

Trace-elements Behavior in the Sedimentary Transport Regime of the Blue Amazon, Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. All authors participated of the samples collection, date and statistical analysis and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Trace elements or trace metals are of great interest in environmental studies due to their toxic and cumulative properties in the biological and sedimentary compartments. The discharge area of the Amazon River mouth receives an immense volume of suspended material with adsorbed trace elements, which mostly ends up depositing in the shelf area influenced by the fluvial-marine currents and physical-chemical properties of the water and sediment. This research aims to quantify and to discuss the routes of trace elements (Cr, Pb, Ni, Zn and Hg), associated with sedimentary transport and deposition in the Amazon Continental Shelf (ACS). The results showed a sediment distribution by zone, with a non-continuous range of erosive processes and areas of deposition for mud and sand sediments. The trace elements contents in the sediments are strongly influenced by the pH, salinity, organic compounds, clay minerals and CaCO₃ content. Fluvial-marine currents were important drive forces for deposition and accumulation of fine sediments in the shelf, especially the North Brazilian Coastal Current (NBCC). Statistical analysis and hypothesis testing confirmed the trend of sediment accumulation by zone, influenced by the physical-chemical parameters.

Keywords: Trace elements; sediment; sedimentary flow; organic matter; Amazon Continental Shelf.

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1. INTRODUCTION

The trace-elements are of great environmental interest, mainly due to the mutagenic and teratogenic effect. Many trace metals such as Pb and Hg have a large bioconcentration factor in marine organisms, being significantly toxic, unlike other transition elements with known biochemical function. At present, anthropogenic activities are the most important entry pathways of trace metals in the marine compartments. The discussion if the main source of metallic contamination is natural or anthropogenic is classic and longstanding. However, the sum of these two sources in the Blue Amazon resulting in an immense volume of trace metals, which partly is carried by the current flow associated with suspended sediments, towards the mouth of the Amazon River following the sedimentation process. The natural composition of the Amazonian soil is considered enriched in trace metals as explained by researchers in 90th decade [1-4]. The balance between the erosion, transport and sedimentation processes interferes with the volume of suspended solids and, consequently, the concentration of trace metals in the fluvial-marine environment. Areas of natural trace elements origin reflect the soil drainage pattern around the main watershed, whereas the anthropogenic impact areas create an abnormal concentration of trace elements, which suggest activities without environmental control, as usually occurs in mining activities.

When a delta or river mouth is observed in a macro perspective, the first impression is the presence of a uniformly distributed environment. It is, however, a false appearance, since the system is far from being considered homogeneous physical-chemical and biological. Environmental factors such as wind, tidal movements, marine currents, and the immense volume of sediments transported daily at the mouths of the Amazonas and Pará rivers, transform the delta and continental shelf into a dynamic and heterogeneous mosaic, strongly controlled by seasonal pressures. This scenario has great influence on the sediment transport regime, controlling the forces of deposition and/or suspension of particles, especially in the region of the coastal zone. In other words, environmental factors interfere seasonally in the transport of sediments, which in turn influence the concentration, transport and/or deposition of trace elements.

The Amazon River presents the highest suspended solids load transported in the world,

about $\sim 1.2 \times 10^9$ t/year [5], and that once reaching the continental shelf will submit to a coastal dynamic, mainly by the influence mainly of the North Brazilian Coastal Current (NBCC) and North Equatorial Current (NEC) along the American continent (Fig. 1). In this mosaic, the coastal zone receives a great contribution of compounds of both natural and anthropogenic origin, becoming an environment susceptible due to low hydrodynamics, which controls the dispersion of organic and inorganic compounds. The Amazon Continental Shelf area (ACS) presents alternations of forces, which interfere with local hydrodynamics. Thus, it is possible to observe an evident zonation in both the chemical and physical-chemical aspects of the water column (salinity, pH and dissolved oxygen), as well as a zonation in the sedimentary composition (granulometry, texture and porosity), which extends over of the platform bed. Studies showed a immense sedimentation of mud fractions through of the inner shelf and sand fractions at the outer shelf [6-8], with great difference in the geochemistry and mineralogy of the region [8]. This zonation interferes with the distribution and concentration of trace elements in ACS. This research aimed to quantify and to discuss the routes of the trace metals (Cr, Pb, Ni, Zn and Hg), associated to sedimentary transport and deposition regimes from Amazon River to Amazon Continental Shelf (ACS) for the period 1999 - 2016.

