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STRATIGRAPHY OF THE IGUAPE-CANANÉIA LAGOONAL REGION SEDIMENTARY DEPOSITS, SÃO PAULO STATE, BRAZIL

PART I: FIELD OBSERVATIONS AND GRAIN SIZE ANALYSIS

By

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RESUMO

No presente trabalho discutimos a história geológica dos eventos quaternários na planície litorânea do Sul do Estado de São Paulo, na área conhecida como região lagunar Iguape-Cananéia, tomando por base observações de campo e estudos de granulometria dos sedimentos, tanto de amostras coletadas pelos A., bem como das obtidas de dois poços profundos perfurados pelo Instituto Geográfico e Geológico do Estado de São Paulo (I.G.G.) e de perfurações rasas executadas pela Geobrás S/A, Engenharia e Fundações.

Os resultados de análises granulométricas permitiram confirmar nos ambientes atuais e reconhecer nos ambientes pretéritos de sedimentação, os seus mecanismos deposicionais.

As areias regressivas, tipo "blanket sands" ou "sheet sands" (KRUMBEIN e SLOSS, 1963, p. 550), já reconhecidas por autores prévios como depósitos praias, embora sem uma caracterização muito clara, são aqui definidas de modo pormenorizado. Tais areias têm importância preponderante na geologia regional da planície litorânea, não só porque ocupam grandes extensões superficiais desta planície, mas também porque, como consequência da sua persistência, constituem-se em importante fonte fornecedora de detritos para os subambientes atuais. Para essa unidade litológica propõe-se a denominação Formação Cananéia.

As sequências transgressivas e regressivas, sotopostas à Formação Cananéia, somente puderam ser reconhecidas e estudadas graças às sondagens do I.G.G.

SUMMARY

The possible geological history of the quaternary events in the coastal plain of the Southern São Paulo State, in the area known as Iguape-Cananéia lagoonal region, is here presented.

Field observations and sedimentological analysis made by the A., geophysical data and examination of the samples from two stratigraphical wells drilled by I.G.G. and the informations from shallow research holes made by Geobrás S/A, Engineering and Foundations, made possible the accomplishment of this work.

Grain size characteristics of the sediments from the present environments were also compared with the grain size characteristics of the sediments from the ancient environments, allowing the recognition of the depositional mechanisms of the ancient sediments.

The regressive deposits, "blanket sands" or "sheet sands" type (KRUMBEIN and SLOSS, 1963, p. 550), already recognized as old beach sands by previous authors, never was clearly characterized. Here they are described, in detail, due to their great importance in the coastal plain regional geology, not only because of their great persistence, but also, as a consequence, because they were the most important source of detrital materials to the present sub-environments. To this lithological unity is proposed the denomination Cananéia Formation.

The recognition of the transgressive and regressive sequences was possible only through the studies of the I.G.G. stratigraphical wells.

INTRODUCTION

The lagoonal region known as Iguape-Cananéia is a strip of land situated between the mouth of the Ribeira de Iguape River and the Ararapira outlet, just at the border of the States of São Paulo and Paraná. Four great islands stretch along a hundred kilometers from northeast to southwest, being called Iguape, Comprida, Cananéia and Cardoso (See figure 1).

The old Ribeira River and the Valo Grande are two water passageways between the Iguape Island and the continent. The Iguape or Pequeno "sea" is a sound between Iguape and Comprida Islands at the northeast tip and Comprida Island and the continent southwestward. The Cubatão or de Dentro "sea" is another sound between Cananéia Island and the continent. The Cananéia or the Fora "sea" is a sound between the Cananéia and Comprida Islands. The inadequately called "bay of Trapandé" is a body of water between the Cananéia and Cardoso Islands.

Iguape Island is an artificial one. It was born after the construction of the Valo Grande Channel, built through division of part of the Ribeira de Iguape River, south from the Iguape Island. The Old Ribeira (Ribeira Velho) channel however keeps on draining part of the Ribeira water north from the Iguape Island. This river was an important one to the earlier explorers as a natural way to get to the inland. In its way to the sea it runs eastward coming as near as 4 km from the Iguape town, then it bends northward tracing a bow figure before entering the ocean; 20 km from the town of Iguape. The old Ribeira harbor less than 3 km from the town of Iguape; is located at a small lake connected to the main course of the Ribeira. The towers of the church of Iguape could be seen from the boats so near they came but they had to keep on travelling for still many hours, navigating more than 53 km, facing the swells of the ocean before reaching the Iguape harbor. It was easier to emload the boats at the Ribeira harbor so the cargoes could reach the town on the backs of "burros" (donkeys). The idea of an artificial channel allowing the boats to reach directly the Iguape harbor had then many defenders. The land between the Ribeira harbor and the town of Iguape is flat which would facilitate the excavation of the channel. After several years of work, the channel known as Valo Grande was open to navigation in 1832. The waters of the Ribeira then had a shortcut to the ocean, increasing therefore their energy for erosion of the banks and filling up of certain parts of the channel. As a result the Valo Grande is menacing the town since then, mainly during floods. Only one year after the channel was finished, this threat was reported in written documents.

The lower Ribeira, including great part of the Old Ribeira (after the Valo Grande) winds in a broad valley with many oxbow lakes, subjected to floods by the tides resulting in marshes and swamps. According to Geobrás report (1965, v. 1, p. 132) the meanders are stabilized within the last sixty years and the river, near and up Tres Barras, is very wider now as can be seen looking at the dry meanders showed in aerial photos. The fixation of the meanders and the increase in the width could be caused by the tides which acquired greater importance after the excavation of Valo Grande.

The Iguape Island has a sinuous outline. Several mountains are scattered on the coastal plain. The main ones are Morro da Paixão, the nearest from the town, Morro dos Engenhos, the highest (500 m above sea level), Morro do Pinheiro, Morro do Icapara, etc. Precambrian gneisses, schists and micaschists are the rocks of these mountains.

The Comprida Island is long and narrow (70 km long while the maximum width is 5 km). A hill of alkaline rocks (42 m high). Morrete, near the southwestern tip, looking to Cananéia "sea", is the only elevation of the island. Except for this hill, the greatest elevations in the whole island is only seven meters above sea level. The southwestern half of the margin of the Comprida Island at the Pequeno "sea" side, is rather craggy, two to four meters high, up to Pedra Balisa or do Tombo (The Pedra Balisa is a rocky knob within the Pequeno "sea", made up of alkaline rocks). The northeastern half is made up of shoals and marshes. Several bands of dunes are developed in Comprida Island, some 7 meters high, mainly at the ocean side.

The Morro do São João, made up of alkaline rocks (according to FREITAS, 1947) and 120 m high (KUTNER, 1962, p. 43), located at the Cananéia Island, opposite to Comprida Island

Morrete, is the only conspicuous elevations of the Cananéia Island. A submerged rocky knob known as "Lage do Argolão" seems to be a liaison between Morro do São João and Morrete. Three nordmarkite samples from Morro do São João were dated by K – A method resulting 82 million years as an average age (AMARAL et al., 1967).

The mountainous Cardoso Island, south of Comprida Island, is constituted mainly of Precambrian rocks.

The salinities of the waters of this lagoonal region are highly variable, related to tides and fresh water run-off. The whole Pequeno "sea", in general, has a low salinity reaching a minimum between the mouth of Valo Grande and the outlet of Icapara (See figure 1). The influence of the Ribeira is less sensible between Pedra Balisa and Cananéia. The lowermost salinity observed in this section was 20°/oo.

The advancing tide in the Pequeno "sea" is toward the northeast at the southwest extremety tip and toward southwest at the northeast extremity. The two currentes meet around Pedra Balisa and the mouth of the Subaúma River. The mechanism of tide propagation was outlined by MINIUSSI (1959). The advancing tide reaching Trapandé Bay is subdivided into two currents, one of them running through Itapitangui and Cubatão "seas" and the other one running through Cananéia "sea" toward the northeast tip of Cananéia Island; both currents meet in the Cubatão "sea" near the mouth of the Iririaia-Açu River. In a second phase of advancing tide both currents meet at the northeastern tip of the Cananéia Island and keep on running toward the northeast to meet the southwestward current around Subaúma, as mentioned before. At the meeting points, erosion prevails causing the formation of bays (Subaúma and Iririaia-Açu).

The winds are variable according to the hour of the day and the season of the year. The prevailing winds however come from the south perpendicular or athwart the shore (Geobrás report, 1965, fig. I-IV-d-01 and I-IV-d-02).

According to KUTNER (1962, p.54) the region is not truly lagoonal since there is no gradation between marine and fluvial environments. The marine influence is more pronounced in front of the outlets to the ocean and the fluvial influence is more strikingly noted in front of the mouthes of the rivers.

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(*) This Service (S.V.R.) was recently extinct and a new institution named "Superintendência de Desenvolvimento do Litoral Paulista (SUDELPA)" was organized to take its roles.

