SPATIAL DISTRIBUTION AND COMPOSITION
OF SUSPENDED SEDIMENTS IN RIA DE AVEIRO LAGOON

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Keywords: Suspended sediments; Ria de Aveiro lagoon; mineralogical composition

ABSTRACT

During four tidal cycles concentration and mineralogical composition of suspended sediments were studied in the Ria de Aveiro coastal lagoon. Temporal and spatial variations were found and seem to be mainly controlled by tidal currents magnitude and bottom properties. The highest mean value of suspended sediments (24 mgL⁻¹) was found at station 3 that combines a zone relatively deeper with a bed locally rich in fine-grained sediments. Besides, water and suspended matter from northern side of S.Jacinto Channel and from Laranjo Bay converge in this area. The lowest suspended sediment mean value (13.2 mgL⁻¹) was observed in station 7, which is also a deeper zone, but with a sandy bed. In general, the mineralogical suite identified is dominated by mica/illite (mean = 45.1%) followed by quartz (mean = 19.9%) and by kaolinite (mean = 12.7%). In almost all stations, higher mean values of suspended sediments concentration and of quartz, Opal C/CT and pyrite occur during spring tides due to the intensity of the tidal currents. During winter neap tide the higher mean values of suspended sediments concentration and of quartz and kaolinite observed in stations close to the tidal inlet suggest that wind-induced resuspension and horizontal advection from the adjacent coastal area is taking place. Semidiurnal variations are explained, especially during the summer, by tidal-current velocity asymmetry (ebb dominance). Seasonal variability, with winter higher suspended sediments concentration and higher values of quartz, kaolinite and calcite, is probably related with wind climate, biological activity and coastal wave regime.

INTRODUCTION

The Ria de Aveiro lagoon, located between 40°52’ and 40°30’ N, is the major portuguese lagunar system, being the main part of a wet system with a total surface of 250 km². Connected to the Atlantic Ocean by an artificial channel (1.3 km long, 350 m wide and 20 m deep), this lagoon has a irregular and complex geometry characterized by extensive intertidal zones and four main channels: S. Jacinto, Ílhavo, Mira and Espinheiro (Figure 1).
The average depth in the lagoon is about 1 m, with exception for the navigation channels where dredging operations maintain a depth of about 7 m (Dias et al., 2000).

The Ria de Aveiro lagoon is geologically very young and its origin is related to the southward transport of sediments by alongshore currents. From centuries X to XVIII this transport of sediments along the Portuguese west coast originated a long spit that isolated the estuary of Vouga river from the coastal ocean (Martins, 1947; Girão, 1951; Abecassis, 1955).

In the Ria de Aveiro channels, the surface sediments are a combination of medium to fine sands with a variable content of finer particles (silt and clay), which increases with the distance from the lagoon mouth. The inner zone of intertidal flats integrates, from top to the bottom, sand, mixed and lutitic flats that are mainly composed, respectively, by medium to fine sand, clay silty and clay sandy sediments (Rocha et al., 2000).

This coastal lagoon corresponds to a mesotidal estuary (Davies, 1964) with a tidal range of 3.2 m for maximum spring tide and of 0.6 m for minimum neap tide (Dias et al., 2000). Two rivers Vouga and Antuã constitute the major sources of freshwater. The total mean freshwater input during a tidal cycle is about 1.8 Mm³ (Moreira et al., 1993), while the tidal prism is 136.7 Mm³ for maximum spring tide and 34.9 Mm³ for minimum neap tide (Dias et al., 2000). Consequently, Ria de Aveiro hydrodynamics is essentially dominated by tidal forcing.

The tides at the mouth are predominantly semidiurnal and are present in the entire lagoon (Dias et al., 1999; Dias, 2001). Tidal currents are strongly dependent on the local geometry. Increasing in narrow and deepest channels (beginning of S. Jacinto and Espinheiro channels), where can be higher than 1 ms⁻¹, never exceeds 0.4 ms⁻¹ in the shallow sections of the channels. Maximum current speed are found three hours after high and low tide, being the ebb tide currents slightly higher than the flood ones (Dias et al., 1998).

Sediments transport model developed by Dias (2001) point out to residence times less than 2 days, at central sector of the lagoon, indicating high water renovation, due to a strong marine influence.

Investigations about suspended sediments concentrations in Ria de Aveiro have been done in the north western channels and show semidiurnal variations (Silva, 1994; Pereira, 1995). A two-
dimensional depth-integrated transport model for cohesive suspended sediments has also been applied to simulate tidal evolution of suspended sediments in the lagoon by Lopes et al. (2000) and indicated that sediments concentrations show spatial, semidiurnal and fortnightly variability. The study of suspended sediments mineralogy has been done by Gomes (1987) but just on rivers discharging in Ria de Aveiro. Therefore, there was no previous research about suspended sediments mineralogy in Ria de Aveiro channels.