2. MATERIALS AND METHODS

2.1 Study Location

The study has been conducted in the Amazon River, nearby coastal zone (CZ) and ACS ($47^{\circ}52'W-4^{\circ}19'N$ and $51^{\circ}04'W-2^{\circ}16'S$) between Orange Cape (State of Amapá) and Pará River mouth (State of Pará; Fig. 1). It is a region dynamic, conditioned by the meeting of continental waters with the Atlantic Ocean on influence mainly at the North Brazilian Coastal Current (NBCC) and North Equatorial Current (NEC). NBCC has an important role in the transport and distribution of fine sediments from fluvial discharges, especially in the inner shelf and coastal zone, since it acts as a barrier or drive force, preventing the dispersion of the sediments towards the open ocean area. The SEC, more seasonally, also contributes to the maintenance of the fine sediments within the inner shelf, towards the north of Orange Cape. Already in the limits of the outer continental shelf, the NEC acts as a barrier to the fine fractions

that eventually managed to disperse, as well as a physical-chemical barrier, limiting the lower river salinity. There is also interference from atmospheric forces as the Intertropical Convergence Zone (ITCZ), generating trade winds and rainfall, which determining the climatic seasons and the hydrological pattern of Amazonian rivers. The climate of the region is 'Am' hot and constantly humid (monsoon climate) for Marajó Bay, and 'Af' equatorial for Amazon and Pará mouths, with a mean temperature of 28 °C and rainfall exceeding 2000 mm/year, especially between the months of December and February. The Amazon coastal zone includes diverse ecosystems as mangroves, dunes, restingas, freshwater coastal, estuaries and river deltas with great aquatic and terrestrial biodiversity associated. A flow model of fluvial-marine currents acting on the coastal zone and ACS was elaborated (Fig. 1).

2.2 Analytical Proceedings

In the water column pH, salinity (s.u.) and dissolved oxygen (mg/L) were measured using multiparameter probes to identify the heterogeneity pattern of the waters under influence of the fluvial-marine currents. Sediments samples (0.0-0.3 m) were obtained between 5 and 100 m isobaths during the months of lowest flow (May and June) in the Amazon River, and storage into polyethylene

bags using a Teflon scoop. The samples were transported to the UFPA and INPA laboratories and freeze-dried before analysis, as described by quality assurance and quality control specifications from the USEPA [9] and CETESB [10]. In the laboratories, the samples were dried at 45 °C, homogenized, sieved and pulverized until very fine sand fraction (63vfs μm mesh sieve). After, the sieved samples were labelled and prepared for analysis. Grain-size and texture analysis was determined by the gravimetric method. All cores were logged immediately after the sampling with the USGS multisensory logger (Geotek) that includes velocity and direction analyzer of the currents, and magnetic sensors. Dry bulk density (DBD) was calculated according equations 1 and 2.

$$DBD = G_s \times \frac{WBD - K_x}{G_s - K_x} \quad (1)$$

$$G_s = \frac{\% \bar{X}CaCO_3 \times 2.70 + \% \bar{X}OC + \% \bar{X}SiO_2 \times 2.05}{100} + (1 - \frac{\% \bar{X}CaCO_3 + \% \bar{X}SiO_2 \times 2.65}{100}) \quad (2)$$

Where: G_s is grain density; WBD is wet bulk density, and calculated as $[1 - F]$, where F is the porosity measured by the USGS multisensory; K_x is the assumed density of seawater and equal 1.025.

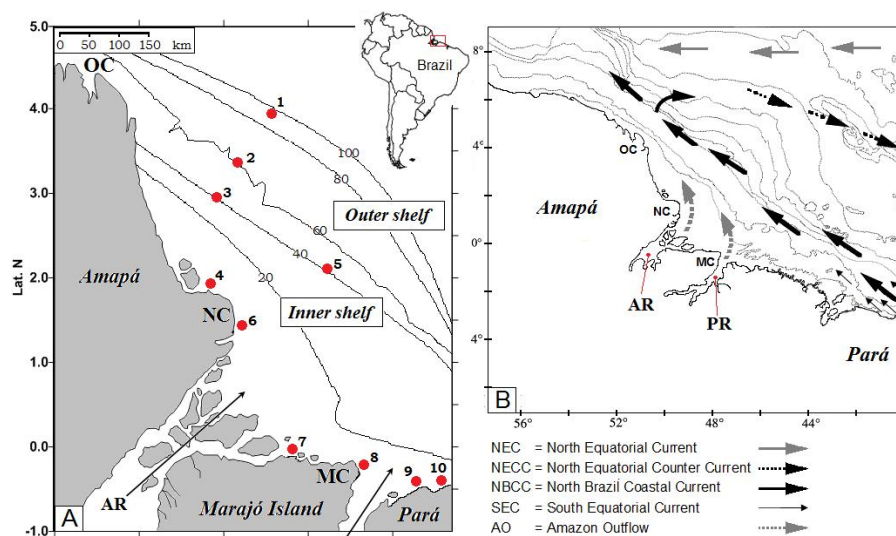


Fig. 1. A) Map of the ACS and coastal zone between Orange Cape (OC) and Pará River mouth, and B) flow model of fluvial-marine currents in the study area

