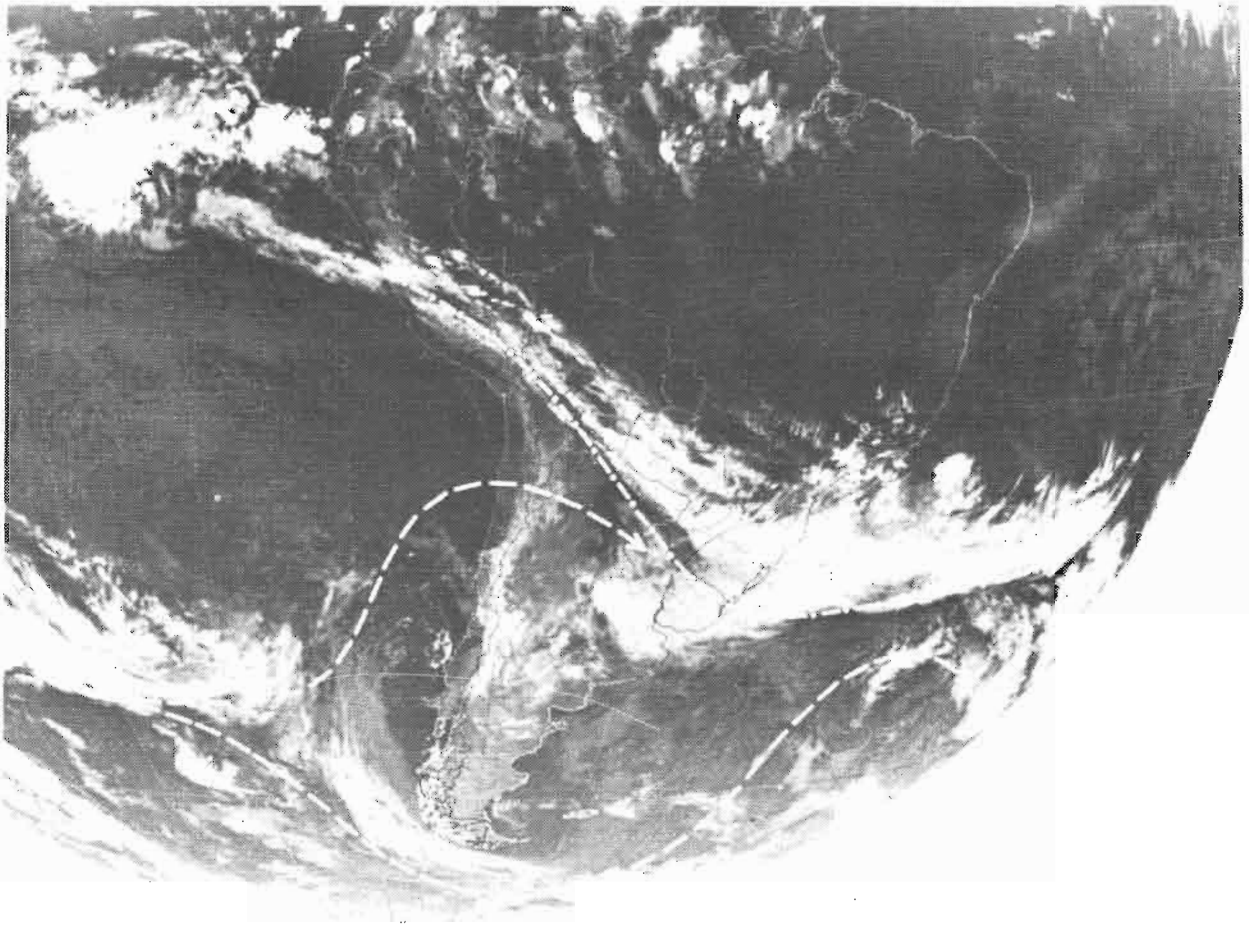
INTERNATIONAL SYMPOSIUM

ON

GLOBAL CHANGES IN SOUTH AMERICA DURING THE QUATERNARY

São Paulo (Brazil), May 8-12, 1989



SPECIAL PUBLICATION Nº 2

EXCURSION ROUTE ALONG THE BRAZILIAN COAST BETWEEN SANTOS (STATE OF SÃO PAULO) AND CAMPOS (NORTH OF STATE OF RIO DE JANEIRO)

Authors: Louis Martin and Kenitiro Suguio

1989

LEGEND FOR THE COVER PHOTOGRAPH

It represents an image received by the "Instituto de Pesquisas Espaciais" (INPE) in São José dos Campos (São Paulo State, Brazil), at 12:17 h (GMT) on June 12th, 1983, from the meteorological satellite "GOES". The undulating white band, with east-westward orientation, represents the cold front which was stationary over the State of Santa Catarina and which provoked heavy rainfall (45% above the mean value) during 1983. The white spot in the upper left corner of the photograph, on the Equator, is agglomerated cumulus-nimbus clouds associated with abnormally warm water of the 1983 "El Niño". The broken lines in the south represent the polar jet bifurcation and the east-west oriented broken line with points gives the position of the tropical jet. At the junction point near the Brazil-Uruguay frontier, wind speeds reached 250 km/h at a height of about 10 km.

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EXCURSION ROUTE ALONG THE BRAZILIAN COAST BETWEEN SANTOS (STATE OF SÃO PAULO) AND CAMPOS (NORTHERN STATE OF RIO DE JANEIRO)

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São Paulo - Brazil

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C O N T E N T S

INTRODUCTION

North to south, Brazil extends between latitudes 5° 16'N and 33° 45'S over a distance of about 4,319 km. East to west, it extends over 4,326 km between longitudes 73° 59'W and 34° 49'W. Brazil has an area of 8,511,965 km^2, which represents almost 50% of the South American continent. Most of its territory is located in the intertropical zone (the Tropic of Capricorn passes slightly north of the city of São Paulo). The Brazilian territory is characterized by moderate altitudes, ranging from 0 to 3,000 m (Pico da Neblina, near the Venezuela frontier reaches 3,014 m); 40% of the country is 0 to 200 m high; 45% between 200 and 600 m, and only 15% is higher than 600 m.

1. GENERAL OUTLINE OF BRAZILIAN GEOLOGY

1.1 - PRECAMBRIAN BASEMENT

Precambrian rocks cover an area of almost 5 million km^2. They have been subjected to varying degrees of metamorphism and most have been intruded by plutonic rocks. The Precambrian rocks were rejuvenated during the Brazilian Folding Cycle (900 to 550 m.y.), which represents the end of geosynclinal-type tectonic evolution in Brazilian territory.

The Brazilian portion of the South American Platform (Fig. 1) underwent a geocratic period with a rather prolonged tectonic calm from the end of the Precambrian to the end of the Jurassic (Almeida, 1967).

1.2 - INTRACRATONIC BASINS

1.2.1 - Pre-Silurian basins

a) São Francisco basin - This is formed of limestones, schists and meta-arenites with a maximum thickness of about 1,000 m. Radiometric dating of these rocks has indicated a minimum age of about 600 m.y.

b) Corumbá-Cuiabá basin - Its central portion is covered by Cenozoic sediments of the Pantanal Matogrossense.

c) Itajaí basin - Is formed of unfossiliferous clastic sediments with a thickness of about 1,000 m.

d) Camaquã basin - Formed of unfossiliferous detrital deposits extensively intruded by andesitic and quartz-porphyric rocks.

1.2.2 - Great Paleozoic basins

There are three large Paleozoic intracratonic basins:

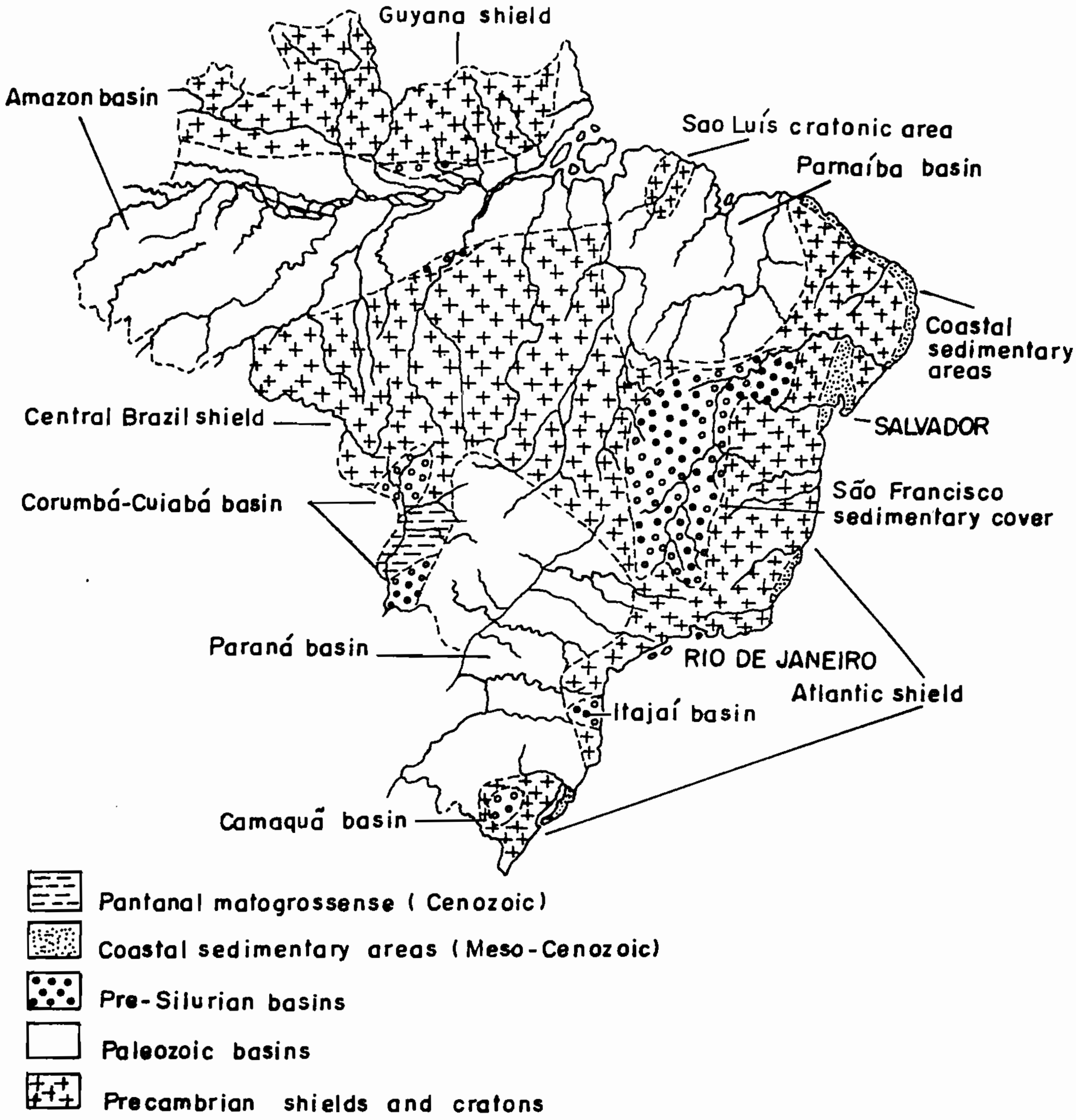

Fig. 1 – General outline of Brazilian geology

Modified from Mendes & Petri (1971)

the Amazon, Parnaíba (Maranhão) and Paraná basins.

The oldest Paleozoic sedimentary deposits belong to the Silurian. The oldest deposits exhibit clear marine characteristics. In the Paraná basin the sedimentary environments were dominantly marine until the Early Devonian. Marine deposits were also present during Permo-Carboniferous times but are less important than the continental deposits. In the Amazon basin, marine sedimentation is evident only until the Carboniferous. In the Parnaíba (Maranhão) basin, marine Carboniferous deposits are abundant although they disappear completely after this period.

The history of the Brazilian intracratonic basins commenced with moderate subsidence in the Silurian, which reached its maximum during the Early Devonian. After this period, subsidence was gradually less important until the Late Mesozoic. The subsidence episodes are punctuated by phases of uplift.

The intracratonic basins gradually disappeared but before they lost completely their characteristic features, they were affected by tectonic movements which began in Late Jurassic time and which followed the separation of Africa from South America. Simultaneously, as new tectonic basins appeared, they were filled by thick marine sediments.

Since the Cretaceous, the most important sedimentation has taken place in coastal rather than intracratonic basins.

1.3 - MESOZOIC SEDIMENTATION

Two types of sedimentary deposits originated during the Mesozoic: coastal formations and inland formations.

1.3.1 - Coastal formations - These were deposited within tectonic depressions and consist of marine and non-marine sedimentary sequences which extend from the Late Jurassic to the Early Tertiary.

Using a wealth of both surface and subsurface information, Asmus & Ponte (1973) established a standard columnar section for the Brazilian marginal basins, which can be subdivided into several sequences. Asmus (1979) recognized four sequences in sections of these basins, which are known by the following informal names:

Continental sequence,
Lacustrine sequence,
Gulf sequence, and
Marine sequence.

a) Continental sequence - It is composed of red shales and intercalated minor arkosic sandstones, with superimposed fine and conglomeratic sandstones. This sequence, according to Ponte et al. (1971) was deposited within an intracratonic basin which was elongated in a north-south direction known as the Afro-Brazilian depression.

However, according to Munne et al. (1972), this sequence could represent alluvial fan and interior lacustrine deposits, characterized by relatively quiet tectonism. This sequence is assumed to be of Upper Jurassic age (Purbeckian).

b) Lacustrine sequence - It comprises alternating shale and sandstone beds with subordinate limestone. Gama Jr. (1970) suggested that its deposition occurred in a deltaic-lacustrine environment, prograding towards tectonic basins bordered by normal faults, which controlled the facies distribution and induced pertubations in the sediments. The tectonic events which were active during the deposition of this sequence can be correlated with Almeida's (1967) Wealdenian Reactivation.

c) Gulf sequence - This sequence is characterized by detrital rocks and limestones of a transitional environment, along with evaporites composed mainly of anhydrites and halites.

The salt migration gave rise to spetacular halokynetic structures, particularly salt domes, especially where evaporite deposits are most common. The marginal basins of Santos, Campos, Espírito Santo and Bahia Sul are particularly important as regards the frequency and dimension of their salt domes.

The occurrence of these structures is limited, northward and southward respectively, by the Maceió and Florianópolis alignments which establish the extent of the deep and stagnant waters in which the evaporites were precipitated. Although normal faults have affected these salt domes, it is assumed that their precipitation occurred under conditions of relatively quiet tectonism. According to Vianna (1980), the age of the Gulf sequence should be assumed as Aptian.

d) Marine sequence - This can be divided into two sub-sequences: shallow platform carbonate and truly marine deposits.

The shallow platform carbonate sub-sequence is composed of calcarenites and calcilutites, frequently with oolitic and pisolitic textures. Laterally, they can change gradually to coarse sandstones landwards or to pelitic facies oceanwards. This sub-sequence occurs continuously from Chuí (State of Rio Grande do Sul) to Natal (State of Rio Grande do Norte), although the ages of its uppermost beds decreases from south to north. In the Santos basin these limestones are Albian, in that of Espírito Santo they are Albian to Turonian, in the Sergipe/Alagoas basin they are Albian to Santonian and in the

Pernambuco basin they are Albian to Eocene. This stage was characterized by weak crustal movements, demonstrated by normal faults near to the marginal portions of the basins.

The truly marine deposits sub-sequence is represented by detrital sediments, ranging from continental shelf to deeper marine environments, it being possible to recognize deltaic systems, continental shelf systems and continental slope systems. This sub-sequence is widespread in all Brazilian marginal basins, with ages ranging from Albian to Recent.

1.3.2 - Inland formations - These are distributed in the interior of the country and are typically continental deposits.

1.4 - CENOZOIC SEDIMENTATION

With the exception of some coastal marine formations, Cenozoic beds are predominantly composed of continental deposits.

1.4.1 - Tertiary deposits - One of the most interesting peculiarities of the Brazilian Tertiary sedimentation is the accumulation of sandy-clayey, often pebbly, sediments within very restricted tectonic basins (For example, the Paraíba basin, São Paulo basin, Curitiba basin, etc.).

Very extensive sandy-clayey, clastic sedimentation which covered the area along the coastline between the states of Rio de Janeiro and Pará occurred during the Late Tertiary. In the Amazon valley, one can observe this type of sedimentary deposit. In the states of Pará and Maranhão, they overlie Miocene rocks. Pliocene continental deposits have been assigned to the Barreiras Formation (Barreiras Group of some authors).

1.4.2 - Quaternary deposits - Extensive areas in the Amazon valley and Pantanal Matogrossense are occupied by Quaternary sediments. Also, in the region of the headwaters of the Xingu and Araguaia rivers, thin Quaternary continental deposits cover a continuous area of about 750 x 750 km.

2. BRAZILIAN COASTLINE

The Brazilian coastline has a length of about 9,200 km. The distribution of sedimentary deposits along this coast is typically related to geological structures and features of the continent.

Silveira (1964) divided the Brazilian coastline into five sectors (Fig. 2): Amazonian or Equatorial coast, North-eastern or Barreiras cliff coast, Eastern coast, Crystalline coast and Southern coast.

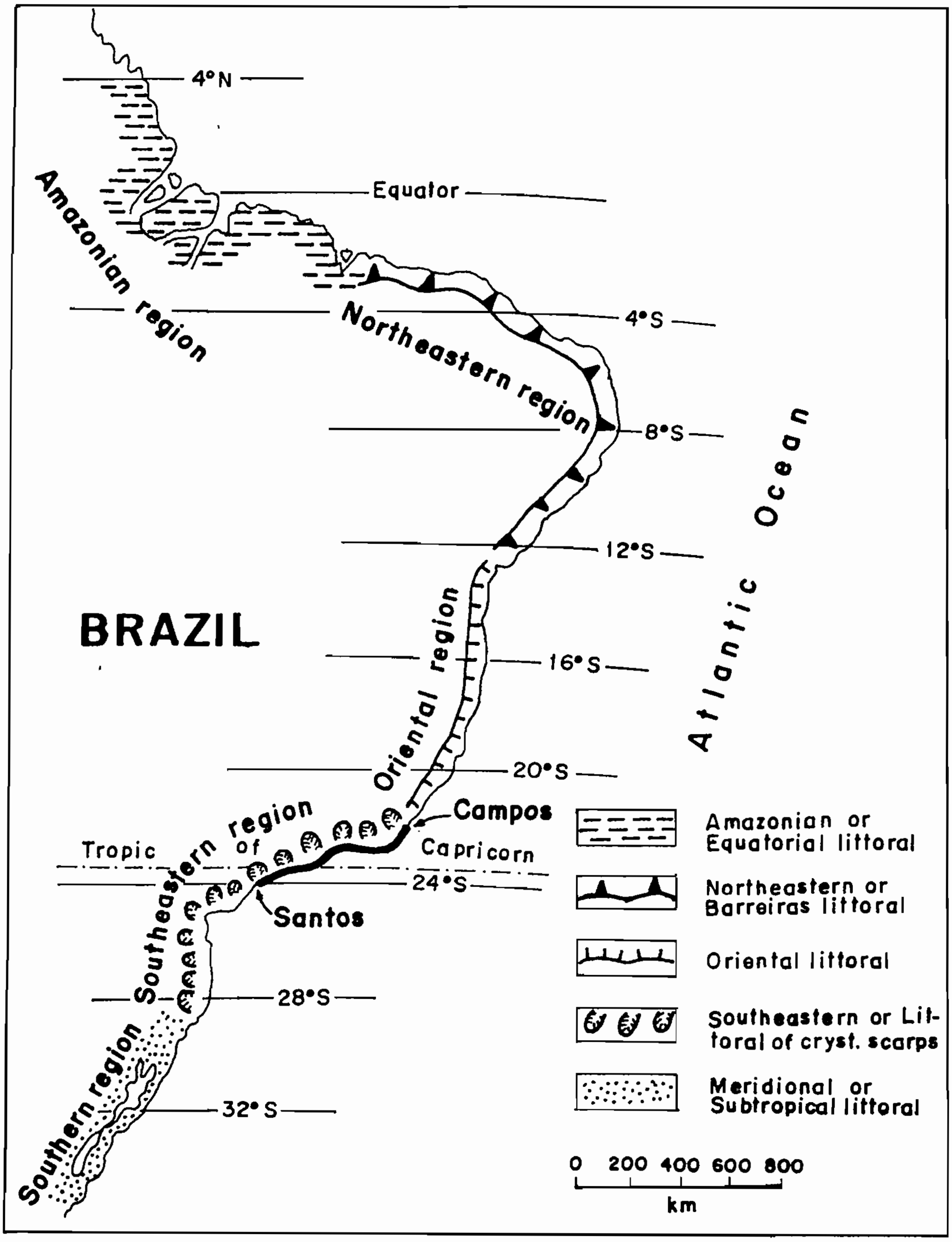

Fig. 2 — Classification of the Brazilian coastline according to Silveira (1964) with indication of the sector to be visited in the excursion.

