THALASSAS

Thalassas, 2004, 20 (2): 9-16
An International Journal of Marine Sciences

MINERALOGICAL CHARACTERIZATION OF THE FINE FRACTION OF THE BEACH AND DUNE SEDIMENTS SITUATED BETWEEN TRÓIA AND COMPORTA (PORTUGAL)

C. JESUS[(1)], J. VIDINHA[(1)], F. ROCHA[(1)] & A. OLIVEIRA[(2)]

Keywords: sediments, fine fraction, beach, dune, mineralogy

ABSTRACT

Recently an innovative mineralogical approach based on the study of the fine-grained fraction trapped in littoral sands, followed by statistical analysis of selected mineralogical ratios, was used to distinguish present-day beach and dune environments in the NW Portuguese coast (Espinho - Mondego Cape).

In this paper we present results from the mineralogical study of the silt+clay fraction entrapped in littoral (beach face, berm and foredune) sand sediments from a section of the Portuguese southwest coast (Tróia-Comporta). According to Dias (1987) and Magalhães (1999) this section present a completely different scenario in terms of physiographical, geological, oceanographical and climatological characteristics in contrast to the NW Portuguese coast and so ideial to test this mineralogical approach in a different environment.

A complex association of minerals has been identified and three mineralogical ratios were constructed (phyllosilicates/quartz+feldspars, quartz/feldspars and carbonate/detrital minerals) which express the relative importance of terrigenous contributions to the beach and dune sands and allow to highlight a number of statistically significant compositional differences between beach face, berm and foredune sands. The environmental contrasts exhibited by the two coastal sections suggest that this ability might be associated with relations that really exist between the different geomorphologic units and it isn't a mere product of local constraints.

(1) Centro de Minerais Industriais e Argilas.
Univ. de Aveiro, Campus Santiago, 3810-193 Aveiro, Portugal, cjesus@geo.ua.pt, jmvidinha@geo.ua.pt, frocha@geo.ua.pt
(2) Instituto Hidrográfico, Div. Geologia Marinha, Rua das Trinas, 49, 1249-093 Lisboa, Portugal,
anabela.oliveira@hidrografico.pt

INTRODUCTION

Silt and clay minerals assemblages have been used for recognition of sediment sources since the sixties. Changes in sources or in current activity often determine modifications of the mineral assemblages. Therefore, mineral (silt and clay) assemblages are useful as indicators of detrital sources. Mineral associations supplied from land to sea often experience further transportation through marine currents as well as re-sedimention processes, so they reflect the combined control of terrigenous supply and transportation agents and can be used to characterize present coastal water masses.

The ability of Folk & Ward's (1957) grain size parameters to distinguish sedimentary environments of the present day coastal zone has been a matter of controversy. In Portugal, that capability may not be present in well to very well sorted coastal sands, as shown by Vidinha (1995) in the Espinho-Cape Mondego coastal section (NW Portugal) and Teixeira (1990) in the Setúbal Peninsula (Lisbon area), confirming previous conclusions forwarded by Shepard & Young (1961).

In alternative to textural approach, Vidinha *et al.*, (1997[a,b,] 1998[a,b]) had developed mineralogical relations to differentiating the depositional environment, supported on the study of the mineralogical composition of the sediments with a granulometry least than 63 μm (silt+clay) imprisoned on the littoral sands.

Preliminary studies in the Espinho-Mondego Cape littoral (NW Portugal), show that although the amount of fine fraction was very small, it presents an interesting potential to differentiate the depositional environments.

We present here the results concerning a selected area, corresponding to the sand-spit Tróia-Comporta (fig.1). The coast under study extending along 18Km is high mesotidal according to Hayes (1979) and corresponds to a low-lying beach and dune section at the Sado estuary inlet. The geology of the Sado basin is essentially formed by Tertiary consolidated sediments and plio-quaternary deposits with Jurassic calcareous on the Arrábida cliffs (northern area).

In this paper a set of mineralogical results is presented and their ability to discriminate coastal sedimentary environments (beach face, berm and dune) is discussed using statistical analysis (Rocha, 1998; Rocha *et al.*, 2000).

