

## Clay Minerals – A Mineralogical Tool to Distinguish Beach from Dune Sediments.

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### ABSTRACT

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The usually textural parameters of sand sediments employed in order to distinguish present-day beach and dune deposits has been a matter of discussion in coastal studies. The results of these studies suggest that it may not be efficient to discriminate when the referred deposits exhibit well-sorted coastal sands, as was observed in limited coastal sections of the Portuguese coast. An innovative mineralogical approach based upon the study of the fine-grained fraction trapped in coastal sands, supported on univariate and multivariate statistical analysis, has been previously applied to a test area in the western Portuguese coast. This paper presents results from the mineralogical study of the clay fraction entrapped in coastal sand samples from the Espinho - Mondego Cape coastal sector in the north of the country following the same methodology. In 45 cross-shore profiles, spaced 2000 m, 130 samples were collected. Three sand samples were taken from each profile, at the beachface, berm and foredune. The mineralogical composition of the clay fraction was analyzed by XRD. Distinct clay mineral associations were identified expressing the relative importance of terrigenous contributions to the beach and dune sediments, stressed by a number of content differences between beachface (illite>> kaolinite, random mixed layers>chlorite), berm (illite>> random mixed layers, kaolinite>chlorite) and foredune deposits (illite>> kaolinite>random mixed layers, chlorite) with significant statistical results. The environmental contrasts exhibited along this coastal sector suggest that this ability might be related with functional factors and not just a product of local constraints.

**ADDITIONAL INDEX WORDS:** *Littoral sands, Beach face, Berm, Dune, clays.*

### INTRODUCTION

The Atlantic coastal sector between Espinho and Cape Mondego (NW Portugal) exhibits sandy beaches (Figure 1 and 2), as a consequence of high energy conditions present along Portugal's occidental coast, in the overall extension of its coast and foredunes, the later fed with sediments remobilized from

neighbouring deposits - beachface and berm.

The sediments of these deposits came, essentially, from Douro's watershed, located at the northern limit of this coastal sector, and from Vouga's watershed, which drains to a wide lagoon (Aveiro lagoon) that in turn connects with the Atlantic Ocean through an artificial inlet.

The usual sedimentological studies of coastal deposits are

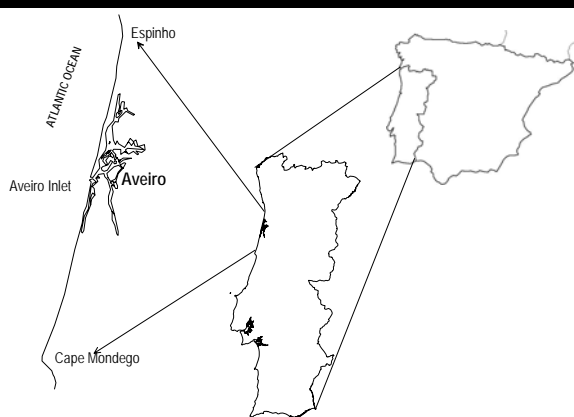


Figure 1. Study area.



Figure 2. Aerial photo from the north sector of the study area.

focused on the sand fractions (e.g. grain-size analysis, quartz morphoscopy, etc.), which result from the fact that the main coastal environments are arenaceous. The common littoral studies in Portugal follow this premise.

However, fifteen percent of the solid load drained to the oceans by the rivers consists in silt and clay sediments (IRION and ZÖLLMER, 1990), the clays representing about half of total marine sediments. It becomes therefore important to look at the silt and clay minerals in beach and dune littoral deposits, even if they occur as trace (<1%) components of sandy sediments, because they can be used as a tool to extract information about the lithology source area, depositional environments, climate and topography, supported namely on clay minerals.

VIDINHA (1995) performed textural studies of the sandy beaches and foredunes on Espinho and Mondego Cape located on the Portuguese coastal sector. Following the common proceedings on this type of studies, the author used FOLK and WARD (1957) parameters with the purpose of proceeding to sedimentary characterization as well as to disclose textural differences between beach and eolian dune sandy sediments.