The purpose of this work is to contribute to the characterization of suspended sediments distribution and composition in the central area of the Ria de Aveiro lagoon and to infer the sedimentary exchanges between ocean and the lagoon.

MATERIALS AND METHODS

Suspended sediments were collected in seven sites (Figure 2) located in the four main channels (1 - mouth of lagoon; 2 and 3 - S. Jacinto Channel; 4 - Mira Channel; 5 and 7 - Espinheiro Channel and 6 - Ílhavo Channel).

Sampling was performed during one summer tidal cycle (September 2001) and one winter tidal cycle (February 2002), at approximately 2-hour intervals, including high tide and low tide measurements. The surveys cover a range of tidal heights at the lagoon mouth from 1.2 m to 2.9 m in summer and 1.1 m to 2.2 m in winter. Water samples were collected from the surface, middle-depth (when depth is higher than 3 m) and 1 m above the bottom at each site using a Van Dorn® bottle.

To determine the concentration of suspended matter, between 1 and 3 L aliquots were filtered with the classic vacuum system using 0.45 µm Millipore® (47 mm diameter) pre-weighted filters. The filters were dried at 40 °C for 24 h and reweighed.

Mineralogical studies were based on X-ray diffraction (XRD) determinations, using a Phillips PW 3040/60 diffractometer. All samples were analysed in the range from 2° to 40° 2θ, at 1° 2θ /min, with Cu-Kα 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).

RESULTS AND DISCUSSION

Concentration

During the study period, the concentration of suspended sediments showed a complex spatial and temporal pattern, depending on the tidal phase and amplitude and on the season (Tables 1 and 2, Figure 2).

The differences in suspended sediments concentration within the lagoon seem to be largely determined by the magnitude of the currents and by the bottom properties. In fact, the highest mean value of suspended sediments (24 mgL⁻¹) was found at station 3 which is located in a zone relatively deeper of the S. Jacinto Channel where the bed is locally rich in fine-grained sediments. Water and suspended matter from northern side of S. Jacinto Channel and from Laranjo Bay converge also in this area. The lowest suspended sediment mean value (13.2 mgL⁻¹) was observed in station 7, which is also a deeper zone, but with a sandy bed. The proximity of this station to the Vouga river mouth seems to reflect the weak contribution of this river in suspended sediments, comparatively to the apparent supply from bottom and shore estuary erosion, during the study period.

In general terms, the higher concentrations of suspended sediments were found close to the bottom denoting resuspension and deposition processes (Tables 1 and 2, Figure 3).

The higher values were observed during the ebb (Tables 1 and 2) and could be explained mainly by the asymmetry in the current velocity over the tidal cycle.

Fluctuations on suspended sediments concentration are a function of current velocity, but advection of sediments resuspended in remote areas and the time taken for the particles to disperse throughout the water column after they have been eroded (scour lag) may
also account. On the other hand, resuspension may not be related with current velocity but with wind-induced turbulence, which presumably was out of phase with tidal currents. The relative importance of each process is difficult to evaluate due to the complexity of the processes and to the lack of observations and of hydrological measurements concurrent with the water sampling campaigns.

Nevertheless, every time currents intensity increases, what happens generally during spring tides, remobilization and transport of sediments become more efficient, therefore higher suspended sediments concentration were observed (Figure 4).

Seasonal variability, with winter higher SSC in almost all stations (Tables 1 and 2), was probably more related with wind climate, biological activity and coastal wave regime than with rivers input, which were below the mean flow during the surveys.

In the winter neap tide winds blow essentially from north with intensities generally higher than 3 ms\(^{-1}\). It is possible that wind-induced turbulence eroded the bottom mud deposits in the large shallow areas, as well as the finer sediments in the intertidal zones. In this case, resuspend particles are subsequently advected through the estuary.

The seasonal variations of SSC can also be influenced by biological processes. The examination under binocular microscope of the suspended sediments retained in the filters showed that biogenic material (predominantly plant fragments, copepods and diatoms) and aggregates are more abundant in the bottom samples during the summer than in the winter.
If flocculation owing to organic processes is important, fine-grained sediments are more easily kept in suspension in the winter situation than in the summer, because flocculation is less important in the first case.

In winter highly coastal wave energetic conditions were observed. Measurements from the wave buoy located in Leixões (northern of Ria de Aveiro) indicated that significant wave heights and periods exceeded 1.5 m (2.5-3.6 m in neap tide) and 7 s, respectively. These conditions probably induced high resuspension of the coastal particles, especially during neap tides. Consequently, more sediment could be supplied to the lagoon system by the flood tidal currents.