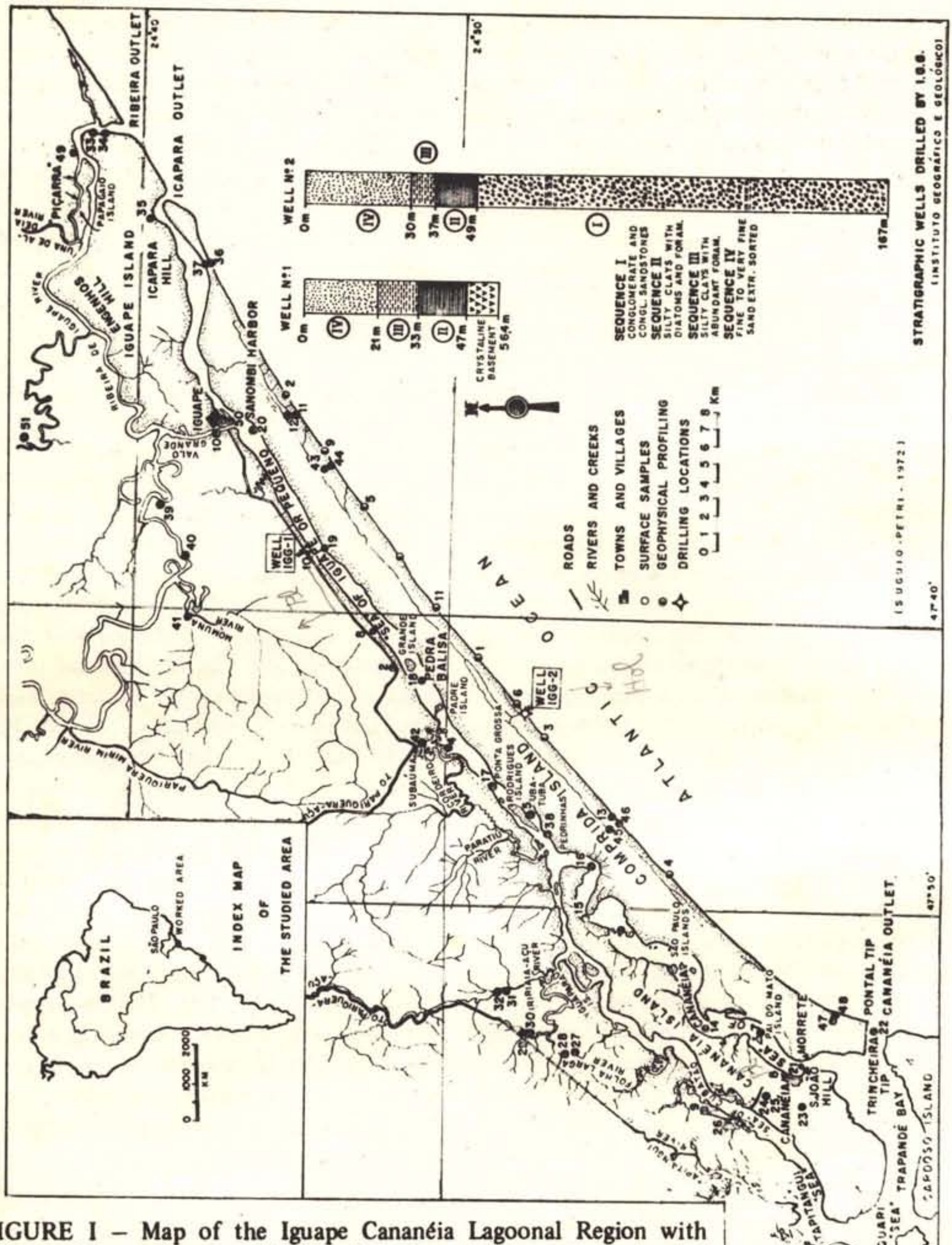

FIGURE I – Map of the Iguape Cananéia Lagoonal Region with points of the surface samples location, deep drilling and geophysical profilings.

REGIONAL GEOLOGY GENERALITIES

There are numerous geological papers published on this region but they are either strictly local or specific so many questions still persist about the local geology, principally related to the coastal plain and environs.

FREITAS (1947) studied the petrography of the alkaline rocks from Cananéia. SILVEIRA (1952) published a regional geomorphological study. BIGARELLA (1946) dealed with problems of late cenozoic sedimentation. KUTNER (1962) studied some aspects of the Recent sedimentation around the Cananéia Island.

The rainy climate (average greater than 2.000 mm/year) is responsible for a heavy forest which allied to a steep topography and lack of roads prevent the development of a systematic geological survey mainly in the mountainous area. It was only in 1964 through a Brasconsult report and in 1965 through a voluminous report from Geobrás S/A, both companies on contract with Serviço do Vale do Ribeira, that more substantial informations on a regional basis were possible which will be valuable for a regional planification directed to the development of the region. The first of the above mentioned reports brings a geological map plotted mainly through photointerpretation. According to this map the basement around the Iguape-Cananéia lagoonal complex are metamorphic ones belonging to the Precambrian Açungui Group: phyllites and micaschists, migmatites and gneisses intruded by granites, adamellites and granodiorites. The alkaline intrusions cut this complex. The Ribeira de Iguape, the main river of the region, goes through other kinds of rocks of the Açungui Group (quartzites, amphibolites, diabases, limestones and calcoschists) before reaching the lagoonal region.

The Geobrás report dealed with a more limited area which coincides with the one we studied. The first integrated out look of the lagoonal region came from this report. Several events which propitiated the present conditions were discussed, based on geomorphological observations. We believe our paper is complementary of this and other reports, bringing informations about all the sedimentary sequence and about the geological events responsible for this sequence. We hope our researches bringing new observations on events older than previous studied ones, will be of value for a better understanding of the dynamics of the geological agents responsible for the present Iguape-Cananéia lagoonal complex.

THE COASTAL PLAIN

The coastal plain is narrow in the northern littoral of the State of São Paulo but in the southern littoral it has a greater geographical importance, acquiring in certain places a width as great as 80 km (Brasconsult, 1964). It is broken however by some high ranges such as the Bananal and Itatins, which approach the sea.

The principal kinds of recent sedimentary deposits in the coastal plain are:

Beaches

The southern beaches of the State of São Paulo are almost continuous interrupted only by a few foothills of some rocky bodies. The beach of the Comprida Island, for instance, is almost 70 km long. Other long southern beaches, outside the present area are: Praia Grande, 44 km long; Peruíbe, 25 km long; Una, 20 km long, etc.

The sands of these beaches are fine-grained, homogeneous and therefore make smooth slopes toward the ocean. Only at occasional sites the waves are violent and so the sands become coarser, for instance, at the southeastern tip of the Comprida Island (Pontal Beach).

Beach ridges

The Comprida Island was born through lateral accretions of old beach ridges so the ages of them become younger as one goes toward the present beach. The oldest ones could be 2.000 to 3.000 years old according to Geobrás report (1965, v. 1, p. 185). The different phases of the growth of the Comprida Island can be observed on aerial photos, by the scars of the old beach ridges. Such scars are described in the Geobrás report and were also studied by PETRI and SUGUIO (1971a).

The aerial photos show that the beach ridges curve near the mouth of the Ribeira, in the Iguape Island. We can assume from this observation that the Iguape was originally an island within the old Quaternary sea (photo 4353 from "Levantamentos Aerofotogramétricos Cruzeiro do Sul S/A" – 1962).

The photos 5561 and 4804 (of the same set) show the bending of the beach ridges around one of the inland extremities of the Juréia Mountains (between the mouth of the Ribeira and Peruíbe, toward the northeast). The old beach ridges are preserved in this area because there is no important rivers which could erode them. The behavior of the Una de Aldeia River (which goes to the Ribeira River, above the Papagaios Island) is very peculiar. Its headwaters are located about 20 km NE from the Juréia headlands. Below this place, the Una Beach begins and between this beach and Una de Aldeia River, a monotonous beach ridges plain is developed which ould be the easiest way for the Una de Aldeia River to meet the ocean. This river, however, goes southwestward, parallel to the shore, and only gradually it bends toward the south flowing into the Ribeira River. It goes from the coastal plain into a crystaline basement area when it would be easier to winds on the coastal plain. Furthermore the airphotos show an erosion of the old beach ridges by the Ribeira de Iguape River near its mouth which could be taken as an evidence of the idea that the Ribeira River once had its course on the now Valo Grande and later eroded the beach ridges in its new way to the sea. The airphotos suggest that the Una de Aldeia River was once developed as a coastal river parallel to the shore, a very common type of river in Brazilian coastal plains.

