Geologia
Série Científica USP

DOI: 10.5327/Z1519-874X2012000100004
Revista do Instituto de Geociências - USP
Geol. USP, Sér. cient., São Paulo, v. 12, n. 1, p. 39-51, Abril 2012

# Is there a true delta at the Ribeira de Iguape river mouth, São Paulo State?

## *Existe um verdadeiro delta na foz do rio Ribeira de Iguape, São Paulo?*

Kenitiro Suguio[1], Roberto Barbosa Rodrigues[2], Denise dos Santos Silva[1]
[1]Instituto de Geociências da Universidade de São Paulo - USP; Departamento de Geologia Sedimentar e Ambiental, Rua do Lago 562, Butantã, CEP 05508-080, São Paulo, SP, BR (gsaigc@usp.br), (denise.silva@usp.br)
[2]Universidade Guarulhos - UnG, Guarulhos, SP, BR (roberbr.exm@hotmail.com)

Received 01 august 2011; accepted 24 january 2012

**Abstract**
The study area corresponds to the coastal plain neighboring the *Ribeira de Iguape* river mouth in the São Paulo State littoral, where the Iguape, Cananeia and Ilha Comprida municipalities are situated. This coastal plain exhibits an area of more than 1,500 km$^2$. It has been interpreted as a consequence of shallow marine sedimentation of Pleistocene and Holocene, attributable to Cananeia and Santos transgressions, occurred during the last two interglacial stades named Sangamon and Holocene, intercalated by the last glacial stade named the Wisconsin according to the North-American nomenclature. However, without any scientific fully justifiable evidence, it has been hypothetically postulated that this coastal plain could represent an oceanic delta associated with the *Ribeira de Iguape* river mouth, which is the most important drainage along the São Paulo State coastline flowing to the Atlantic Ocean. This article has presented the data obtained by essentially sedimentological studies, based on grain size and heavy mineral analyses, which brought important subsidies for a negative response to the question: "is there a true delta at the *Ribeira de Iguape* river mouth (São Paulo State, Brazil)?".

**Keywords:** Delta; Relative sea level; Late quaternary; São Paulo State coastline.

**Resumo**
A área de estudo está situada na planície costeira adjacente à foz do rio Ribeira de Iguape no litoral Sul do Estado de São Paulo, onde se localizam os municípios de Iguape, Cananeia e Ilha Comprida. Essa planície costeira apresenta mais de 1.500 km$^2$ de extensão. Tem sido interpretada como consequência da sedimentação marinha rasa pleistocênica e holocênica, atribuível às transgressões Cananeia e Santos, ocorridas durante os dois últimos estádios interglaciais denominados de Sangamoniano e Holocênico, intercalados pelo último estádio glacial denominado Wisconsiniano, segundo as denominações adotadas na América do Norte. No entanto, sem qualquer evidência plenamente justificável, tem sido postulado hipoteticamente que esta planície representaria um delta oceânico associado à foz do rio Ribeira de Iguape, que constitui a drenagem mais importante do litoral paulista, que demanda ao Oceano Atlântico. Este artigo apresentou os resultados de estudos essencialmente sedimentológicos baseados em análises granulométricas e de minerais pesados, que trazem importantes subsídios para uma resposta negativa à questão: "existe um verdadeiro delta na foz do rio Ribeira de Iguape (Estado de São Paulo, Brasil)?".

**Palavras-chave:** Delta; Nível relativo do mar; Quaternário tardio; Litoral Paulista.

## INTRODUCTION

The word delta has a very old origin. Herodotus (about 484 to 425 years B. C.) would have used it for the first time more than 400 years B.C., due to its great morphologic resemblance with the Greek alphabet fourth letter delta, when referred to the Nile river mouth alluvial plain in Egypt, with the two most important distributaries. Its introduction within the geological literature occurred much later by Lyell (1832), who also defined it in 1853 as "an alluvial terrain originated by a river in its mouth, nevertheless without any clear shape" (Moore, 1966).

Barrell (1912) used this word to designate "a partially subaerial deposit built by a river when it flows within a permanent water body" (Le Blanc, 1975). Trownbridge (1930) proposed that the substantive delta and the adjective deltaic could be used to designate deposits formed by a river at the vicinities of its mouth. According to Bates (1953), the delta could be "a sedimentary deposit built by a jet flow within a permanent water body", when it could pass to incorporate the submarine fans too. In general, for a delta deposition, the fluvial courses flow into more or less quiet water bodies (lake, lagoon, sea or ocean, and even another river), where partially reworked sediments are deposited in part submerged or emerged, whose subaerial portion exhibits changeable geometrical shapes with a roughly triangular form.

Gradually, additional resembled coastal plains have been studied, such as the Colorado (Mckee, 1939; Thompson, 1968), Niger (Allen, 1965), Orenoco (Van Andel, 1968) and Rhone (Oomkens, 1970) river deltas, where the concept of delta was modified to accommodate new remarkable features. Fisher (1969) adopted a more generalized definition, according to which, "delta could be a depositional system fed by a river, that gives rise to an irregularly prograded coastline".

Baccocoli (1971) described for the first time the Brazilian Quaternary deltas, the author adopted this word to nominate "sedimentary accumulations resulting from the velocity loss of the water current, which flows within a much more voluminous water body, being the deposits then formed subaerial or subaqueous". Coleman and Wright (1971, 1975) discussed about the coastal processes, their effects and significances on delta formations, recognizing the following fundamental factors: fluvial regime, coastal processes, climate factors, and tectonic behavior.

Wright (1978) enlarged even more the generalization of this concept, the delta was defined by the author as "subaqueous and subaerial coastal accumulations built by sediments carried by a river, at its adjacencies or in a close relationship with the delta, including the deposits secondarily modeled by several agents of the receiver basin, such as waves, currents and tides." By this definition, a delta could incorporate the complete spectrum of the littoral sedimentary accumulations, such as: beaches, aeolian dunes, tidal plains, marshes, mangroves, lagoons, barrier islands, and bays.

Nevertheless, discrepancies found in the definitions of deltas seem to assume that the sediments must be supplied by a river, although they could be more or less reworked by active coastal processes within the receiver basin. Moreover, among the fundamental factors of the enumerated and discussed deltation (deltaic sedimentation) by Coleman and Wright (1971, 1975), the relative sea-level changes were not mentioned by these authors, whose significance was recognized and emphasized for the first time by Suguio and Martin (1981) in the Brazilian Quaternary deltas previously studied by Baccocoli (1971), which were latterly considered in detail by Martin, Suguio and Flexor (1993).