The results obtained by VIDINHA (op cit.) pointed to the non-existence of significant textural differences between beach, which involve beach face and berm, and dune sandy sediments. This author imputed the observed lack of textural differences to the well calibrated sandy composition showed by all those littoral deposits.

Considering the IRION and ZOLMER (1990) evidence, laboratorial preliminary results (VIDINHA et al., 1998) confirm the residual presence (lower than 1%) of fine fraction (lower than 63 µm), particularly the clay fraction (lower than 2 µm), entrapped on sandy sediments.

Nevertheless, additional studies to look for the potential of the mineralogical composition and “crystallinity” of this fraction to discriminate emerged littoral deposits were carried out (VIDINHA et al., 2002<sup>a,b</sup>), replacing the relative inefficiency of the sandy fraction into the environmental discrimination. Therefore, the fine-grained sediment analysis can be looked at as a helpful, alternative

and additional tool to the common classic methods supported on sand sediments, to distinguish between dune and beach sediments.

## METHODS

A total of 45 cross-shore profiles, spaced 2000 metres, have been sampled along this coastal section. Three sand samples were collected in each profile, from the beachface (at mid-tide level), from the back-beach (at the middle of the higher berm) and from the upwind fore dune slope. Each sample was taken from the uppermost sand layer in order to preserve the textural signature of the last depositional event.

The fine fractions (<63 µm) were extracted by wet sieving of the total sediment.

The clay fractions (<2 µm) were analysed on orientated aggregates mounted on glass slides, each one with 1 ml of concentrated suspension of this fraction, which benefits the clay minerals basal (001) X-ray reflections. These slides were dried at room temperature (glycolated and heated at 500°C. The clay mineralogy has been determined by X-ray Diffraction (XRD), using PANALYTICAL Phillips X’Pert PW3040/60 equipment, with the X’Pert 2.0 and Profit software.

The semi quantification of the clay mineral assemblages was undertaken measuring the peak areas on the obtained diffratograms and the peak intensities being corrected using specific “reflection powers” as recommended by BARAHONA (1974), SCHULTZ (1964), THOREZ (1976), MELLINGER (1979) and PEVEAR and MUMPTON (1989).

Therefore, for the semi quantification of the identified main clay minerals, peak areas of the specific XRD reflections were calculated and weighted by empirically estimated factors (GALHANO et al., 1999; OLIVEIRA et al., 2002): illite (10Å peak, in natural specimen); kaolinite (7Å peak, in natural specimen), chlorite (7Å and 14Å peaks, in 500°C heated specimen) and smectite (17Å peak, in glycolated specimen); smectite 17 Å peak area was divided by 4, illite peak area by 0.5, chlorite 7Å peak area\* (after 500°C heating) by 1.25, kaolinite 7 Å peak area (depleted of the previously calculated chlorite area) by 1; for the

Table 1: Statistical results from the clay minerals identified in beach and dune sediments. Legend: *M*, mean; *Md*, median; *Mx*, maximum; *Mn*, minimum; *Std*, standard deviation; *Mad*, median absolute deviation.

	Beach face sediments			Berm sediments			Dune sediments		
	<i>M (Md)</i>	<i>Mx (Mn)</i>	<i>Std (Mad)</i>	<i>M (Md)</i>	<i>Mx (Mn)</i>	<i>Std (Mad)</i>	<i>M (Md)</i>	<i>Mx(Mn)</i>	<i>Std (Mad)</i>
Illite (I)	58.6(60.3)	77.3(37.3)	7.8(3.5)	60.4(60.5)	76.3(40.5)	6.6(3.9)	58.7(58.0)	76.5(48.2)	6.1(3.8)
Kaolinite (K)	12.8(12.3)	27.0(0.2)	6.5(4.8)	13.4(13.8)	23.3(2.8)	4.6(3.0)	17.3(18.6)	30.9(0.5)	8.9(5.9)
10-14Å RML	13.6(13.6)	37.7(0.0)	8.9(6.9)	11.8(11.9)	30.0(0.0)	6.7(3.0)	8.7(8.0)	21.2(0.0)	4.8(2.9)
Chlorite (C)	8.1(7.1)	32.7(0.0)	8.3(6.6)	7.0(6.1)	14.7(0.0)	4.4(3.3)	7.5(3.6)	27.4(0.0)	9.6(3.6)
K/S RML	4.0(3.4)	14.0(0.1)	3.2(1.9)	4.5(3.3)	14.7(0.0)	3.4(1.8)	5.1(4.4)	16.2(0.0)	3.9(2.9)
I/C RML	1.8(0.0)	28.5(0.0)	4.9(0.0)	2.0(0.0)	14.1(0.0)	3.9(0.0)	1.9(0.0)	21.0(0.0)	4.4(0.0)
Smectite (S)	1.1(0.9)	5.8(0.0)	1.1(0.5)	1.0(1.1)	2.5(0.0)	0.8(0.6)	0.8(0.8)	3.7(0.0)	0.8(0.8)