MATERIALS AND METHODS

In the present study 34 beach-dune profiles in the littoral located between Tróia and Comporta were selected, spaced along the shore 500 meters. In every profile the superficial sediments deposited had been sampled (at least 1 litre, each sample), in order to preserve the textural signature of the last depositional event. Three sand samples were taken from each profile: foreshore (beach face at mid-tide level), back-beach (at half width of the higher berm) and foredune (upwind slope).

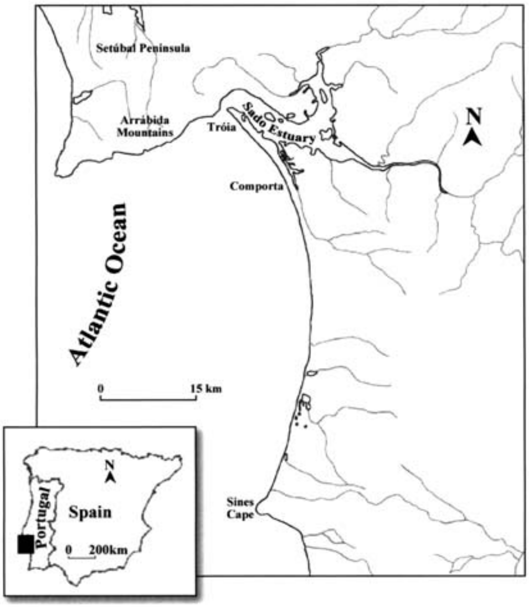

Figure 1.
Location map of the study area

In the laboratory, the fine (silt-clay) fraction was extracted by wet sieving, after ultrasonic processing of the total sample. The fine fraction mineralogical analysis was carried out by XRD in randomly orientated specimens of the fine fractions, based on the methodology of Rocha (1993). All samples were analysed in the range from 2º to 40º 2θ, at 1º 2θ/min, with Cu-Kα radiation. The XRD reflections were evaluated with the Phillips X'Pert 1.2 and Profit software.

Identification of minerals was performed in the diffractograms in accordance with methodology proposed by Schultz (1964) and Thorez (1976) and retaken by Rocha (op. cit.).

The relative content of each identified mineral was estimated on the basis of its characteristic peak area corrected by the corresponding reflective power recommended by Barahona (1974), Schultz (1964), Thorez (1976), Mellinger (1979) and Pevear & Mumpton (1989), with an analytical error of 1%.

Three mineralogical indexes were computed (according to Vidinha 2000): phyllo-silicates/quartz +feldspar (Phy/Qz+Feld), quartz/feldspar (Qz/Feld) and carbonates/detrital minerals (C/D) for each sample, and subsequently submitted to statistical analysis.

Phy/Qz+Feld and Qz/Feld *ratios* are related with the transport of detrital materials from the hydrographic basins of the nearby continental region (in the first case, the higher values indicating the lower hydrodynamic of the transportation agent, in the second case the opposite). The transversal variation of quartz (chemically and physically stable mineral) in relation with feldspars (minerals with low stability under most marine conditions, Rothwell, 1989) permits considerer the index of mineralogical maturity of sediments, in terms of there quartz contents in relation to the other minerals (K feldspars and plagioclase). The lower values indicate lower maturity.

C/D *ratio* expresses the dichotomy between the detrital transport and the biogenic component, the higher values indicating the lower contribution of detrital materials with higher contribution of biogenic materials.

In order to know if the fine fractions of the sedimentary environments present significant differences Mann-Whitney and two-samples Kolmogorov-Smirnov test were used.

The statistical non-parametric tests should be used in cases in which the parametric tests presuppositions do not verify (i.e., populations with normal distributions and variance homogeneity). The unique presupposed needed for this non-parametric tests is that the values of the variable in compare would be continuously distributed. In practices, we know that there is no inconvenient if this presupposition not verifies (Magalhães, F.; 1999).

The Mann-Whitney test is sensitive to the location parameter, since it is based in the order of observations and in differences of the observations location.