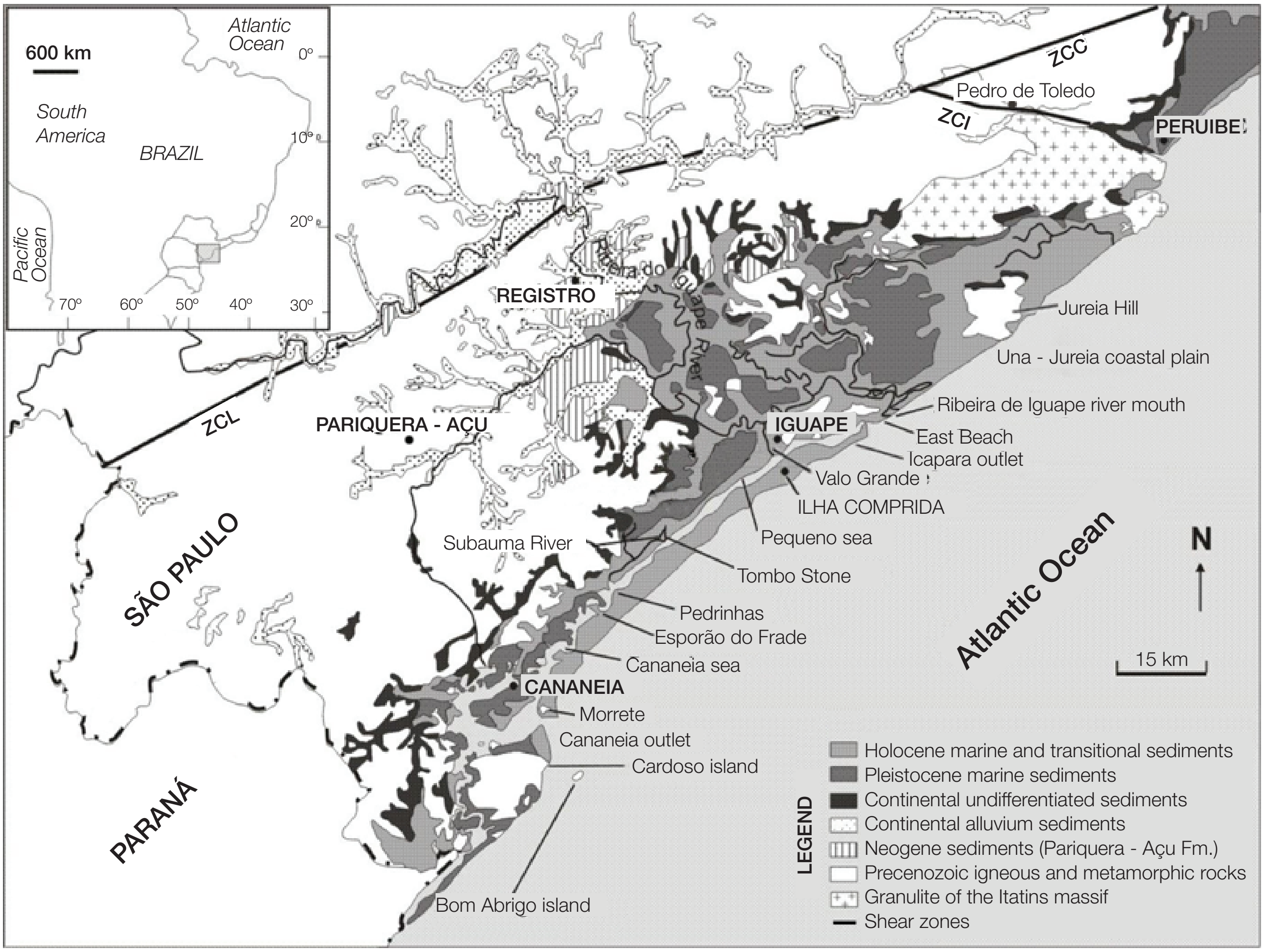
The main objective of this paper was to demonstrate, according to the present concept of delta and using some conventional sedimentological methods (grain size and heavy mineral analyses), which were submitted to convenient statistical treatments, that the coastal plain neighboring the Ribeira de Iguape river mouth is not a true delta.

## STUDY AREA

The area studied is located in the downstream *Ribeira de Iguape* river, which represents the most important drainage along the São Paulo State coastline demanding the Atlantic Ocean. The coastal plain adjacent to its mouth extends for more than 1,500 km$^2$, with the shape of a large erosion amphitheatre filled by the Cananeia Formation (Suguio and Petri, 1973) pleistocene sediments and the Ilha Comprida Formation (Suguio and Martin, 1994) holocene deposits of shallow marine environments, which are mapped in a reconnaissance scale, by Suguio and Martin (1978a, 1978b), and in a regional map of *Instituto de Pesquisas Tecnológicas* – IPT (1981), as seen in Figure 1.

The coastal plains situated at Doce (Espírito Santo State) and Paraíba do Sul river (Rio de Janeiro State) mouths, previously studied by Suguio, Martin, and Dominguez (1982) and Martin et al. (1984), must be considered as essentially deltaic. However, the Ribeira de Iguape river mouth coastal plain geological evolution during the Quaternary was formerly interpreted by Suguio and Martin (1978a, 1978b) as closely related to the relative sea level changes, which occurred during the Cananeia and Santos transgressions.

However, without any field surveys and/or laboratory studies, unexpected speculations sporadically appear stating that this coastal plain could represent a true delta. From scientific data obtained by grain size analysis, subjected to a suitable statistical treatment, and by heavy minerals



ZCL: Lancinha Shear Zone; ZCC: Cubatão Shear Zone and ZCI: Itariri Shear Zone. Extracted from Guedes (2009).

**Figure 1.** Regional geologic map of the Institute of Technological Researches (1981, modified).

studies of selected samples, an undoubtful scientific argument is here presented that, according to the up-to-date definition of delta, there is no a true delta in the Ribeira de Iguape river mouth. This is said because its geological evolution through progradations subsequently to the above-mentioned marine transgressions occurred practically without significant fluvial contribution to the sediment supply.

## MATERIALS AND METHODS

### Bibliographical researches

The bibliographical surveys extended to the previous works are closely related to the theme carried out elsewhere or in the study area. Therefore, besides the publications related to the definition of delta, few reports as from Brasconsult S.A. (1964) and Geobrás-Engenharia e Fundações (1966) and more specific papers from Suguio and Martin (1978a and 1978b) were taken into consideration.

### Sampling of sediments

Thirty samples were collected with each of them weighing about 1 kg on April, 25 and 26, 2009; the samples came from the Ribeira de Iguape river bottom (samples RR – 01 to RR – 18, equidistant of approximately 1 km), and they were obtained downstream of the Jaire village, with the Van Veen type bottom sampler, as well as from the river right marginal bank as far as the proximities of Valo Grande Channel (Figure 2).

From the higher banks (more than 5 m) of the Ribeira de Iguape river, represented by sandy cliffs, between the sampling stations RR – 01 to RR – 16, the samples FC – 01 to 04 of the Cananeia Formation were obtained. They have been collected manually and/or aided by a geologic hammer, from approximately 1 m above the water surface at the sampling time.

From a low sandy sea cliff (near 2 m above local high tide level) at North of the Icapara hill, on Mar Pequeno margin and the Ilha Comprida rearguard, three samples (IC – 01 to IC – 03) of the homonymous lithostratigraphic unit (Ilha Comprida Formation), from the bottom to the top of the outcrop, were manually picked up.

At the Jureia beach, along the sandy spit at Northward of the Ribeira de Iguape river mouth (Figure 3), five samples were obtained (PR – 01 to 05). They were about 1 km equidistant among them, with a previous removal of 10 cm deep superficial sands, to avoid fortuitous contamination by human and/or other animal tramps.

### Grain size analysis

After being dried at a 60°C oven, the collected raw samples were quartered through a Jones splitter for obtaining an adequate sample bracket, without any loss of the representativity of the grain size frequencies in the studied samples. Afterwards, the fractions smaller than 0.062 mm of diameter constituted of silts and clays, according to the Wentworth (1922) grade scale, were discarded by elutriation with a continuous ascending water flow. Then, approximately 100 g of the sands were subjected to the laboratory sieve analysis in 0.5 $\phi$ (phi) grade scale intervals using an electric laboratory vibrator.

The fundamental statistical parameters (mean diameter, standard deviation, asymmetry, and kurtosis) of the grain size distributions of essentially sandy fractions (diameters from 0.062 to 2 mm) were calculated, according to Folk and Ward (1957). As stated by Suguio (1971), the grain size frequency distribution is a fundamental physical property of detrital sediments. When submitted to the graphic method by Sahu (1964) supplied with indications of their sedimentary environments, they are characterized by different energy and viscosity levels obtained by a multivariable discriminant analysis applied to their grain size data.