This ancestral river later would have been captured by a tributary of the Ribeira de Iguape River

Comprida Island Dunes

The constant winds at the ocean side of the Comprida Island have reworked the beach sands and transported them inland resulting in four aligned dune ridges, some up to 7 m high, parallel to the shore. The first two ridges (at the side of the continent) are stabilized by vegetation; the third one rather stabilized and the fourth one still active. The heavy minerals reworked by the winds make up some layers of the dunes. The average size of the heavy minerals from the dunes is smaller than the average size of the heavy minerals from the beaches. The predominant colors of the heavy minerals are dark because they are mainly magnetite and ilmenite. Consequently the cross-beddings of the dunes show up very clearly by alternation of light and dark layers (See photos 1 and 2).

The depressed zones between the dunes are the natural ways for the creeks developed as a result of the highly humid climate. They are often rather stagnant because of the flat ground, so swamps are ubiquitous. Inasmuch as the dunes are better developed at the ocean side so the swamps are also more frequent at this side. Near the northeast tip of the Comprida Island at its narrower width, about 500 meters, the dunes occupy all the width from the ocean to the Pequeno "sea".

Regressive sands

A blanket or sheet sand (KRUMBEIN and SLOSS, 1963, p. 550) make up most of the coastal plain from the studied area northward up to Peruíbe area and southward down to the State of Paraná. According to these authors, this kind of deposition was possible on an area undergoing very slow subsidence and fed by detritus enough to cause regression of the sea, so the material would be located at a level slightly below base level. The strandline deposits are spread as a near by continuous succession of parallel beaches.

The total area of the regressive blanket sand preserved in the Iguape-Cananéia lagoonal region, considering also the ocurrences beyond the limits of the studied area, would be approximately 900 km2 as shown by SILVEIRA's map (1952, p. 125). The average thickness of this blanket sand as shown by the logs of the wells drilled by Geobrás and I.G.G. was estimated as 30 meters. Applying the concept of persistence factor P, defined by McGUGAN (1965, p. 126) to our blanket sand we came to 90×10^6 (P = lateral extension of the unity divided by the average thickness of the unity). This number falls within the values calculated by McGUGAN for several deposits of great extension and uniform lithology, one extreme being 0.000027×10^6 and the other one, 633×10^6. The persistence factor of the Cananéia blanket sand being 90×10^6 is high even under the blanket sands standards.

The extreme uniformity of the grain sizes, with 4/5 of the grains falling within 0.25 and 0.125 mm (fine sand) is a conspicuous quality of these sediments. This sand, locally called "piçarra", principally on cliffs or gullies where it is hardened by a limonitic cement, according to chemical analysis did by I.G.G. technicians (in Geobrás, 1965, v. 1, p. 172), forms banks 2 to 6 meters thick, elevated up to 6 meters above the sea level. This uplift is very regular in the whole area forming a very flat "foot step" (See photo 3). Some evidences of this "footstep" can be found at places far to the inland in the Ribeira basin, forming isolated elevations in the middle of extensive coastal plain lowland, being selected places for banan plantations (See foto 4). According to BIGARELLA et al. (1965, umpublished work), in the inland parts of the littoral plain, in the continent, the altitudes of the "piçarras", cliffs increase to values as great as 9,90 m. We propose to call this unity of regressive sands, Cananéia Formation.

We think the extensive sands which make up part of the coastal plains and along beaches of the southern littoral of the State of São Paulo, at least from Itanhaem down to the south are the results of reworking of these regressive sands, inasmuch as they have same textural characteristics. According to FULFARO (1971, verbal information) these characteristics were observed also in the samples from beaches of Bertioga (northern part of Santos city). The sands of dunes and of the bottons of the bodies of water of the Iguape-Cananéia lagoonal region are reworked regressive sands as well. Furthermore, in the middle of dunes at the sides of the Cubatão – Pedro Taques road far to the northeast (near Santos), there are banks made up of sands very similar to the Cananéia "piçarras".

We selected an outcrop located 2.5 km from Cananéia, at the left side of the road Cananéia to ferry-boat pier, as standard one for these sands (see figure. 2) From top to bottom we observed the following sequence:

(a) A very white leached portion (b) A brownish-black portion, with abundant humic acids and a limonitic level forming a crust 1 to 2 cm thick at the base (c) Horizontal to sub-horizontal parallel well stratified beds. (d) Beds with an almost rythmic lamination very clearly stratified. (e) An argillaceous bed, 2 to 3 cm thick. (f) Thick beds with an incipient stratification.

All these layers with different structures have a typical "piçarra" texture of fine and well sorted sands, except the argillaceous bed.

The first two portions resulted from weathering agents and leaching from rain waters associated with the humic acids from plants. The limonite is also a consequence of these phonomena, probably originated from the action of the humic acids on magnetite. This outcrop doesn't show other types of structures observed and described at other localities including cross-beds, irregular beds, slumping structures, etc. All these sedimentary structures are more clearly seen when the heavy minerals concentrate along certain layers.

We shall describe bellow the observed structures of the "piçarra" in the Iguape-Cananéia region.

Horizontal, parallel stratification – This stratification is the most common type observed in the outcrops. The structure is not clear on fresh surfaces due to the extreme sorting of the grains; it is better seen on weathered surfaces or on rain or wave washed surfaces. The stratification is incipient or well developed; in the first case the thicknesses of the layers are centimetric and in the second case there may be rythmic laminations, contributing for the clearness of the structures the concentrations of heavy minerals along the laminae. This stratification is very similar to the one observed in the sands of the present beaches resulting from the reworking of the "piçarras" presenting also heavy minerals concentrations. It must be stressed that the horizontal parallel stratifications have a great lateral persistence with only scattered little discontinuities or sunk parts shaped as V, 3 to 5 mm wide along the magnetite laminae. The shape and the size of these discontinuities are very regular bespeaking against an organogene structure as could be made by a burrowing animal. We didn't find any evidence of organic activity in other outcrops of the "piçarra".

Cross-beds – We found only small scale cross beds The thicknesses of the whole sets didn't go beyond few meters and the individual sets, few centimeters, and they never were more than 1 meter long. The predominant type is the trough cross-beds, the tabular one was seldom observed. It seems that the trough type resulted from cut and filling because this type passes in the same horizon to horizontal parallel stratification. Sometimes, we have a vertical sequence of cross-beddings (Figures 3 and 4). Incipient structures are sometimes observed which could be ripple drift cross laminations (See figure 4). There seems to be a direct connection between cross-beddings and the front of growth of old beach ridges.

Irregular stratifications and slumping structures – There occur irregular stratifications between beds of horizontal parallel stratifications few centimeters thick. These structures also become clearer when there are layers rich in dark color heavy minerals. This structure, when better developed, looks like ripple drift cross lamination.

Slumping structures were seldom seem; the causes for their scarcity may be the smoothness or the site of deposition, the texture of the sands practically without argillaceous components, a rather calm environment of sedimentation, etc. They were verified in just one locality, near the Icapara outlet, on the Iguape Island side, where the laminae became outstanding by the dark minerals rich layers. They are thoroughly folded, recurved and broken. It seems to be a local structure without importance in the environment of deposition of the "piçarra".

Argillaceous beds – These beds was seen only in the outcrop at the side of the road Cananéia-ferry boat pier above described (Figure 2). Here this bed had 2 to 3 cm of thickness, extending for many meters and disappearing only when covered by the rubbles. It is abruptly cut however at several points without thinning out; interrupted for several meters and reappearing at the same level and with the same thickness. These interruptions might be explained by an erosive phase immediately after the mud deposition and the abrupt interruption almost perpendicular to the bedding plane might be connected with cracks developed before the separation of the bed.

Limonitic structures – Every sedimentary structures above described were syngenetic or penecontemporaneous to the deposition. The limonitic structures however were developed through a concentration of ferruginous matter at the ground water level by the same mechanism verified in other Brazilian regions (BARBOUR, 1966; SUGUIO and BARBOUR, 1969). The iron ions could come either from the ground water or from the weathering of magnetite and other mafic minerals by humic acids.

Mangrove Deposits

The mangrove have a limited distribution in the southern littoral of the State of São Paulo. The most expressive are those related to the Ribeira de Iguape river and its tributaries. They are developed also in the northeastern half of

"PIÇARRA" FEATURES IN THE CANANÉIA ISLAND (S.P.)