The Kolmogorov-Smirnov test is more complete since it has as null hypothesis (H_0) the identity of the two samples distribution, that is to say, the test is not only sensitive to the location differences but also dispersal, asymmetry and flattening differences of the distributions in study (Sokal, R. & Rohlf, F.; 1987).

RESULTS AND DISCUSSION

The silt-clay content of the beach and dune deposits sediments tend to decrease transversally from the beach face to the berm (fig.2).

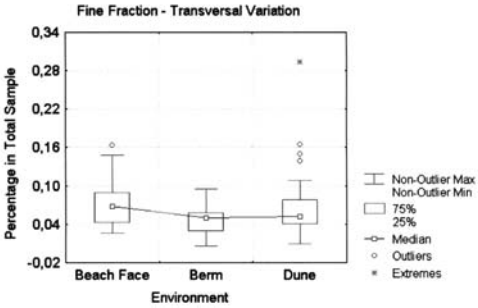

Figure 2. *Transversal variation of the fine fraction percentage in the sampled sediments*

This accumulation of fine sediments (<63µm) during the swash action is probably related to the infiltration of water, carrying the fine particles along. According to Hughes & Turner (1999) this fact contributes in a significant way for the up and downslope transport of sediments by swash flows. These authors verified that a reduction in energetics and hence sediment transport during the backwash may occur due to the infiltration of a portion of swash lens into an unsaturated beach face during uprush. In consequence, the proportion of fine sediments in the berm is lower than on the beach face.

Between the berm and dune geomorphologic environments exist a landward insignificant increase of fine sediments (table 1) that could be explained by the efficient aeolic transport in the berm environment, with some retention of fine sediments in dune deposits caused by local vegetation.

Table 1.
Application of the Mann-Whitney and Kolmogorov-Smirnov tests to medians values and distributions of fine fraction percentages, respectively;
(*) significant at a 0.05 level.

	Beach face *versus* Berm	Beach face *versus* Dune	Berm *versus* Dune
Mann-Whitney test	(*) t_s = 2.629; p=0.01	t_s = 0.272; p=0.27	t_s = 1.260; p=0.21
Kolmogorov-Smirnov test	(*) p<0.01	p>0.10	p>0.10

The fine fraction mineralogy of the different cross-shore profiles was organized, as shown by figure 3, in order to distinguish the three geomorphologic units under study (beach face, berm and dune).

The fine fraction (<63µm) of the studied sediments presents, as their most representative minerals: phyllosilicates (Phy, mainly micas), quartz (Qz) and calcite (Ca). These main minerals are usually accompanied by a relatively complex group of accessorial minerals, such as: K feldspars (Fk), plagioclase (P), Opal C/Ct (Op), zeolites (Ze, mainly clinoptilolite- heulandite), gypsum (Gy), bassanite (Bas), anhydrite (An), dolomite (Do), hematite (Hm), and magnetite-maghemite (Mm) and pyrite (Py).

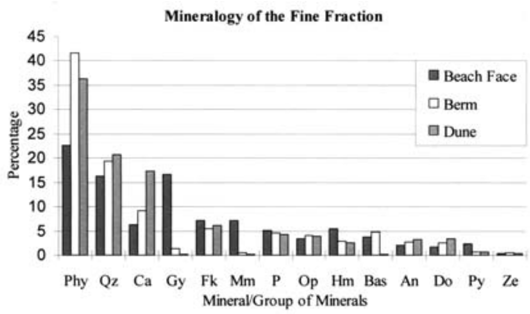

Figure 3.
Fine Fraction Mineralogy of the studied sedimentary environments (mean values).

Phy *- Phyllosilicates;* ***Qz*** *- Quartz;* ***Ca*** *- Calcite;*
Gy *- Gypsum;* ***Fk*** *- K feldspars;* ***Mm*** *- Magnetite/Maghemite;*
P*- Plagioclase;* ***Op*** *- Opal C/Ct;*
Hm *- Hematite;* ***Bas*** *- Bassanite;* ***An*** *- Anhydrite;*
Do *- Dolomite;* ***Py*** *- Pyrite;* ***Ze*** *- Zeolites.*

The results obtained so far suggest that the mineralogy's heterogeneity decrease landward, with some of the identified accessory minerals almost absent in the fine fraction of the dune sediments, such as: gypsum, magnetite-maghemite, bassanite and pyrite.