### Heavy minerals

These minerals represent accessory components of detrital sediments, which commonly occur in very low frequencies (less than 1% to a maximum of some percents), characterized by a density higher than the most common minerals in sands, like the quartz and feldspar, with a density of approximately 2.6 g/cm$^3$.

Emery and Noakes (1968) classified the heavy minerals according to their densities and economic values in "heavy" heavy minerals like gold, tin and platinum (d = 6.8 to 21 g/cm$^3$); "light" heavy minerals as ilmenite, rutile, zircon, and monazite (d = 4.2 to 5.3 g/cm$^3$) and gems (precious stones), such as the diamond (d = 2.9 to 4.1 g/cm$^3$).

In this study, the contained heavy minerals were used as provenance and mineralogical maturity indices of detrital sediments, and the most adequate are the "light" heavy minerals, mainly the "non-micaceous transparent heavy minerals". The presence or even the absence of certain minerals of this group, besides changes in contents and/or shapes or colors of some minerals, allowed the reconstitution of geological and/or geographical evolution through the time in this area. One of the useful parameters is the ZTR index proposed by Hubert (1962), which corresponds to the addition of numerical frequencies in percentages of zircon, tourmaline, and rutile. It represents the ultra-stable fraction of non-micaceous transparent heavy minerals, preferentially preserved within the heavy fractions of more mature sediments, due to their higher physical and chemical hard-wearing properties. Therefore, the higher this index, that is, nearer to 100, the bigger is its mineralogical or chemical maturity, and this fact could be interpreted as a consequence of greater frequencies and/or intensities of reworking processes.

As stated by Rittenhouse (1943), the higher the density characteristic of heavy minerals give rise to their association with coarser quartz grains, during their subaqueous transportation as, for example, within fine (0.125 – 0.250 mm) and very fine (0.062 – 0.125 mm) sands. So, the numerical frequencies of heavy minerals contained in different samples are comparable only within the same grain size intervals. Then, if sand exhibits a median diameter of 0.177 mm, for example, the hydrodynamically compatible heavy minerals could have 0.133 and 0.088 mm of median diameters, respectively, in tourmaline and zircon grains. It shows that, within the same sample, tourmaline would be preferentially associated with fine sand and zircon with very fine sand.

Amongst the several procedures of heavy mineral separations, when they are mixed with light minerals, the present paper adopted that of the heavy liquid bromoform ($CHBr_3$), whose density is variable between 2.85 to 2.9 g/cm$^3$ and, therefore, is intermediary between the heavy and light minerals. Then, the majority of the heavy minerals sinks and light minerals floats in this liquid. After the separation, the heavy minerals were washed with ethyl alcohol and, subsequently, after the separation and rejection of the opaque paramagnetic minerals such as magnetite, the samples were prepared for setting up on glass slides. The medium for obtaining petrographic slide was the Canada balsun with a refraction index of about 1.52, which was subsequently superimposed by a cover glass.

The available heavy mineral grains mounted for microscope examination were sufficient for counting 150 grains of heavy minerals in a sample for every grain-size. This study was carried out on 20 selected samples of 30 ones submitted to the grain size analysis. These heavy minerals

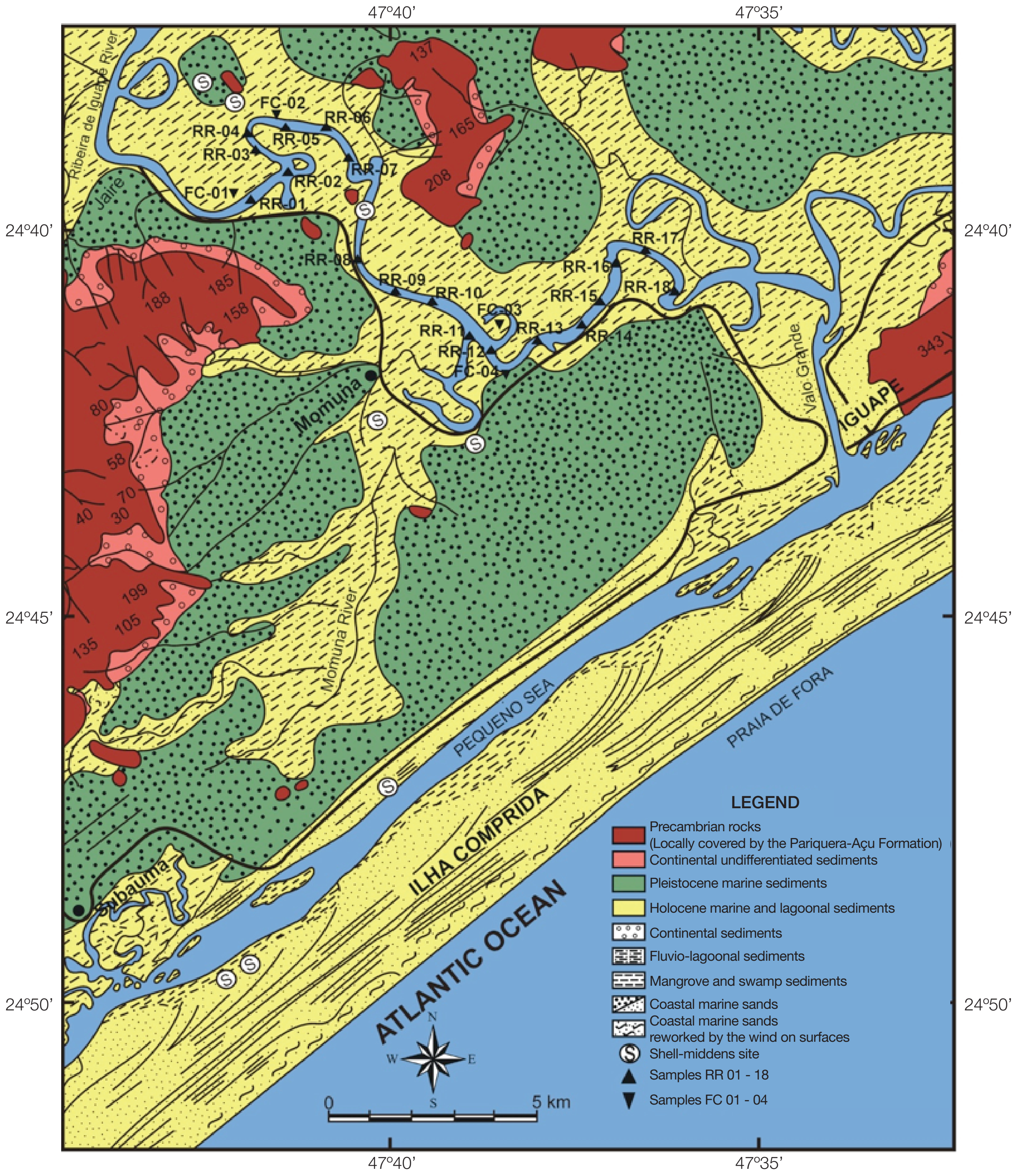


**Figure 2.** Partial geologic map of the *Ribeira de Iguape* river mouth coastal plain based on Suguio and Martin (1978b), with the sampling stations RR – 01 to RR – 18, along the *Ribeira de Iguape* river (São Paulo State), as well as the sampling stations FC – 01 to FC – 04 of the Cananeia Formation.

were studied in eight samples of the series RR (03, 05, 09, 11, 13, 15 and 16), four of the series FC (01 to 04), three of the series IC (01 to 03), and five samples of the series PR (01 a 05).

The preliminary results of non-micaceous transparent heavy minerals under petrographic microscope using polarized light allowed the identification of the species of heavy minerals, as well as their crystalline habits and furthermore other particularities as their shapes, inclusions and colors.