NEAR FERRY BOAT PIER TO CANANÉIA TOWN

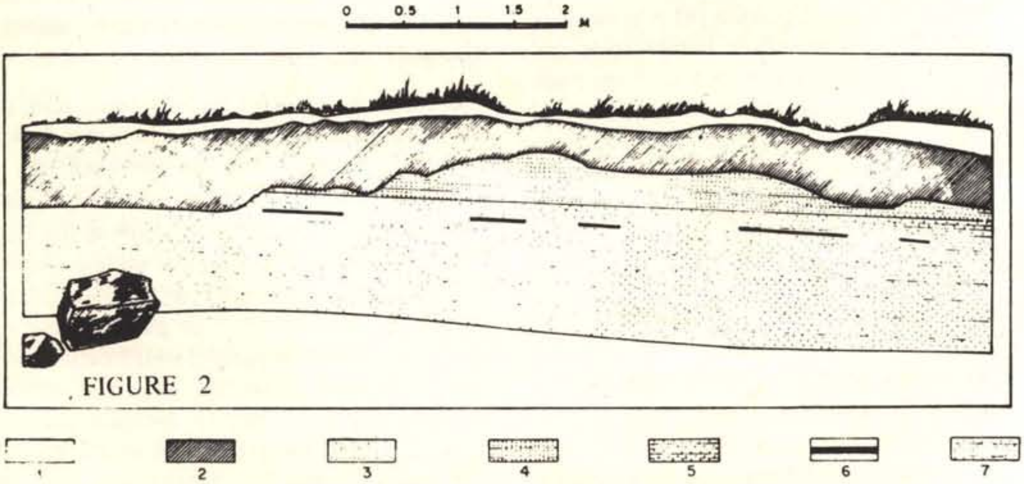

FIGURE 2

1 - LEACHED "PIÇARRA" (WHITE). 2 - "PIÇARRA" WITH HUMIC ACID AND BASAL LIMONITE LAYER. 3 - "PIÇARRA" WITH INCIPIENT STRATIFICATION PARTIALLY "LIMONITIZED". 4 – "PIÇARRA" WELL STRATIFIED AND "LIMONITIZED" 5 – "PIÇARRA" VERY WELL STRATIFIED. 6 – CLAY LAYER (2 TO 3 CM THICK). 7 - "PIÇARRA" WITH INCIPIENT STRATIFICATION.

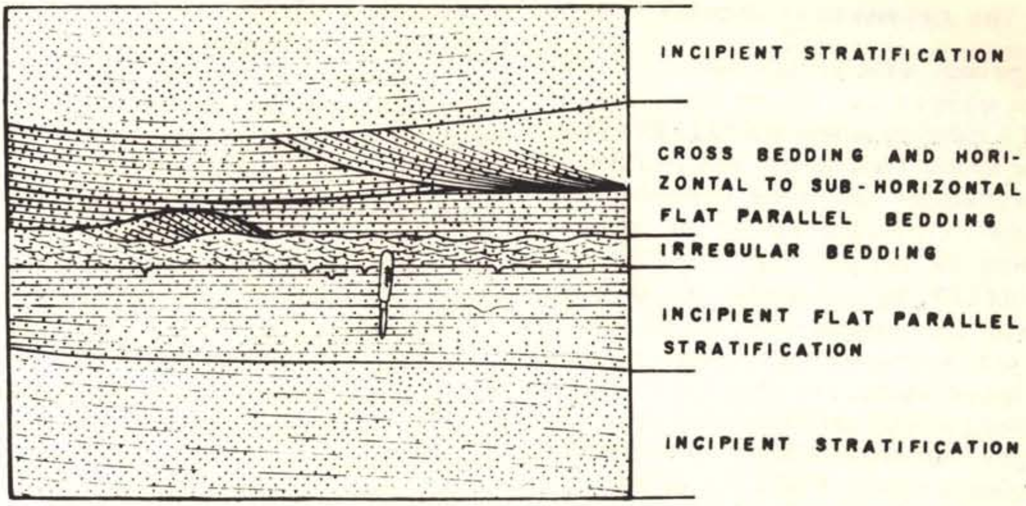

FIGURE 3 – Cross bedding and parallel bedding "Piçarra" of Iguape Island – Icapara outlet (scale = knife)

the Comprida Island at the Pequeno "sea" side and around Cananéia Island. The mode of a granulometrically analysed mangrove sample fell within the 0.25 - 0.125 mm interval as in the "piçarras," but with a greater contribution of the coarser and finer materials.

Fluvial Deposits

The materials brought from the highlands to the Cananéia-Iguape lagoonal region by the rivers do not seem to represent an important fraction. According to Geobrás (1965, v. 1, p. 221), the Ribeira de Iguape River, the most important one in the region, immediately down Eldorado Paulista works like a vast decantation pool in holding practically all the material coming from the higher basin.

The sands on the channel of the river near its mouth can be explained by the geological nature of the coastal plain made up of the regressive sands. The other rivers draining directly toward the lagoons are small, with a low declivity and do not contribute significantly to the lagoonal sedimentation, most of them influenced by the tides.

Deposits of the bottom of the lagoonal region

The sediments here are the result of interaction of marine and fluvial environments. The bottom sediments were analysed by Geobrás geologists and by us. Their textures are clearly related to that of the "piçarra" even though disguised by finer argillaceous material.

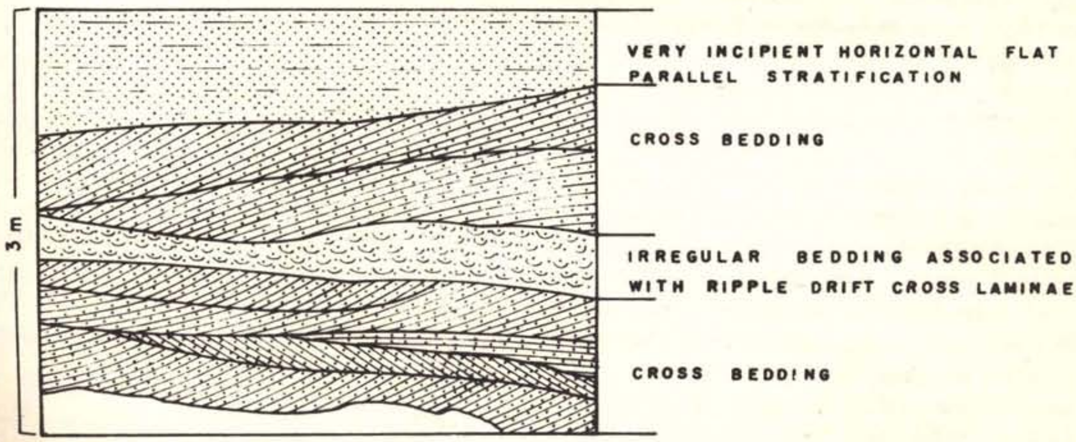

FIGURE 4 – Cross bedding in the "Piçarra" of the comprida Island between Ubatuba-Pedrinhas.

THE GEOPHYSICAL STUDIES

Some ideas on the crystaline basement covered by the sediments were possible thanks to KOLLERT's resistivity surveys and ELLERT's gravimetric studies. These surveys were restricted to the northeastern half of the Comprida Island and the corresponding part of the continent bordering the Pequeno "sea".

KOLLERT did two profiles, one along the beach of the Comprida Island (at the oceanic side) and the other on the continent, along the road Iguape-Subaúma (See figure 1).

Along the beach the basement would descend gradually southwestward down to 2 km SW from the place of I.G.G. well n.o 2 (KOLLERT's point n.o3) and then would ascend gradually but always keeping a lower level in relation to the continent profile. The basement must keep on ascending southwestward, because near the southwestern tip of the Comprida Island, alkaline rocks crop out (Morrete, as referred above). KOLLERT supposed that a fault occurred between Comprida Island and the continent explaining in this way the difference of the levels of the basement. However, this difference could be explained as well simply by regional dip of the basement toward the ocean. The altitude of the basement at I.G.G. well n.o 1 is minus 45 meters and the supposed altitude of the basement at the Comprida Beach (KOLLERT's point n.o 5) is minus 85 meters. The difference of level of 40 meter in a distance of 4 kilometers will give a slope value of 1/100 (or 0º 34').

ELLERT (verbal information) later did some gravimetric profiles, perpendicular to the Comprida Island from the ocean to Pequeno "sea" in order to test the fault hypothesis. According to this author the Comprida Island basement forms a "footstep", lower in altitude in relation to the basement of the continent, that is, there is no continuous slope from the basement of the continent to the basement of the Comprida Island. It is possible therefore that a fault occurs striking NE and partially coinciding with the Pequeno "sea". The Pedra Balisa, in the middle of the Pequeno "sea", made up of alkaline rocks could be either an elevation of the basement by differential erosion before faulting or, which we think more probable, that the fault line is located between Pedra Balisa and Comprida Island.

According to ELLERT, the lowermost point of the basement in Comprida Island at the ocean side, is located 5.7 km from KOLLERT'S point 3 and not in this point as interpreted by this author. The lowermost point we called point 13.

The point 13 would represent the hinge of two tilted blocks, the SW block dipping NE and the NE block dipping SW. It is possible that a fault occurs through this hinge and this fault would cross the Pequeno "sea" fault and would continue through the valleys of Cordeiro River, flowing toward Pequeno "sea" and Pariquera-Mirim River, flowing toward Ribeira de Iguape River. These two valleys are remarkably aligned in spite of the flowing at opposite directions. Southwestward from this tectonic line Cordeiro – Pariquera-Mirim, the Pequeno "sea" fault would disappear.