2.1 - AMAZONIAN OR EQUATORIAL COAST

This sector is 1,500 km long and may be up to several hundred kilometers wide, mostly consisting of frequently flooded lowlands. Behind these lowlands, there is a low plateau (5 to 15 m high) of older sediments (Tertiary to Quaternary), that is never covered by water. In several localities this plateau reaches the ocean and thus forms small cliffs (Franzinelli, 1982). This situation is more common in the eastern portion of the Amazonian coast. In this part the coast exhibits submergence features.

2.2 - NORTHEASTERN OR BARREIRAS CLIFF COAST

A common feature observed between the Parnaíba river mouth (State of Maranhão/State of Piauí) and the city of Salvador (State of Bahia) is the presence of the Barreiras Formation (Bigarella and Andrade, 1964; Mabesoone et al., 1972 and Bigarella, 1975a). For the greater part, these sediments overlie an eroded surface of Precambrian crystalline rocks, but in some places they are situated on Cretaceous sediments.

In the vicinity of the cape of São Roque, the coastline trend changes abruptly by forming an "elbow" separating the northern and southern coastlines. The northern portion has a semi-arid climate, in which dunes are actively forming behind the beaches (Perrin & Passos-Costa, 1982), while the southern portion is humid.

One of the peculiarities of the northeastern coast, besides the Barreiras Formation outcrops, is the existence of beach-rocks (Branner, 1904; Mabesoone, 1964 and Bigarella, 1975b).

2.3 - EASTERN COAST

This part of the Brazilian coastline extends from Salvador to the southern State of Espírito Santo. From Salvador to Itacaré the coastline is situated along the southern side of the Recôncavo Cretaceous sedimentary basin. Quaternary sedimentary deposits are well developed, except at the margins of the Todos os Santos bay.

From Itacaré to Ilhéus, excluding the small Almada sedimentary basin, the coast is cliffy with several outcrops of the crystalline basement. Southwards, the coastline is characterized by extensive bands of the Barreiras Formation situated between Precambrian rocks and the sea, with marine Quaternary plains, often related to short streams (small deltas), being found within restricted embayments in this formation. Many reef alignments occur in this part of the coast. Coral reefs are also observed in the Southern State of Bahia, mostly in the Abrolhos area (Rathbunn, 1876 and 1879; Leão, 1982 and Leão _et al_., 1982).

2.4 - CRYSTALLINE COAST

From the southern State of Espírito Santo to the cape of Santa Marta (State of Santa Catarina), the coastline delineates a long concave line, whose most inland point is the bay of Paranaguá (State of Paraná). Just as the northeastern coast in characterized by the Barreiras Formation, the crystalline coast is represented by rocks of the Brazilian Complex. From Guanabara bay to the State of Paraná, coastal plains and beaches are frequently absent, and the coastline is abruptly intercepted by the eastern margin of the, often more than 800 m high, Brazilian Atlantic Plateau (Planalto Atlântico). Headlands oblique to the coastline reach the sea in many places, thereby delineating small bays. Some of these bays have been filled to varying degrees by Quaternary marine sediments. One of the characteristics of this part of the Brazilian coastline is that the great majority of the nearby rivers flow towards the interior of the continent rather than to the sea.

2.5 - SOUTHERN COAST

South of Laguna (State of Santa Catarina), the coastline is essentially low and sandy. Very well developed beach-ridge plains have governed the formation of lagoonal systems, some of which cover considerable areas, such as the Patos lagoon (10,000 km^2) and the Mirim lagoon. Unconsolidated fine sands have been frequently reworked by aeolian action, forming very high sand dunes.

THEME I

THE QUATERNARY EVOLUTIONARY HISTORY OF THE BRAZILIAN COAST

1. RELATIVE SEA LEVEL CHANGES

1.1 - EVIDENCE OF QUATERNARY SEA-LEVELS

It has been observed that relative sea-level changes during the Quaternary were quite important factors in the evolution of coastal plains in Brazil.

Evidence has been cited by several authors, such as Hartt (1870), Branner (1904), Freitas (1951), and Bigarella (1965). However, they were studied initially from a geomorphological viewpoint and were assumed to be Tertiary in age; presently they are considered as Quaternary. Until the 1960's research on past sea-levels was very scarce in Brazil (Suguio, 1977). One of the first studies, which was somewhat systematical and which included radiocarbon ages, was conducted by Van Andel & Laborel (1964).

After 1974, relative sea-level changes during the Quaternary, mostly during the last 7,000 years, have been studied by several groups of scientists. These groups finished the studies of Quaternary formations in the states of São Paulo and southern Rio de Janeiro (Martin & Suguio, 1975, 1976a, 1976b, 1976c, 1978a, 1978b; Suguio & Martin, 1976a, 1976b, 1978a, 1978b, 1978c, 1982a, 1982b; Martin et al., 1979b, 1980b; Suguio et al., 1980); in the states of Bahia, Sergipe and Alagoas (Bittencourt et al., 1979a, 1979b, 1982a, 1982b, 1983a, 1983b; Martin et al., 1978, 1979a, 1980a, 1980b, 1980c, 1981a, 1981b, 1982, 1983, 1984a; Vilas-Boas et al., 1979, 1985; Dominguez, 1983; Dominguez et al., 1981a, 1981b, 1983); in the northern State of Espírito Santo (Suguio et al., 1982 and Martin et al., 1984); in the northern State of Rio de Janeiro (Martin et al., 1984c, 1984e, 1985b; Suguio et al., 1985); in the states of Paraná and Santa Catarina (Martin and Suguio, 1986; Martin et al., 1986; Suguio et al., 1986), and in the State of Rio Grande do Sul (Tomazelli et al., 1982, Villwock et al., 1987).

1.1.1 - Sedimentological evidence - Quaternary marine deposits situated above the present sea-level offer indisputable evidence of ancient levels higher than present. Systematic geological mapping and radiocarbon dating of these deposits has allowed us to distinguish several generations of sandy terraces constructed after the maximum sea-levels related to different transgressive episodes of the Quaternary.

1.1.2 - Biological evidence - This is represented by vermetidae (gastropods), oyster and coral incrustations, as well as by sea-urchin holes, situated above the present life-zone of these animals, indicating ancient sea-levels higher than the present (Laborel, 1979). Moreover, many Pleistocene and Holocene marine terraces exhibit frequent Callichirus burrows situated above the present life-zone of this animal (Suguio & Martin, 1976b, Suguio et al., 1984, Rodrigues et al., 1985).

1.1.3 - Pre-historic evidence - Several shell-middens, constructed by ancient inhabitants (paleo-indians) of the littoral zone, are found in coastal plains of southeastern and southern Brazil. The geographical position of these shell-middens, frequently situated in the interior of the continent (more than 30 km from the present shoreline), can only be explained by a lagoonal extent which was greater than that of today, and consequently by a sea-level higher than the present (Martin et al., 1984d, 1986d, 1986e).

1.2 - ANCIENT SEA-LEVELS HIGHER THAN THE PRESENT

1.2.1 - High sea-levels before 120,000 years B.P. - Two high sea-levels, probably more ancient than 120,000 years B.P. (Sangamon = Riss/Würm), are very well represented only in the coastal plain of the State of Rio Grande do Sul. Villwock et al., (1986) assumed these levels to be Middle and Lower Pleistocene in age and named them respectively as Barrier II and I (Fig. 3). Tentatively, they could be attributed respectively to the Yarmouth (Mindel/Riss) and Aftonian (Günz/Mindel) interglacial stades. Scattered across the coastal plains in the states of Santa Catarina, Paraná and probably São Paulo (behind Icapara hill, near the town of Iguape), there are some sandy or gravelly (more than 13m - high) terraces, of probable marine origin, which could be correlated with the Barrier II of the State os Rio Grande do Sul. No evidence of ancient sea-level related to the Barrier I of this State was found in other places.

1.2.2 - High sea-level of 120,000 years B.P. - At this time the relative sea-level was probably situated 8±2 m above the present level. This high sea-level episode is known as the Cananéia Transgression in the coastal plain of São Paulo State (Suguio & Martin, 1978), and as the Penultimate Transgression in the coastal plains of the states of Bahia, Sergipe and Alagoas (Bittencourt et al., 1979). The age of this transgression has been established through five datings obtained from coral samples, collected from the basal portion of marine terraces in the coastal plain of the State of Bahia, using the Io/U method (Martin et al., 1982). Although very well preserved

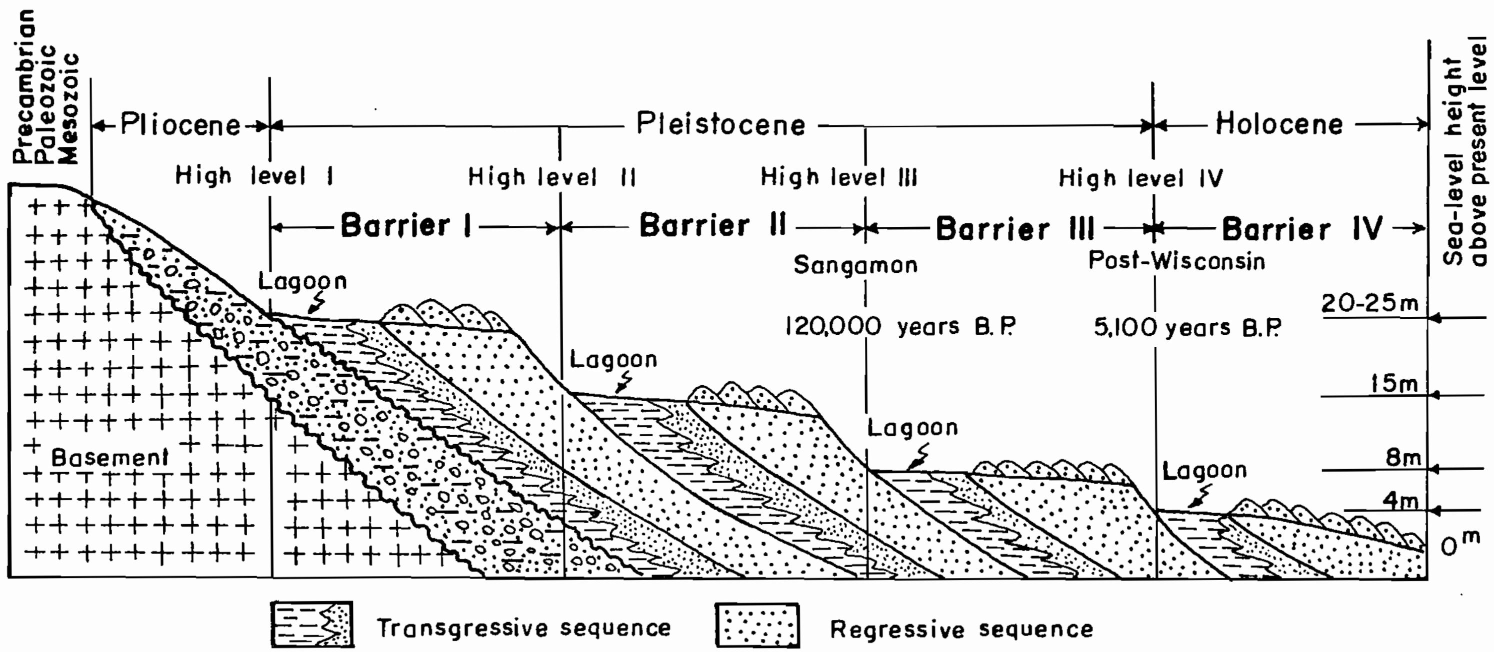

Fig. 3- Barrier-island lagoonal systems I to IV formed during four stages of Quaternary high sea-levels along the State of Rio Grande do Sul coast.
Modified from Villwock et al. (1986)

in certain areas, such as in the Cananéia and Paranaguá coastal plains the outcrops of this formation in the southern and southeastern coasts of Brazil did not yield any material which could be dated to obtain absolute ages. However, carbonized tree trunks collected from basal clay beds of these outcrops indicate that their ages are beyond the limit of the ^{14}C method. According to Massad (1985), clay beds situated in basal portions of the Cananéia (Pleistocene) and Santos (Holocene) formations exhibit quite different geotechnical properties, the first being overconsolidated and the second soft to very soft.

The records of this ancient sea-level are represented by essentially sandy marine-built terraces which occur, at least, from the State of Paraíba to the State of Rio Grande do Sul. From their hydrodynamic sedimentary structures and fossil Callichirus burrows it is possible to reconstruct the positions of ancient relative sea-levels during their deposition (Suguio & Tessler, 1987). However, the scarcity of absolute ages does not allow the construction of a relative sea-level fluctuation curve for around 120,000 years B.P., and the comparison of the heights of more-or-less synchronous reconstructions obtained in different places along the Brazilian coast.

1.2.3 - Holocene high sea-leves - The most recent high sea-levels are very well defined as a function of numerous reconstructions of ancient high sea-levels in space and time, which have been carried out using more than 700 radiocarbon ages (Suguio et al., 1985).

Moreover, the positions of some shell-middens, when compared with radiocarbon ages and $\delta^{13}C_{(PDB)}$ values of their mollusc shells, have supplied us with very interesting additional information on relative sea-level fluctuations during the last 6,000 years (Flexor et al., 1979).

Using all of this data, it has been possible to delineate complete or partial relative sea-level fluctuation curves for several sectors of the Brazilian coast. In order to have relatively homogeneous curves, only very short segments of coastline (60 to 80 km), with the same geologic framework and sufficiently numerous data, were considered.

1.3 - RELATIVE SEA-LEVEL FLUCTUATION CURVES DURING THE LAST 7,000 YEARS FOR SEVERAL SECTORS OF THE BRAZILIAN COAST

The last transgressive-regressive phase, known as the Santos Transgression in São Paulo, is represented in Rio Grande do Sul by Barrier IV deposits about 3 to 4 m high. The last 7,000 years of this transgression are very well known, due to numerous sedimentary, biological and prehistorical data gathered along the Brazilian coast (Fig. 4).

Fig. 4 – Location map of the studied sectors along the Brazilian coast.

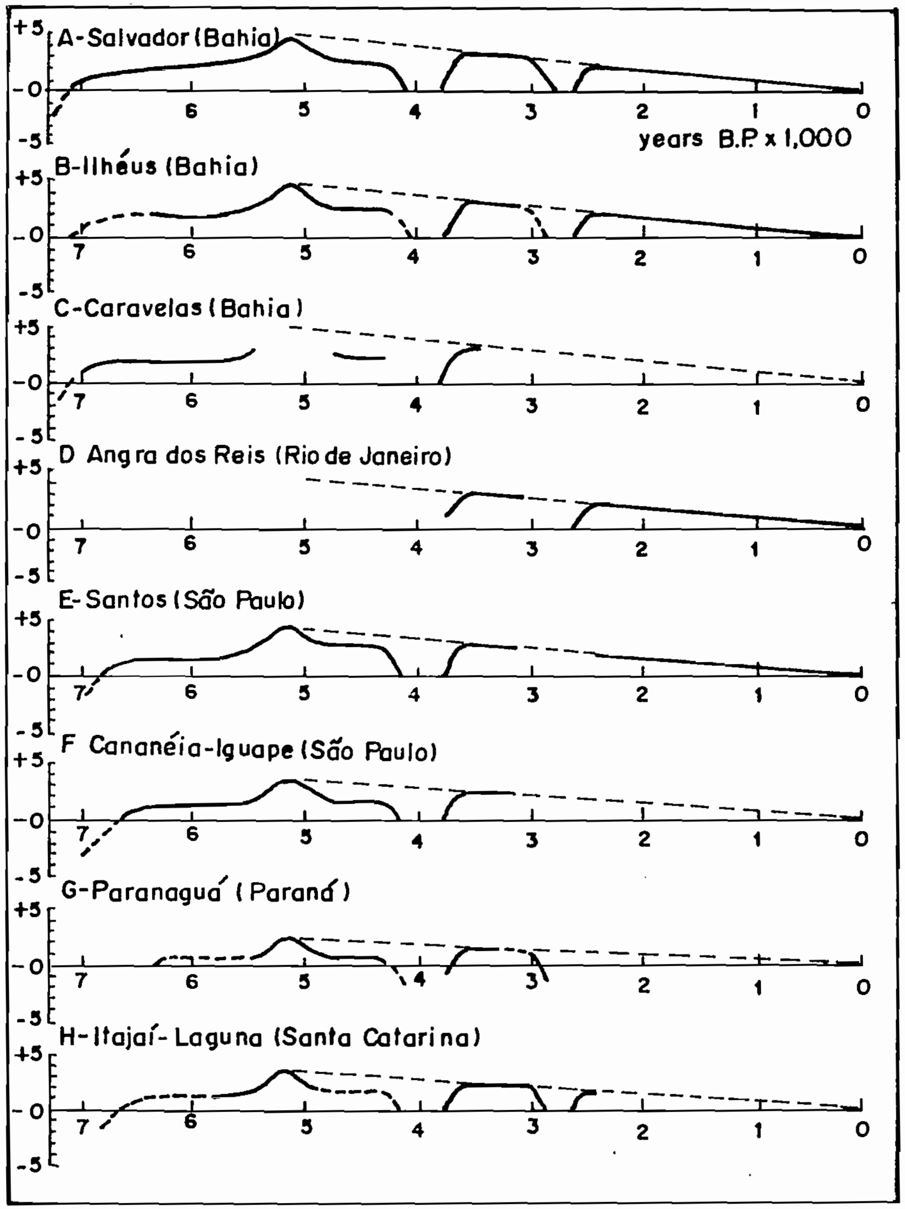

Fig. 5 – Relative sea-level variation curves for the last 7,000 years along several sectors.

The position of a number of shell-middens, together with dating of the shells they contain and the $\delta^{13}C_{(PDB)}$ values of carbonate of these same shells, has yielded interesting information about relative sea-level oscillations during the last 5,500 years.

1.3.1 - Commentary on Holocene variation curves - It is clear from Fig. 5 that in all sectors the relative sea-level has been higher than at present, with a maximum always occurring at about 5,100 years B.P. All the curves have the same general shape, although some are shifted vertically. All sectors seem to have experienced, after 5,100 years B.P., two rapid oscillations of relative sea-level of 2 to 3 m, these being too large to be glacio-eustatic in origin.

On the other hand, in some well-delineated coastal sectors it has been possible to demonstrate Holocene beach-line shifts as a consequence of vertical neotectonic movements. For instance, in the Todos os Santos bay (State of Bahia), located on the Recôncavo graben, vertical movements have resulted in pronounced shifts of Holocene shorelines (Fig. 6). The same is true for parts of the coast in the State of Rio de Janeiro affected by the Guanabara graben, as well as south of the Cape of São Tomé, north of Macaé (Fig. 12). Some parts of the coast, for example in the State of São Paulo, may have been affected by regional flexures, although this phenomenon apparently did not have a very great influence during Holocene time.

In all of the sectors illustrated in Fig. 5, with the exception of Angra dos Reis, there is a record of marine terraces which are about 123,000 years old (Barrier III of Fig. 3). Nowhere do the innermost parts of this terrace, of roughly the same age, exhibit significant differences in elevation. If the shift of almost 1.5 m in maximum height at 5,100 years B.P., between the sectors of Salvador and Paranaguá, were tectonic in origin, the records of the high marine level of 123,000 years B.P. would be shifted very greatly (almost 60m), which is not at all the case. Thus, it is likely that the shifts observed between certain sectors curves are the result of deformation of the geoid surface.