Legend: NC= North Cape; MC= Maguari Cape; AR=Amazon River; PR= Pará River; isobaths in meters. Sampling sites ($N_{SS}=10$)

The concentration of CaCO_3 in the sediments was determined by titration method [11]. Weigh 10g of dry and sifted sediment into a 200 mL porcelain dish and add 50 mL of HCl 0.5 mol/L. The mixture is heated for 5 minutes in electric plate and allowed to cool. Add 10 mL of distilled water and 3 drops of phenolphthalein. The titration is done with NaOH 0.25 mol/L solution. The calculation of the CaCO_3 concentration is obtained by equation 3.

$$\text{CaCO}_3 = \frac{(100 - [\text{NaOH}]) \times 12.5}{10} \quad (3)$$

Where: CaCO_3 (g/kg); 100 is the volume of HCl 0.5 mol/L used multiplied by 2; 10 is the mass in grams of sediment.

The organic carbon (OC) was determined by the volumetric method with potassium dichromate [12]. Add 0.5 g of dry and sifted sediment, 10 mL of $\text{K}_2\text{Cr}_2\text{O}_7$ 0.2 M, and 10 mL of H_2SO_4 concentrated in Erlenmeyer of 250 mL and make up to 50 mL with distilled water. The vial should be heated in electric plate until boiling, not allowing, however, drop of the mixture. Allow the mixture to cool and add 1 mL of orthophosphoric acid and 3 drops of the diphenylamine indicator (10 g/L). The titration is done with solution of ferrous sulfate ammoniacal $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ 0.05 M, and the calculation is done by equation 4. Total organic matter (OM) was estimated by hot acidic extraction with excess hydrogen peroxide (30%) at 100°C [13]. The calculation is the mass difference of the dry sample before and after the oxidation. With the results of the organic matter, the organic carbon content (OC_{calc}) was estimated through equation 5, for later comparison with the organic carbon analyzed (OC_{anal}). SiO_2 was determined by spectrophotometry [11,14]. Weigh 1 g of sediment in Erlenmeyer of 500 mL and add 4 mL of NaOH 30% solution and to boil in electric plate for 5 minutes. After, allow to cool, transfer the mixture to 200 mL volumetric flask and make up to volume with distilled water. Filter again and pipette 0.20 mL of the filtrate with micropipette (Seligson) and place in 150 mL beaker. Add 50 mL of distilled water and 2.5 mL of ammonium molybdate solution. After 10 minutes, add 2.5 mL of tartaric acid solution 28% and 30 mg of ascorbic acid (reducing agent). Pass the contents into a 100 mL flask and make up to volume with distilled water. Leave the flask to stand for 12 hours, and then take samples for spectrophotometer reading at 695 nm. The calculation is done by equation 6.

$$\text{OC} = 0.06 \times V \times (40 - V_a \times f) \quad (4)$$

$$\text{OM} = \text{OC} \times K_x \quad (5)$$

$$\text{SiO}_2 = \text{Spectro} \times F_1 \times 10 \quad (6)$$

Where, Eq. 4: OC (g/kg); V = volume of potassium dichromate and V_a = volume of ammoniacal ferrous sulfate consumed in the titration; f = 40/ volume of ammoniacal ferrous sulfate used in the blank titration; 0.06 = correction factor. Eq. 5: OM (g/kg); $K_x = 1.8$ [15]; 1.9 [16] and/or 2.1 [17]. Eq. 6: SiO_2 (g/kg); Spectro = spectrophotometer reading; $F_1 = \text{SiO}_2$ concentration (%) in standard solution divided by the standard reading corresponding to 0.2 mL.