On the other hand, we verify a clear tendency for the increment of quartz and calcite (and, on a lesser scale, dolomite) on the dune deposits.

As it was referred before, we computed, for each analyzed sample, three mineralogical *ratios*: phyllosilicates/(quartz+feldspars), quartz/feldspars and carbonates/detrital minerals.

These *ratios* were subsequently submitted to statistical analysis allowing to highlight the mineralogical compositional differences between the three studied geomorphologic units (beach face, berm and foredune sands).

Their main statistical parameters (such as Median, Minimum and Maximum values), for each one of the studied geomorphologic units, are shown on tables 2 (carbonates/detrital minerals - C/D *ratio*), 3 (phyllosilicates/quartz+feldspars - Phy/Qz+Feld *ratio*) and 4 (quartz/feldspars - Qz/Feld *ratio*).

Table 2. *Main statistical parameters of the C/D ratio.*

C/D Ratio			
	Beach Face	Berm	Dune
Median	0,11	0,14	0,31
Minimum	0,02	0,08	0,16
Maximum	0,73	0,44	0,45
N	35	34	35

Table 3. *Main statistical parameters of the Phy/Qz+Feld ratio*

Phy/Qz+Feld Ratio			
	Beach Face	Berm	Dune
Median	0,82	1,32	1,16
Minimum	0,16	0,75	0,42
Maximum	1,95	2,55	1,85
N	35	34	35

Table 4. *Main statistical parameters of the Qz/Feld ratio*

Qz/Feld Ratio			
	Beach Face	Berm	Dune
Median	1,30	2,10	2,07
Minimum	0,57	1,00	0,97
Maximum	10,00	3,73	3,50
N	35	34	35

In general terms, phyllosilicates/(quartz+feldspars) and quartz/feldspars *ratios* show an increment of their median values from Beach face to Berm deposits, then a decrease (very discrete in the late *ratio*) from Berm to Dune deposits.

On the other hand, carbonates/detrital minerals *ratio* show a slight increase of its median values from Beach face to Berm deposits, then a more pronounced increase from Berm to Dune deposits.

The transversal variation of the C/D *ratio* expresses the variation of the carbonates (calcite and dolomite) in relation to the main siliciclastic detrital minerals (quartz + phyllosilicates + k-feldspars + plagioclases) as shown in figure 4.

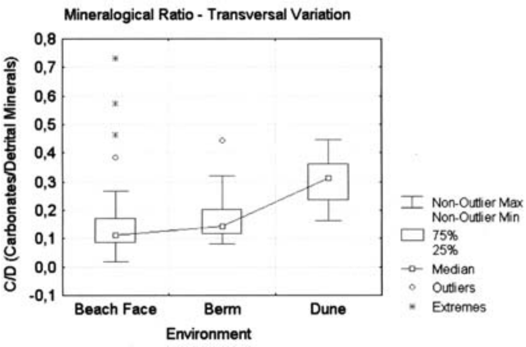

Figure 4.
Transversal Variation of the C/D (Carbonatos /Detrital Minerals)

In order to test the capacity of this *ratio* to discriminate sedimentary environments, there were applied the non-parametric tests of Mann-Whitney (table 5) and Kolmogorov-Smirnov (table 6) to successive pairs (beach face *versus* berm, beach face versus dune and berm versus *dune*).

Table 5.
Application of the Mann-Whitney test to the medians values of the mineralogical ratios;
(*) significant at a 0.05 level.