An examination of the geoid map of Brazil (Fig. 7) shows that the part of the north-south coast of the State of Bahia containing the Salvador, Ilhéus and Caravelas sector is more or less parallel to the geoid contours. On the other hand, the part of the coast containing the Angra dos Reis, Santos, Cananéia and Paranaguá sectors runs approximately northeast-southwest, cutting obliquely across the lines of equal geoid height. A horizontal east-west or north-south displacemente of the geoid relief would have no effect on the first three curves, but would trigger a shift in the others. For example, the

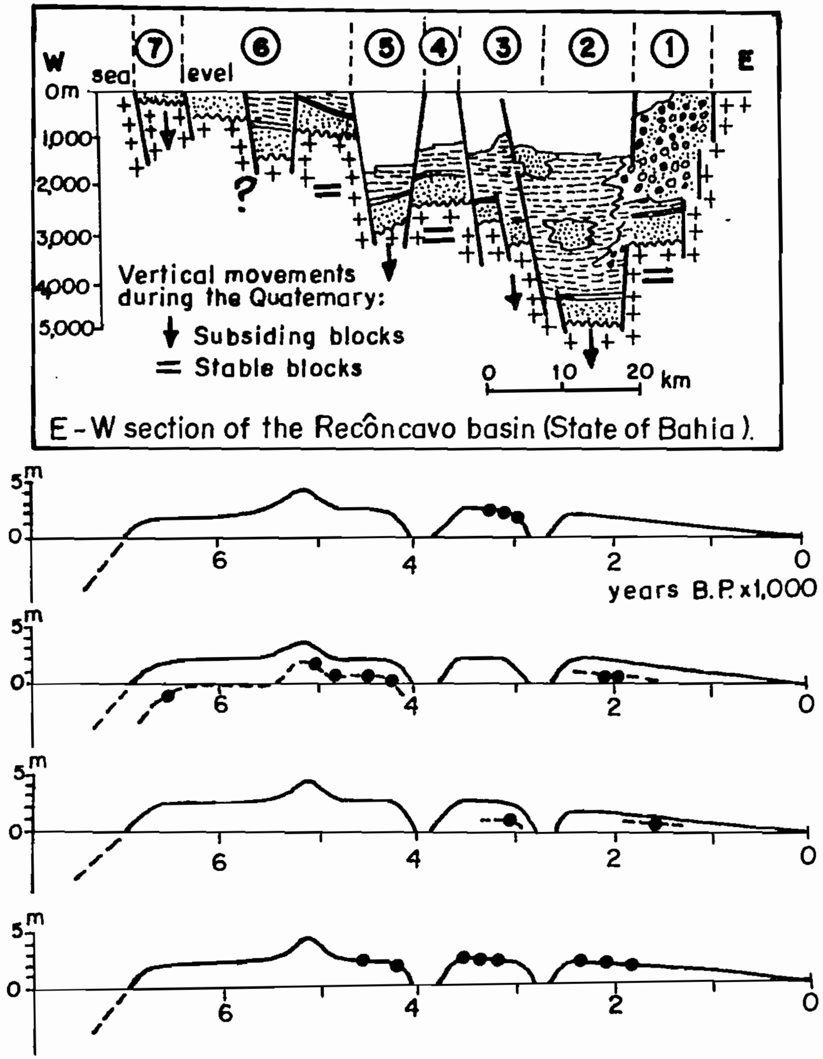

Fig. 6 - Positions of reconstructions of old sea-levels in various sectors (faulted blocks) of the Recôncavo basin plotted against the Salvador curve used as a reference curve.

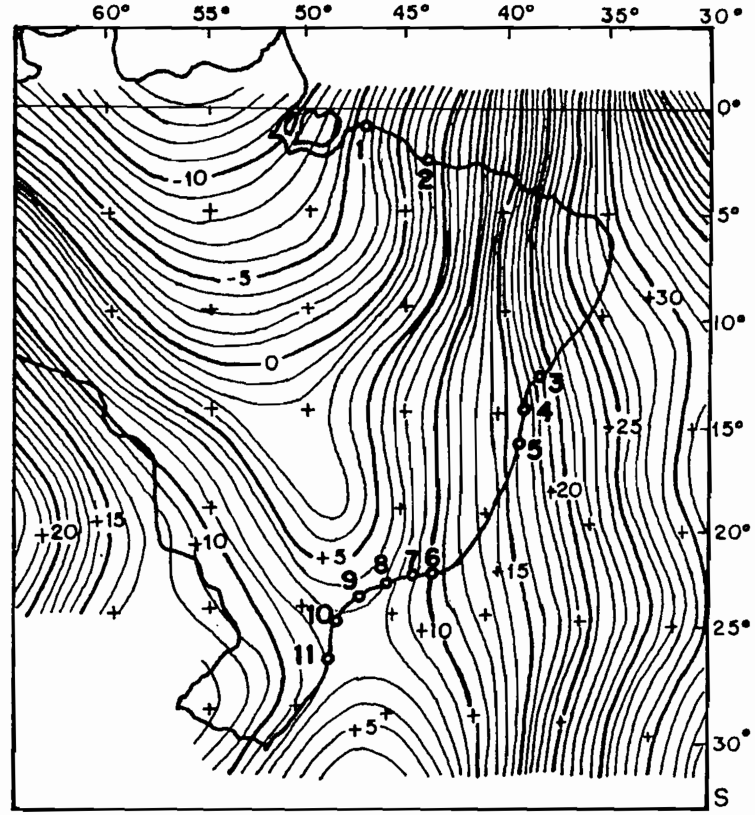

Fig. 7 - Geoidal map of Brazil showing the present configuration of iso-elevation curves with approximate locations of Belém (1), São Luís (2), Salvador (3), Ilhéus (4), Caravelas (5), Rio de Janeiro (6), Angra dos Reis (7), Santos (8), Cananéia (9), Paranaguá (10) & Florianópolis (11).

submersion phase that affected a major part of the Brazilian coast before 5,100 years B.P. could have been associated with a temporary elevation of the geoid with the subsequent emersion related to a lowering of the same surface. In fact, a slight displacement of the geoid relief could explain the shifts observed between the curves of Angra dos Reis, Santos, Cananéia and Paranaguá, as shown schematically in Fig. 8. If this hypothesis is correct, then the Holocene sea-levels in northern Brazil would be shifted equally in relation to the correspondig levels in the Salvador region. Unfortunately, there are no reconstructions available at present for ancient sea-levels in this part of the Brazilian coast. However, it is interesting to observe that, for instance, the coast between São Luís and Belém exhibits suggestive submergence features, constituted by indented shorelines, with active cliffs carved in the Barreiras Formation, and downstream portions of the rivers transformed into "rias".

Thus, the high Holocene marine levels of Brazil, which can be neither glacio-eustatic nor tectonic in origin may be explained, at least in part, by regional uplift of the overall geoid surface prior to 5,100 years B.P., followed by its sinking and minor eastwards displacement. Similarly, regional depression of the geoid, followed by uplift on a scale of centuries, can explain the rapid oscillations since 5,100 years ago.

1.4 - CONSEQUENCE OF RELATIVE SEA-LEVEL FLUCTUATIONS AND LONGSHORE DRIFT OF SEDIMENT UPON COASTAL SANDY SEDIMENTATION

In summary, regardless of origin, the northeastern, eastern and southeastern coasts of Brazil were submerged until about 5,100 years B.P., followed by emergence until today, including two quick oscillations. This is not a common global situation during this time interval. For example, along the Atlantic coast and the Gulf of Mexico of the United States, relative sea-level never intercepted the present level during the Holocene (Fig. 9). Evidently, coastal evolution during this time interval cannot have been the same in these areas. Submerged coasts such as those of the United States, are characterized by barrier-island/lagoonal systems, while emergent coasts such as those of Brazil are characterized by extensive beach-ridge plains. A situation equivalent to that presently occurring in the United States could have existed in Brazil about 5,100 years B.P.

1.4.1 - Role played by relative sea-level fluctuations - According to Brunn (1962), once the equilibrium profile in a coastal zone is established, a later sea-level rise will disturb this equilibrium, which will be re-established by its landward migration. In consequence, the beach prism will be eroded and

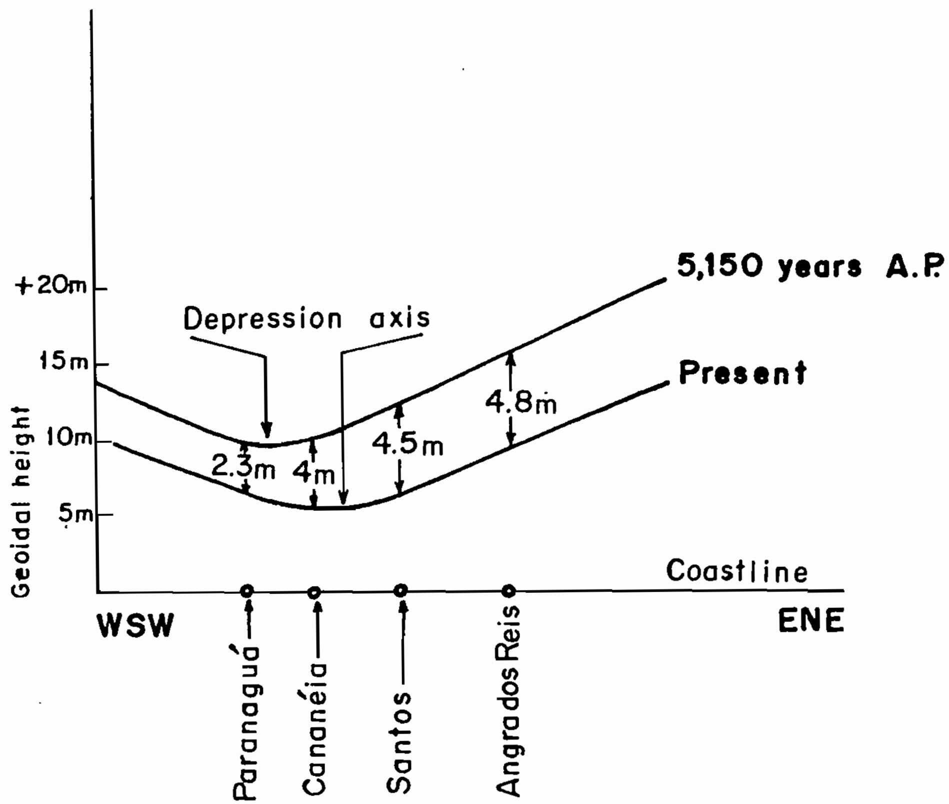

Fig. 8 - Present geoid profile between Paranaguá and Angra dos Reis compared to that about 5,150 years B.P. The vertical shift can be obtained by a simple lowering of the geoid relief in conjunction with a slight horizontal displacement toward the east.

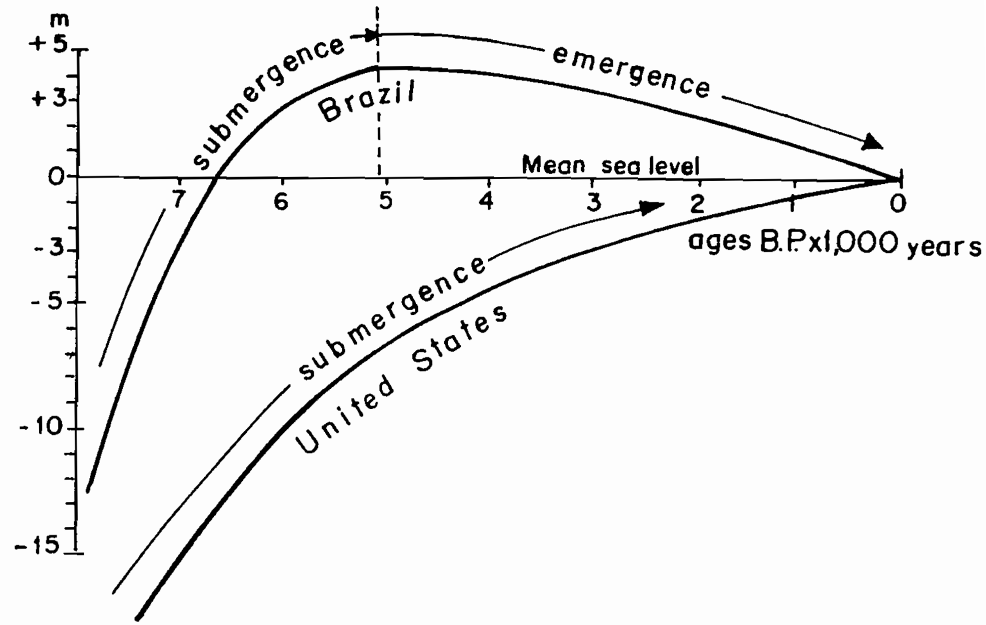

Fig. 9 – Schematic average curves of relative sea-level changes along the central Brazilian and southeastern United States coasts during the past 7,000 years.

the resulting material will be transported and deposited in foreshores areas. This process will induce an elevation of foreshore bottom in equal magnitude to sea-level rise, thus keeping water depth constant.

Field and laboratory experiments performed by several authors (Schwartz, 1965, 1967 and Dubois, 1976, 1977) have ratified the Bruun (op.cit.) hypothesis. Although this rule has been developed only for the inverse situation, that is relative sea-level rise, the equilibrium destroyed in coastal sedimentation dynamics during sea-level fall must also be restored (Fig. 10). In fact, relative sea-level fall with decreasing water depth will produce disequilibrium in the profile, which will become more aggraded. In consequence, waves will move the unconsolidated foreshore sediments landwards, depositing them in the beach prism and then propitiating coastal progradation. This transference will stop only when previously existing water depth is attained. Comparatively, this process is analogous to that in which the storm beach profile is restored by sediment transfer from foreshore to beach prism in a swell profile, as is widely recorded in the literature (Davies, 1972; King, 1972; Komar, 1973, 1976; Swift, 1976). Analogously, this mechanism can be observed perfectly during a monthly tide cycle. During syzigyal tides corresponding to a "mini-transgression", backshore erosion and foreshore deposition will occur and, on the contrary, during quadrature tides, corresponding to a "mini-regression", backshore deposition and foreshore erosion will occur.

Thus, it is obvious that, in gentle slope sandy coasts, a relative sea-level fall will induce intensive transportation of sand from the inner continental shelf onto the beach. If longshore drift is minimal or absent, shoreline progradation will occur through accretion of successive beach-ridges.

1.4.2 - Role played by longshore drift of sands - The transportation of sands along a sandy beach is mostly caused by longshore currents generated by waves. In fact, near to the beaches, the waves do not find sufficient depth for their advancement, and are broken. This phenomenon is accompanied by liberation of large amounts of energy which will be partially used to put sands in suspension and, in part, to generate longshore currents. Obviously, this mechanism is active only when the fronts approach shorelines obliquely.

The velocity of this current is very slow but its influence is very effective where sand was put into suspension by wave-break and, therefore, a very significant volume of sand will be transported in this way. Several calculations have shown that the maximum velocity of longshore currents is attained when waves reach the shoreline with inclinations between 46°

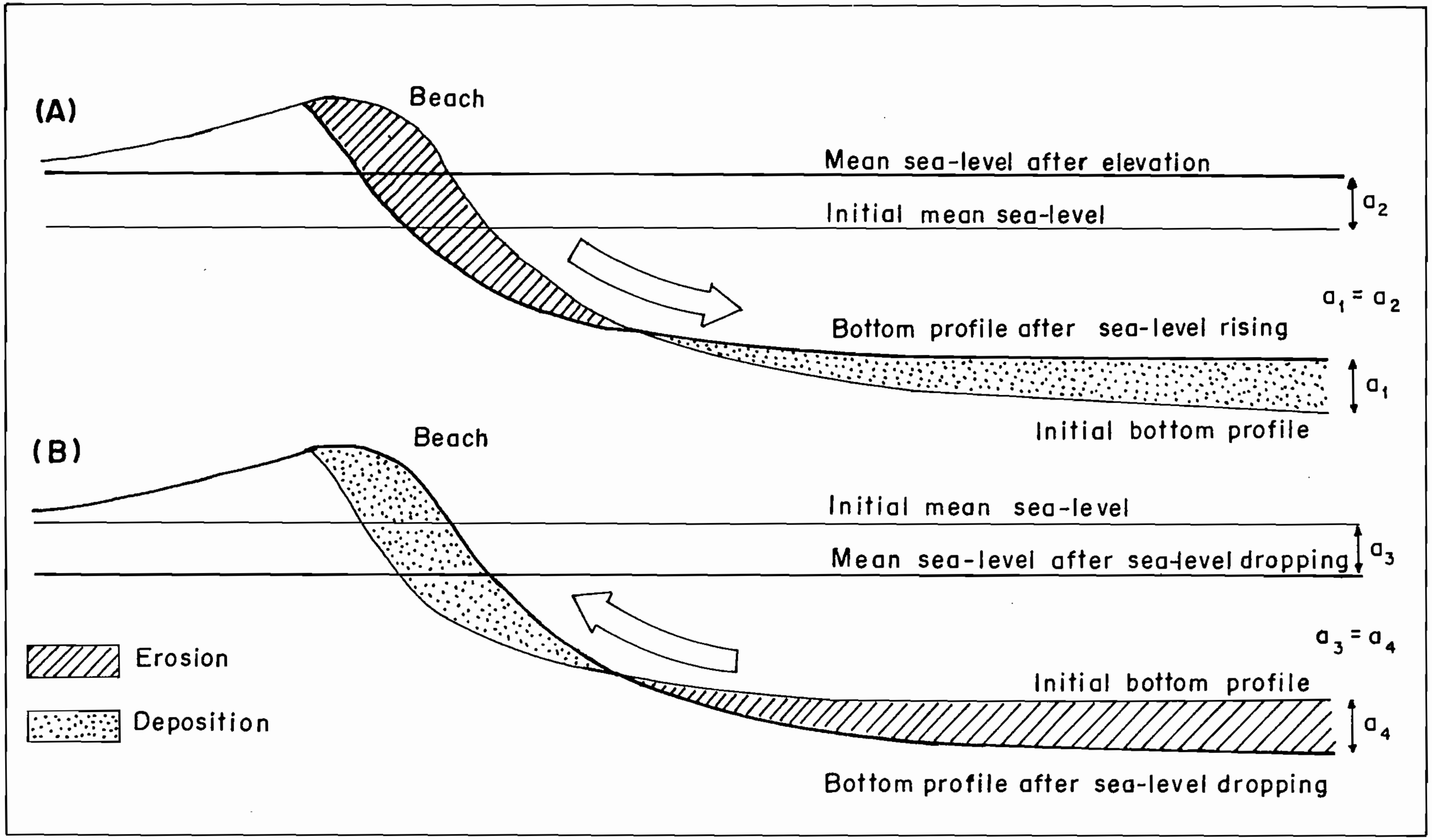

Fig. 10 - Behaviour of littoral zone equilibrium bottom profile as a function of sea-level rise (mod. from Bruun, 1962), and as a function sea-level drop (Dominguez, 1982).

and 58° (Larras, 1981). A combination of the spreading effect of broken waves and longshore currents will provoke pulsative transportation of sand. Obviously, the direction of transportation will depend upon the angle of incidence of wave fronts which reach the shoreline.

Certainly, during relative sea-level fall, sand supplied for re-establishment of the equilibrium profile will be partially transported along the beach as a consequence of this mechanism. This transportation will continue until sand is retained by an obstacle. This explains the great differences which can exist within an area which is subjected to a uniform sea-level fall. Sandy deposits will be much less developed or even absent where coastal transit is dominant and they become important where a trap or obstacle has facilitated their retention. There are many kinds of obstacles, such as shoreline embayments, islands, shoals (forming areas with low energy), headlands of crystalline rocks, important river mouths, etc.

1.5 - EVOLUTIONARY MODEL VALID FOR THE SECTOR OF THE COASTAL PLAIN BETWEEN MACAÉ (STATE OF RIO DE JANEIRO) AND MACEIÓ (STATE OF ALAGOAS)

This model is, strictly, only valid for the mentioned sector and, in other places, records corresponding to one or more stages may be absent (Fig. 11).

1.5.1 - Stage a: Sedimentation of the Barreiras Formation - Continental deposits of the Barreiras Formation have been deposited during the Pliocene, under semi-arid paleoclimate and subjected to concentrated and torrential rainfall, giving rise to coalescing alluvial fans which, according to Ghignone (1979) filled extensive segments of the Brazilian coast. Relative sea-level was much lower during this period than it is today and, then, their sediments covered most of the adjacent continental shelf (Bigarella & Andrade, 1964). Deposits of the Barreiras Formation occur from the State of Rio de Janeiro to the mouth of the Amazon river.

1.5.2 - Stage b: Maximum of the Ancient Transgression - According to Vilas-Boas et al (1981), the paleoclimate became more humid at the end of Barreiras Formation sedimentation, giving rise to the Anciente Transgression, with extensive erosional cliffs carved into this formation. The original cliffs have been preserved only in the coastal plains of the states of Bahia, Sergipe and Alagoas and, probably, they have been destroyed in other areas by the Penultimate Transgression.