Trace metals Cr, Pb, Ni and Zn were extracted using mixture $[\text{HNO}_3 + \text{HCl}]:\text{HClO}_4:\text{HF}$ (Merck 2:1:1) in an open system and determined in a flame atomic absorption spectrometry Shimadzu AA 6800 (Standard Method 3111B - APHA, [18] modified). The element identification accuracy as well as the possible contamination of samples in the analyses both were controlled according to the four calibration solutions, including the baseline (zero) solution. Total Hg was extracted adding [dry sediment + V_2O_5] (1:1) and $\text{HCl}:\text{HNO}_3:\text{H}_2\text{SO}_4$ (Merck 3:1:6) in a test tube closed, and determined in cold-vapor atomic absorption (Standard Method 3112B and 3500-HgB - APHA, [18] adapted). The element content in the sample solutions was identified using the addition method of certified mixtures with established content of elements. Statistical data processing was performed using Statistica StatSoft® 7.0; Microcal Origin® 9.0 software's.

3. RESULTS AND DISCUSSION

3.1 Sedimentary Transport and Deposition

The area between the coastal zone and the edge of the inner continental shelf of the ACS (~ 300 km) is very dynamic, with intense processes of erosion and sedimentary deposition, and influenced by fluvial discharges and fluvial-marine currents, both of seasonal pattern. The morphology of the Amazon region is another selective factor in the sedimentary deposition process. Information on local bathymetry and morphometry helps the construction of transport models and more reliable sedimentary deposition. For ACS the tendency was for a

strong sedimentary deposition in the shallower areas and closer to the coastline, especially above the mouth of the Amazon and Pará rivers, above sampling site 4 and towards Orange Cape. The granulometric analysis indicated the presence of mud sediments with high percentage of fine silt and clay fractions (70-88%) in the sediments of the CZ and Inner Shelf, with enrichment by organic matter in the coastline, and high levels of sandy sediments (90-95%) on the outer shelf. Within this apparently well-defined mosaic, however, tendencies of fine sediment accumulation were observed in isolated or alternating areas with deposition of sandy sediment fractions. The deposition range at the coastline is not continuous, with alternations of deposition of fine sediments and silt-sandy and sandy-silt sediments, as the results showed (Fig. 2), confirming the studies of others authors [19,20], indicating a diffusive sediment transport mechanism [21,22]. A previous analysis of the granulometry and mineralogy of the sediments of the coastal zone and the mouth of the Amazon River [5], besides randomly sampled sites in marginal soils, suggests areas of intense erosion between the North Cape and Orange Cape (Fig. 1). Independently of the flow and direction of marine currents demonstrated, areas of fine sediment and mud sediment deposition were also estimated between sampling sites 1 and 2, in the direction of the Orange Cape. These results are confirmed by previous studies [7,19,20,23-25], which observed accumulation of muddy sediment occurring along the southern shoreline, with alternating erosion spots and sandy deposition (Fig. 2). The deposition of both fine sediments and sand-silt coarse sediments coincides with the range of carbonate (CaCO_3) and silicate (SiO_2) determined (Fig. 3). Especially the carbonates, these interfere in physical-chemical properties such as alkalinity and pH of the interstitial waters and at the interface water-sediment, influencing the rates of mobilization and metallic deposition. It was possible to identify a pattern in the grain density (G_s) and dry bulk density (DBD), especially as a function of the silicate concentration. In addition to the fluvial and/or marine origin, autochthonous and allochthonous sources of detrital material also interfered in the concentration of carbonates and organic matter in the sediments, which may be influencing the diagenetic processes and the motility of trace elements.

The alternation of marine currents and the variation of sea level, as a function of seasonality, affect the concentration and texture

of terrigenous materials in different ways. Several studies have shown that the continental waters loaded with sediments of the Amazon River are transported to the northwest along the South American coast by the action of the NBCC, with more or less influence of the NEC (Fig. 1) as a function of time. Most of these sediments are deposited on the continental shelf or transported within this SE – NW orientation axis. During periods of low sea level, the discharge of the Amazon River is much closer to the Amazon Cone and the transport of terrigenous sediments to the region tends to increase [26]. This is reflected in the observations that sedimentation in the Amazonian Cone is currently minimal [27], and that the transport of terrigenous sediments to the ACS area was greater during the glacial periods (moments of marine regression) than in the interglacial periods [28,29]. The alternation of forces of the marine currents by seasonality is another important factor for the construction of transport models and sedimentary deposition. Tiedemann and Franz [30] discuss the influence of the North Equatorial Counter Current (NECC) on sediment transport in the opposite direction of the NBCC. According to the authors, during the first half of the year, when the Intertropical Convergence Zone (ITCZ) is in its southernmost position, the NECC does not exist. The combination of the lower sea levels and glacial climates, which may have affected the seasonal movements of the ITCZ, certainly played an important role in the deposition of the terrigenous sediments inside the platform in the Plio-Pleistocene. Actually, a combination of mechanisms may be responsible for sedimentation in the ACS, especially in the prodelta and delta regions [31]. According to the author, seaward transport of sediment may be the result of several mechanisms acting simultaneously. The river plume transports a small quantity of sediment seaward in suspension, between 2 – 4% during high and falling discharge, respectively [32,33], and some sediment conceivably could be transported within this SE – NW orientation axis from the Amazon river mouth, as mentioned.