Table 2: Esquevin (IE) and Kubler (IK) crystallographic indexes from illites identified in beach and dune sediments.

	Beachface sediments			Berm sediments			Dune sediments		
	<i>M (Md)</i>	<i>Mx (Mn)</i>	<i>Std (Mad)</i>	<i>M (Md)</i>	<i>Mx (Mn)</i>	<i>Std (Mad)</i>	<i>M (Md)</i>	<i>Mx (Mn)</i>	<i>Std (Mad)</i>
IE	0.43 (0.43)	0.66 (0.24)	0.11 (0.10)	0.42 (0.44)	0.65 (0.24)	0.10 (0.07)	0.56 (0.56)	0.79 (0.29)	0.12 (0.08)
IK	0.39 (0.35)	0.90 (0.20)	0.12 (0.05)	0.30 (0.30)	0.55 (0.00)	0.11 (0.08)	0.35 (0.36)	0.50 (0.20)	0.07 (0.05)

different random mixed-layers, values intermediate between end-members were used.

ESQUEVIN (1969) and KUBLER (1964) "crystallinity" indexes, the later according to KISCH (1991) analytical recommendations, were also calculated by XRD to determine the octahedral composition (Al rich *versus* Fe-Mg rich) of the illites as well as the order/disorder degree of their crystallographic structures.

Data descriptive statistics were determined and later submitted to *Kolmogorov-Smirnov* non-parametric statistical test with the aim to evaluate how significant the differences between the samples distribution are.

## RESULTS

Clay fractions of the studied littoral deposits are composed by illite, kaolinite, 10-14Å expandable random mixed layers (RML) and chlorite, as main minerals, associated with kaolinite/smectite RML (K/S), illite/chlorite RML (I/C), as well as smectite (S) – Table.1.

Illite is clearly the main clay mineral, with contents reaching more than fifty percent of the sample. Kaolinite and 10-14Å expandable RML show a lower expression in the same sediments while all the other clay minerals (kaolinite/smectite and illite/chlorite RML and smectite) exhibit discrete concentration lower than ten percent. Illite, as well as kaolinite/smectite and illite/chlorite RML and smectite, show a similar content in all the littoral deposits, while 10-14Å RML decrease in the dune deposits direction. With an opposing trend, kaolinite shows a higher content in the dune deposits than in beach face and line. Chlorite shows similar contents for the three littoral deposits. However the median values suggest a decrease towards dune deposits.

The *Kolmogorov-Smirnov* non-parametric statistical test (Table 3) displays the weight of some clay minerals contents in the sampled deposits. The results from its application point out to significant differences in kaolinite and 10-14Å RML contents between beach face and dune sediments, as well as kaolinite, 10-14Å expandable RML and chlorite contents between berm and dune sediments.

Looking to the illite crystallographics indexes, i.e., Esquevin (IE) and Kubler (IK) indexes (Table 2), it was concluded that the IE shows evidence of increasing towards the dune deposits, while the IK has an opposite behaviour.

The non-parametric statistical test used allowed for judgement on the significance of some results (Table 4), suggesting that the IK from the illites of the beach face are significantly different from the berm, as well as between the berm and dune illites. On the other hand, IE from the dune illites is significantly different from those of the beachface and berm.