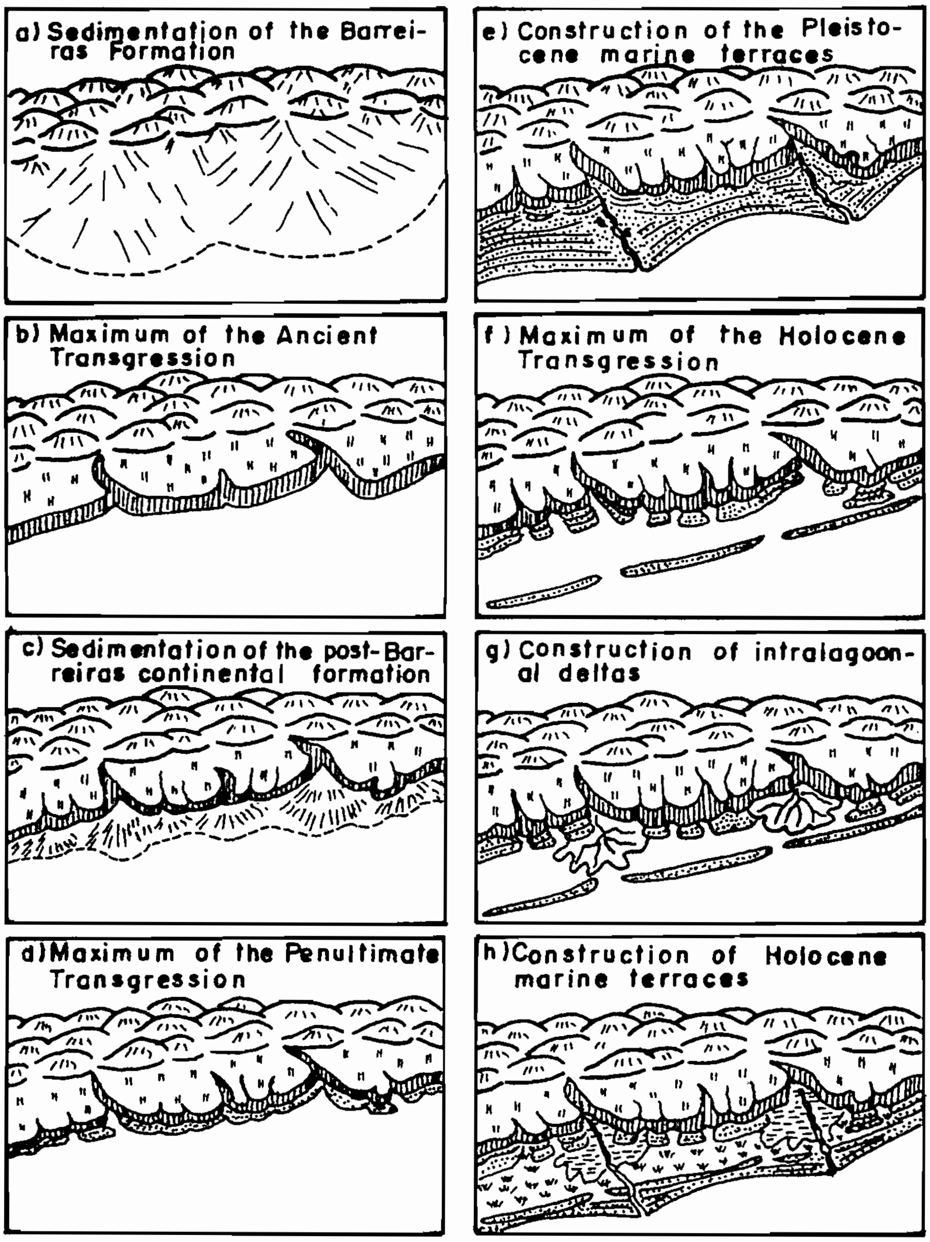

Fig. 11 - Evolutionary model during the Neo-Cenozoic valid for the sector of the coastal plain between Macaé (State of Rio de Janeiro) and Recife (State of Pernambuco).

1.5.3 - Stage c: Sedimentation of the post-Barreiras continental deposits - After the maximum level of the Ancient Trangression and during the following regression, the paleoclimate re-acquired semi-arid characteristics, at least in the areas corresponding to the states of Bahia, Sergipe and Alagoas. This return to semiaridity propitiated sedimentation of new continental deposits as coalescing alluvial fans, which were laid down at the foot of the cliffs carved into the Barreiras Formation during stage b.

1.5.4 - Stage d: Maximum of the Penultimate Transgression (about 120,000 years B.P.) - During this period, corresponding to the maximum of the Penultimate Trangression (Cananéia Transgression), the sea eroded totally or partially the continental deposits formed during stage c. The downstream courses of the rivers were drowned and transformed into estuaries and lagoons and, where continental deposits of the previous stage were completely eroded, the sea reached the cliffs of the Ancient Transgression, which were sometimes entirely eroded.

1.5.5 - Stage e: Construction of the Pleistocene marine terraces - Regression occurred in this phase, which was followed by coastal plain progradation through successive accretion of sandy ridges, giving rise to extensive coastal plains.

1.5.6 - Stage f: Maximum of the Holocene Transgression - The drainage net established on the Pleistocene marine terraces eroded totally or partially these deposits and, sometimes, the valleys reached the Barreiras Formation. The downstream courses of the rivers were once again drowned by relative sea-level rise during the Holocene Transgression (Santos Transgression), which were transformed into estuaries. Barrier islands and lagoonal systems were formed continuously and attained huge dimensions in some places. Mollusc shells and wood fragments contained within lagoonal deposits have yielded radiocarbon ages of less than 7,000 years B.P., indicating that barrier-islands were formed previously to the maximum level of this transgression.

1.5.7 - Stage g: Construction of intralagoonal deltas - In the interior of lagoonal systems, formed around the mouths of the major rivers flowing into the Atlantic Ocean, occurred the deposition of intralagoonal deltas, which were essentially nourished by fluvial sediments.

1.5.8 - Stage h: Construction of Holocene marine terraces - The relative sea-level fall subsequent to the maximum level of 5,100 years B.P. promoted the construction of successive sandy ridges, departing from the original barrier-island and forming marine terraces. The sea-level fall caused, besides the construction of marine terraces, the gradual transformation of lagoons into lakes, followed by salt marshes and swamps. Several lakes, as for example the Lagoa Bonita in the Doce river mouth or Lagoa Feia in the Paraíba do Sul river mouth, which still occur in these coastal plains, represent vestiges of ancient much more extensive lagoons. Small and relatively rapid transgressive episodes of the Holocene, clearly shown on sea-level fluctuation curves, played a very important role on the construction of coastal plains. A second lagoonal episode has been recorded in the Doce river coastal plain, associated with a transgressive event of 3,800 - 3,600 years B. P. (Suguio et al., 1982), with the construction of new barrier-islands and the drowning of lowlands situated between the sand ridges of first generation Holocene terraces. In the Jequitinhonha river coastal plain, these transgressive episodes are represented by drowned river mouths associated with the shifting of river courses by the processes of avulsion (Dominguez, 1983).

THEME II

EVOLUTIONARY MODEL OF A QUATERNARY COASTAL PLAIN AT THE MOUTH OF A MAJOR RIVER (PARAÍBA DO SUL RIVER, STATE OF RIO DE JANEIRO)

1. INTRODUCTION

At the mouths of the most important rivers which flow into the Atlantic Ocean, along the Brazilian coast, there are important prograding zones which Bacoccoli (1971), based on Scott & Fisher's (1969) definition, has interpreted as deltas. According to this author, some of them (like the Amazon river) would be of the tide-dominated highly destructive type, while others, like the Parnaíba, Jaguaribe, São Francisco, Jequitinhonha, Doce and Paraíba do sul rivers would be of the wave-dominated highly destructive type. Moreover, Bacoccoli (op.cit.) considered all of these deltas to be Holocene in age. Furthermore, he proposed an evolutionary scheme in which they were formed after the maximum of the Flandrian Transgression and, in some cases, with an intermediate estuarine episode, before giving rise to typical deltas whose implied construction is a generalized shoreline progradation.

However, along the Brazilian coast, there are also extensive progradation zones which bear no relation to ancient or present fluvial mouths. One of these areas is situated in Caravelas (State of Bahia), where, with the exception of fluvial facies, there are all of the types of sedimentary deposits which are present in other "Quaternary brazilian deltas". Bacoccoli (op.cit.) suggested that its deltation was related to the Mucuri river, an insignificant fluvial course located in the south of the area. Thus, the Caravelas region would represent a typical "wave-dominated destructive delta" which originated in the absence of a river! This progradation area without fluvial contribution immediately attracted our attention. Apparently, in this case, the source of sandy material must be searched for outside of the area.

A glance at the parameters considered by several authors who have studied the deltas shows that they never considered the role played by oscillations of relative sea-level. The relative sea-level fluctuations are an effect of true sea-level changes (eustasy) and modifications of land levels (tectonism and eustasy). Therefore, it is evident that the reconstructions of ancient sea-levels represent relative and not absolute positions. Consequently, it is normal to find discrepancies between reconstructions of ancient sea-level positions in a certain moment in different places of the world, which is particularly conspicuous during the last 7,000 years. In "Theme

I" it has been shown that the central portion (northeastern, eastern and southeastern parts) of the Brazilian coast was in submergence until 5,100 years B.P., followed by emergence of about 4 to 5 m until the present. In the eastern Atlantic coast and Gulf of Mexico in the United States, the relative sea-level was about 5 m below present level until about 5,000 years B.P., rising progressively toward its present level. Therefore, the evolutionary model of the Mississippi delta, for example, situated in the Gulf of Mexico, could not be applied directly in Brazil. Previous authors who have studied the Doce river (State of Espírito Santo) such as Bandeira Jr. et al.(1975),and the Paraíba do Sul river (State of Rio de Janeiro) coastal plains, such as Lamego (1955) and Araújo et al. (1975), due to lack of absolute ages did not consider the role played by relative sea-level fall.

Considering Bacoccoli's (op.cit.) limited field evidence, which was accumulated during very rapid excursions to the Paraíba do Sul, Doce, Jequitinhonha and São Francisco river deltas, his maps were excessively schematic. According to this author, the São Francisco river coastal plain has an area of 2,000 km^2, but its real surface area is only 750 km^2. On the other hand, this author attributed an area of 300 km^2 for the Jaguaribe river delta, but this area is entirely occupied by active dune fields which cover the Barreiras Formation deposits. Identically, the Coleman & Wright (1975) map of the São Francisco river delta, in which they assumed it to be a wave-dominated highly destructive delta, was shown to be untrue.

Therefore, we decided to ignore the preliminary studies and, based on our previous experience in other sectors of the Brazilian coast, we accomplished detailed surveys in the coastal plains of the São Francisco, Jequitinhonha, Doce and Paraíba do Sul river mouths, which allowed us to reconstruct their evolutionary history during the Quaternary. On the other hand, since the most important portion of these coastal plains was not constructed directly by fluvial sediments, it is possible to call into question the use of the word "delta" as the most suitable designation for these progradational features (Dominguez et al., 1982).

2. PARAÍBA DO SUL RIVER COASTAL PLAIN

2.1 - GENERALITIES

The Paraíba do Sul river coastal plain is situated in the Northern State of Rio de Janeiro, with an area of about 3,000 km^2, being 120 km long in a north-south direction and with a maximum width of 60 km (Fig. 12).

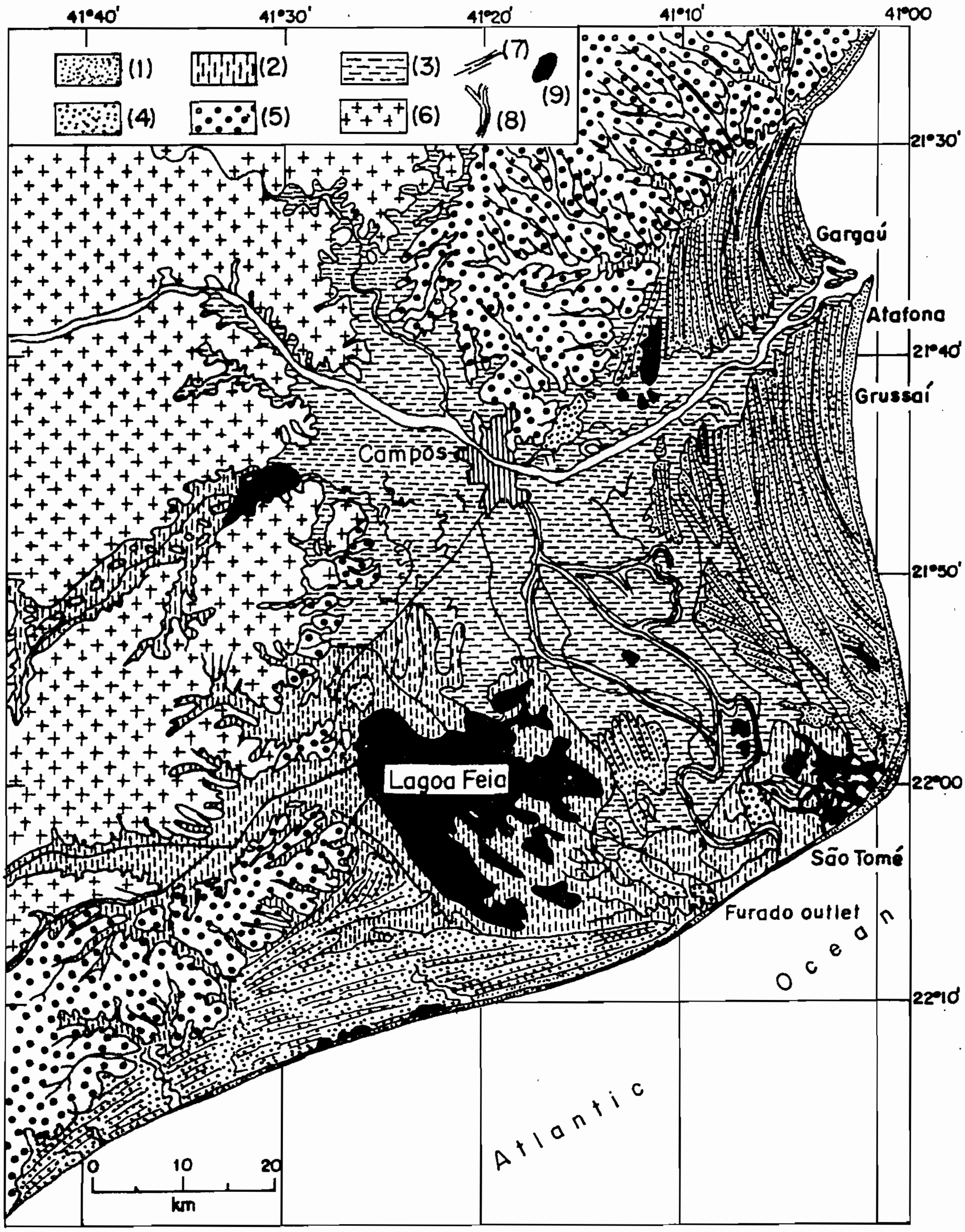

Fig. 12 — Geologic map of the Paraíba do Sul river coastal plain in northern half of the State of Rio de Janeiro.

(1) Holocene marine terraces, (2) Lagoonal deposits, (3) Fluvial deposits (Intralagoonal delta), (4) Pleistocene marine terraces, (5) Barreiras Formation (Tertiary), (6) Crystalline basement (Precambrian), (7) Beach-ridges alignments, (8) Fluvial paleochannels, (9) Lakes.

The climate in the area is subtropical with a rainy season between December and March, a mean annual pluviosity of about 1,100 mm in the city of Campos and a mean annual temperature of 23.9ºC. The dominant winds come from the ENE and SSE, the cold fronts which arrive periodically in the region, mainly during the winter. These is no statistically representative data concerning the waves, but all of the morphological evidence suggests that the dominant littoral transportation is from south to north.

The Paraíba do Sul river arises from the junction of the Paraibuna and Paraitinga rivers, between Serra do Mar and Serra da Bocaina, in the State of São Paulo. This river extends approximately 950 km and its hydrographic basin has an areas of about 45,000 km^2. Its mean discharge is about 800 m^3/s in the city of Campos but this value is very changeable during the year; according to Araújo et al. (1975), its annual mean discharge in 1937 was 1785 m^3/s, while in 1954 it was 341 m^3/s.

2.2 - GEOMORPHOLOGY

This region comprises three geomorphological provinces, each one characterized by its relief as well as by its drainage network, consisting of the (a) Mountainous area, (b) Tertiary plateau and (c) Quaternary plain (Fig. 20).

a) Mountainous area - This area is composed of Pre-cambrian crystalline rocks. Two sub-areas can be recognized, the first one composed of sharp-peaked steep slope mountains and the second one characterized by a smooth relief with "half-orange" hills. The drainage networks are rectangular in the first sub-area, with main rivers following the schistosity and secondary rivers accompanying fracture systems, whereas in the second sub-area the drainage network is mostly dendritic.

b) Tertiary plateau - This is a homoclinal surface, with slight seaward inclinations furrowed by a subparallel drainage network. This plateau is well developed in the northern part, where it is 50 m high, although in the city of Campos it is lower than 14 m. It constitutes a narrow band in the southern portion, being absent in the central part. There is a scarp-line along the contact between the Tertiary plateau and the Quaternary plain. This region is also characterized by the presence of lakes enclosed within paleovalleys excavated in the Barreiras Formation, which were developed through blockage by alluvial deposits.

c) Quaternary plain - This extends from the city of Macaé in the south as far as the locality of Manguinhos to the north. Its flat surface has a slight seaward inclination and a maximum height of 12m. This area is intensively occupied by man, with very little preservation of its original characteristics. An extensive system of artificial drainage channels has lowered the water table, desiccating many lakes and swamps. Artificial marginal dikes have been constructed along the Paraíba do Sul river to prevent flooding of great parts of the Quaternary plain.

Many different types of lakes and lagoons are situated on the Quaternary plain. Some lakes, such as Carapebus, Cabiúnas and Paulista, have been formed by the blocking of Pleistocene lowlands by Holocene marine sediments, whereas others are situated between Holocene beach ridges (for example, the Mololô, da Flecha, das Ostras and Salgada lakes). The Lagoa Feia, which occupies a considerable area in the central portion of the Quaternary plain, is testimony to the presence of large paleolagoon which existed between 6,000 and 4,000 years B.P., where the Paraíba do Sul river built upon an intralagoonal delta.

2.3 - QUATERNARY DEPOSITS OF THE PARAÍBA DO SUL RIVER COASTAL PLAIN (FIG. 12)

2.3.1 - Pleistocene marine sands - These sands constitute continuous terraces about 60 km long and 10 km wide (maximum) distributed almost entirely within the southern portion of the Quaternary plain. Ancient beach ridge alignments are perfectly visible on aerial photos, with the space between ridges occupied by swampy lowlands.

The heights of these Pleistocene terraces are abnormally low in comparison with other areas along the Brazilian coastline. On the Carapebus lake margin, for instance, these terraces in contact with the Barreiras Formation are situated only about 3 m above the present lake level. Near to the present lake beach, the uppermost portion of this terrace is only 1m above the present lake level, and here the top to the Holocene barrier enclosing the Carapebus lake is clearly above the Pleistocene terrace. In the southernmost extremity of the coastal plain, the present backshore sands are advancing on lower Pleistocene terraces. Here, Pleistocene sands can be distinguished from the present beach sands, because the former exhibit whitish to brownish colors while the latter are yellowish.

In the northern part of the coastal plain, there is also evidence of Pleistocene terraces which form a more-or-less regular 5 km wide band at the foot of the Barreiras Formation scarps.

2.3.2 - Holocene marine sands - These are found dominantly on both sides of the Paraíba do Sul river near the present mouth, forming a triangular area with a base of about

60 km and a height of 20 km. Very clearly visible beach ridge alignements allow us to easily distinguish these from the Pleistocene terraces when observed on aerial photos (Martin *et al.*, 1981b). Downstream of the town of São João da Barra, the right hand margin beach ridges exhibit very accentuated unconformities in their alignments.

Samples of mollusc shells from beach ridges have been dated by the radiocarbon method and the following ages have been obtained:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-42	4,390 ± 200	Bah. 1094
PS-41	4,380 ± 200	Bah. 1093
PS-35	3,850 ± 200	Bah. 1102
PS-33	2,100 ± 200	Bah. 1100
PS-32	1,980 ± 190	Bah. 1099
PS-34	1,070 ± 160	Bah. 1101

In southern portion of the coastal plain, between São Tomé and Macaé, the Holocene marine sandy deposits are very scarce, being limited to a narrow band which follows the present shoreline.