Mann-Whitney test			
	Beach face *versus* Berm	Beach face *versus* Dune	Berm *versus* Dune
C/D	t_s = 1.950; p=0.051	(*)t_s = 5.339; p=0.00	(*)t_s = 5.845; p=0.00
P/Qz+F	(*)t_s = 5.641; p=0.00	(*)t_s = 3.882; p=0.00	(*)t_s = 2.437; p=0.01
Qz/F	(*)t_s = 4.045; p=0.00	(*)t_s = 4.341; p=0.00	t_s = 0.276; p=0.78

Using the non-parametric test of Mann-Whitney (table 5), there are no significant (p=0.05) differences between the beach face and berm deposits.

Table 6.
Application of the Kolmogorov-Smirnov test to the distributions of the mineralogical ratios; The comparison marked (*) is significant at a 0.05 level.

Kolmogorov-Smirnov test			
	Beach face *versus* Berm	Beach face *versus* Dune	Berm *versus* Dune
C/D	(*)p<0.05	(*)p<0.01	(*)p<0.01
P/Qz+F	(*)p<0.01	(*)p<0.05	p>0.25
Qz/F	(*)p<0.001	(*)p<0.001	p>0.10

However, the non-parametric test of Kolmogorov-Smirnov (table 6) indicates that all environments are significantly different (with p<0.05), concretely the distributions of the three populations. This fact points to:

- •different provenience of the sediment in the same environment because the *ratio* distribution varies considerably in the three environments which takes us to consider several sources that affect differently the three environments;

- •different pos-depositional evolution between the three environments through the littoral.

Considering the first hypothesis we could explain the high content of carbonates in the dune deposits by assuming two sources of carbonates: detrital particles (since in the northern area - Arrábida cliffs - there is abundant Jurassic calcareous) and accumulation of biogenic particles (e.g. nannoplankton and fragments of bivalves shells).

As it was referred, the Phy/Qz+Feld *ratio* is related with the transport of detrital materials from the hydrographic basins of the nearby continental region, its higher values indicating lower hydrodynamism of the transportation agent.

Observing the variation of this *ratio* (fig. 5) the minimum value corresponds to the beach face which leads to a small amount of phyllosilicates (<2µm) relatively to quartz and feldspars contents in this environment. We already see that the beach face is the richer in fine sediments, however is the poorest in phyllosilicates (fig.6). These minerals have larger propensity to be carried by the uprush to the swash action upper limit than the other coarser minerals in the fine fraction (quartz and feldspars), which are trapped in the sands, as a result of infiltration. This way, the maximum value corresponds to the berm deposits, and it could be explained by the accumulation of phyllosilicates in the process of landward transport related with the berm wash over.

This *ratio* decreases in the foredune deposits, most probably because of the aeolic dynamics that allows the quartz accumulation but not of the phyllosilicates.

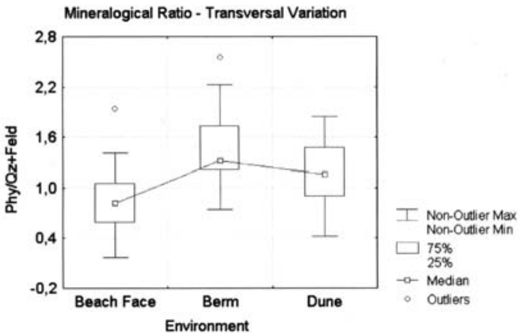

Figure 5.
Transversal Variation of the Phy/Qz+Feld

The Mann-Whitney test (p=0.05) suggest (table 5) that exist significant differences between the environments, while Kolmorov-Smirnov test (table 6) puts in evidence significant differences between the beach face and the other two geomorphologic units.

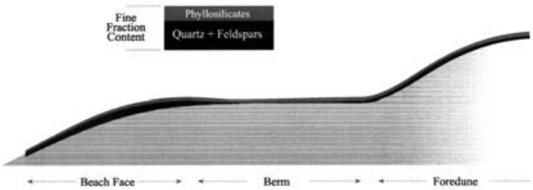

Figure 6.
Schematic illustration of the profile variation of fine fraction with the phyllosilicates and quartz+feldspars proportions.

The Qz/Feld *ratio* is related with the transport of detrital materials from the hydrographic basins of the nearby continental region and with the maturity of sediments, increasing as the sediment maturity increase also.