3.2 Trace Metals Distribution

The trace metal contents varied between Cr 39-84; Pb 55-108; Ni 16-34 and Zn 66-135 mg/kg and Hg 42-83 ng/g. The following behaviours were observed: 1) tendency to greater fraction of fine sediments in the Inner Shelf by direct influence of the high sedimentary load of the

Amazon River mouth; 2) absence of OM in the sediments of the Outer Shelf by the continuous flow of the ocean currents from southeast to northwest; 3) a strong seasonality in the volume of sediment transported due to rainfall. The

concentration of trace metals in the sediments followed the same convergence observed for the sediment flow, establishing a pattern with higher levels of trace metals in the CZ and Inner Shelf, and lower levels in the Outer Shelf (Fig. 4).

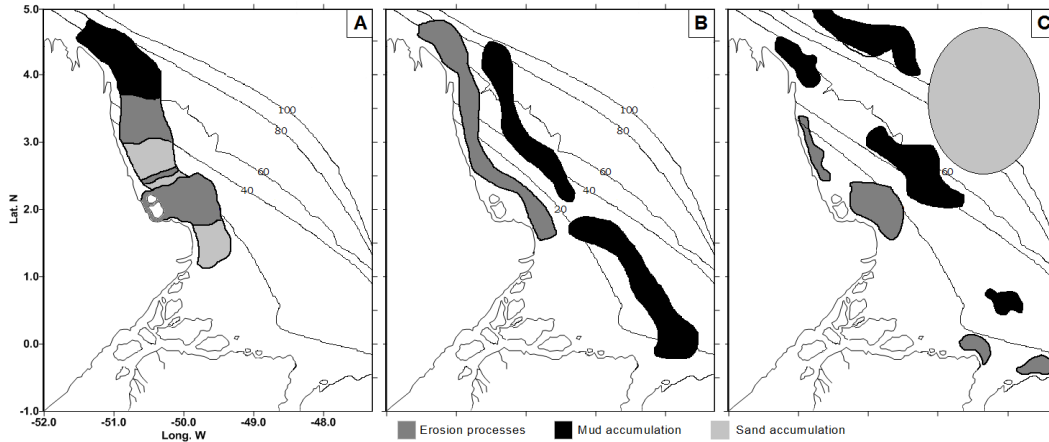


Fig. 2. Flow, transport and sedimentary deposition models in coastal zone and ACS based on A) Nittrouer and DeMaster [20]; B) Nittrouer et al. [19]; C) this study

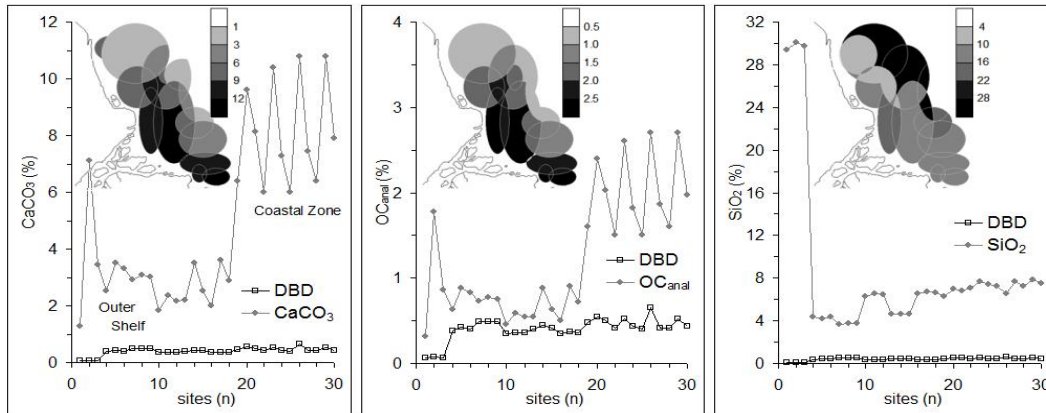


Fig. 3. Variation of CaCO_3 , organic carbon (OC) and SiO_2 along the coastal zone and ACS as a function of the range of variation of the dry bulk density (DBD) Sampling sites in triplicate ($N=30$)