## ANALYTICAL RESULTS

### Statistical parameters

The grain size parameters of the sandy fractions (0.062 to 2 mm of diameter) from four different series (RR, FC, IC and PR), divided into six groups of samples, were obtained by the moment analytical technique of Pearson

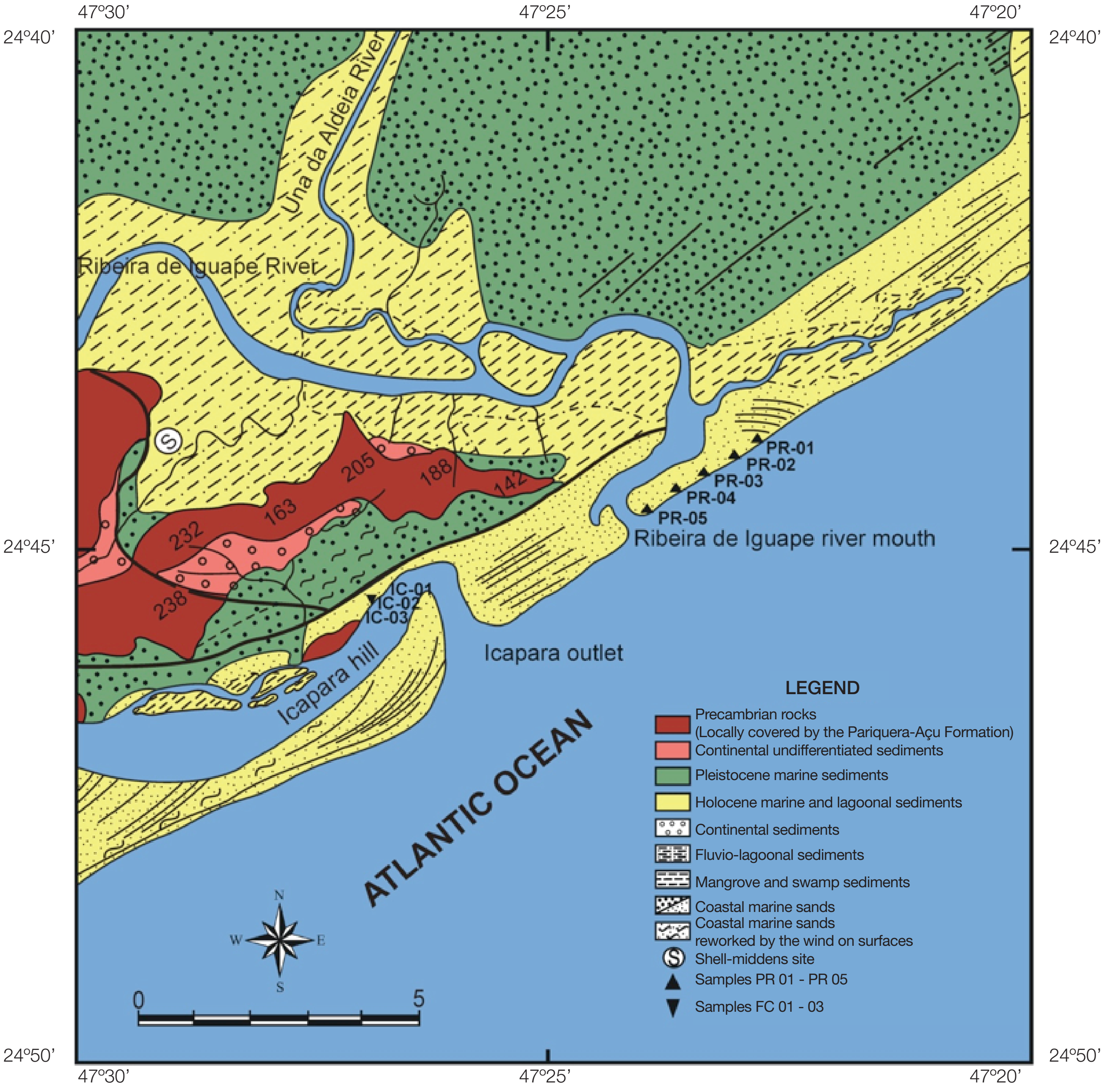


**Figure 3.** Partial geologic map of the *Ribeira de Iguape* river mouth coastal plain based on Suguio and Martin (1978b), with the sampling stations IC – 01 to IC – 03 and PR – 01 to PR – 05, from the Ilha Comprida Formation and the Jureia beach, respectively.

through the program “moment 4.1” and by Folk and Ward (1957) method.

As a function of the objectives of this paper, from the obtained four statistical parameters, only the mean diameters and the standard deviations were here discussed in more details. However, other parameters as the kurtosis were also important in the construction of Sahu (1964) diagram.

Geologically, the mean diameter reflects the average sizes of the particles in a detrital sediment, which are influenced by the supplying source, the depositional processes, and the stream velocities (Suguio, 1971). Table 1 shows the mean diameters obtained for the samples studied.

As expected, the average values of the mean diameters from the three groups of fluvial samples decrease gradually from upstream to downstream, from coarse sand (0.500 to 1 mm) in the two first groups as far as fine sand (0.125 to 0.250 mm) in the last groups. This progressive downstream fining could be envisaged mostly due to the hydrodynamic competence decreasing and secondarily by the physical abrasion action during the transportation of the grains.

However, the mean diameter average values of sand samples from the remaining three groups, composed by the Cananeia (Pleistocene), the Ilha Comprida (Holocene) formations and from the present beach (Jureia beach) exhibit very resembling values within the fine sand (0.125 to 0.250 mm) interval, which changed from 0.144, 0.153 and 0.138 mm, respectively. This fact suggests same source (provenance) for the remaining three groups, but probably different from the fluvial sands. Other aspect that must be emphasized is that the Cananeia Formation, samples (FC – 01 to FC – 04) of the group 4, were collected from cliffs adjacent to the group 1 (RR – 01 to RR – 06) and 2 (RR – 07 to RR – 12) fluvial samples. However, their medium mean diameters were very different, with about 0.530 mm (coarse sand) and 0.518 (coarse sand) for the fluvial samples groups 1 and 2, and 0.144 mm (fine sand) for the Cananeia Formation group.

The standard deviation, as stated by Folk and Ward (1957), is an indication of the grain size sorting degree, which is changeable from 0 to more than 4, in which the perfect sorting is represented by zero. This parameter measures the individual values dispersions around the mean grain size and it is equivalent to the inverse of the granulometric selection of sediments. Table 2 shows the standard deviation values calculated for the studied samples.

Also, in this case it was relatively foresightful that the average values of the standard deviations from the three groups of fluvial sediments, represented by six samples, could increase their sorting degrees from upstream to downstream, changing from moderately sorted in the two first groups to well sorted in the last group, probably as a consequence mainly of gradual fining by selection during the transportation of the sand grains. It must be also emphasized that the average values of the remaining three groups are distinct from the fluvial sediments ones, where the average values indicated moderately sorted in the two first groups evolving to well sorted in the last one. Meanwhile, the average values of the three remaining groups exhibited mostly sorted to very well sorted sands.