## DISCUSSION

Illite is the most representative clay mineral in the sampled littoral deposits, followed by 10-14Å expandable RML and kaolinite. These clay minerals and, with a lower content, chlorite, smectite and K/S and I/C RML, form the clay mineral association identified in all of the sampled deposits. Despite the observed contents similarity, mainly among the most representative clay minerals, the content analysis carried out pointed to some significant differences.

Considering the most representative clay minerals in the beachface and berm sediments they show a content relation represented by  $I >> 10-14\text{\AA}$  expandable RML,  $K > C$ , while in the

Table 3: Results from the application of Kolmogorov-Smirnov non-parametric test to compare the clay minerals content identified in beach and dune sediments. *Max Dif. Neg.*, maximum negative difference; *Max Dif. Pos.*, maximum positive difference; *p*, p-level of significance. Default p-level of 0.05.

	Beachface vs berm			Beachface vs dune			Berm vs dune		
	<i>Max Dif. Neg.</i>	<i>Max Dif. Pos.</i>	<i>p</i>	<i>Max Dif. Neg.</i>	<i>Max Dif. Pos.</i>	<i>p</i>	<i>Max Dif. Neg.</i>	<i>Max Dif. Pos.</i>	<i>p</i>
Illite (I)	-0.152	0.022	$p > 0.10$	-0.111	0.170	$p > 0.10$	-0.069	0.261	$p > 0.10$
Kaolinite (K)	-0.177	0.144	$p > 0.10$	-0.408	0.055	<b><math>p &lt; 0.005</math></b>	-0.421	0.147	<b><math>p &lt; 0.005</math></b>
RML 10-14	-0.099	0.216	$p > 0.10$	-0.056	0.343	<b><math>p &lt; 0.025</math></b>	-0.065	0.406	<b><math>p &lt; 0.005</math></b>
Chlorite (C)	-0.196	0.222	$p > 0.10$	-0.126	0.234	$p > 0.10$	-0.244	0.395	<b><math>p &lt; 0.005</math></b>
K/S RML	-0.126	0.048	$p > 0.10$	-0.203	0.053	$p > 0.10$	-0.151	0.083	$p > 0.10$
I/C RML	-0.094	0.022	$p > 0.10$	-0.075	0.022	$p > 0.10$	-0.028	0.064	$p > 0.10$
Smectite (S)	-0.182	0.102	$p > 0.10$	0.000	0.215	$p > 0.10$	-0.029	0.240	$p > 0.10$

Table 4: Results from the application of Kolmogorov-Smirnov non-parametric test to compare Esquevin and Kubler Index from the illites. *Max Dif. Neg.*, maximum negative difference; *Max Dif. Pos.*, maximum positive difference; *p*, p-level of significance. Default p-level of 0.05.

		<i>Max Dif. Neg.</i>	<i>Max Dif. Pos.</i>	<i>p</i>
		Beach face vs berm	IE	-0.186
	IK	0.000	0.332	<b><math>p &lt; 0.025</math></b>
Beach face vs dune	IE	-0.456	0.000	<b><math>p &lt; 0.001</math></b>
	IK	-0.014	0.167	$p > 0.10$
Berm vs dune	IE	-0.529	0.001	<b><math>p &lt; 0.001</math></b>
	IK	-0.343	0.023	<b><math>p &lt; 0.025</math></b>

dune sediments the relation is represented by  $I \gg K > 10\text{-}14\text{\AA}$  expandable RML.

10-14Å RML shows a decreasing trend from the beachface to dune sediments, followed by chlorite, as the median suggests, with kaolinite showing an opposing trend. The nonparametric statistical tool used, as seen above, suggests that the observed content differences of these clay minerals between berm and dune deposits are significant. The explanation for this kaolinite increasing trend is found on the 10-14Å expandable RML content decreasing in the same direction, followed by the chlorite (remember the data are closed). This 10-14Å expandable RML content reduction results from the structural instability of these random mixed-layers when submitted to weathering processes, which was favoured by the dune vegetation cover that allows the sediments imprisonment and consequently favouring the weathering intensity.

