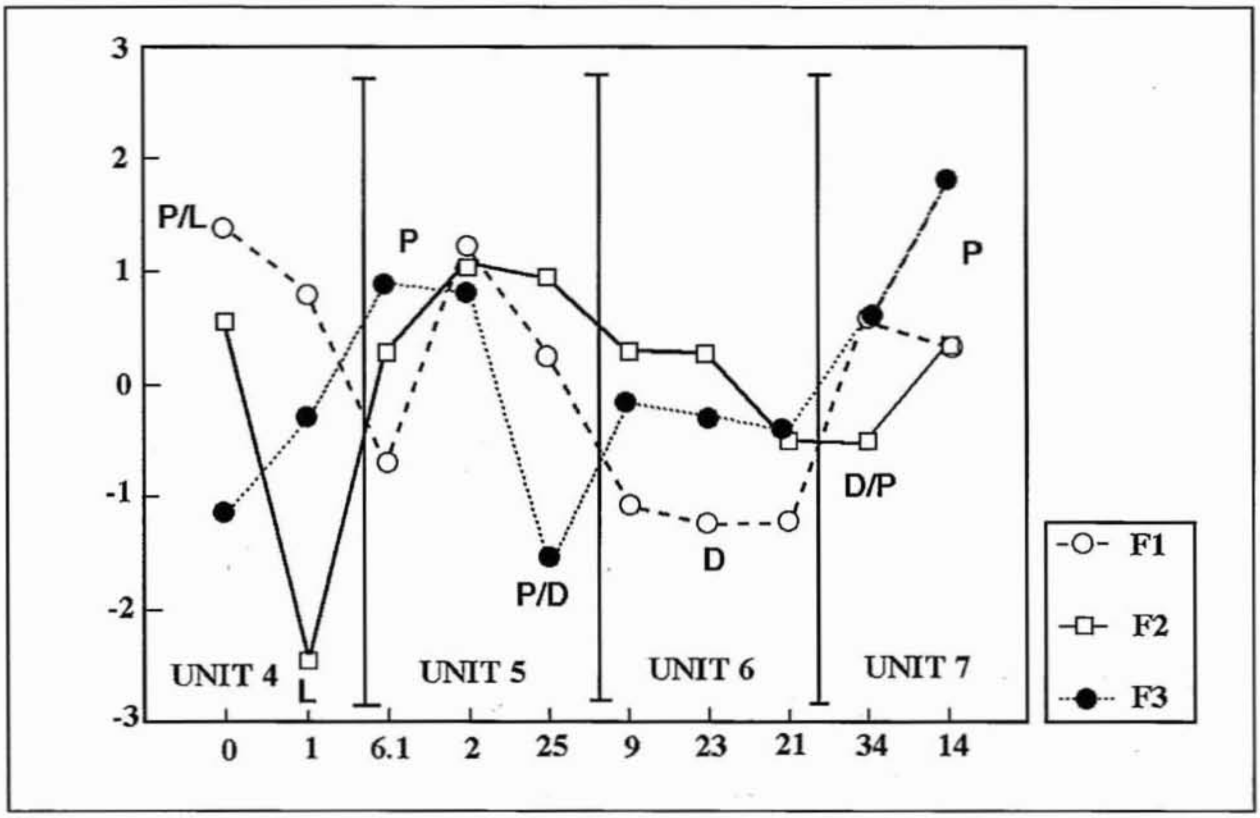

Fig. 19 - Penedo Norte: vertical evolution of the Factor scores (). D – Marine, Distal; P – Marine, Proximal; L - Lagoon.

Factor 1 expresses a depositional environment characterized by marine influence, comprising episodes of intensive detrital supply. The presence of hematite in this association (more clearly than in the other outcrops) may reflect some events of sub-aerian (fluvio-deltaic?) sedimentation. Factor 2 expresses a transition towards lagoon environments. Factor 3 explains post-depositional variables typical of marine environments.

The vertical evolution of the Factor scores (Fig. 17) shows the impact of each Factor in the characterized zones recognized in the Penedo Norte section. It provides additional data about paleoenvironmental evolution. Along Unit 4 the evolution of the three Factor scores points out to a transition from a proximal marine to a lagoon environment. In Unit 5, oscillations of the relative impact of each Factor show an evolution towards a more marine environment. The evolution of the Factors along Unit 3 reveals a distal marine environment. During the deposition of the sediments from Unit 4, environments reverted to more proximal marine ones.

CONCLUSIONS

1. Sediments of Foz da Fonte section are characterized by the following features: illite predominates over smectite, and kaolinite appears in significant amounts along all the section. Clay minerals and non clay mineral assemblages point out to source areas on which a semi-arid climate may have prevailed.

2. Sediments of Penedo Sul section are characterized by predominance of smectite over illite. Kaolinite becomes significant in the lower strata of the section (chlorite is but vestigial).