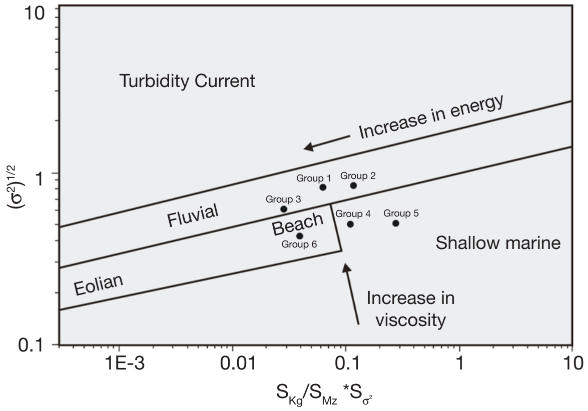


**Figure 4.** Representation of the six groups of samples here studied according to Sahu (1964) diagram.

## Sahu diagram

According to Suguio (1971), the frequency of grain size distribution is a fundamental physical property of the detrital sediments, which provides information on the transportation energy and on the kinetic energy levels and associated conditions within a sedimentary environment. The grain size parameters can be important tools for depositional environmental discriminations of distinct levels of transportation energy and its use was previously proposed by several authors, such as Folk and Ward (1957), Passega (1957), Friedman (1961), Sahu (1964), among others. In this paper, Sahu (1964) method was chosen.

Sahu presented an empirical diagram, where five different sedimentary environments with indications of increasing energy and fluidity of the depositional environments are outlined. It was used the grain size statistical parameters defined by Folk and Ward (1957) and, through a multivariable discriminatory analysis, the limits between eolian and beach (including shallow-marine), shallow marine and fluvial and finally between fluvial and turbidity current environments were established.

Sahu (1964) observed that grain size parameters such as mean diameter (Mz), standard deviation (σi), and kurtosis (Kg), calculated as stated by Folk and Word (1957), for sandy fractions of a correlatable group (equal or more than two) of samples, are useful for interpreting the depositional phenomena. After trying several combinations of these parameters, the author concluded that the best discrimination

**Table 1.** Maximum, medium, and minimum values of the mean diameters of six groups of samples from the *Ribeira de Iguape* river mouth (São Paulo State).

| Sample groups | Mean diameter | | |
|---|---|---|---|
| | Maximum | Medium | Minimum |
| 1 (RR – 01 to RR – 06) | 0.15 ϕ<br>(≅0.900 mm) | 0.91 ϕ<br>(≅0.530 mm) | 1.41 ϕ<br>(≅0.380 mm) |
| 2 (RR – 07 to RR – 12) | 0.44 ϕ<br>(≅0.730 mm) | 0.96 ϕ<br>(≅0.518 mm) | 1.53 ϕ<br>(≅0.350 mm) |
| 3 (RR – 13 to RR – 18) | 1.53 ϕ<br>(≅0.350 mm) | 2.34 ϕ<br>(≅0.195 mm) | 3.09 ϕ<br>(≅0.116 mm) |
| 4 (FC – 01 to FC – 04) | 2.46 ϕ<br>(≅0.183 mm) | 2.80 ϕ<br>(≅0.144 mm) | 3.11 ϕ<br>(≅0.117 mm) |
| 5 (IC – 01 to IC – 03) | 2.41 ϕ<br>(≅0.188 mm) | 2.71 ϕ<br>(≅0.153 mm) | 2.99 ϕ<br>(≅0.127 mm) |
| 6 (PR – 01 to PR – 05) | 2.42 ϕ<br>(≅0.187 mm) | 2.85 ϕ<br>(≅0.138 mm) | 3.09 ϕ<br>(≅0.118 mm) |

**Table 2.** Maximum, medium, and minimum values of the standard deviations (or sorting degrees) of six groups of samples from the *Ribeira de Iguape* river mouth (São Paulo State).

| Sample groups | Standard deviation (Sorting degree) | | |
|---|---|---|---|
| | Maximum | Medium | Minimum |
| 1 (RR – 01 to RR – 06) | 0.65 (moderately sorted) | 0.51 (moderately sorted) | 0.33 (very well sorted) |
| 2 (RR – 07 to RR – 12) | 0.84 (moderately sorted) | 0.72 (moderately sorted)ç | 0.55 (well sorted) |
| 3 (RR – 13 to RR – 18) | 0.62 (moderately sorted) | 0.47 (well sorted) | 0.27 (very well sorted) |
| 4 (FC – 01 to FC – 04) | 0.68 (moderately sorted) | 0.45 (well sorted) | 0.30 (very well sorted) |
| 5 (IC – 01 to IC – 03) | 0.31 (very well sorted) | 0.31 (very well sorted) | 0.30 (very well sorted) |
| 6 (PR – 01 to PR – 05) | 0.65 (moderately sorted) | 0.36 (well sorted) | 0.28 (very well sorted) |

between the different environments, as well as between the several depositional processes, is obtained by the values of $\sqrt{\sigma i^2}$ in the $y$ axis against [$^s$(Kg)/$^s$(Mz)] x ($^s\sigma i^2$) in the $x$ axis on a bilogarithmic diagram. The meanings of the parameters are as:

$\sqrt{\sigma i^2}$ = average variance of a group of n samples, where $n \geq 2$;
$^s$(Kg) = standard deviation of kurtosis values of the same group of samples;
$^s$(Mz) = standard deviation of mean diameter values of the same group of samples, and
$^s(\sigma i^2)$ = standard deviation of variance values of the same group of samples.

The samples were gathered in the following six groups: 1 (RR – 01 to RR – 06), 2 (RR – 07 to RR – 12), 3 (RR – 13 to RR – 18), 4 (FC – 01 to FC – 04), 5 (IC – 01 to IC – 03) and 6 (PR – 01 to PR – 05), as shown in Figure 4.

The Ribeira de Iguape river bottom sediments represented by groups 1 to 3, as could not be different, clearly indicated their fluvial sedimentary environments. Moreover, meanwhile the groups 1 and 2 indicated similar fluidity, they exhibited distinct energy levels, and the group 3 was characterized by fluidity and energy levels higher than the previous groups. Groups 4 an 5 are composed of samples from Cananeia (Pleistocene) and Ilha Comprida (Holocene) formations, respectively, which suggest that their deposition occurred in a shallow marine environment with different energy levels. Finally, group 6, which is composed of samples from a present beach, indicated this environment. The shallow marine environment suggested by group 4, from cliffs of the Ribeira de Iguape river marginal banks, was sampled 15 to 20 km from the present shoreline. This is very significant because it indicates the local paleo-environments about 120,000 years B. P. (Before Present), when the Cananeia Formation was deposited.

## Heavy mineral frequencies

After the identification of the non-micaceous transparent heavy minerals under the petrographic microscope, a minimum of 150 grains from each sample was counted in 20 sand samples separated in fine

**Table 3.** Distribution of non-micaceous transparent heavy minerals in numerical frequency (percentage) within the fine sand of the studied samples.