The illite content analysis provides evidence of the lack of significant differences between the beachface and berm deposits. However, the Esquevin crystallographic index analysis (Table 1) suggests a visibly compositional trend of the illites to evolve from a ferro-magnesian term (lower indexes) to an aluminous term (higher indexes) from the beachface and berm to dune sediments, respectively.

On the other hand, the Kubler index points to illites with a higher to medium structural order (lower indexes numerical values) on the beachface and berm sediments and medium to lower in the dune sediments.

The non-parametric statistical tool used confirms that the observed compositional and structural differences, indicated by the referred indexes, are significant (Table 3).

The aluminous illites trend from the beach face and berm to dune deposits is an end result of the lower weathering processes susceptibility of the aluminous illites, in contrast with the ferrous-magnesian illites that show a higher susceptibility to the same processes. The same processes are responsible for the higher structural disorder exhibited by dune illites, when compared with the beach face and berm illites high structural order. Those illites crystallochemical results based on Esquevin and Kubler indexes, make possible the fields' definition on the ESQUEVIN (1969) graphic (Figure 3).

The clay mineral content analysis as well as the illite crystallographic indexes analysis point to a visible lack of differences between beach face and berm. This confirms the sedimentary interchange between those beach profile units and the processes that shaped the berm during construction, involving the swash and the washover sediment transport from the beach face to the berm. However, the relative stability of the foredune given by the vegetation cover allows some clay mineral transformations that imprint a distinct clay mineral association, therefore becoming different from the beach face and berm association.

## CONCLUSION

The clay fraction study on beachface, berm and dune sediments point to similar clay associations:

The major clay minerals are illite, kaolinite, 10-14Å expandable mixed layers and chlorite associated to kaolinite/smectite, illite/chlorite random mixed layers, as well as with smectite, as minor clay minerals.

In spite of this association similarity, it was found that some clay minerals, specifically kaolinite, 10-14Å expandable mixed layers and chlorite, show significant content differences between beach sediments and dune sediments.

The absence of significant clay minerals content, differences between beach face and berm, as well as illite crystallochemical characteristics, was explained as an end result of the sedimentary

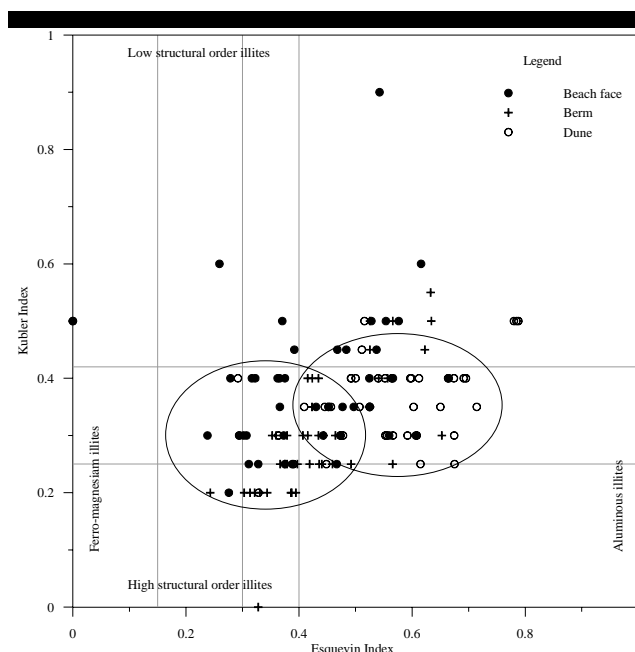


Figure 3. Esquevin (1969) graphic with beach face, berm and dune illites crystallographic indexes. The preferential distribution fields were marked with circles.

dynamic that link these morphological units of the beach profile. This illustrates that they embody one single sedimentological unit.

On the other hand, the record of significant clay minerals content differences and also of crystallochemical illites differences between beach and dune sediments, point to post-deposition transformations making possible the distinction of the related littoral deposits.

The use of the clay minerals associations as well as of their crystallochemical indexes on sedimentological studies of littoral deposits, even with a residual occurrence, is a valuable tool in order to discriminate those deposits; in particular, the wave dominated deposits (beachface and berm) of the eolian dominated deposits (foredune).

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