3. Sediments of Penedo Norte section are characterized by smectite predominance. However, illite becomes a major clay mineral in the upper strata of the section just where dolomite contents increases. Compared to those of the other two sections, these sediments display features that are characteristic of sedimentation in a deeper sea environment.

4 . Clay mineral assemblages allow to recognize seven mineralogical units (Fig. 19). The vertical evolution of the factor scores for each of the outcrops confirms the established zoning. It also reveals the impact of each Factor on the different distinctive zones, and therefore contributes to the characterization of a paleoenvironmental evolution (Fig. 20).

5. The time span of Unit 1 (Foz da Fonte and Penedo Sul sections) deposition is characterized by temperate climate and weak hydrolysing conditions in the source areas. Environment was infralittoral.

6. Unit 2 (Foz da Fonte and Penedo Sul) time span is characterized by some climate changes and circalittoral deposition environments that evolve to an infralittoral one.

7. Sediments of the Unit 3 (Foz da Fonte and Penedo Sul) reveal a subtropical climate and a somewhat more distal infralittoral deposition environment.

8. Sediments of the Unit 4 (all sections) also reveal a subtropical climate and an infralittoral environment that changes to circalittoral.

9. Unit 5 (Penedo Norte) indicate a deposition environment similar to that for Unit 3 but under milder temperate conditions.

10. Unit 6 (Penedo Norte) reveal a circalittoral deposition environment characterized by still more temperate conditions.

11. Finally, Unit 7 (Penedo Norte) is related to a more distal, infralittoral environment. Climate conditions in the source areas were typical of more contrasting and hydrolysing conditions that were in favour of smectic soils formation.