| Sample | Zircon | Tourmaline | Rutile | Hornblende | Epidote | Sillimanite | Kyanite | Staurolite | Hypersthene | Clinopyroxene | Tremolite | Andalusite | Garnet | Monazite | TOTAL | ZTR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR – 03 | 2.0 | 21.2 | 2.0 | 53.0 | 4.0 | 13.9 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 25.17 |
| RR – 05 | 15.8 | 20.4 | 8.6 | 13.8 | 21.7 | 3.3 | 2.0 | 9.9 | 0.7 | 0.0 | 0.0 | 3.9 | 0.0 | 0.0 | 100.0 | 44.74 |
| RR – 07 | 3.3 | 7.9 | 3.9 | 57.2 | 9.9 | 7.9 | 7.2 | 2.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 15.14 |
| RR – 09 | 2.0 | 24.8 | 2.0 | 48.4 | 7.2 | 11.8 | 2.0 | 1.3 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 28.76 |
| RR – 11 | 2.0 | 26.8 | 3.3 | 43.1 | 9.2 | 7.8 | 2.0 | 5.2 | 0.0 | 0.0 | 0.6 | 0.0 | 0.7 | 0.0 | 100.0 | 32.03 |
| RR – 13 | 3.2 | 21.3 | 0.0 | 44.5 | 7.7 | 11.0 | 1.3 | 5.2 | 1.3 | 0.0 | 0.0 | 3.9 | 0.0 | 0.0 | 100.0 | 24.52 |
| RR – 15 | 11.1 | 27.5 | 1.3 | 36.6 | 7.8 | 7.2 | 1.3 | 5.2 | 0.0 | 0.7 | 0.0 | 1.3 | 0.0 | 0.0 | 100.0 | 39.67 |
| RR – 16 | 20.0 | 16.0 | 2.0 | 38.0 | 8.0 | 9.3 | 5.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 38.00 |
| Average | 9.9 | 20.7 | 2.9 | 41.8 | 9.4 | 9.0 | 2.9 | 4.0 | 0.4 | 0.1 | 0.1 | 1.1 | 0.1 | 0.0 | 100.0 | 31.01 |
| PR – 01 | 1.3 | 14.6 | 3.2 | 66.2 | 3.2 | 7.6 | 1.9 | 0.0 | 0.6 | 0.6 | 0.6 | 0.0 | 0.0 | 0.0 | 100.0 | 19.11 |
| PR – 02 | 5.2 | 22.7 | 3.2 | 39.0 | 13.0 | 11.0 | 3.2 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 31.17 |
| PR – 03 | 4.0 | 18.0 | 0.0 | 46.0 | 9.3 | 14.0 | 1.3 | 3.3 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | 100.0 | 22.00 |
| PR – 04 | 27.5 | 26.8 | 13.1 | 20.9 | 3.9 | 3.9 | 0.0 | 2.0 | 0.0 | 0.7 | 0.0 | 1.0 | 0.0 | 0.0 | 100.0 | 67.33 |
| PR – 05 | 1.3 | 27.3 | 0.0 | 27.3 | 17.5 | 11.7 | 5.8 | 1.9 | 1.3 | 0.0 | 0.0 | 5.2 | 0.6 | 0.0 | 100.0 | 25.58 |
| Average | 7.8 | 21.9 | 3.9 | 39.9 | 9.4 | 9.6 | 2.4 | 1.8 | 0.5 | 0.3 | 0.1 | 2.5 | 0.1 | 0.0 | 100.0 | 33.03 |
| FC – 01 | 11.1 | 53.3 | 6.7 | 10.4 | 2.2 | 0.9 | 3.7 | 1.5 | 0.7 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 100.0 | 71.12 |
| FC – 02 | 5.2 | 26.6 | 3.9 | 0.0 | 20.8 | 11.0 | 22.7 | 1.3 | 0.0 | 0.0 | 0.0 | 7.8 | 0.6 | 0.0 | 100.0 | 35.72 |
| FC – 03 | 19.0 | 39.2 | 9.2 | 3.3 | 5.9 | 7.8 | 5.2 | 3.9 | 0.0 | 0.0 | 0.0 | 5.9 | 0.0 | 0.7 | 100.0 | 67.33 |
| FC – 04 | 3.3 | 19.6 | 5.2 | 41.2 | 5.2 | 17.6 | 7.2 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 28.11 |
| Average | 9.6 | 34.8 | 6.2 | 13.7 | 8.5 | 9.3 | 9.7 | 1.7 | 0.3 | 0.0 | 0.0 | 3.8 | 0.2 | 0.2 | 100.0 | 50.57 |
| IC – 01 | 5.2 | 44.8 | 5.2 | 11.7 | 7.8 | 9.7 | 9.1 | 5.2 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 55.20 |
| IC – 02 | 30.3 | 31.0 | 5.2 | 16.8 | 7.1 | 3.2 | 3.9 | 1.3 | 0.6 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 66.46 |
| IC – 03 | 7.9 | 25.2 | 3.3 | 34.4 | 15.2 | 7.9 | 2.0 | 3.3 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 36.43 |
| Average | 14.5 | 33.7 | 4.6 | 21.0 | 10.0 | 6.9 | 5.0 | 3.3 | 0.9 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 52.70 |

(0.125 – 0.250 mm) and very fine (0.062 – 0.125 mm), according to Tables 3 and 4.

The following sequence of heavy minerals, in decreasing abundance order, was identified within the fine sand fraction. It is composed of hornblende, tourmaline, epidote, sillimanite, zircon, kyanite, rutile, staurolite, andalusite, hypersthene, garnet, clinopyroxene, tremolite, and monazite. The heavy minerals kyanite, hypersthene, clinopyroxene, tremolite, garnet, and monazite were not found in all the samples.

Differently from the fine sand fraction, the very fine sand fraction is composed of the sequence formed by tourmaline, hornblende, zircon, epidote, sillimanite, rutile, kyanite, staurolite, andalusite, hypersthene, garnet, clinopyroxene, and tremolite. From these minerals, kyanite, hypersthene, clinopyroxene, tremolite, garnet, and monazite were not present in all the studied samples.

## Mineralogical maturity

As stated by Pettijohn (1976), the maturity degree of a detrital sediment is indicative of the stage attained in its way towards a more stable final product, which depends on the acting genetic process, both in intensity and in frequency. The mineralogical or chemical maturity depends also on the time interval involved. If the time was excessively short, and even the process intensity was high, the final product will be immature, but when time is sufficiently long and intensity is high, the final product will exhibit high maturity degree.

Among several parameters proposed for the evaluation of the mineralogical maturity, the ZTR index of Hubert (1962) is used. According to this parameter, the Ribeira de Iguape river bottom sediments (series RR) are the most immature, because their average values changed from 32 to 34.2% for fine and very fine sands, respectively. On the

**Table 4.** Distribution of non-micaceous transparent heavy minerals in numerical frequency (percentage) within the very fine sand of the studied samples.