2.3.3 - Lagoonal deposits - In the São Tomé area and around Lagoa Feia, which constitute the central portion of the coastal plain, there is an extensive area of clayey-sandy lagoonal deposits with organic matter and abundant mollusc shells. Some of these shells and wood fragments were sampled and the following ages have been obtained which probably represent the time of maximum submersion:

Sample number	Radiocarbon age (years B.P.)	Sample type	Laboratory number
PS-06	7,060 ± 260	shells	Bah. 1120
SD-10A	7,010 ± 250	shells	Bah. 1005
SD-03	6,860 ± 250	shells	Bah. 1007
PS-07	6,730 ± 260	shells	Bah. 1121
PS-26	6,570 ± 250	wood	Bah. 1133
PS-22	6,560 ± 260	wood	Bah. 1135
PS-09	6,470 ± 240	shells	Bah. 1123
PS-08	6,060 ± 240	shells	Bah. 1122
SD-10B	6,000 ± 200	wood	Bah. 1003

Sample number	Radiocarbon age (years B.P.)	Sample type	Laboratory number
PS-03	5,560 ± 230	shells	Bah. 1117
PS-25	5,460 ± 230	wood	Bah. 1132
PS-19	5,410 ± 230	shells	Bah. 1109
SD-04A	5,140 ± 200	shells	Bah. 996

In the southern portion of the coastal plain, in the limit between the Pleistocene and Holocene terraces, there is a narrow lowland which has been occupied by a lagoon linked to the central lagoon. Samples of mollusc shells from these lagoonal deposits were also dated by the radiocarbon method, indicating the following ages:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-14	6,620 ± 240	Bah. 1107
PS-12	6,590 ± 250	Bah. 1105
PS-14A	6,000 ± 230	Bah. 1108
PS-13	5,930 ± 240	Bah. 1106

Two sub-zones, separated by a lower area parallel to the beach ridges as well as to the present shoreline, can be distinguished in the Holocene terrace situated at the south of the Paraíba do Sul river mouth. Mollusc shells sampled from the southern extremity of this zone have been dated as 3,780 ± 170 years B.P. (Bah. 1280).

Four lagoons, the majority presently desiccated are present between beach-ridges to the NW of the town of São Tomé; these were sampled and the mollusc shells from these localities yielded the following ages:

Salgada lake:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-08	3,065 ± 150	Bah. 1102
PS-16	2,930 ± 180	Bah. 1114

das Ostras lake:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
SD-05	2,925 ± 150	Bah. 999
PS-15A	3,120 ± 180	Bah. 1111
PS-15B	3,180 ± 180	Bah. 1112

da Flecha lake:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-17	4,050 ± 190	Bah. 1113
SD-07	3,000 ± 150	Bah. 1001

Mololô lake:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-18	4,100 ± 190	Bah. 1116
SD-06	3,000 ± 150	Bah. 1000

Samples of mollusc shells from a paleolagoonal lowland between beach ridges at the north of the Paraíba do Sul river mouth have provided the following ages:

Sample number	Radiocarbon age (years B.P.)	Laboratory number
PS-31	2,530 ± 170	Bah. 1098
PS-89	2,490 ± 170	Bah. 1261
PS-30	2,360 ± 200	Bah. 1097

2.3.4 - Fluvial deposits - The fluvial deposits, consisting of yellowish silty clays, occupy an area of about 1,280 km^2 in the Paraíba do Sul river coastal plain, mostly along the Campos - São Tomé axis, where several paleochannels are distinguished on aerial photos. The distribution pattern geometry of these fluvial deposits through the coastal plain suggests that they have been formed mainly as an intralagoonal delta. Shallow drillings (some tens of meters) undertaken by Petrobrás have shown that the fluvial deposits are underlain by paleolagoonal deposits.

2.3.5 - Palustrine deposits - Peats and organic clayey-sandy sediments are typical palustrine deposits, which occur at the margin of lakes, in lowlands between beach ridges and also along drowned fluvial valleys located westward of the coastal plain.

2.3.6 - Mangrove deposits - These sediments are very restricted in area, forming narrow bands around the Guaxindiba and Açu river mouths as well as near to the outlet of the da Flecha channel. They are most developed, perhaps, at Gargaú, northward of the Paraíba do sul river mouth.

2.4 - PALEOGEOGRAPHIC EVOLUTION

2.4.1 - Previous studies - This coastal plain was previously studied by Lamego (1955), Bacoccoli (1971, Fig. 13), Araújo _et al._, (1975), Dias (1981), Dias & Gorini (1979 and 1980) and Dias _et al._ (1981, 1984a, 1984b). However, these authors never considered the role played by relative sea-level fall in its paleogeographic evolution.

According to Araújo _et al._ (op.cit.), "...the construction of the Paraíba do Sul river Holocene deltaic complex began after the maximum level of the Flandrian transgression, which developed in two distinct phases: one abandoned and another active...". The paleogeographic reconstruction of these authors was based upon Lamego's previous (op.cit.) idea, who recognized four phases of "deltation": Mississippi-type delta, Rhone-type delta, Paraíba-type delta and Lagoa Feia tidal type delta.

It is not possible to deny the existence, in the Campos-São Tomé axis, of evidence of a delta dominated by fluvial processes. However, a delta of this type could not be built through progradation towards a high-energy open sea, as proposed by Lamego (op.cit.) and Araújo _et al._ (op.cit.) (Fig. 14). It is necessary, therefore, to assume that the sediments carried by the Paraíba do Sul river were deposited in a low-energy environment. The existence, in front of fluvial sediments, of lagoonal deposits which are very rich in mollusc shells clearly demonstrates that, at least during part of its history, the Paraíba do Sul river flowed into a lagoon, where an intralagoonal delta was constructed.

Obviously, the above mentioned model proposed by Lamego (op.cit.) was based upon models which had been developed in other parts of the world, where the energy conditions involved are quite different.

2.4.2 - New model - Relative sea-level changes, associated with paleoclimatic fluctuations, controlled the origin of the Brazilian coastal plains, including the Paraíba do Sul river coastal plain. It is possible to recognize the following evolutionary stages:

a) Stage I: Deposition of the Barreiras Formation - Continental deposits of the Barreiras Formation were deposited during the Pliocene, under semiarid paleoclimatic conditions and a relative sea-level which was much lower than it is today.

b) Stages II and III - These stages correspond, respectively, to the Ancient Transgression (older than 120,000 years B.P.) and to deposition of coalescing alluvial fans post-Barreiras Formation, which have not yet been recognized in the

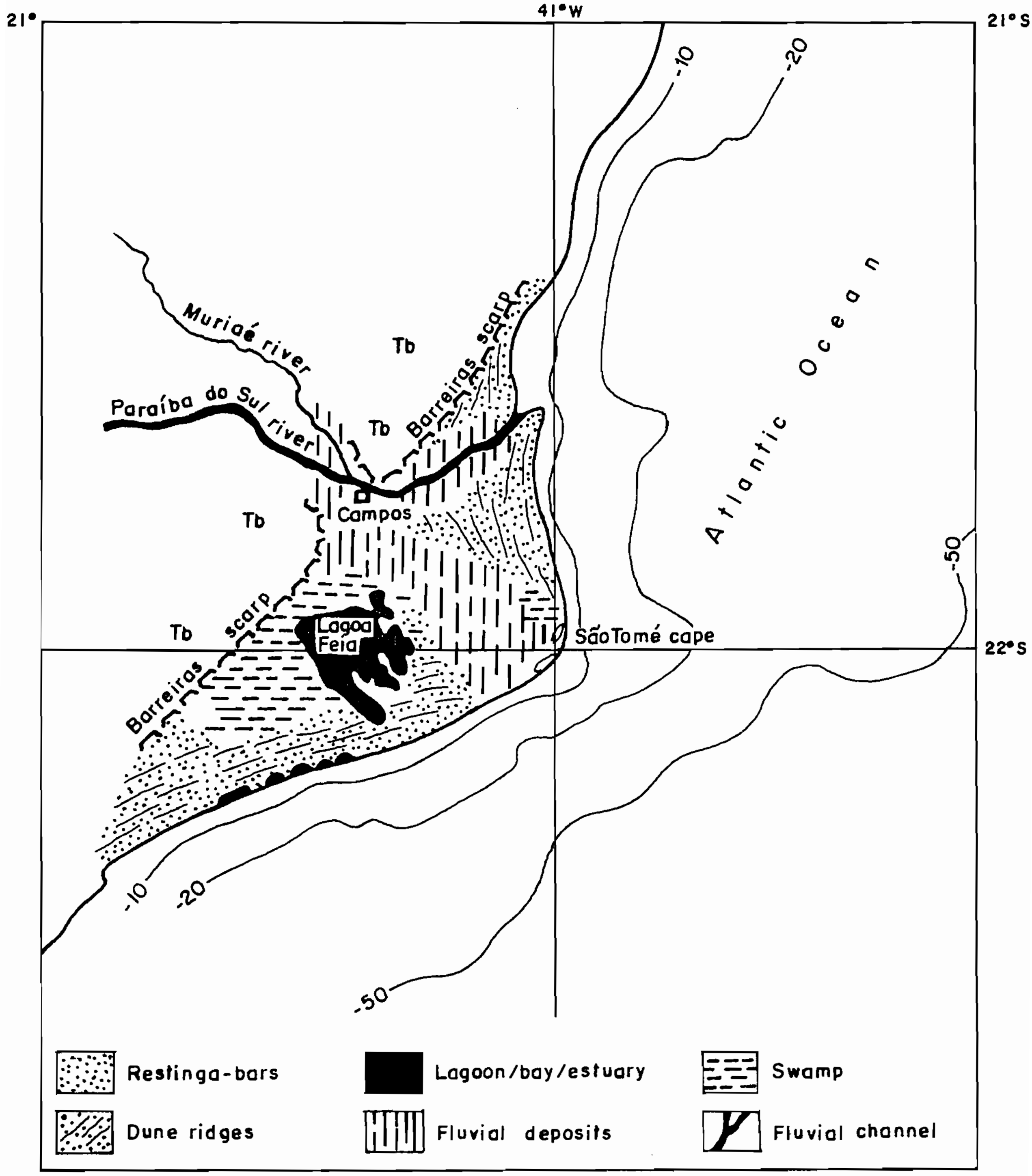

Fig. 13 - Geologic map of the Paraíba do Sul river mouth coastal plain according to Bacoccoli (1971).

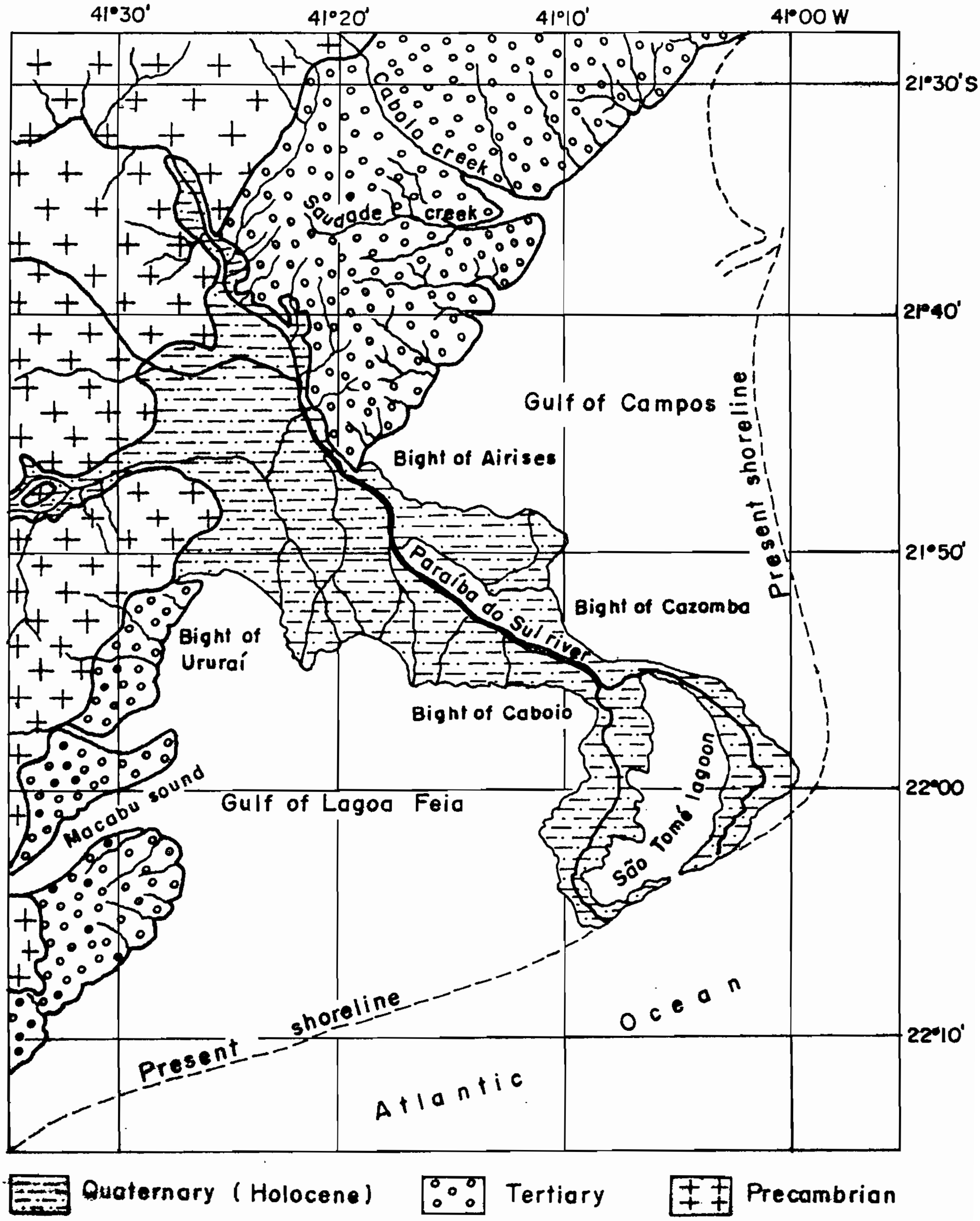

Fig. 14 – First stage in the evolution of the Paraíba do Sul river Holocene delta according to Lamego (1955) and Araújo et al. (1975).

Paraíba do Sul coastal plain.

c) Stage IV: Maximum of the Penultimate Transgression (120,000 years B.P.) - At that time the relative sea-level was about 8 ± 2 m above the present level. The Barreiras Formation deposits were partially eroded, giving rise to sea cliffs. The downstream course of the Paraíba do Sul river was drowned and transformed into an estuary.

d) Stage V: Construction of the Pleistocene marine terrace - Regression occurred during this phase followed by coastal plain progradation, through the successive accretion of sandy ridges, giving rise to extensive coastal plains. Many valley mouths were closed by sand bars, with the formation of lagoons and lakes. The geometry of beach ridges (for example in the area of Quiçamã) suggests that these were constructed during several phases of different sea-levels, like those which occurred during the Holocene in the last 5,000 years.

e) Stage IV: Maximum of the Holocene Transgression - The drainage network established on the Pleistocene marine terraces eroded totally or partially these deposits and sometimes, the valleys reached the Barreiras Formation. The downstream courses of the Paraíba do Sul river was once again drowned due to relative sea-level rise during the Holocene Transgression (Santos Transgression). Barrier islands were formed continuously when the residual Pleistocene beach ridges were isolated from the open sea, with the formation of huge lagoon behind the barrier islands. This phase has been dated by mollusc shells and wood fragments collected from paleolagoonal deposits. At that time, the morphology of the Paraíba do Sul river coastal plain was similar to that observed presently along the southeastern coast of the United States where lagoons and barrier islands exist in front of Pleistocene marine terraces. In the Paraíba do Sul river coastal plain, this phase is shown by a barrier which can be recognized in the region between São Tomé and Carapebus lake. However, as a consequence of local neotectonic movements, this barrier is still presently displaced landwards. Evidently, during the maximum of the Holocene Transgression, this barrier was in a more distal position on the continental shelf.

f) Stage VII: Construction of the intralagoonal delta - During the existence of the lagoon, the Paraíba do Sul river built an extensive delta (Mississippi-type delta of Lamego, op.cit.). At that time, the Paraíba do Sul river probably consisted of many paleochannels, with one of them situated near to the present position. During sea-level fall, after 5,100 years B.P., the lagoon was gradually desiccated and the shortest E-W channel prevailed, assuming the total discharge of the Paraíba do Sul river.

g) Stage VIII: Construction of the Holocene marine terrace - It has not been possible to distinguish the several generations of beach ridges associated with the three episodes of relative sea-level fall which occurred after 5,100 years B. P. However, it has been possible to recognize two lagoonal lowlands situated within the Holocene terrace. The older is situated in the southern portion of the Holocene plain, which probably formed during submergence between 3,800 and 3,600 years B.P. A sample of mollusc shells has yielded an age of 3,780 ± 170 years B.P. (Bah. 1280). In the northern portion of the Holocene plain, there is another lagoonal lowland, from which three samples of mollusc shells were collected which have provided the following ages: 2,530 ± 170 years B.P. (Bah. 1098), 2,490 ± 170 years B.P. (Bah. 1261) and 2,360 ± 200 years B.P. (Bah. 1097), in accordance with a period of submergence which occurred between 2,700 and 2,500 years B.P.

2.5 - PRESENT AND PAST DYNAMICS NEAR THE PARAÍBA DO SUL RIVER MOUTH

Waves from two different directions are observed at the mouth of the Paraíba do Sul river. The waves from the S-SE quadrant are related to polar air masses penetrating the South American continent and are frequently observed during autumn and winter. The waves from the NE are associated with trade winds. The waves from the S-SE are much stronger than those from the NE and dominate in the longshore transportation of sediments. When NE waves are superimposed upon S-SE waves, only the latter are active in the longshore drift of sediments. The northwards longshore transportation of sediments is demonstrated by the geometry of Holocene beach ridges (Dominguez et al., 1983) and by the fact that accumulation is occurring to the S (updrift) of the Barra do Furado breakwater, whereas erosion is accelerated to the N (downdrift). This breakwater was constructed in 1982.