Mineralogical Composition

The mineralogical suite identified in the suspended sediments is, for all sampling sites, dominated by mica/illite (mean = 45.1%) followed by quartz (mean = 19.9%) and by kaolinite (mean = 12.7%). K-feldspars, plagioclases, calcite and opal C/CT are common as accessory minerals. Less common and always in very small quantities, pyrite, anhydrite, dolomite, siderite, amphiboles, zeolites, goethite and gibbsite were also identified.

The mineralogical composition of the studied samples shows the "signature" of the mineralogical composition of the soils and rocks outcropping in the hydrographic basins being drained to the lagoon. In the surrounding region of the Aveiro lagoon outcrop Paleozoic and Proterozoic gneisses, migmatites, granitoids, micaschists and schists, northwards, as well as Cretaceous sandstones and shales, southwards. Actually, the identified mineralogical suites are clearly similar to the fine fractions (<63µm) mineralogy identified in the Vouga watershed soils (Pereira, 1989) and in sediments and metasediments from Aveiro region (Delgado et al., 1992; Rocha, 1993; Rocha et al., 2000; Chaminé et al., 2001, 2002).

The central sector of the lagoon, being the most influenced by the sea waters influx-reflux and characterized by higher hydrodynamism, shows the vanishing of the mineralogical signatures of the detrital inputs coming from north, east (from the Vouga watershed soils) and south.

Actually, the mineralogical suites are similar, along the tide cycles, at any sampling stations. Nevertheless, the results (Figure 5) show some discrete variations, sometimes with seasonal character, of the relative abundance of each one of the identified minerals.

The seasonal analysis of the suspended matter mineralogical composition (Figure 5) point out to a discrete increase of quartz and kaolinite during winter. Nevertheless, this trend is not shown for quartz from stations 6 (ebb tides) and 7 (always).

During summer, mica/illite and chlorite show, for the majority of the stations, a relative increase during
Figure 5.
Box-Plot of contents of some minerals present in suspended sediments (f- flood; e- ebb; SD- standard desviation).
Spatial Distribution and Composition of Suspended Sediments in Ria de Aveiro Lagoon

flood tides; however, relative abundance of quartz and kaolinite increase during ebb fluxes, as a consequence of tidal currents velocities effects on resuspension, transport and deposition of particles. This behaviour becomes more complex during winter, some stations showing a trend exactly the opposite of the one showed during summer.

Among all the identified minerals, calcite is the one showing a distribution more homogeneous along the sampling periods, being its higher concentration values related to flood tides. Exceptions were stations 3 and 5, during spring tides and station 2 during winter neap tide.

The increase of quartz and kaolinite identified during winter seems to be explained by the input of oceanic particles into the lagoon, particularly during spring tides. In fact, these two minerals occur abundantly in the bottom sediments of the adjacent continental shelf (Abrantes et al. 2000) as well as, northwards (up to Douro and Minho), in the suspended sediments of the NW Iberian Margin (Oliveira, 2001; Oliveira et al., 2002). However, it must be taken into account that this increase is sometimes related to the ebb fluxes, therefore being someway dependent of erosion of the bottom sediments.

Along the tidal cycle, the compositional variability shown by the studied samples from station 1 (located close to mouth) point out to suspended sediments exchange between the lagoon and the ocean, with seasonal character.

Mica/illite denotes (Figure 5) an output trend (from the lagoon to the shelf) during the winter spring tides, whereas quartz and kaolinite show an opposite tendency, being transported from the ocean to the lagoon during this period. On the other hand, during summer tides, mica/illite shows an increase along the floods, being quartz and kaolinite exported to the shelf.

Calcite plays a role as Proxy to the ocean biogenic contribution, being related to the flood phases, and showing (Figure 4) its higher concentration values close to the mouth, decreasing inside the lagoon with the increase of distance from the mouth.

CONCLUSIONS

The sedimentary dynamics of the Aveiro lagoon is essentially dominated by tidal forcing. As in other estuarine systems, the suspended sediments concentration fluctuated with tidal amplitude and phase and show seasonal variability.

The mineralogical composition of the suspended sediments is a function of the fluvial input, bottom composition and oceanic contribution. During the study period suspended sediment composition show temporal and spatial variability. Calcite plays a role as proxy to the ocean biogenic contribution.

Exchanges of mica/illite, quartz and kaolinite between the lagoon system and the coastal ocean occurred during the study period.

AKNOWLEGEMENTS

The authors would like to thank the Departments of Biology and Physics of Aveiro University (for using their boats and equipment), Prof. João Dias (from Physics Department of Aveiro University), Mr. Rui Marques (from Biology Department of Aveiro University) and the colleagues of the Geosciences Department who contributed for the fieldwork. The first author also thanks the Ministério da Ciência e do Ensino Superior for the PhD Grant.

REFERENCES


(Received: January, xx, 200x. Accepted: July, xx, 200x)