Figure 7 shows that the fine fraction sediments of the beach face present a *ratio* value lower than the other two environments, which leads to sediments less matures in a high sediment dynamic environment.

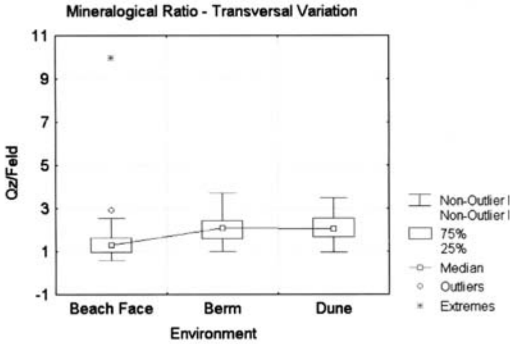

Figure 7.
Transversal Variation of the Qz/Feld

Through the Mann-Whitney test (table 5) we observe that there are significant differences only in the cases of beach face versus berm and beach face *versus* dune.

Using the Kolmogorov-Smirnov test (table 6), exists a very significant difference between the *ratios* distributions of beach face *versus* berm and beach face versus dune; however it seems that there is no significant difference between the *ratio* distributions of berm and dune environments.

CONCLUSIONS

1) The fine fraction mineralogy in Tróia sandy spit is mainly composed by phyllosilicates (mainly micas), quartz and calcite accompanied by a relatively complex group of accessorial minerals.

2) The mineralogy's heterogeneity decrease landward, with some of the identified accessory

minerals almost absent in the fine fraction of the dune sediments, such as: gypsum, magnetite-maghemite, bassanite and pyrite.

On the other hand, we verify a clear tendency for the increment of quartz and carbonates (calcite and dolomite) on the dune deposits with the last ones increasing in a major proportion in relation to quartz minerals, according to the C/D *ratio* transversal variation. This calcite content in fine sediments seems to have both origins: detrital and biogenic.

3) The results show that the fine fraction, although in very small amounts, exhibits an interesting discriminating potential of the deposition environment, as Vidinha *et al.* (1998 a, b) observed in the Espinho - Cape Mondego costal sector - NW of Portugal, particularly the mineralogical *ratio* C/D that has significant differences in the two tests between the dune and the beach environments (beach face and berm) as well as the Phy/Qz+Feld and Qz/Feld *ratios* that seem to be useful to distinguish the beach face from the two others deposits (berm and dune).

4) The environmental contrasts exhibited by the two coastal sections (NW and SW Portuguese coast) suggest that this ability might be associated with relations that really exist between the different geomorphologic units and it isn't a mere product of local constraints.

ACKNOWLEDGEMENTS

This research was partially supported by the Portuguese Science Foundation "Fundação para a Ciência e a Tecnologia (F.C.T.)" through a scholarship granted to the first author.

REFERENCES

Barahona, E. (1974). Arcillas de ladrillería de la provincia de Granada: evaluación de algunos ensayos de materias primas, Ph.D. Thesis, Granada Univ., Spain, 398pp.

Dias, J.M. (1987). Dinâmica Sedimentar e Evolução recente da Plataforma Continental Portuguesa Setentrional , Ph.D. Thesis, Lisboa Univ., Lisboa, 384p..

Folk, R. & Ward, W. (1957). Brazos River Bar: A Study in the Significance of the Grain size Parameters, Journ. Sedim. Petrol., 27 (1), pp.3-26.

Hayes, M.O. (1979). Barrier island morphology as a function of tidal and wave regime. In: Leatherman, S. (Ed.), Barrier Islands from Gulf of St. Lawrence to the Gulf of Mexico, Academic Press, New York.

Hughes, M. & Turner, I. (1999). The beachface. In: Short, A.D., Handbook of Beach and Shoreface Morphodynamics, 5, John Wiley & Sons, pp.119-144.

Magalhães, F. (1999). Os sedimentos da Plataforma Continental Portuguesa: Contrastes Espaciais, Perspectiva Temporal, Potencialidades Económicas, Ph.D. Thesis, Lisboa Univ., Lisboa, 289 p..