Another possibility would be an erosion valley, without faulting, crossing the Pequeno "sea" fault. In this case the Cordeiro – Pariquera-Mirim line would not be tectonic.

The uplift of the continent block and the sinking of the Comprida Island block would propitiate the development of coarse sedimentation, rather thick at the valley depression as found at I.G.G. well n.o 2. The conglomeratic sediments would pass laterally to finer deposits.

The crystaline basement slope between the place of I.G.G. well n.o 2 and Pedra Balisa, where the basement outcrops is of about 2º (17 m in a distance of 500 m), whereas the slope between I. G.G. well n.o 1 and KOLLERT's point n.o 5 is 0º 34'. The displacement of the basement therefore was greater at the Pedra Balisa region. It is evident that the basement dips northeastward from Pedra Balisa to I.G.G. well n.o 1, whereas in Comprida Island it dips southwestward. The positions of the two tilted blocks are therefore reverse.

THE STRATIGRAPHIC DRILLINGS IN THE AREA

The drillings of the Instituto Geográfico e Geológico

The Instituto Geográfico e Geológico drilled two wells in 1964, in the region, based on KOL-

LERT's study. The purpose of the two wells were to study the late cenozoic sedimentary sequences.

The first one was drilled in the continent, beside the road Iguape-Subaúma, about 10 km from Iguape (approximately latitude 24° 46' and longitude 47° 38'). The second one was drilled in Comprida Island, about 29 km from its southwestern tip at the ocean side (approximately latitude 24° 52' and longitude 47° 42'). The two wells are separated by a distance of 14.5 km (See figure 1).

We were able to recognize 4 sequences based on the lithological characteristics, which sequences that were later confirmed by the microorganisms studies, of the sediments cut by those two wells: In the well n.o 2, sandy and conglomeratic beds with subordinate sandy clay layers are the oldest beds, supposedly resting on the crystaline basement (Sequence I). Above these beds the sediments are fine, constituted mainly by silty clays (SequenceII). Following these beds, the sediments become silt-sandy (Sequence III). The uppermost beds up these two wells are predominantly fine, well sorted sands so loose they were the only sediments not allowed to be cored (Sequence IV). The sediments of the last sequence cover most of the present coastal plain, sometimes weakly cemented by ferruginous matter, forming the "piçarras" previously referred.

The Geobrás drillings

This Company drilled 79 percussion wells, 72 of them along Valo Grande (24 in each margin and 24 in the channel, and 7 scattered in the Comprida Island and Pequeno "sea").

The drillings didn't go beyond 34.45 m deep and so only the sequence IV was cut. However, significant data were acquired which together with data from other sources made possible a reasonable picture of the characteristics and environment of deposition of this important sequence of sediments.

Beside the studied samples from the described wells, additional samples from 16 localities in Comprida Island, Pequeno "sea", Icapara outlet, mouth of the Ribeira, Ribeira and Valo Grande were collected by the Geobrás.

Other institutions, for instance, "Departamento de Estradas de Rodagem" of the State of São Paulo, drilled in the area for different purposes. Several wells were drilled in the Cubatão "sea", near Aroeira, to know the conditions of the terrain for a bridge. According to the described profiles, beds of clay rich in organic matter rest on 5 m silty sand. Below the silty sand the weathered rock appears, which pass into fresh granite.

GRAIN SIZE ANALYSIS

Introduction

KUTNER (1962) studied the grain sizes of 95 samples from the bottom sediments of Cananéia "sea", Cubatão "sea" and Itapitangui "sea", around Cananéia Island, with the purpose of recognizing and evaluating the different agents and factors responsible for the present sedimentation in the region. According to this author the sediments generally are homogeneous with TRASK's sorting coefficient between 1.o and 4.o, the values lower than 2.5 being more common so they would be very well sorted.

The Geobrás S/A, as mentioned before, drilled shallow wells as part of the program of an extensive survey for S.V.R. Only sequence IV, constituted by regressive "blanket sands" was cut by these wells. And also 16 samples of the surface sands were collected. From the samples collected during these surveys, 87 were submitted to mechanical analysis in the "Instituto de Pesquisas Tecnológicas" of the University of São Paulo. A great majority of these samples are fine, almost pure sands.

The extreme uniformity in grain sizes of the sediments from the lagoonal region is well evidenced by the 182 samples analysed in those two works. All these sediments are provenient from "piçarras" (sequence IV) or reworked "piçarras" (sequence V); in this case there may be some grain size alterations in order to restore the equilibrium with the new dynamic conditions of a different environment. In other words: The sands deposited in equilibrium with the dynamic conditions of a regressive sea making up the blanket sands would possibly have to modify their grain sizes even in a small degree, in order to get in equilibrium with the conditions of new environments of sedimentation (redeposition): beaches, dunes or lagoonal bottoms. If so, the simple comparisons of the average or mean diameters, of TRASK's coefficient (So) or of homogeneity index, calculated by KUTNER (idem) and Geobrás (idem) are not enough for one to become aware of these minimum discrepancies of great significance for the recognition of such environments.

With this possibility in mind we analysed 37 "piçarra" and its resedimentation products, collected by us. The data of 32 samples from the two wells drilled by I.G.G., analysed by the geologist CARLOS TORRES, kindly granted by him, were also included in this study. These drillings data were essential in the textural characterization of the sequences I, II and III, that do not crop in the studied area.

Sampling

We collected 51 samples from the Iguape-Cananéia lagoonal region. Most of them come from "piçarra" banks; other samples come from the bottom of Cananéia and Pequeno "seas", recent beaches and dunes and river channels. The samples underwent mechanical analysis, heavy minerals couting and Foraminifera and Algae inventories. In this paper are presented only the results of the mechanical analysis. Details about the provenance of these samples are presented in the part II of this Project.

Method of analysis

The grain size of 37 samples chosen at random were analysed. They were initially split, down to 50 to 60 grams. These fractions were sieved for particles larger than 0.062 mm and analysed by pippete in the case of smaller particles.

The samples from the bottoms of the lagoons were analysed not taking into account possible operational errors during sieving, decantation, etc., that is, without controlling by comparison of the total weight before and after the analysis. We proceeded this way because according to KUTNER (1962, p. 45), when this material is dried up the particles stick together into slumps of silt and clay practically impossible to desintegrate.

Results and interpretations

Cumulative curves – The cumulative curves were drawn on arithmetic probability paper with "phi" scale. These curves were grouped into 7 classes, according to their geological provenances:

a) *Surface samples*

Group 1 – "Piçarras"
Group 2 – Dunes from Comprida Island
Group 3 – Bottom sands from Cananéia and Pequeno "seas"
Group 4 – Beaches from Comprida Island

b) *Subsurface samples*

Group 5 – "Piçarras"
Group 6 – Sequences II and III
Group 7 – Basal sands and conglomeratic sands (Sequence I).

The cumulative curves for the "piçarra" were remarkably uniform principally those from the surface samples. Furthermore, the beach and dune sands, originated from reworking of the "piçarras" have cumulative curves without any appreciable differences from those of the "piçarras", even when some statistical parameters were compared as, for instance, the mean diameters or TRASK's sorting coefficients. The bottom sands, though predominantly constituted by reworking "piçarras" have, notwithstanding substantial participation of argillaceous materials because of the lagoonal environment. The samples from the groups 6 and 7 came from environments of sedimentation completely different from other groups, so their cumulative curves are perfectly distinguished from the curves of the remaining ones (See figures 5a to 5f).

SAHU's graphic method (1964) – The size frequency distributions of a sediment is more or less a reflection of the energy of the agent of transport as well as they provide some indications of the kinetic energy conditions within the depositional environments. Several statistical parameters were devised to express these relations (FOLK and WARD, 1957; PASSEGA, 1957; FRIEDMAN, 1961, 1967; SAHU, 1964, etc.). We were lucky with the application of the SAHU's method. In this method the mean "phi" deviation of all samples of a group (at least two samples) in the ordinate against the ratio using the standard deviation of kurtosis, mean size and variance of the group of samples in the abcissa are utilized on a log-log plot. The parameters used in this graphic method are those developed by FOLK and WARD (1957). The SAHU's graphic as applied to the Late Cenozoic sediments of the studied region is shown in figure 6. Every one of the seven natural groups listed above was plotted as a point in the graphic. The distributions of the points in the graphic allowed the following interpretations:

Point group 1 – Surface "piçarra": Deposition in a low energy shallow sea.

Point group 2 – Dune samples from Comprida Island: Deposition in a high energy aeolian environment.

Point group 3 – Bottom sands from Cananéia and Pequeno "seas": Deposition in a low energy fluvial environment.

Point group 4 – Beach sands from Comprida Island: Deposition in a rather great energy beach environment (energy between those of the groups 1 and 2).

Point group 5 – Subsurface "piçarras": Deposition in a low energy shallow sea. The position of the point representing these samples in the graphic, relatively far from the one representing the group 1, might be explained by the provenance of these samples, from horizons stratigraphically lower than the samples of the group 1.