| Sample | Zircon | Tourmaline | Rutile | Hornblende | Epidote | Sillimanite | Kyanite | Staurolite | Hypersthene | Clinopyroxene | Tremolite | Andalusite | Garnet | Monazite | TOTAL | ZTR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR – 03 | 9.2 | 23.5 | 3.9 | 27.5 | 15.0 | 5.2 | 7.2 | 7.2 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 36.61 |
| RR – 05 | 19.0 | 23.2 | 4.2 | 35.2 | 8.5 | 4.2 | 0.0 | 4.2 | 0.0 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 100.0 | 46.48 |
| RR – 07 | 5.7 | 14.6 | 7.0 | 45.2 | 10.8 | 8.9 | 5.1 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 27.39 |
| RR – 09 | 8.4 | 26.5 | 1.3 | 34.2 | 9.0 | 14.8 | 3.9 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 100.0 | 36.13 |
| RR – 11 | 7.1 | 23.2 | 0.0 | 9.0 | 38.1 | 16.8 | 0.0 | 3.2 | 0.6 | 0.0 | 0.6 | 1.3 | 0.0 | 0.0 | 100.0 | 30.33 |
| RR – 13 | 9.3 | 21.2 | 1.3 | 33.1 | 19.2 | 7.3 | 0.0 | 4.0 | 0.7 | 0.0 | 0.0 | 3.3 | 0.7 | 0.0 | 100.0 | 31.79 |
| RR – 15 | 7.5 | 20.5 | 1.4 | 45.2 | 12.3 | 3.4 | 2.1 | 2.1 | 1.4 | 0.0 | 0.0 | 4.1 | 0.0 | 0.0 | 100.0 | 29.46 |
| RR – 16 | 5.9 | 31.4 | 1.3 | 33.3 | 9.8 | 9.8 | 5.9 | 2.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 100.0 | 38.57 |
| Average | 9.5 | 23.0 | 3.3 | 32.8 | 15.3 | 8.8 | 3.0 | 3.1 | 0.7 | 0.1 | 0.2 | 1.2 | 0.2 | 0.0 | | 34.59 |
| PR – 01 | 13.2 | 27.6 | 3.3 | 28.9 | 15.8 | 2.0 | 5.3 | 3.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 44.08 |
| PR – 02 | 4.1 | 42.6 | 5.4 | 20.3 | 17.6 | 4.1 | 4.1 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 52.08 |
| PR – 03 | 27.7 | 27.7 | 10.1 | 12.2 | 11.5 | 2.0 | 3.4 | 3.4 | 0.7 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 100.0 | 65.55 |
| PR – 04 | 22.2 | 30.6 | 7.6 | 13.9 | 12.5 | 4.2 | 2.1 | 3.5 | 0.0 | 0.0 | 0.7 | 2.1 | 0.0 | 0.0 | 100.0 | 60.42 |
| PR – 05 | 19.6 | 29.4 | 3.9 | 17.6 | 7.8 | 7.2 | 9.8 | 3.3 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 52.95 |
| Average | 17.3 | 31.6 | 6.1 | 18.6 | 13.0 | 3.9 | 4.9 | 3.2 | 0.3 | 0.0 | 0.1 | 0.7 | 0.0 | 0.0 | | 55.01 |
| FC – 01 | 25.7 | 33.8 | 28.4 | 2.0 | 0.0 | 2.0 | 6.1 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 87.94 |
| FC – 02 | 9.9 | 19.2 | 2.0 | 39.7 | 11.9 | 7.9 | 7.3 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 31.13 |
| FC – 03 | 20.3 | 35.0 | 8.4 | 5.6 | 4.2 | 8.4 | 3.5 | 8.4 | 0.7 | 0.0 | 0.0 | 5.6 | 0.0 | 0.0 | 100.0 | 63.64 |
| FC – 04 | 9.2 | 20.9 | 2.0 | 39.6 | 13.1 | 9.2 | 2.0 | 3.3 | 0.0 | 0.7 | 0.0 | 3.3 | 0.0 | 0.0 | 100.0 | 32.03 |
| Average | 16.3 | 27.2 | 10.2 | 21.0 | 7.3 | 6.9 | 4.7 | 3.9 | 0.2 | 0.2 | 0.0 | 2.2 | 0.0 | 0.0 | | 53.73 |
| IC – 01 | 10.8 | 46.8 | 7.9 | 5.8 | 10.1 | 4.3 | 4.3 | 4.3 | 0.0 | 0.0 | 0.0 | 5.8 | 0.0 | 0.0 | 100.0 | 65.47 |
| IC – 02 | 40.3 | 30.5 | 14.9 | 1.9 | 3.9 | 1.9 | 5.2 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 85.72 |
| IC – 03 | 7.8 | 36.6 | 11.8 | 15.0 | 11.8 | 11.1 | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 100.0 | 56.21 |
| Average | 19.6 | 38.0 | 11.5 | 7.6 | 8.6 | 5.8 | 4.9 | 1.9 | 0.0 | 0.0 | 0.0 | 1.9 | 0.2 | 0.0 | | 69.13 |

other hand, the sediments collected between the fluvial samples RR – 01 to RR – 06 and RR – 11 to RR – 13, from the late Pleistocene Cananeia Formation presented an average ZTR index between 50.6 to 53.7% for fine and very fine sands, respectively. The sediments proceeded from the Holocene Ilha Comprida Formation (IC) exhibit the biggest average ZTR values changeable between 52.7 to 69.1 % for fine and very fine sands, respectively, since they are reworking products of the Cananeia Formation. The samples from the Jureia beach (PR) presented an average ZTR index value intermediary between the Cananeia (FC) and the Ilha Comprida (IC) formations, with 33.6 to 55% for fine and very sands, respectively.

## Heavy minerals and their source rocks

The great majority of the heavy minerals are accessories of the Precambrian crystalline rocks (igneous and metamorphic), which have been quantitatively reduced during the transportation of the sediments, according to their physical resistances and chemical stabilities.

Therefore, the heavy mineral assemblages represent an important property of detrital sediments especially in sands and sandstones, in the elucidation of their provenances. Nevertheless, some of them are selectively destroyed during the weathering, transportation, and diagenesis, the remaining heavy minerals are commonly the unique evidence of provenances (or their source rocks) in many sands and sandstones.

Zircon occurs as colorless to yellowish grains, rounded or euhedral as short or long prisms, with pyramidal or fragmented extremities, and/or exhibiting mineral inclusions and growth zonings. This mineral could have been derived from the coastal complex and from the Açungui Supergroup Precambrian crystalline rocks.

Tourmaline is found in green, grey, rose, and blue varieties, with rounded or subrounded shapes but also prismatic and containing eventual inclusions. It could have been originated from granites and associated pegmatites and metamorphic crystalline rocks.

Rutile is encountered as very rounded, reddish, and orange colored grains, and scarcely as subangular or twinned grains. Its source rocks could be chararnockites, granulites, biotite-sillimanite gneisses and migmatites of the Coastal Complex Precambrian rocks.

The hornblendes grains present greenish or brownish colors and they are frequently very altered with elongated shape and rounded or rugged edges. They could be originated from the Mesozoic basic dykes that intruded the Coastal Complex migmatites and granitoids.

The sillimanite grains are colorless, and occur as short or long prisms. The possible source rocks of this mineral are the Precambrian basement metamorphic rocks.

The staurolite grains predominate as rounded shapes and yellowish colored, which could be originated from Açungui Supergroup metamorphic rocks. The epidote occurs as rounded, prismatic or irregular grains with greenish yellow color, its possible source rocks could be the gneisses and migmatites of the Coastal Complex.

The kyanite grains are commonly colorless, elongated and angular and, as stated by Nascimento (2006), they could be derived from the adjacent continental shelf relict sediments and from the Açungui Supergroup aluminous rocks.

## FINAL CONSIDERATIONS

Sahu (1964) graphic method demonstrated its efficiency, as emphasized by Suguio (1971), who studied the same area (Cananeia-Iguape and Ilha Comprida coastal plain) under a different point of view, and permitted to clearly establish the fluvial (RR series), shallow marine (FC and IC series) and beach (PR series) depositional environments of the samples here analyzed, including past and present sedimentary deposits.

The heavy minerals assemblages frequencies as well as the ZTR index values suggest that the *Ribeira de Iguape* river modern and probably past sediments could have been supplied mainly by source rocks of its hydrographic basin, represented mostly by the Açungui Supergroup crystalline rocks. On the other hand, the Cananeia and the Ilha Comprida formations, as well as the modern Jureia beach sediments, were and continue to be supplied mainly by the adjacent ocean, through the littoral currents, and not by the adjacent hydrographic basin.

Therefore, the *Ribeira de Iguape* river mouth coastal plain sediments, during the late Quaternary and presently, are mostly supplied by the adjacent shallow marine environment, meanwhile the fluvial origin sediments that reach the river mouth are almost totally scattered by the littoral currents.

Thus, during the late Quaternary as well as presently, there was never a true delta in the *Ribeira de Iguape* river mouth. Therefore, the deposition was not strictly related to the sediments supplied by the river. The local sedimentation, as previously stated by Suguio and Martin (1978a, 1978b), was mainly conditioned by the glacial eustasy, relative sea-level changes, represented by the Cananeia and Santos transgressions, respectively, of late Pleistocene and Holocene epochs of the Quaternary period.

## REFERENCES

ALLEN, J. R. L. Late Quaternary Niger delta and adjacent areas: sedimentary environments and lithofacies. *American Association of Petroleum Geologists Bulletin*, n. 23, p. 547-600, 1965.