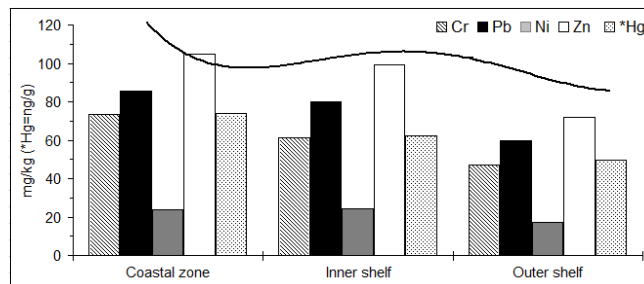


Fig. 4. Bars – medium concentration of the trace metals; solid line – curve of tendency in the CZ and ACS, Blue Amazon – Brazil

An important aspect in the flow of metals is the high capacity of metallic adsorption by the clay minerals in the sedimentary transport regime. The high cation exchange capacity observed in the clay and OM particles, associated to the slightly acidic pH conditions in the fluvial-marine system, facilitated the mobilization of the trace metals, contributing to the distribution of these throughout the Inner Shelf, especially the bivalent forms. The bioavailability of a trace metal, and consequently its toxicity, both depend on the form in which the metal is found (degree of speciation). Factors such as pH, Eh, alkalinity, levels of carbonates, redox potential, CO₂/O₂ rates, suspended solids (OM and clay minerals), oxygen and temperature interfere with the motility/precipitation ratio of trace metals. Based on the results obtained and on the morphological characteristics of the ACS, the main mechanisms of transport and deposition of trace elements associated to sedimentary transport are suggested. The most observed transport process, through the correlation analysis between the concentration of the metallic contents and the contents of organic compounds, was the metallic transport adsorbed to the particles of organic matter. This explains the strong correlation between the two parameters. In rivers of the Amazon with high organic matter the solubility is achieved by the combination of complexation and reduction processes, while the deposition is related to the adsorption mechanisms, in this case, directly influenced by the cation exchange capacity (CEC). Most trace elements under favorable pH conditions are adsorbed to suspended organic matter and deposited in the sediments through flocculation. Colloidal particles larger and more complex than organic particles are formed, which can follow two distinct paths: 1) follow long distances through the flow streams to settle away from the formation area, as observed in the depositional areas identified in the direction of the Orange Cape, far away from the coastline; or 2) deposited almost immediately in the sediments by the flocculation-precipitation process, as observed in the deposition areas near the coastal zone (Fig. 2). Increasing the pH from slightly acidic (5.5) to alkaline (> 8.0), as it moves away from the coastal zone, allows the formation of carbonate complexes and trace elements hydroxides, especially for strongly ionizable metals. In this case, the salinity contributed to raise the instability of the colloids, resulting in coagulation followed by precipitation. This transport and sedimentation pattern was well observed for the iron. With its reduction of Fe³⁺ to

Fe²⁺, co-precipitation of other metals such as Zn, Ni, Cu and Hg occurred. The erosive phenomenon known as "Terras-caídas" (fallen lands) is very common in the great rivers of white water of the Amazon, has been well observed in the coastal zone. It is a natural event resulting from the joint action of fluvial-marine currents and winds in the daily tidal movement processes that, combined with deforestation due to the irregular occupation of hillside areas, have intensified the rate of erosion in the region. It is an important source of detrital material rich in organic compounds and clay minerals that will follow one of the transport and sedimentation routes already described. Although it has not been observed or even quantified in the study area, it is important to mention the inverse deposition process called remobilization. The remobilization of trace elements from the sediments and interstitial water to the water column depends on its ionization state, the nature of the bond between the particles and the strength of that bond. The physical-chemical and biological processes that occur at the water-sediment interface, especially due to the alternation between aerobic and anaerobic conditions, will define the direction of the metallic flux in the sedimentary accumulation range. Thus, it is plausible that in some periods (seasonality) the remobilization is greater than sedimentary deposition, especially in non-reducing water-sediment interface areas, as in the boundary between the inner and outer oceanic shelf.