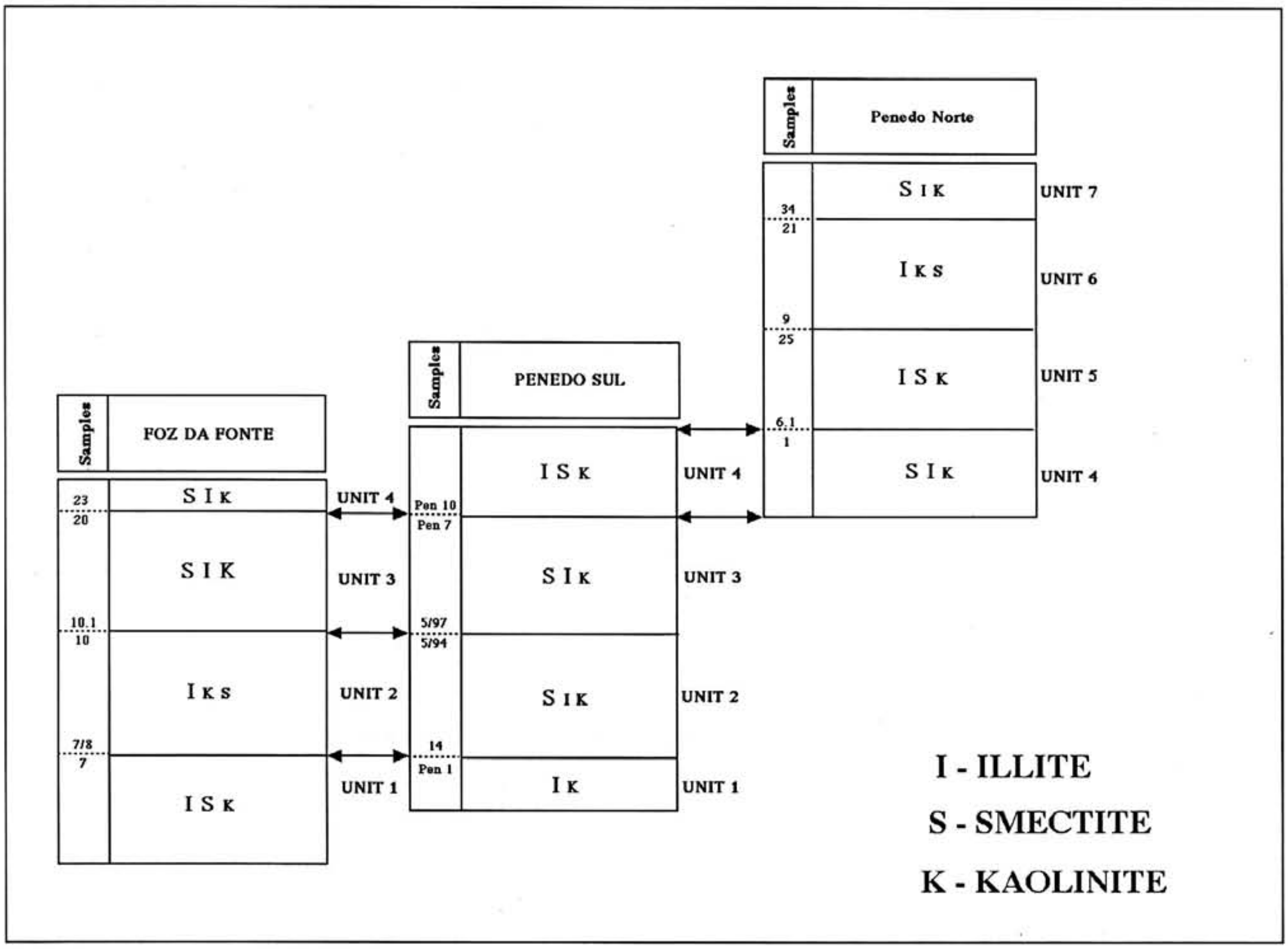

Fig. 20 - Clay mineral assemblages of the mineralogical units defined in the studied sections.

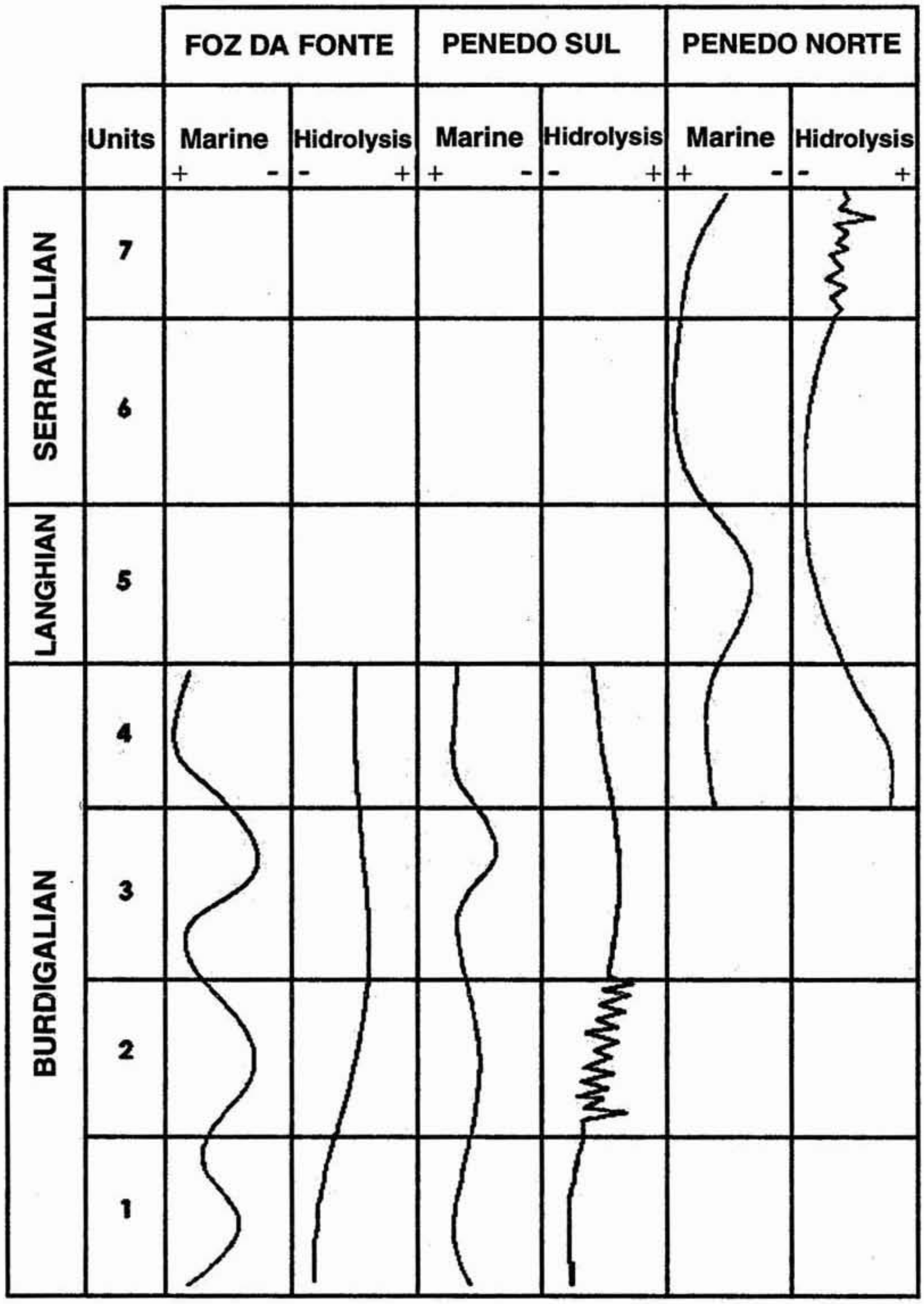

Fig. 21 - Paleoenvironmental evolution.

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