BACCOCOLI, G. Os deltas marinhos holocênicos brasileiros: uma tentativa de classificação. *Boletim Técnico da Petrobrás*, n. 14, p. 5-38, 1971.

BARRELL, J. Criteria for the recognition of ancient delta deposits. *Geological Society of America Bulletin*, n. 23, p. 377-446, 1912.

BATES, C. C. Rational theory of delta formation. *American Association of Petroleum Geologists Bulletin*, n. 37, p. 2119-2162, 1953.

BRASCONSULT, S. A. *Plano de desenvolvimento do Vale do Ribeira e litoral sul*: comentário sobre a formação geológica regional. São Paulo, Capítulo 2, 1964.

COLEMAN, J. M.; WRIGHT, L. D. Modern river deltas: variability of process and sand bodies. In: BROUSSARD, M.L. (editor). *Deltas*: models for exploration. Houston: Houston Geological Society, 1975. pp. 99-149.

COLEMAN, J. M.; WRIGHT, L. D. Analysis of major river systems and their deltas, procedure and rationale, with two examples. Coastal Studies Institute, Louisiana State University. *Technical Report*; n. 95, p. 1-125, 1971.

EMERY, K. O.; NOAKES, L. C. Economic placer deposits of the continental shelf. *Technical Bulletin of the Economic Commission for Asian and Far East,* v. 1, p. 95-110, 1968.

FISHER, W. L. Facies characterization of Gulf coast basin delta system, with Holocene analogous. *Gulf Coast Association of Geological Societies Transactions*, p. 239-261, 1969.

FOLK, R. L.; WARD, W. C. Brazos river bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, v. 27, p. 3-26, 1957.

FRIEDMAN, G. Distinction between Dune, Beach and River Sands from their Textural Characteristics. *Journal of Sedimentary Petrology*, v. 31, p. 151-163, 1961.

GEOBRÁS, ENGENHARIA E FUNDAÇÕES S.A. *Complexo Valo Grande, Mar Pequeno e Rio Ribeira de Iguape*. 1966. Relatório GEOBRÁS S. A., Engenharia e Fundações para o Serviço do Vale do Ribeira, Departamento de Águas e Energia Elétrica, 2 volumes.

GUEDES, C. C. F. *Evolução sedimentar quaternária da Ilha Comprida, Estado de São Paulo*. Dissertação (Mestrado) – Instituto de Geociências, Universidade de São Paulo, São Paulo, 2009. 131 p.

HUBERT, J. F. A zircon-tourmaline-rutile maturity index and the independence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones. *Journal of Sedimentary Petrology*, v. 32, p. 440-450, 1962.

IPT – INSTITUTO DE PESQUISAS TECNOLÓGICAS. *Mapa geológico do Estado de São Paulo*. São Paulo, IPT: 1981. 2 mapas, nota explicativa. Escala: 1: 1.000.000.

LE BLANC, R. J. Review of studies of deltaic sedimentation. In: BROUSSARD, M.L. (editors). *Deltas models for exploration*. Houston: Houston Geological Society, 1975. p. 13-85.

LYELL, C. *Principles of geology*. v. 2. London: John Murray, 1832. 330p.

MARTIN, L.; SUGUIO, K.; FLEXOR, J. M.; DOMINGUEZ, J. M.; AZEVEDO, A. E. G. Evolução da planície costeira do Rio Paraíba do Sul (RJ) durante o Quaternário: influência das flutuações do nível do mar. In: CONGRESSO BRASILEIRO DE GEOLOGIA, 33., 1984, Rio de Janeiro. *Anais*... Rio de Janeiro: SBG, 1984. v. 1, p. 84-97.

MARTIN, L.; SUGUIO, K.; FLEXOR , J. M. As flutuações de nível do mar durante o Quaternário superior e a evolução geológica de "deltas" brasileiros. *Boletim IG-USP, Publicação Especial*, v. 15, p. 1-186, 1993.

MCKEE, E. D. Some types of bedding in the Colorado river delta. *Journal of Geology*, v. 47, p. 64-81, 1939.

MOORE, D. C. Deltaic Sedimentation. *Earth-Science Reviews*, v. 1, p. 87-104, 1966.

NASCIMENTO, D. R. *Morfologia e sedimentologia ao longo sistema praia – duna frontal da Ilha Comprida, SP*. 211 p. Dissertação (Mestrado) – Instituto de Geociências, Universidade de São Paulo, São Paulo, 2006.

OOMKENS, E. Depositional sequence and sand distribution in deltaic complex. *Geologie en Mijnbouw*, v. 46, p. 265-278, 1970.

PASSEGA, R. Texture characteristic of clastic deposition. *Bulletin of American Association of Petroleum Geologists*, v. 41, p. 1952-1984, 1957.

PETTIJOHN, F. J. *Rocas sedimentarias*. Buenos Aires: Eudeba, 1976. 731 p.

RITTENHOUSE, G. Transportation and deposition of heavy minerals. *Geological Society of America Bulletin*, v. 54, p. 172-1780, 1943.

SAHU, B. K. Depositional mechanisms from size analysis of clastic sediments. *Journal of Sedimentary Petrology*, v. 34, p. 73-83, 1964.

SUGUIO, K. Textural modifications of well sorted sands as a repense to dynamic processes in the sedimentary environments. *Journal of Marine Geology*, v. 7, p. 13-25, 1971.

SUGUIO, K.; MARTIN, L. Geologia do Quaternário. In: FALCONI, F.F.; NIGRO JUNIOR, A. (org.) *Solos do litoral de São Paulo*. Santos, SP: Mesa Redonda ABMS/ASSECOB, 1994. p. 69-97.

SUGUIO, K.; MARTIN, L. Significance of Quaternary sea-level fluctuations for delta construction along the Brazilian coast. *Geo-Marine Letters*, v. 1, p. 181-185, 1981.

SUGUIO, K.; MARTIN, L. Formações quaternárias marinhas do litoral paulista e sul-fluminense (Quaternary marine formations of the State of São Paulo and southern Rio de Janeiro). In: INTERNATIONAL SYMPOSIUM ON COASTAL EVOLUTION IN THE QUATERNARY (Special Publication), 1978, São Paulo. *Proceedings*... São Paulo: IGc-USP, 1978a, p. 1-55.

SUGUIO, K.; MARTIN, L.; DOMINGUEZ, J. M. L. Evolução da planície costeira do rio Doce (ES) durante o Quaternário: influência das flutuações do nível do mar. In:

SIMPÓSIO DO QUATERNÁRIO NO BRASIL 4., 1982. Rio de Janeiro. *Atas*... Rio de Janeiro: Cenpes-Petrobras, 1982. p. 93-116.

SUGUIO, K.; PETRI, S. Stratigraphy of the Iguape-Cananéia lagoonal region sedimentary deposits, São Paulo State, Brazil. Part I: field observations and grain size analysis. *Boletim IG-USP*, Série Científica, v. 4, p. 1-20, 1973.

THOMPSON, R. E. W. Tidal flat sedimentation on the Colorado river delta, northwestern Gulf of California. *Geological Society of America Memoir*, v. 107: 1-133, 1968.

TROWNBRIDGE, A. C. Building of Mississippi. *American Association of Petroleum Geologists Bulletin*, v. 14, p. 867-901, 1930.

VAN ANDEL, T. H. The Orinoco delta. *Journal of Sedimentary Research*, v. 37, p. 297-310, 1967.

WENTWORTH, C. K. A scale of grade and class terms for clastic sediments. *Journal of Sedimentary Petrology*, v. 30, p. 377-392, 1922.

WRIGHT, L.D. River deltas. In: DAVIS, R.A. (editor). *Coastal sedimentary environments*. Nova York: Springer-Verlag, 1978. p. 5-68.