Aspects of present and past dynamics in the area have been better seen in the Paraíba do Sul river mouth area, which is characterized by the following features (Fig. 15):

a) Strong asymmetry between the northern and southern parts of the river mouth; the southern part is formed by a series of beach ridges, while the northern part is characterized by an alternation of sandy ridges and swampy lowlands.

b) The presence of a well-developed sand spit. The construction of this sand spit was followed by intensive coastal erosion, resulting in the destruction of many houses in Atafona. The Atafona coastline was displaced in a landwards direction

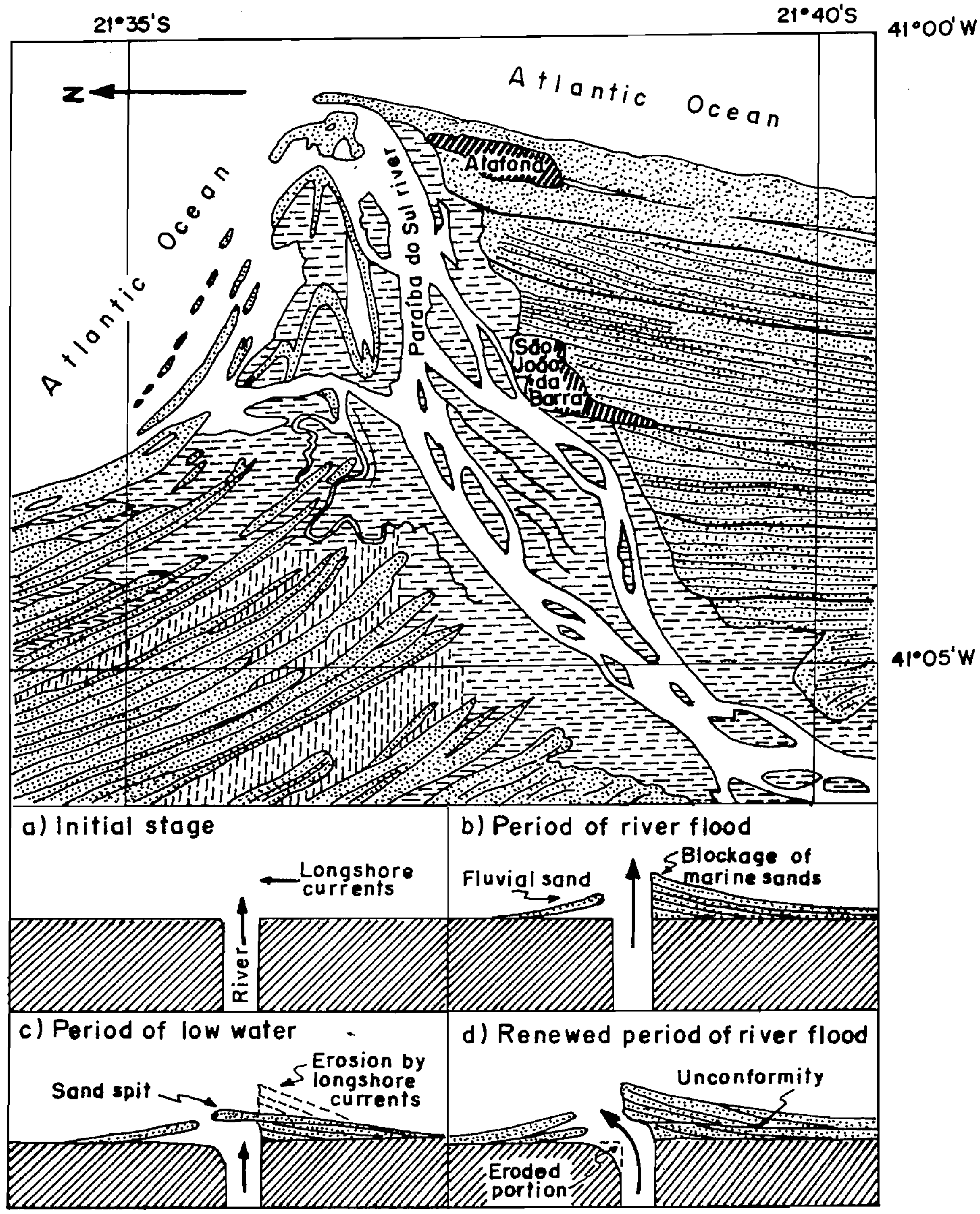

Fig. 15 – Situation of the Paraíba do Sul river mouth area in 1976, and the mechanism of blockage of sands supplied by longshore currents generated by waves coming from SSE.

by about 100m between 1956 and 1976 (Fig. 16a and 16b). In February 1976, during flooding of the Paraíba do Sul river, the sand spit was almost completely destroyed. By February 1981, a new 300 m - long sand spit had formed.

c) Stepwise unconformities of beach ridge alignments which can be related to periods following sand spit formation. In favourable conditions, river flow near its mouth will form an obstacle which can block transportation of sands, in the same way as an artificial jetty on the coast. In general, these structures are founded on land, extending seawards after wave breakage, completely interrupting the coastal transportation of sediments. Consequently, sediments will be retained by the obstacle, in such a way that the updrift shoreline will be subjected to rapid progradation. At the same time the downdrift shoreline will be eroded, causing rapid retrogradation (Fig. 15).

If the proposed model is correct, then the degree of roundness of sands on both side of the Paraíba do sul river mouth must be different (Suguio et al., 1984). This hypothesis has been tested, using 21 sand samples collected between the city of Macaé (the southern limit of the coastal plain) and the village of Guaxindiba (its northern limit) as well as 3 samples from the Paraíba do Sul river bed and 24 samples from Holocene terraces on both sides of the river mouth. The degree of roundness of quartz particles was studied in the sand fraction between 0.5 mm and 1 mm because, according to Cailleux & Tricart (1959), grains with a diameter about 0,7 mm are most representative for detecting any differences which may exist. Initially, five classes of roundness were considered: 1 = angular, 2 = sub-angular, 3 = sub-rounded, 4 = rounded and 5 = very rounded; conclusions were ratified using only three classes of roundness: 1 = angular, 2 = sub-angular + sub-rounded and 3 = rounded + very rounded.

Very significant differences have been found between the degree of roundness of present beach sands from one side and the other of the river mouth (Fig. 17). The sands from the northern part lack very rounded grains and their histograms are very similar to those for sands from the Paraíba do Sul river bed. The sand from the southern part have 20 to 60% of very rounded grains, the rest consisting of rounded to sub-angular grains, these being supplied mostly by the adjacent continental shelf. A similar pattern has emerged from a study of the degree of roundness of sands from Holocene terraces of the Paraíba do Sul river coastal plain (Fig. 18). These differences in degree of roundness suggest that the river sands are being deposited almost entirely to the north of the river mouth.

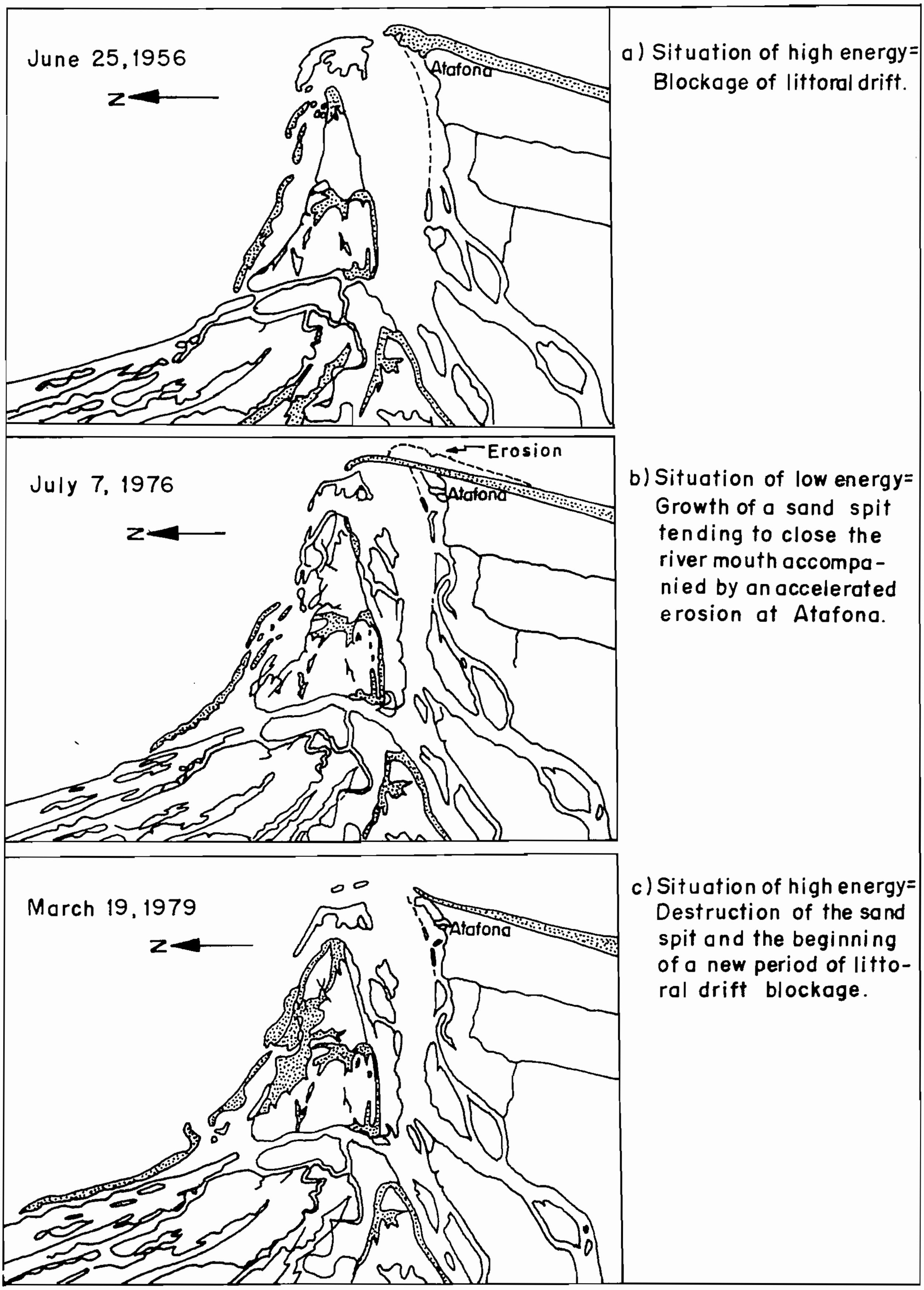

Fig. 16 – Evolution of the Paraíba do Sul river mouth area from 1956 to 1979 (modified from Dias, 1981).

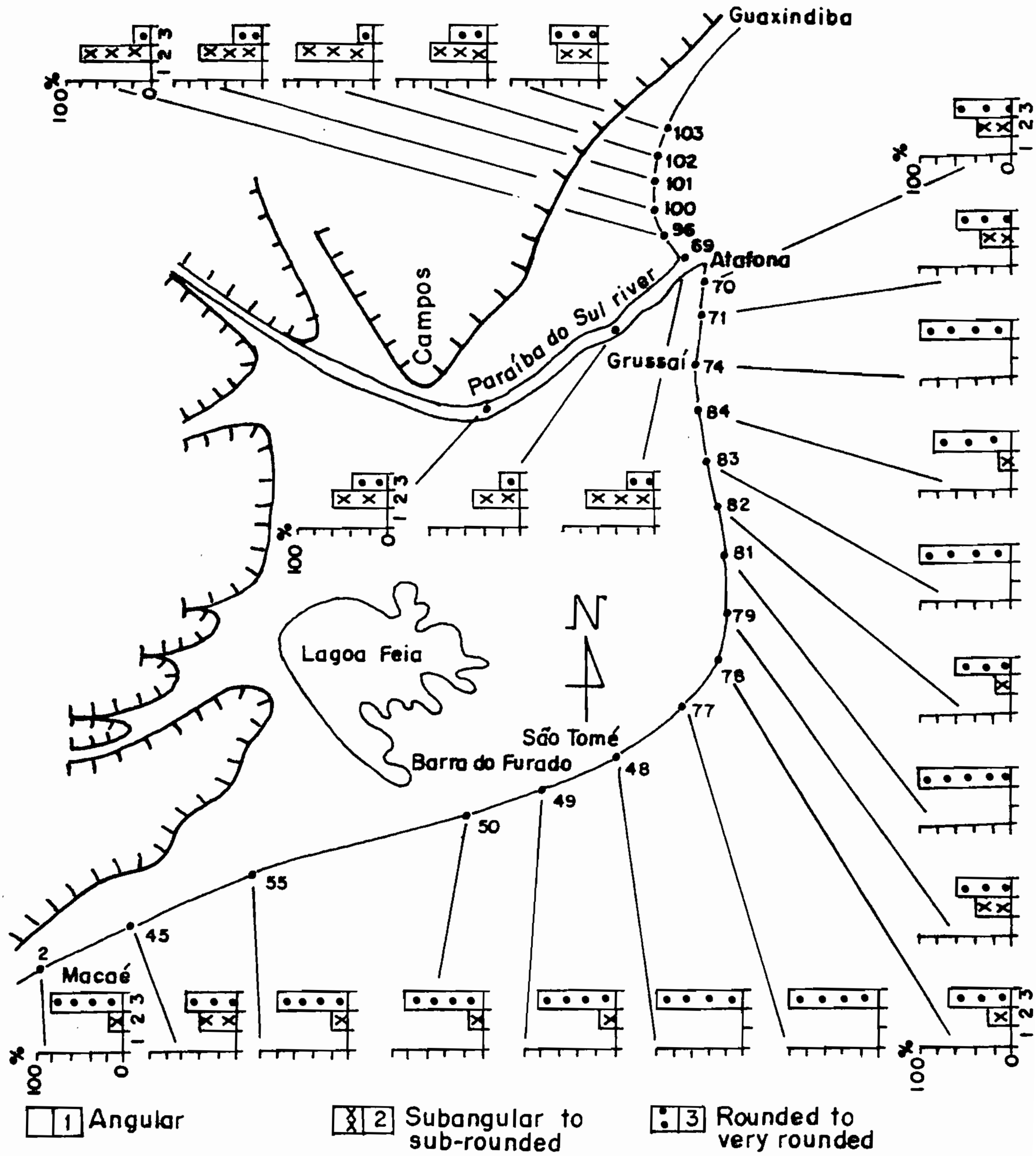

Fig. 17– Roundness degrees of present beach and fluvial sands of the Paraíba do Sul river mouth measured in the interval 0.5–1.0 mm (3 classes).

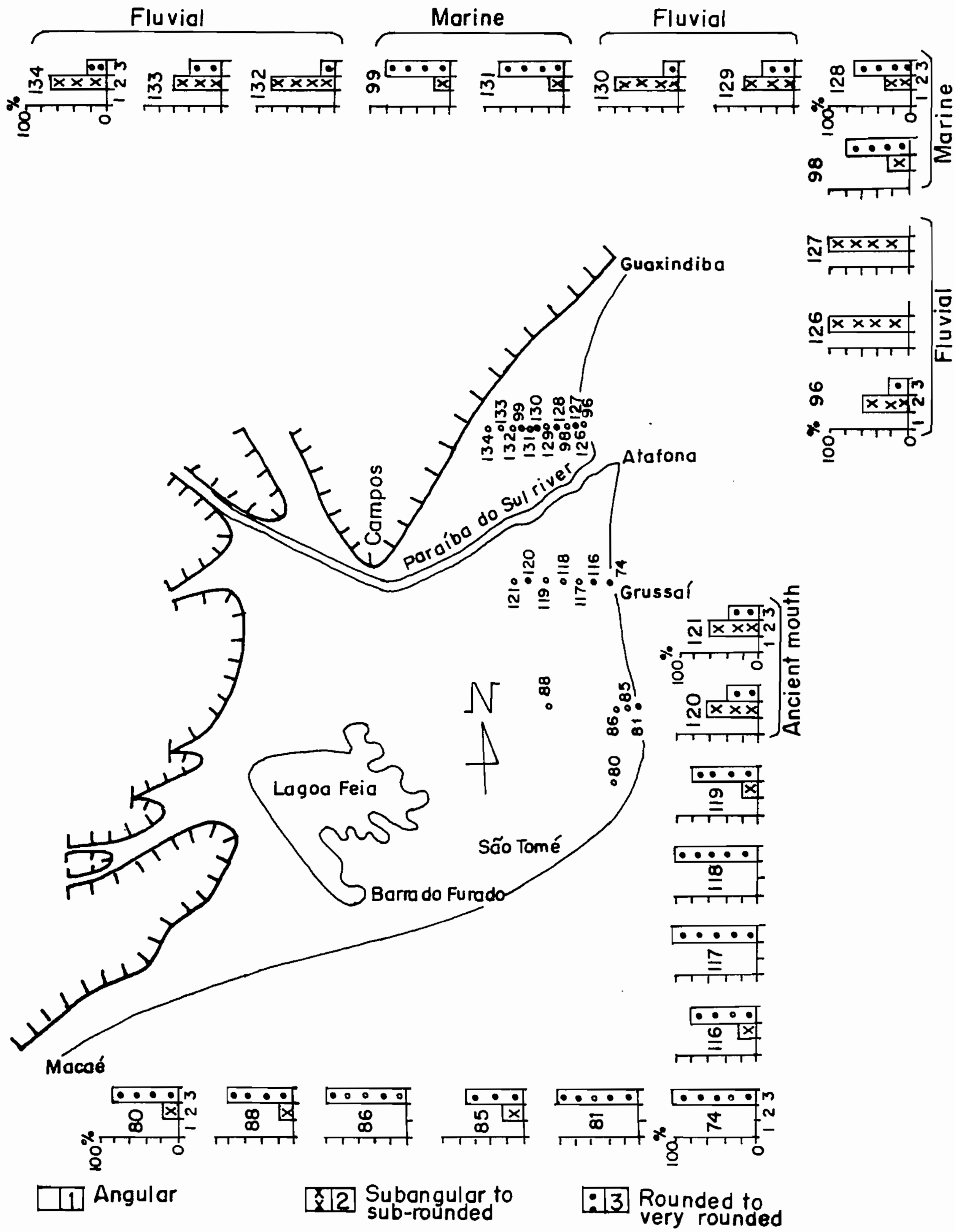

Fig. 18 – Roundness degrees of sands from Holocene terraces of the Paraíba do Sul river coastal plain measured in the interval 0.5-1.0mm.

2.6 - EVIDENCE OF NEOTECTONIC ACTIVITY

The coastal plain of the Paraíba do Sul river can be subdivided into two parts by a line connecting Campos city to the São Tomé Cape. Northwards of this line there are well developed Holocene deposits on both sides of the river mouth, while southwards they are very restricted in area.

There is some evidence that the Holocene sand barrier situated at the SW of São Tomé is being displaced landwards, advancing upon older deposits, suggesting that this area is subsiding. In fact, in this area it was possible to find present beach sands covering lagoonal deposits whose mollusc shells have been dated as 6,620 ± 240 years B.P. (Bah. 1107) and 6,000 ± 230 years B.P. (Bah. 1108). In the southern extremity, which lacks lagoons or paleolagoons, the Pleistocene terrace present an abnormally low altitude and yellowish sands of present beaches are advancing upon Pleistocene whitish sands.

In fact, the Bouguer map of the region (Fig. 19) shows that there are two distinct areas separated by the Campos-São Tomé axis. Northwards, with dominantly positive anomalies, there is a more-or-less stable area, whereas southwards, with mostly negative anomalies, there is possibly an area which is undergoing subsidence.

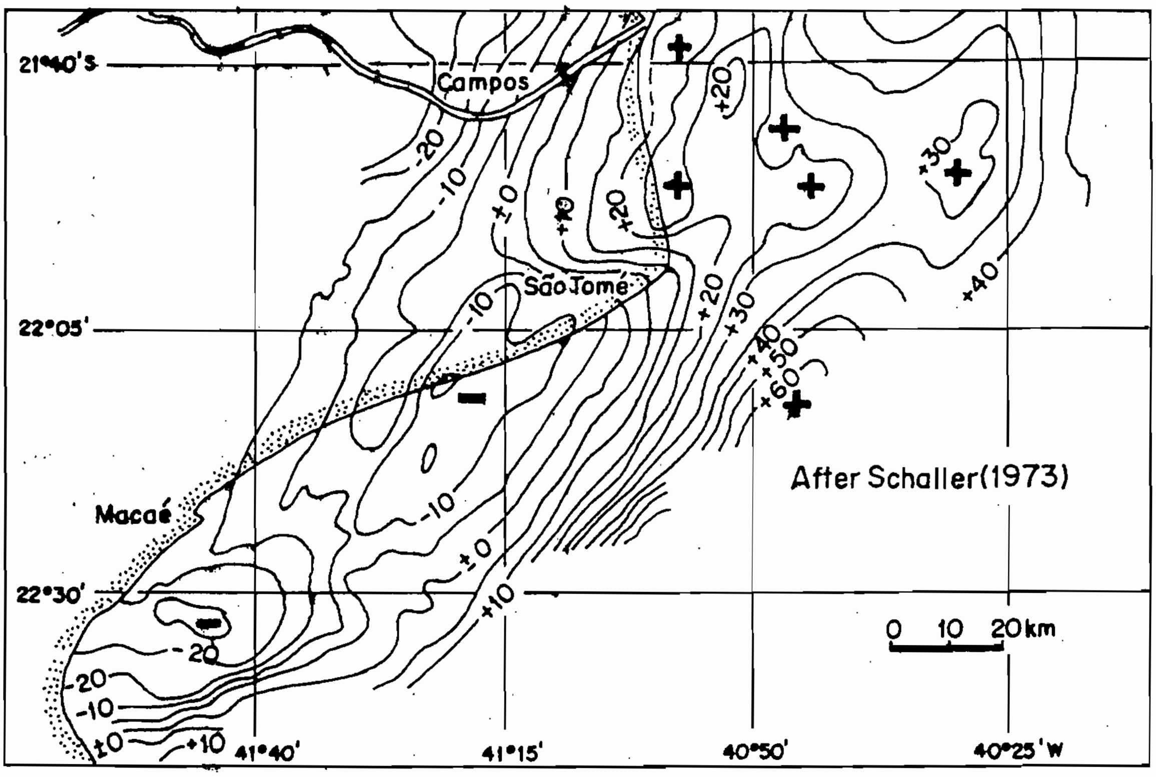

Fig. 19— Gravimetric evidence of compartimentation of the Paraíba do Sul river coastal plain into two tectonically differentiated zones, one subsiding and other uplifting, throughout Bouguer map of the area.

THEME III

PALEOCLIMATIC CHANGES DURING THE HOLOCENE, REGISTERED IN LITTORAL DEPOSITS

1. INTRODUCTION

The study of paleoclimatic changes is an important subject, involving numerous disciplines. The study of soils, of erosional and weathering processes and of sedimentation within oceanic and continental basins can be used in paleoclimatic interpretations. In geophysics, knowledge of paleoclimatic changes is necessary to provide control, with ancient examples, on the theoretical analysis of the atmosphere/oceans/continents/ cryosphere system. This knowledge can be used to determine the relationships between the evolution of this system and certain external factors, such as astronomical parameters, solar activity, the magnetic field, etc. In archeology, the knowledge of paleoclimatic changes will allow us to better understand the evolution of man.