The trace metals have great environmental interest, mainly due to the bioaccumulation, mutagenic and teratogenic effects. Many trace metals such as Pb and Hg have a large bioconcentration factor in marine organisms, being significantly toxic, unlike other transition elements with known biochemical function. At present, anthropogenic activities are the most important entry pathways of trace metals in the marine compartments. The discussion if the main source of metallic contamination is natural or anthropogenic is classic and longstanding. However, the sum of these two sources in the Blue Amazon resulting in an immense volume of trace metals, which partly is carried by the current flow associated with suspended sediments, towards the mouth of the Amazon River following the sedimentation process. The natural composition of the Amazonian soil is considered enriched in trace metals as explained by researchers in 90th decade [1,3,4].

3.3 Statistical Analyses

The linear regression analyzes for the parameters pH, salinity, ΣCaCO_3 and organic matter content associated to trace elements are presented in the Fig. 5. A high linear regression was observed between the analyzed parameters, and the pH (Fig. 5A) and the salinity (Fig. 5B), both measured in the water column at the water-sediment interface, were inversely proportional to the concentration of trace elements, meanwhile ΣCaCO_3 (Fig. 5C) and organic matter (Fig. 5D) were directly proportional. In all cases, the degree of dependence of the trace elements in relation to the physical-chemical characteristics was very evident. These results are explained by the fact that bivalent metals are precipitated primarily for sediments in acidic to slightly acidic conditions, usually remaining suspended in alkaline conditions. Carbonates, as they become less soluble, they precipitate and thus act as secondary carriers of trace elements. The organic matter has high capacity of metallic adsorption due to its negative charge surface, on other hands, because it has high CEC.

The Pearson correlation indexes were high, confirming the strong degree of association between the analyzed parameters. The determination coefficients adjusted ranged from 0.8156 (ΣCaCO_3 versus trace elements) to 0.9141 for regression between pH and the sum of trace metals. In these cases, the results indicate that from 81.6% to 91.4% of the dependent variable (trace elements) is explained

by the predictive variable, and other lower-level factors should act on the residual values (18.4 to 8.6%). The results of the hypothesis tests (Table 1) confirm the results presented in Fig. 5. The F values of the four regressions are very significant for a $P < 0.0001$. In all cases, the values determined were greater than the values of $F_{05}(1; 109) = 3.48$, rejecting the null hypothesis, on other hands, that they are distinct events without association. In all four analyzes there was regression, accepting the alternative that imposes that the parameters analyzed in pairs are proportional, either directly or indirectly. The test of significance determined values of t , which in module, were higher than the t -critic obtained in the table (0.05; 109), suggesting that the paired sets do not belong to the same group (different means), being in this case related by association or equivalence. The clusters (Fig. 6) and the distance matrix analyzed for the physical-chemical parameters allowed to group the sampling sites among themselves in function of their spatial similarities. The results evidenced the areas of the inner and outer shelf of the ACS and coastal zone, suggesting a physical-chemical separation in the sedimentary compartment.