Mellinger, R.M. (1979) - Quantitative X-ray diffraction analysis of clay minerals. *An evaluation, Saskatchewan Research Council, Canada, SRC Report* G-79: pp.1-46

Pevear, D.R. & Mumpton, F.A. (1989) - Quantitative mineral analysis of clays. *CMS Workshop Lectures*, 1, The Clay minerals Society, Colorado (USA).

Rocha, F. (1993). Argilas aplicadas a estudos litoestratigráficos e paleoambientais na Bacia Sedimentar de Aveiro, Ph.D. Thesis, Aveiro Univ., Aveiro, 399 p..

Rocha, F. (1998). Statistical analysis of mineralogical parameters used as lithostratigraphic and environmental markers, *Proceedings of the 2nd Mediterranean Clay Meeting*, Univ. Aveiro, 1998, Vol. 1: pp.128-152.

Rocha, F.; Vidinha, J.; Caetano, P.S. & Gomes, C. (2000). Statistical analysis of mineralogical parameters used as lithostratigraphical markers, *Acta Universitatis Carolinae Geologica* (Praga), 45(2-4), pp147-151.

Rothwell, R.G. (1989). Minerals and Mineraloids in Marine Sediments, an optical identification guide, Elsevier Applied Science, New York, pp.65-78.

Schultz, L.G. (1964). Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale, U.S. Geol. Surv., Prof. Paper, 391-C, pp. 1-31.

Shepard, F. & Young, R. (1961). Distinguishing between beach and dune sands, Journ. Sedim. Petrol., 31 (2), pp.196-214.

Sokal, R. R. & Rohlf, F. J. (1987). Introduction to Biostatistics, Second Edition, W. H. Freeman and Company, New York, pp. 220-228.

Teixeira, S. (1990). Dinâmica das praias da Península de Setúbal (Portugal), Msc. Thesis, Fac. Ciências de Lisboa, Lisboa, 189p.

Thorez J. (1976) - Practical identification of clay minerals, G. Lelotte, Bruxelles.

Vidinha, J.M. (1995). Caracterização Morfológica e Textural do Litoral entre Espinho e Cabo Mondego (Portugal), Msc. Thesis, Fac. Ciências de Lisboa, Lisboa, 195p.

Vidinha, J.M., Rocha, F., Andrade, C. & Gomes, C. (1997[a]). Caracterização mineralógica da fracção fina dos sedimentos de praia e duna do litoral entre Espinho e Torreira (Portugal): resultados preliminares, IV Reun. Quaternario Iberico, pp. 121-124.

Vidinha, J.M., Rocha, F., Andrade, C. & Gomes, C. (1997[b]). Análise Geoestatística de parâmetros granulométricos e texturais em sedimentos actuais de praia e de duna (Espinho-S. Jacinto, Portugal), Abstr. "2º Simp. Margem Contin. Atlant. Ibérica", Cádiz. pp. 247-250.

Vidinha, J.M., Rocha, F. Andrade, C. & Gomes, C. (1998[a]). Mineralogical characterization of the fine fraction of the beach and dune sediments situated between Espinho and Torreira (Portugal), Geostatistical approach, Cuaternario y Geomorfología, 12 (3-4), pp.49-56.

Vidinha, J.M., Rocha, F. Andrade, C. & Gomes, C. (1998[b]). Aplicação de índices mineralógicos na diferenciação de ambientes litorais de deposição - Espinho / S. Jacinto, Portugal, 1º Simpósio Interdisciplinar Sobre Processos Estuarinos - SIPRES, pp.81-84.

Vidinha, J.M.; Rocha, F.; Andrade; C. Gomes, C. & Freitas, M.C. (2000). The behaviour of mineralogical *ratio*s in beach and dune sediments, *Abstr. 3º Simp. Margem Contin. Atlant. Ibérica*; Univ. Algarve, Faro, pp. 407-408.

(Received: January, 30, 2004. Accepted: July, 16, 2004)