During the last 2 million years, the terrestrial environment has been subjected to accentuated changes which has been recorded in all latitudes. In intertropical regions dense rain forests, for example, have been periodically rarefied or displaced towards the Equator. These changes are constinuously registered within oceanic or lacustrine deposits. Modern dating techniques allow us to establish the chronology of the most important events with an acceptable precision. Several sedimentological, geochemical and paleoecological methods are available to define paleoenvironments which permit, through comparison of specialized data and statistical analyses, a quantitative paleoclimatic interpretation of these environments.

Scientific investigations carried out along the Brazilian coast during the last 15 years have shown that relative sea-level changes and paleoclimatic variations have been the most important factors in its Quaternary evolution. Studies of the registered paleoclimatic changes have been carried out in the following areas:

a) Records of inversions in dominant wave directions, in connection with changes in atmospheric circulation.

b) Records of changes in upwelling intensities at Cabo Frio (State of Rio de Janeiro).

c) Records of changes of flow energy of the Paraíba do Sul river, in connection with probable variations in pluviosity.

2. RECORDS OF INVERSIONS IN DOMINANT WAVE DIRECTIONS

2.1 - GENERALITIES

It was emphasized in "Theme I" that relative sea-level fall associated with littoral transportation played an important role in construction of Brazilian sandy coastal plains during the Quaternary, which are characterized by the horizontal accretion of numerous beach ridges. A detailed study of their geometry has allowed us to reconstruct the direction of littoral transportation during their sedimentation. It is evident that knowledge of the direction of transportation during a certain period will permit the deduction of the dominant wave directions within that time interval.

2.2 - PRESENT DOMINANT WAVE DIRECTIONS IN THE CENTRAL PORTION OF THE BRAZILIAN COAST

In this part of the Brazilian coast there are presently two types of waves. The first type is most frequent and comes from the NE quadrant, being derived from trade winds. The second type comes from S-SE quadrant, being related to the penetration of cold polar air masses into the South American Continent. This type is more frequent during austral autumn and winter and its effects are felt as far as latitude 12°S. In fact, during austral autumn and winter, the air mass circulation over South America is characterized by the passage, within the middle and upper troposphere, of a succession of meridian waves and, on the surface, by corresponding frontal systems. In the ocean, the frontal systems are accompanied by waves which come from the southern sector. It is important to emphasize that the latter, which are stronger than the former, play an important role in the littoral transportation of sediments. A few days or even hours of strong waves from the southern sector, related to the transit of cold polar fronts, is a much more important factor in sediment transportation than several months of weak waves from the northeastern sector. This fact is often forgotten when only their frequencies are taken into consideration. In this paper, the dominant waves are not necessarily the most frequent, but are those which are the most capable of promoting unidirectional littoral transportation of sediments.

Presently, the dominant littoral drift in the São Francisco river mouth area (10°S) is from N to S, whereas in the areas of the Doce river mouth (19°S) and the Paraíba do Sul river mouth (22°S) the dominant littoral drift is from S to N. Consequently, the dominant waves come from the north in the São Francisco river and from the south in the Doce and Paraíba do Sul rivers.

2.3 - PAST (5,000 YEARS B.P. TO PRESENT) WAVE DIRECTIONS IN THE CENTRAL PORTION OF THE BRAZILIAN COAST

It has been possible to demonstrate that the littoral drift in the São Francisco river mouth area, during the last 5,000 years, occurred from N to S and that the average direction in the Paraíba do Sul river mouth area was from S to N. However, in the Doce river mouth area, the direction of littoral drift changed about 10 times during the same time interval. Between 0 and 2,500 years B.P., the littoral transportation (which was generally from S to N) was submitted to 3 inversions from N to S. Between 2,500 and 4,100 years B.P. the direction of transportation was constant from S to N, although two relative sea-level oscillations occurred during this period and evidence of inversions may have been destroyed. Between 4,100 and 5,100 years B.P., 7 inversions of the direction of transportation from N to S were recognized. Prior to 5,100 years B.P. the littoral transportation was from N to S, although the absence of records of beach ridges from this period does not permit us to know when it commenced. An evaluation of the volume of sands which were mobilized during each of these periods will probably enable us to establish a more precise chronology for these events (Fig.20).

2.4 - PALEOCLIMATIC INTERPRETATION

In 1983, the year of an important natural phenomenon known as "El Niño", the polar advections were blocked in Southern and Southeastern Brazil as a consequence of a powerful and permanent subtropical jetty current, generated by the presence of abnormally warm waters along the Peruvian coast. Due to this blockage, the frontal zones and the associated southern sector waves did not ascend northwards and the northeastern waves did not become active.

Inversions in the direction of littoral transportation and, consequently, of dominant waves which have been registered within the Doce river coastal plain can be explained by the occurrence of two successive systems of atmospheric circulation. During periods when the dominant waves come from the southern sector, the atmospheric circulation must be equivalent to the present situation, which is characterized by the northward ascension of polar air masses and by frontal systems and associated waves during autumn and winter. On the other hand, when littoral transportation is mostly from north of south, the dominant waves come from the northeastern sector and the waves from the southern sector do not reach the Doce river mouth area. It is quite possible that the frontal systems could have been blocked in Southern Brazil during phenomena similar to the "El Niño", which occurred in 1983. However, in this case it is necessary to imagine a situation in which the "El Niño"

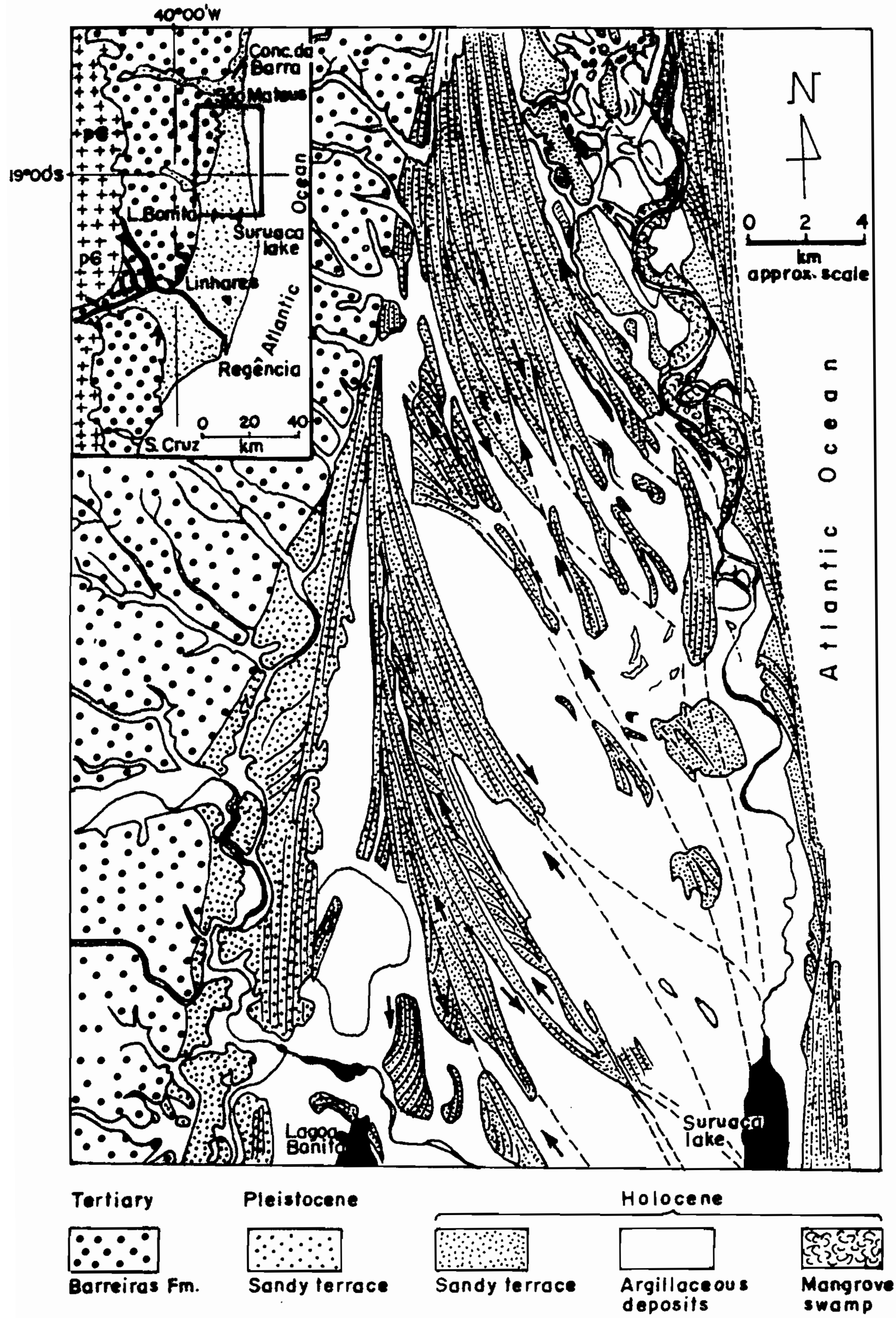

Fig. 20 – Doce river coastal plain (State of Espírito Santo) showing littoral drift inversion episodes recognized by geometry of beach ridges in sandy plains.

phenomenon extends for many years to several tens or even hundreds of years.

3. RECORDS OF CHANGES IN UPWELLING INTENSITIES AT CABO FRIO (STATE OF RIO DE JANEIRO)

3.1 - GENERALITIES

The designation "frio" (cold), which was applied to this cape on the Brazilian coast (Fig.21) by Portuguese navigators in the 16th century, already testifies to the fact that there is a local thermal anomaly here. The annual mean temperature map of surface waters in the tropical and subtropical Atlantic ocean (Bohmecke, 1936, in Neumann, 1965), established after the data collected by the Oceanographic Vessel "Meteor", confirms the existence of a negative thermal anomaly within the Cabo Frio region. The occurrence of an upwelling phenomenon was defined through the many hydrological studies in the area (Allard, 1955; Emillson, 1961; Ikeda _et al_., 1974; Mesquita _et al_., 1979). However, it was principally during the "Projeto Cabo Frio" (Cabo Frio Project) that the physical and chemical characteristics of this coastal upwelling constituted the objective of several studies (Moreira da Silva, 1968a, 1968b, 1973a, 1973b, 1973c; Rodrigues, 1973, 1977; Valentin, 1974, 1984; Fahrback & Neinecke, 1979).

3.2 - CHARACTERISTICS OF THE SOUTH ATLANTIC WATER MASSES

Between the surface and a depth of 100 m, there are warm water masses. Defant (1937) demonstrated that the properties of this type of water are due to intensive radiation, an excess of evaporation in relation to precipitation and a weak transmission through the tropical thermocline. These waters are partially transported southwards by the Brazilian current, which is a continuation of the southern ramification of the Equatorial current which flows southwards, following the continental slope. From 22°S southwards, the Brazilian continental slope is expanded, the Brazilian current distance from the coast controlling the limits of the area occupied by coastal waters. They are composed of a mixture of water from the Brazilian current, oceanic water and water with strong terrigenous influence. The water of the Brazilian current which is transported southwards is mixed to form a water mass named by Thomsen (1962) as the _South Atlantic Tropical Waters_ or simply _Tropical Waters_, whose temperatures change between 18° and 24.5°C, with sanilities greater than 36‰. An increase in density, due to the gradual loss of heat to the atmosphere during their southwards displacement, provokes the descent of these _Tropical Waters_, which are mixed with colder and less saline southern waters, giving

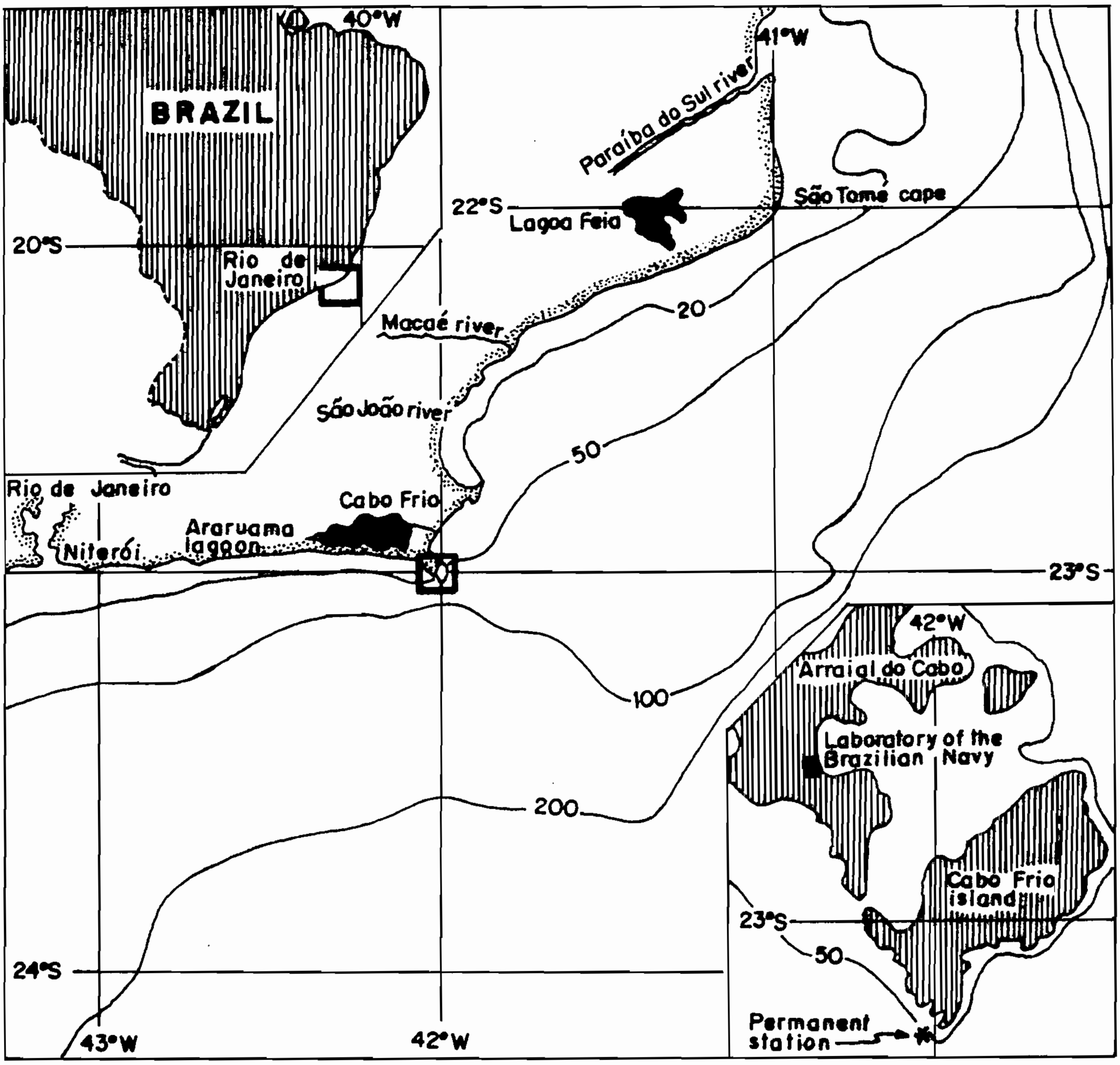

Fig. 21– Index map of the local upwelling site near the town of Cabo Frio (State of Rio de Janeiro).

rise to Subtropical Waters, which integrate with the South Atlantic Central Waters of Sverdrup et al. (1942), sinking beneath the Brazilian current at the subtropical convergence level (between 30 and 40°S). They are characterized by a temperature lower than 18°C and a salinity lower than 36‰. This water mass is related to the Cabo Frio upwelling, being situated at a depth of between 200 and 300 m.

3.3 - UPWELLING MECHANISMS

Allard (1955) was the first author to recognize a correlation between wind direction and changes in surface water temperatures at Cabo Frio. Temperature is at a minimum when winds come from the NE and increases when the winds come from the SSE.

During spring and summer, the dominant winds related to trade winds come from the NE. In autumn and winter, the northeastern wind regime is disturbed by the passage, within the middle and upper troposphere, of successive meridian waves and, on the surface, by corresponding frontal systems, which are followed by winds from the S, SE and SW.

The winds from the NE and ENE provoke the divergence of coastal waters, distancing the Brazilian current from the coast and provoking an upwelling of South Atlantic Central Waters on the continental shelf and occasionally up to the surface.

The center of the phenomenon is situated near to Cabo Frio and, more precisely, within a zone situated at the foot of the southwestern slope of Cabo Frio island (Fig. 21). This situation is related to coastal topography: the distancing of the coast creates, in relation to the Brazilian current flow, a divergence effect which, associated with the Coriolis force, propitiates the ascension of deep waters at Cabo Frio. Moreira da Silva (1968a, 1968b, 1973a, 1973b, 1976) demonstrated that the upwelling occurs in two phases: (a) distancing oceanward of the Brazilian current allows the South Atlantic Central Waters to ascend on to the continental slope occupying the bottom of the continental shelf; (b) under influence of northeastern winds, the cold waters ascend to the ocean surface. On the other hand, as a consequence of the passage of cold fronts, the winds come from the N (pre-frontal) and then subsequently from the SW, S and SE (post-frontal). The latter will produce the retention of Coastal Waters and, consequently, the submersion of cold waters.

During spring and summer the mean temperature of the waters in the Cabo Frio region will be cold, with a possible increase in temperature during periods of actuation of southern sector winds. On the contrary, during winter and autumn the mean temperatures of the waters will be warm, with a possible decrease in temperature related to the influence of northeastern winds (Fig. 22). Thus, upwelling in the Cabo Frio region is related to three principal factors: (a) local topography, (b) position of the axis of the Brazilian current and (c) wind regimes.

3.4 - CONSEQUENCE OF THE INTERMITTENT PRESENCE OF COLD WATERS IN THE CABO FRIO REGION

In Maricá, situated less than 100 km SW of Cabo Frio, the annual mean pluviosity is about 1,400 mm and the climate can be classified as Aw (tropical with rainy summers and dryer winters), according to Köppen's (1948) classification. The intermittent presence of cold waters provokes a significant decrease in precipitation (750 mm/year at the Arraial do Cabo Station) and the climate becomes Bsh (semiarid hot), according to the same classification. This dry microclimate has induced hypersalinity in the Araruama lagoon and in the Lagoa Vermelha.

3.5 - WIND REGIME DISTURBANCE DUE TO THE "EL NIÑO" PHENOMENON

In 1983, the year of the important "El Niño" phenomenon along the Peru and Equador coasts, the wind regimes in Southern Brazil were strongly perturbed.

3.5.1 - What is "El Niño"? - Normally, the southern Pacific anticyclone is centered on Easter island, constituing an extensive high pressure zone. Simultaneously, the Western Pacific is submitted to low pressure which leads the northeastern trade winds towards the Western Pacific along the Equator. Occasionally, an inversion of these pressure gradients is produced between the Eastern and Western Pacific and then at the same time, an inversion of winds occurs. This phenomenon is known as the <u>Austral</u> <u>Oscillation</u>.

We have seem that, in general, the trade winds always present the same direction (towards the W). Then they exert a superficial tension on the ocean surface and, consequently, a great volume of upper oceanic waters accumulates in the Western Pacific. This water layer is composed essentially of warm waters, and causes a difference in sea-level between the Eastern and Western Pacific of 30 to 40 cm. Consequently, an upwelling of cold waters occurs along the South American coast. During the <u>Austral</u> <u>Oscillation</u> phenomenon, the pressure inversion over the Pacific ocean is weakened or even inverts the direction of trade winds. Sea-level then tends to return to normal through a wave known as "Kelvin". This wave moves eastwards at about

3m/s, causing a thickening of the warm water layer in the Eastern Pacific and, simultaneously, an increase of the ocean surface temperature in all of the Equatorial region, as well as to the north and south of the Equator. This appearance of warm water along the coasts of Peru and Equador, generally around Christmas time, is named the "El Niño" phenomenon.

3.5.2 - Consequences - Several "El Niño" phenomena which have occurred during the last tens of years have exhibited slightly different ocean atmospheric circulation models. For example, the "El Niño" of 1982/1983 can be distinguished from the previous ones by its intensity, its duration and its global climatic effects. In terms of pluviosity, the 1982/1983 "El Niño" was characterized, in South America, by the existence of two contrasting zones: one marked by severe dryness and another by catastrophic inundations. The dry zone corresponds to Northeastern Brazil and part of the Amazon area, while the flood zone was situated in the north of Argentina, Uruguay, Paraguay Southern Brazil and part of Bolivia. The extension of these zones changed through time and, in June to August of 1983, precipitation was about 350% above normal.