Point group 6 – Samples from sequences II and III: Deposition in turbidity conditions, high energy and viscosity.

Point group 7 – Conglomerates and conglomeratic sands from the base (sequence I): Deposition in turbidity conditions with energy and viscosity higher than those from group 6.

The points plotted in the SAHU's graphic, relative to sequence V (recent beaches, dunes and bottom sands), represent sedimentary environments clearly coincident with the environments of the samples collected. As for the older sediments their environments were deduced by other methods and even here the SAHU's graphic confirmed those interpretations. The points 1 and 5 indicated deposition in a low energy shallow sea. beeing concordant with previous interpretations, based on other characteristics such as the shape of the rock body (Persistence factor), stratigraphic position in relation to the geological events, etc. Similarly the points 6 and 7 were also located in the graphic in positions that agree with previous interpretations. A remarkable fact is that the points representing the groups 2 and 4 located in the graphic very far from the groups 1 and 5. As we have stated above the samples from these groups were not clearly distinguished by other methods but they are clearly separated by SAHU's method. Even so the points 2 and 4 were not plotted exactly into the areas corresponding to their true environments, their locations show an unmistakable liaison with the environments of the samples. Another fact that can be considered is about the location of the point group 3, which indicated fluvial environment. About this conclusion it is very interesting to mention that KUTNER (idem, p. 50) had recognized a hydrodynamic mechanism in the channels around the Cananéia Island with a characteristic of *"two directions flux type river."*

We consider, therefore, as confirmed the hypothesis of reworking of the "piçarras" adjusting themselves to the new energetic conditions of the different environments of deposition.

CONCLUSIONS

Field observations and grain size analysis made by the authors, in connexion with the previous works data, permit to reach some conclusions:

a) There are an extensive sedimentary deposit, blanket sand type, constituted by homogeneous and very well sorted fine sand, in the Iguape-Cananéia lagoonal region.

b) Not only because their great persistence, but also, as a consequence, these sedimentary deposits are the most important source of detrital materials to the present sub-environments.

c) In spite the great similarity, it is possible to recognize the little modifications to which the "piçarras" sediments are submitted in their texture, during resedimentation processes in modern environments by application of the SAHU's method (1964).

d) It is possible to recognize also some well defined sedimentary sequences below the Cananéia Formation, revealed by the I.G.G. drillings.

Other characteristics and the final considerations about the Neocenozoic sedimentary sequences in the Iguape-Cananéia lagoonal region will be presented in the second part of this paper.