$$MS_R = \sum (\hat{y} - \bar{y})^2 \quad (7)$$

$$MS_{RD} = \frac{\sum (y - \hat{y})^2}{n - 2} \quad (8)$$

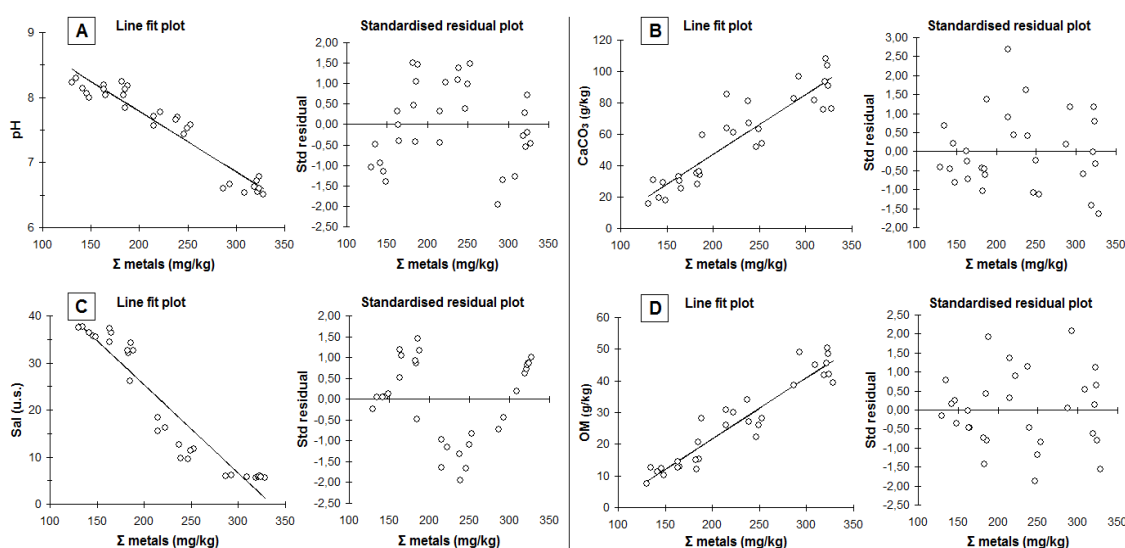


Fig. 5. Linear regression analysis for the pH, salinity, ΣCaCO_3 and organic matter content associated to dependent variable the trace elements

Table 1. Values resulting from linear regression analysis for trace elements (df=109)

	R^2	R^2_{adj}	R_p	MS	F	P	t
pHxM	0.9141	0.9110	-0.9561	11.20	297.85	<0.0001	75.92
SalxM	0.8995	0.8959	-0.9484	4601.51	250.71		22.41
$\Sigma CaCO_3 \times M$	0.8219	0.8156	0.9066	19039.18	129.26		-3.65
OMxM	0.8952	0.8914	0.9461	4871.16	239.07		-5.72

R^2_{adj} = adjusted; R_p = Pearson correlation; MS= mean square defined by equations 7 and 8.

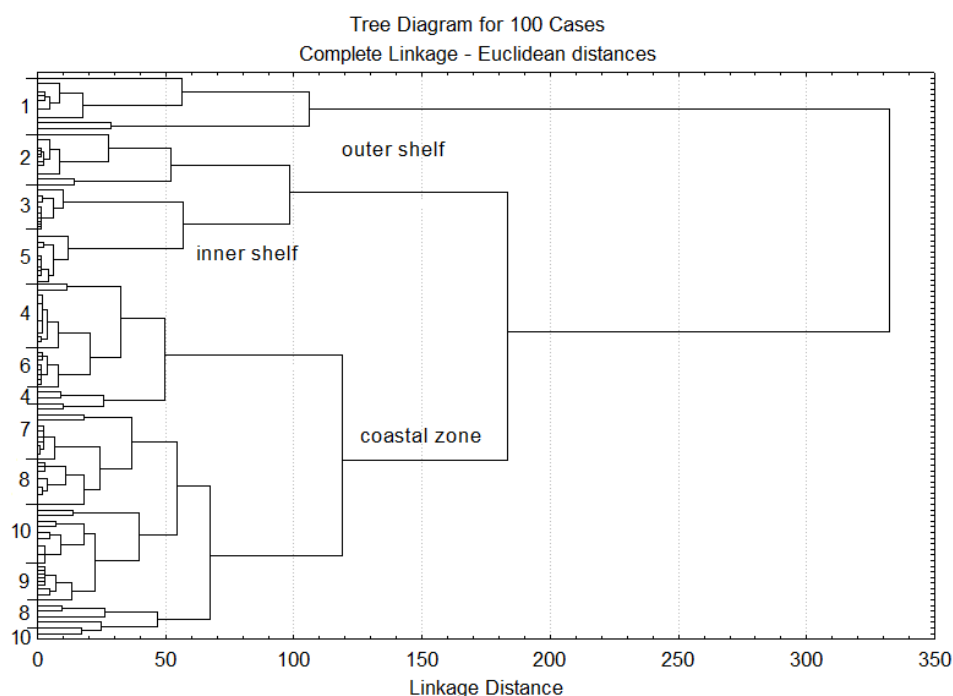


Fig. 6. Cluster for the sampling sites
(N= 100 cases; complete linkage and Euclidian distances)

4. CONCLUSION

From this study it was concluded that sediment transport, distribution and deposition in the study area are directly influenced by fluvial-marines currents, especially by NBCC, which contributes to the dispersion of fine sediments in the SE – NW direction. The trace elements followed the tendency of deposition imposed by the fine and muddy sediments, adsorbed to the organic and argillominerals compounds. $CaCO_3$ and organic carbon presented a similar distribution pattern in the sediment compartment and were important determinants for precipitation of trace elements. In addition, pH and salinity near the water-sediment transition range were inversely proportional to trace element distribution, all with high correlation indices. In the coastal zone the sedimentation process was not continuous, with

alternations between the erosive processes and the accumulation of muddy sediments. The zonation imposed by sedimentary deposition suggests that the inner oceanic shelf is the main area of occurrence of diagenetic processes.

CONSENT

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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