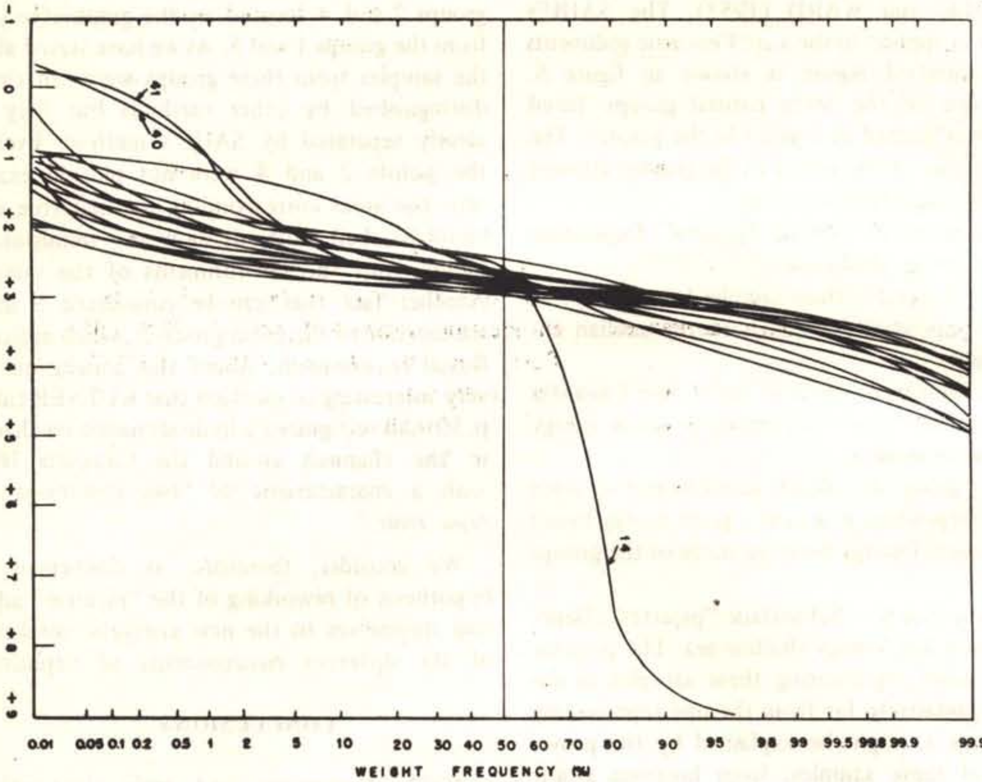

FIGURE 5.a – Cumulative curves of group 1 samples

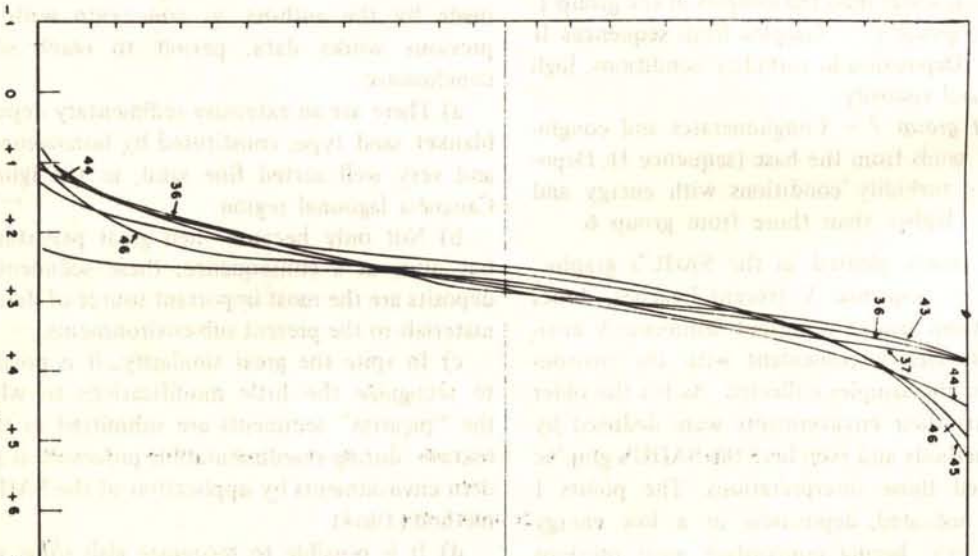

FIGURE 5.b – Cumulative curves of groups 2-4 samples

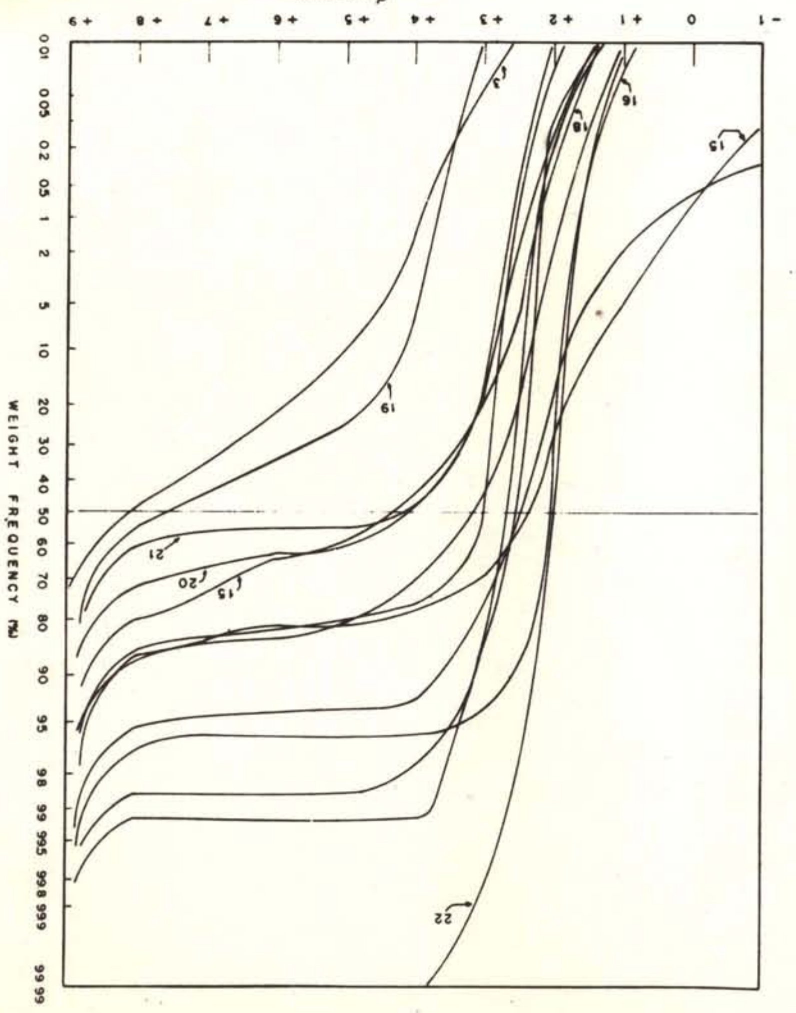

FIGURE 5.c – Cumulative curves of group 3 samples

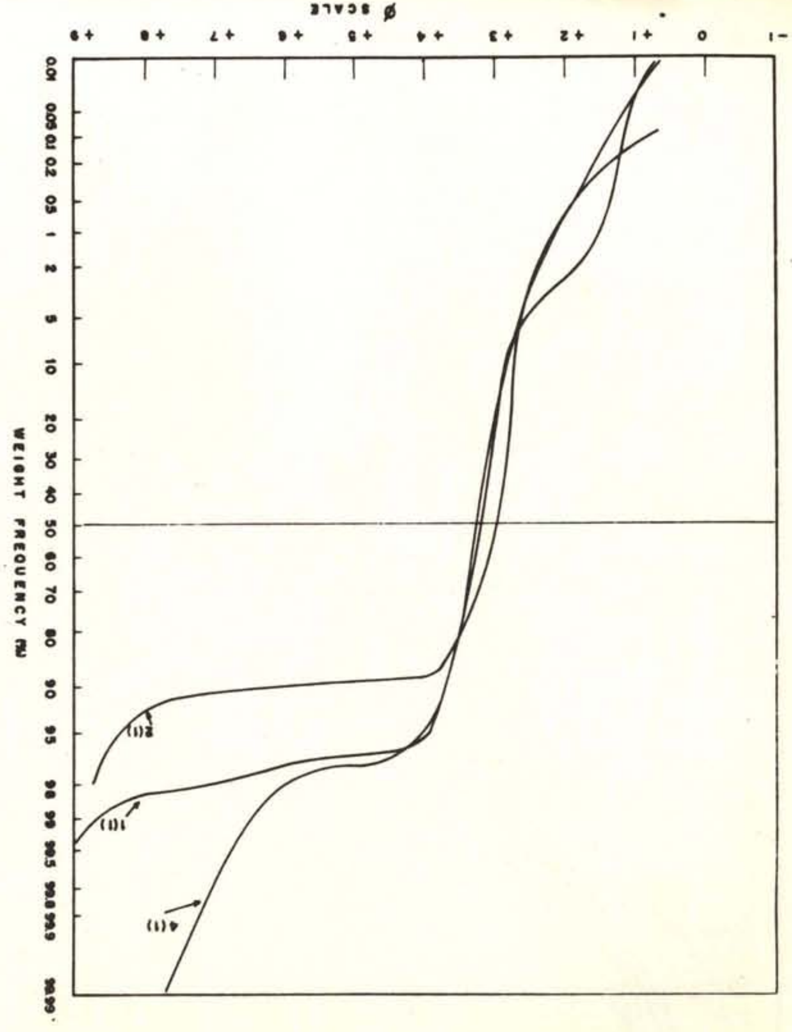

FIGURE 5.d – Cumulative curves of group 5 samples

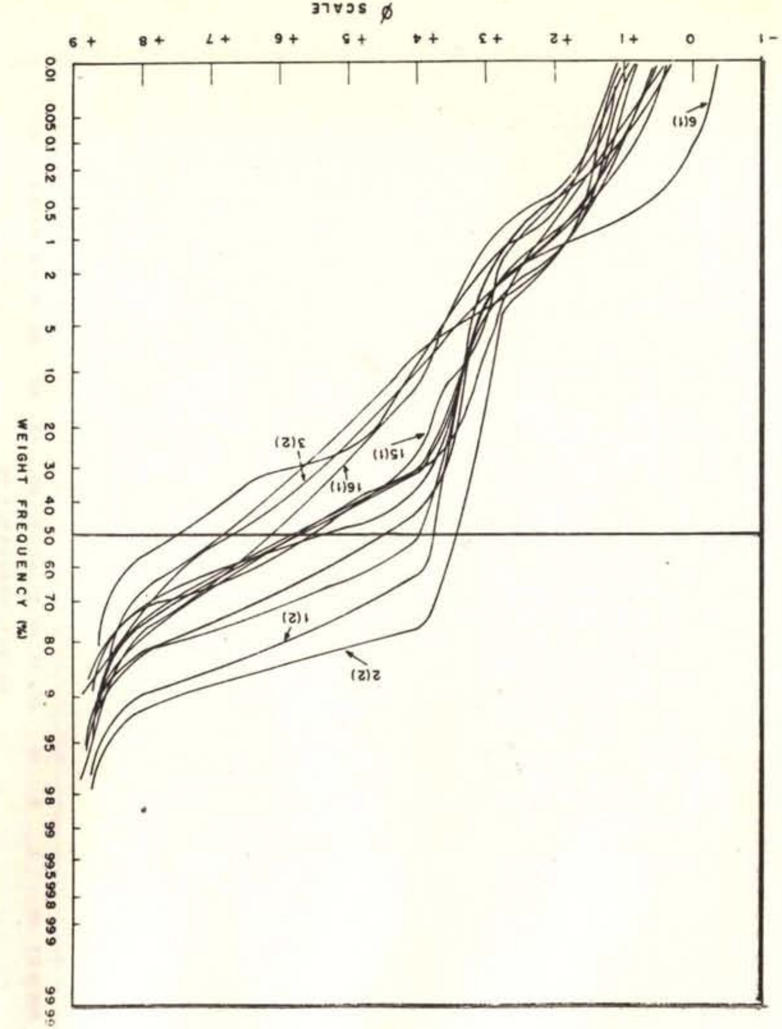

FIGURE 5.e – Cumulative curves of group 6 samples

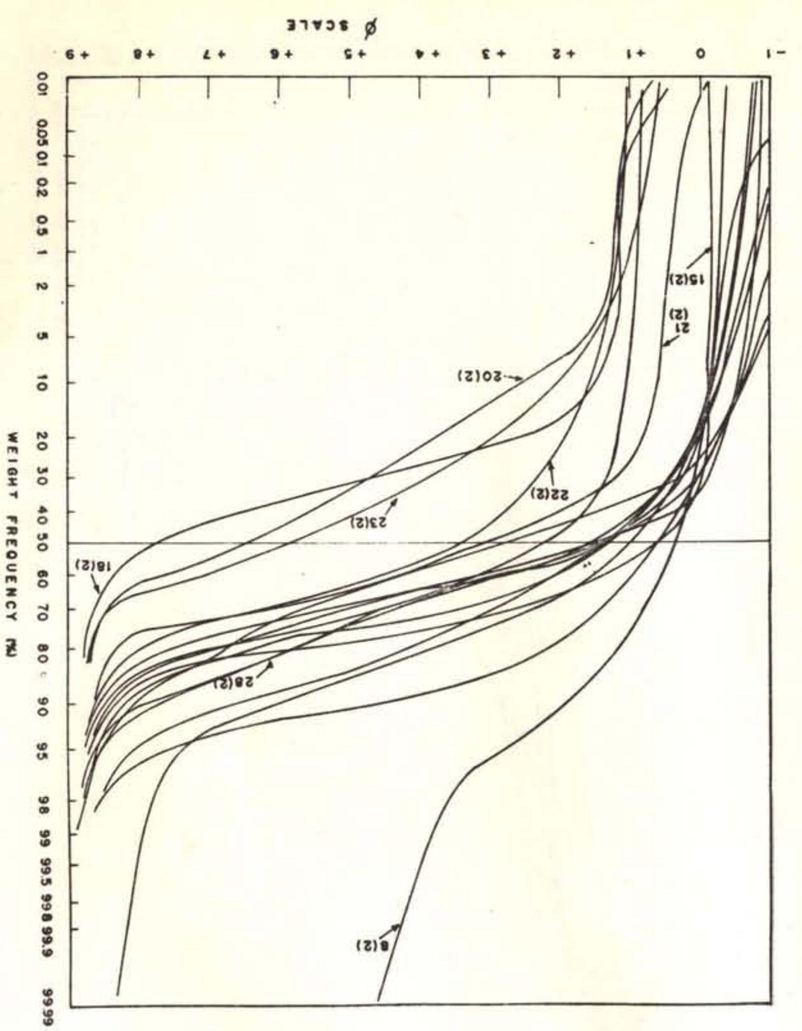

FIGURE 5.f – Cumulative curves of group 7 samples

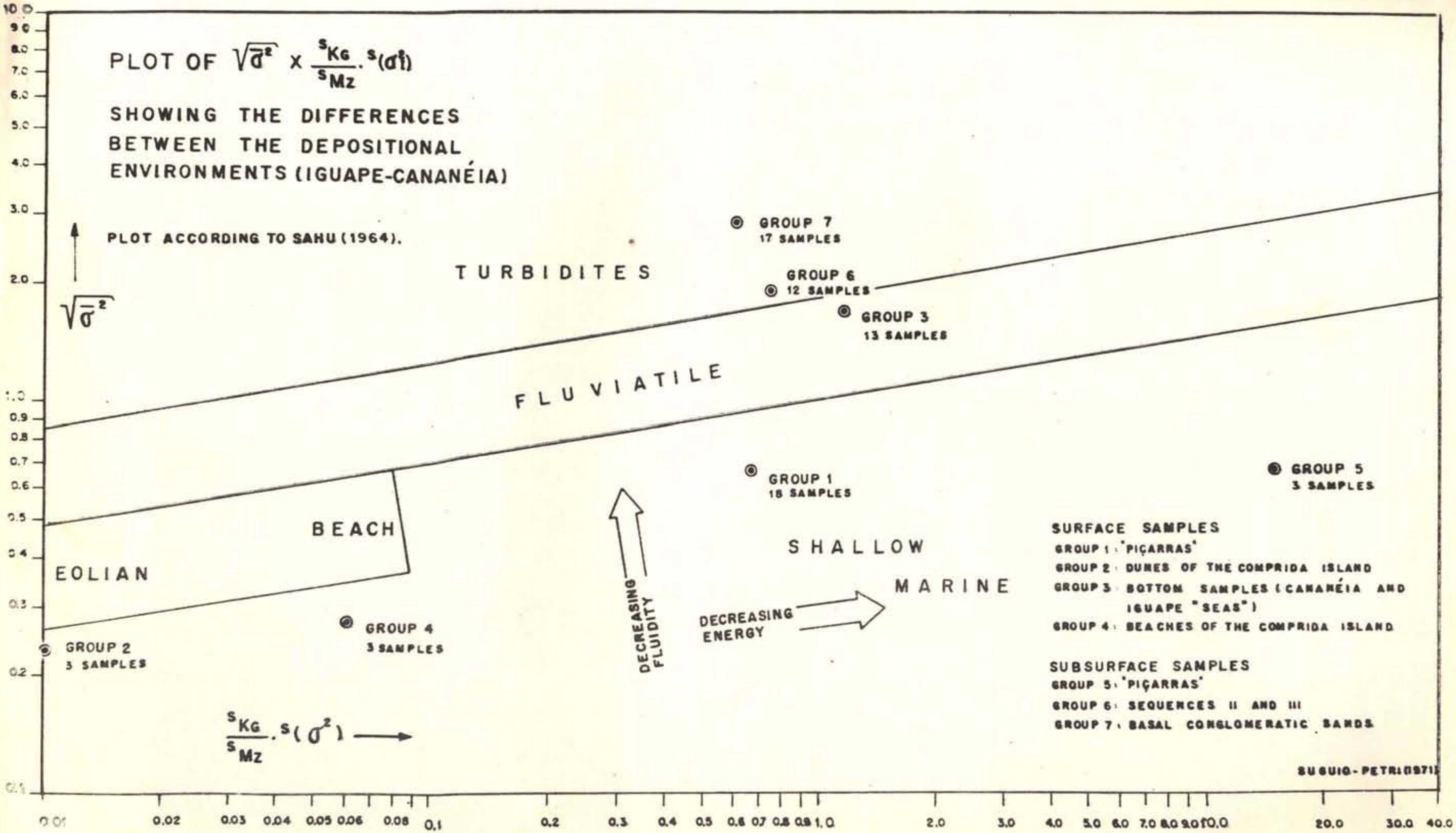
PLOT OF $\sqrt{\bar{\sigma}^2} \times \frac{s_{KG}}{s_{Mz}} \cdot s(\sigma_1^2)$
SHOWING THE DIFFERENCES BETWEEN THE DEPOSITIONAL ENVIRONMENTS (IGUAPE-CANANÉIA)
PLOT ACCORDING TO SAHU (1964).
$\sqrt{\bar{\sigma}^2}$
TURBIDITES
FLUVIATILE
BEACH
EOLIAN
SHALLOW MARINE
DECREASING FLUIDITY
DECREASING ENERGY
GROUP 7 17 SAMPLES
GROUP 6 12 SAMPLES
GROUP 3 13 SAMPLES
GROUP 1 18 SAMPLES
GROUP 5 3 SAMPLES
GROUP 4 3 SAMPLES
GROUP 2 3 SAMPLES
SURFACE SAMPLES
GROUP 1: 'PIÇARRAS'
GROUP 2: DUNES OF THE COMPRIDA ISLAND
GROUP 3: BOTTOM SAMPLES (CANANÉIA AND IGUAPE "SEAS")
GROUP 4: BEACHES OF THE COMPRIDA ISLAND
SUBSURFACE SAMPLES
GROUP 5: 'PIÇARRAS'
GROUP 6: SEQUENCES II AND III
GROUP 7: BASAL CONGLOMERATIC SANDS
$\frac{s_{KG}}{s_{Mz}} \cdot s(\sigma^2)$
SUGUIO-PETRI (1971)
10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1
0.01 0.02 0.03 0.04 0.05 0.06 0.08 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 20.0 30.0 40.0

FIGURE 6

PHOTO 1

DUNES NEAR THE BEACH – Locality: Southeastern extremity of the Comprida Island.

PHOTO 2

MAGNETITE AND ILLMENITE CONCENTRATION IN THE BEACH – Locality: "Praia de Fora" beach of the Comprida Island.

PHOTO 3

"FOOTSTEP" FORMED BY CANANÉIA FORMATION – Locality: Town of Cananéia, faced to Cananéia "sea".

PHOTO 4

"TESTIMONY" OF CANANÉIA FORMATION – Locality: Iguapé-Biguá road (The houses and the forest are situated on the erosion "testimony" and the banana plantation in the lower parts of the area).

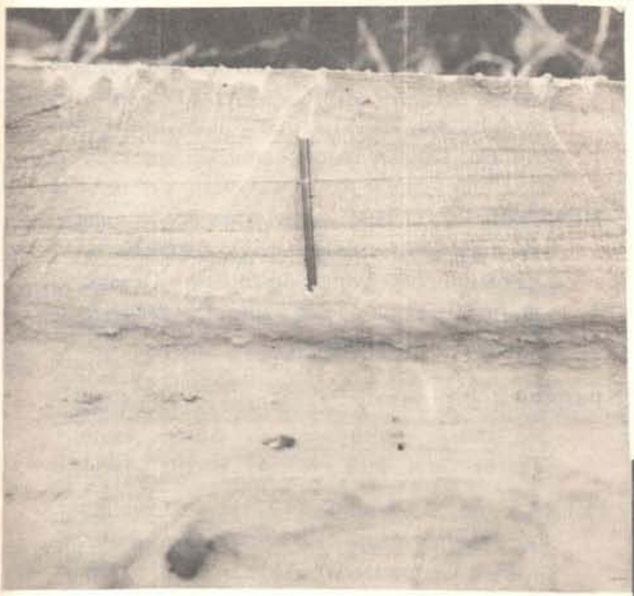

PHOTO 5

STRATIFICATION OF PRESENT BEACH SAND – Locality: Iguape Island, near the Icapara outlet

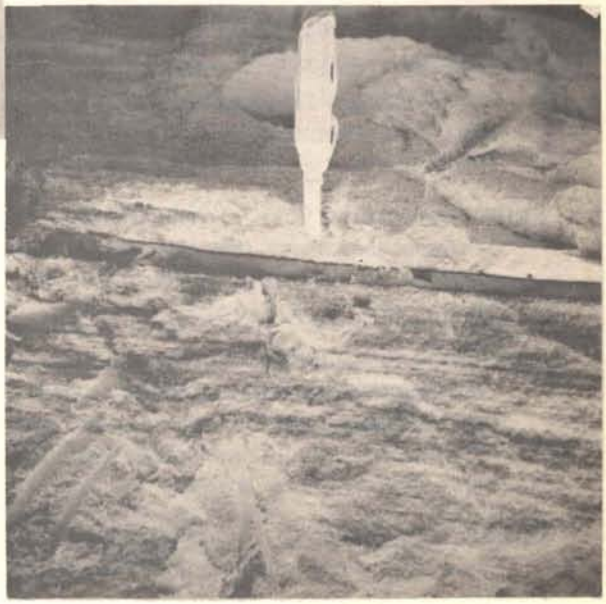

PHOTO 6

BEDDING AND ARGILLACEOUS LAYER OF THE CANANÉIA FORMATION – Locality: Cananéia Island, where the figure 2 scheme was made)

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