One of the characteristics of atmospheric circulation, during the "El Niño" climax between March and August 1983, consisted of the permanence of a strong jetty current upon the South American continent. This jetty blocked the ascension of polar air masses and the cold fronts were stabilized over Southern and Southeastern Brazil. This zone of blockage was progressively displaced northwards and, in December, was situated in the Rio de Janeiro region. As a consequence of this blockage, SW, S and SE winds were also blocked and consequently, for example, in the Cabo Frio region only the NE winds were permanently active.

3.6 - RESPONSE OF THE ATLANTIC OCEAN CABO FRIO UPWELLING TO THE PACIFIC OCEAN "EL NIÑO" PHENOMENON

During August of 1983, in response to the Peruvian coast "El Niño" phenomenon, the surface ocean waters near Cabo Frio were abnormally cold (Fig. 22d). This situation is perfectly understandable, considering that after the blockage of cold fronts in Southern Brazil, as a consequence of the "El Niño" phenomenon the southern sector winds did not reach as far as the Cabo Frio region and the northeastern winds became very effective.

In 1976, which also corresponds to an "El Niño" year, it is possible to find an inverse situation: from March 15th. to July 15th. the water was permanently warm in the Cabo Frio

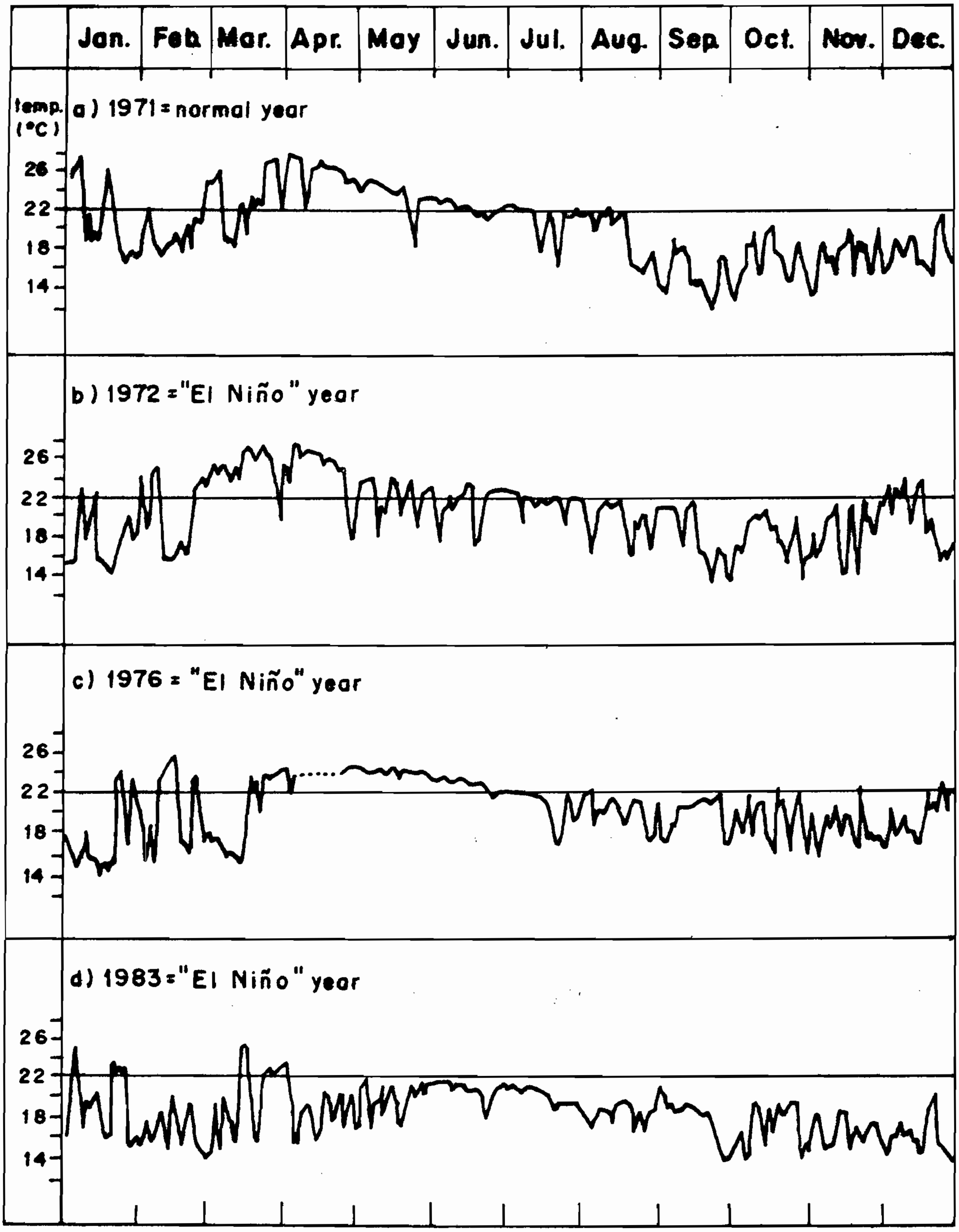

Fig. 22 — Comparison between surface water temperatures at Cabo Frio station during normal and "El Niño" years.

region (Fig. 22c), indicating that there were no winds from the NE during this period. As the "El Niño" was weaker than in 1983, it is possible that the zone of blockage was situated more northwards and that the Cabo Frio region was free from norh-eastern winds.

In 1972, which also corresponds to an "El Niño" year, it is possible to observe from March to September the presence of several periods of cold water (Fig. 22b), contrary to 1971 (Fig. 22a), which can be considered as a normal year. This fact explains why many more periods of northeastern winds were produced in 1972, between March and September, than in 1971. In 1972, the surface water temperatures were more-or-less comparable to those of 1983, although these temperatures were slightly elevated.

Thus, it appears that a relationship exists between the intensification or disappearance of upwelling in Cabo Frio and the occasional presence of warmer waters along the Equador and Peruvian coasts. According to the intensity of the "El Niño" phenomenon, the warm waters reach more-or-less southwards along the South American Pacific coast, modifying the position of the jetty current which diagonally crosses this continent. The presence or absence of northeastern winds, which give rise to the Cabo Frio upwelling, will depend upon the position of this jetty current. Depending upon the situation, there will either exist reinforcement or disappearance of upwelling.

3.7 - POSSIBILITY OF REGISTRATION OF CABO FRIO UPWELLING INTENSITY VARIATIONS DURING THE HOLOCENE

The "El Niño" phenomenon could modify, on an annual scale, the Cabo Frio upwelling intensity as a consequence of atmospheric circulation perturbations. Previous studies have also shown that, during the Holocene, at the Doce river mouth coastal plain, littoral drift directions changed on a time scale of tens or hundreds of years. These changes are probably a consequence of variations in the dominant wave direction, related to modifications in atmospheric circulation similar to that initiated by the "El Niño" phenomenon. However, it is necessary, in this case, to imagine the existence if not of a permanent "El Niño", then at least of annual events or situations during several tens or hundreds of years.

This hypothesis seems to be reinforced by the occurrence of alternating wet and dry periods, on a secular time scale in the southern part of Cape Santa Helena on the Equador coast (Bogin, 1982).

3.8 - CHANGES IN CARBONATE SEDIMENTATION, AS A CONSEQUENCE OF CABO FRIO REGION MICROCLIMATE VARIATIONS, WITHIN LAGOA VERMELHA

3.8.1 - Descriptions - Lagoa Vermelha is a very small hypersaline lake situated in the Cabo Frio region. There is no subaerial source of freshwater flowing into this lake. It is isolated within sandy deposits and does not receive any terrigenous supply, probably being nourished by subterraneous percolation from the Araruama lagoon.

A short core sample (about 1 m long) from this lake was studied from a geochemical and mineralogical viewpoint by Santelli (1988), Fig. 23.

Due to its isolation, the sediments of the Lagoa Vermelha are essentially composed of carbonates and organic matter. The carbonates form 46 to 96% of the sediments. X ray diffraction analyses have shown that the carbonates are composed of magnesian calcite in proportions which range from 20 to 100% along the core, aragonite in proportions which vary from 6 to 72% between 13 and 42 cm depth, as well as dolomite in proportions variable between 43 and 100% from 56 cm to the base of core. A study by electron microscopy has shown that, between a depth of 13 and 43 cm, there is substantial well crystallized aragonite, demonstrating that this mineral was directly precipitated and that its presence is not related to the activity of micro-organisms. The frequency of P_2O_5 is practically constant from 5 to 32 cm depth, increasing regularly from 32 to 56 cm and becoming more-or-less constant from 56 cm to the base of core.

From the combined data, it is possible to recognize two portions with different characteristics: the upper portion from 5 to 46 cm and the lower one from 46 cm to the base of the core.

The $\delta^{13}C_{(PDB)}$ variation curves of carbonates from sediments have also allowed us to distinguish two parts. Between 5 and 46 cm the mean value is $-4^{o}/_{oo}$, while from 46 cm to the base of the core it is $-10.5^{o}/_{oo}$. In addition, the $\delta^{18}O_{(PDB)}$ values of carbonates have enabled us to differentiate the same zones. From 5 to 46 cm, the values are very constant at around $+ 2^{o}/oo$, but it is important to note the existence of 4 peaks with values which are significantly more negative at depths of 18, 28, 36 and 46 cm. Beneath 48 cm the $\delta^{18}O_{(PDB)}$ values are clearly more positive. It appears to be possible to distinguish two sub-zones in the lower half of the core: from 48 to 78 cm depth the mean value is $+ 3^{o}/oo$, whereas from 81 to 93 cm it is $+ 4^{o}/oo$.

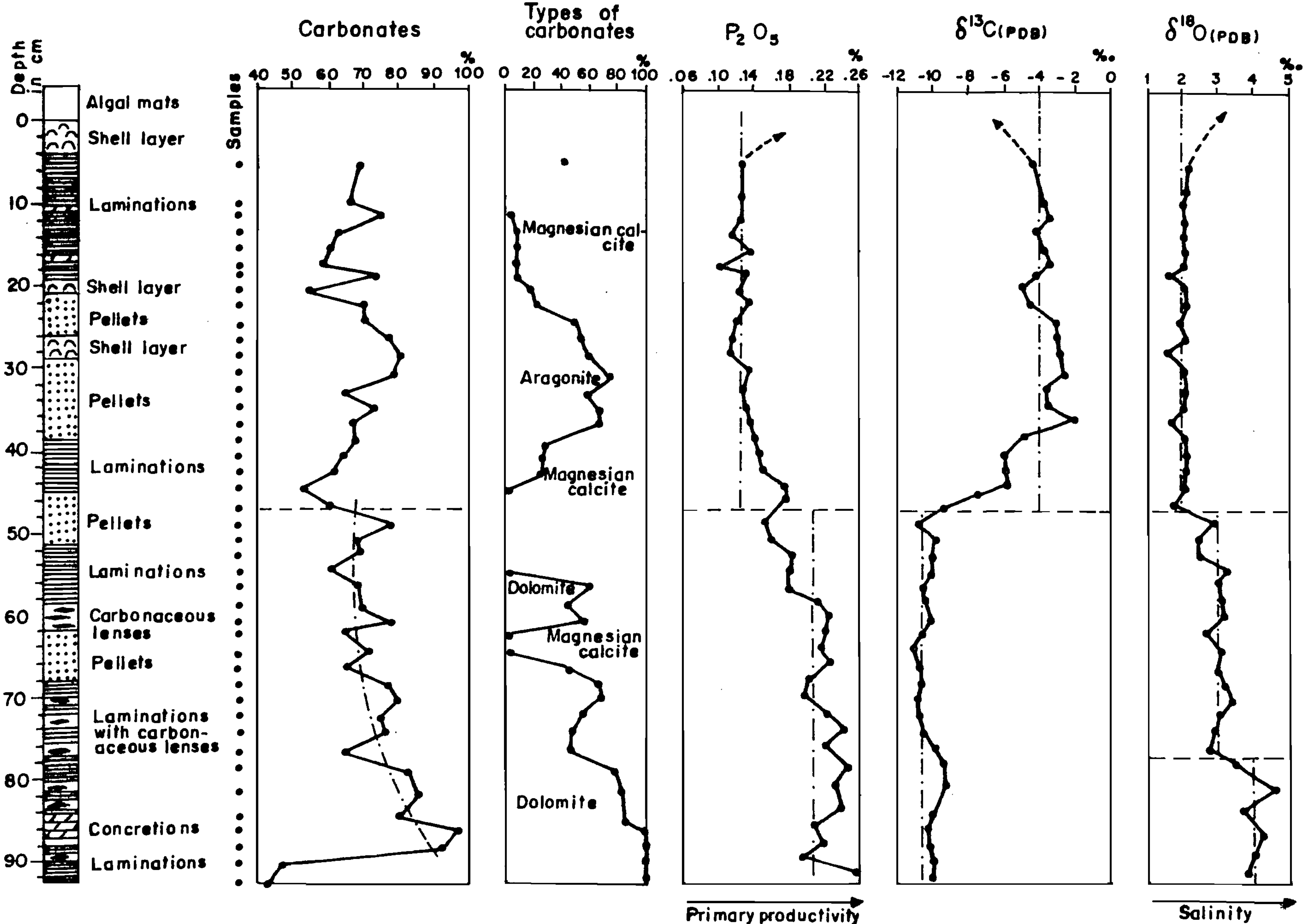

Fig. 23 - Mineralogical, chemical and isotopical compositions of a core sample from Lagoa Vermelha, a hypersaline coastal lagoon of the State of Rio de Janeiro.

3.8.2 - Interpretations - The surface layer, which characterizes present conditions, was not analysed. However, it is interesting to observe that, today, there are no living bivalve molluscs within the lake, although they are very frequent between 5 and 46 cm depth. Moreover, at 5 cm depth the carbonates are partially composed of dolomite; this mineral disappears subsequently and reappears only in the lower portion of the core. Finally, there is at present a formation of carbonate crusts around the margin of Lagoa Vermelha.

Considering this preliminary information, it is apparent that the carbonates found in this core sample were precipitated in different environments. During sedimentation of the lower portion of the core, the environment was clearly more saline than during the formation of the upper portion. Primary productivity, indicated by the P_2O_5 content, was similarly much more significant. In some places the $\delta^{13}C_{(PDB)}$ values of carbonates show that the environment was very rich in micro-algae, cyanobacteria and photosynthetic bacteria and that there were very few organisms with carbonate tests. On the other hand, during sedimentation of the upper portion of the core the environment was characterized by much lower levels of salinity and by a great abundance of organisms with carbonate tests. In some places, in the lower portion of the core the degradation of algal organic matter, due to a suitable Mg source, associated with strong evaporation, provoked the precipitation of dolomite. On the contrary, in the upper portion, the transition from an environment which was very rich in algae to one very rich in carbonate tests, associated with a decrease in salinity, propitiated the precipitation of aragonite. The presence of dolomite at the top of the core and the great abundance of algae, associated with the absence of living molluscs suggests that, presently, the environment could be similar to that which occurred during the deposition of the lower portion of this core.

Since Lagoa Vermelha is completely closed, the recorded salinity variations could be related to changes in the precipitation/evaporation ratio. This fact was ratified by analyses of deuterium and ^{18}O in waters of Lagoa Vermelha and the ocean, which showed a linear enrichment of deuterium in relation to ^{18}O, indicating that evaporation was the most important mechanism controlling the hydraulic budget of the lake.

These changes in the precipitation/evaporation ratio are necessarily related to modifications of the regional micro-climate and thus to changes in the Cabo Frio upwelling intensity. The decrease or disappearance of upwelling will induce an increase in precipitation and a decrease in evaporation. On the contrary, a reinforcement will provoke a decrease in precipitation and an increase in evaporation.

Unfortunately, at present there are no dates available, to establish the chronology of events. As the studied core did not penetrate all of the carbonate sequence, it is possible that other oscillations may be present within deeper sediments.

4. RECORDS OF STRONGER AND WEAKER ENERGIES AT THE MOUTH OF A RIVER

Previously we discussed the importance of relative sea-level changes, during the last 5,000 years, as an important source of sands supplied to beaches. These sands are frequently transported by littoral drift until they are impeded by an obstacle and their accumulation by horizontal piling results in beach ridges.

The mouth of a major river could be one of these obstacles. In fact, during strong discharge phases river flow will impede littoral drift, having the same effect as the construction of an artificial breakwater. This mechanism will produce accumulation on the updrift side and possible erosion on the downdrift side; however, this side can be compensated by sands supplied by the river (Fig.15b). In periods of weak discharge, river flow pratically disappears and littoral drift will construct a sand spit which tends to close the river mouth. Simultaneously, it will produce the partial erosion of previously formed sediments which had projected outwards from the normal alignment of the beach (Fig. 15c). If the weaker energy period is very long, the sand spit will be sufficiently widened and will be resistent to the following period of high energy. In certain cases only its extremity will be destroyed; the blockage provoked by the river flow is displaced and a new phase of accumulation will begin (Fig. 15d). These displacements are marked by successive stepwise unconformities of beach ridge alignments.

It is possible to assume that periods of high energy are related to episodes of abnormally high rainfall such as in 1983 and that low energy periods are related to abnormally dry episodes.

THEME IV

CHANGES IN NATURAL ENVIRONMENTS

1. THE SERRA DO MAR AND CUBATÃO

1.1 - INTRODUCTION

The Serra do Mar is an intrinsically unstable area, mostly during heavy rainfalls when its slopes are subjected to several kinds of mass movement phenomena. Due to its strategic geographic location, as a natural barrier between the littoral and the hinterland, some human influence in the area is unavoidable. Thus, man's activities have introduced an acceleration of natural processes, frequently with catastrophic consequences.

When we observe the Serra do Mar in São Paulo State, there is a strong concentration of mostly industrial activities in the Cubatão area, which gives rise to many serious problems, such as:

a) Risk of occurrence of many mass movements (examples: mudflows, rockslides, etc.). This is due to the progressive destruction of arboreal vegetation by pollutants carried by winds from the industries towards steep mountain slopes.

b) Occupation of unsuitable sites by low income-earning populations, with frequent destruction of the terrain, increasing the risk of the occurrence of landslides with the consequent destruction of their habitations.

c) Modifications of the terrain introduced in steep mountain slope areas by the construction of highways and railways, the implantation of ducts for oil, gas, etc. which also decrease the stability of slopes.

Out with the Cubatão area, the danger of an ecological disaster diminishes, although problems are still present on a minor scale. They are represented by human activity on unsuitable sites with the construction of housing, mining operations, etc.

1.2 - CHARACTERIZATION OF THE SERRA DO MAR

The Serra do Mar represents an extensive steep slope mountainous area separating the Atlantic Plateau (Planalto Atlântico) from the coastal plains, which approaches the shoreline especially between Southern Rio de Janeiro and Northern Santa Catarina States. Usually, the altitudes of the Serra do Mar ranges between 1,000 and 1,200 m, but in some places, such as in Serra da Bocaina, it may reach 2,000 m.

In São Paulo State, the Serra do Mar is best characterized from Peruíbe in the SW to the northern limit with Rio de Janeiro State. From Peruíbe southwards is less typical, due to the Ribeira de Iguape coastal plain expansion.

On the other hand, the so called Baixada Santista (Santos lowland) is uncommon within Brazilian coastal plains. There is an estuarine zone which is still incompletely filled by sediments and which is well drained by meandering channels with a strong tidal influence. The transportation and deposition of terrigenous sediments supplied by the Serra do Mar occur mostly along these channels. Areas subjected to tidal influence are covered by mangrove vegetation and present an abundant and typical fauna.

1.3 - ORIGIN

The Serra do Mar is composed of Precambrian crystalline rocks (older than 570 million years), although its scarp is relatively recent in geological terms. It originated following the processes that produced the South Atlantic ocean, with the separation of South America and Africa, about 120 million years ago. The processes of continental rupture and ocean opening developed major fault systems, oriented more-or-less parallel to the present shoreline, and established a stepwise relief, which is represented strikingly in the emerged portion of southeastern Brazil by the Serra do Mar and Serra da Mantiqueira.

From its formation until now the Serra do Mar has been continuously re-shaped by a combination of two processes: (a) spasmodic reactivation of original faults whose activities are probably diminishing through time, and (b) denudation processes with variable intensities, related to global changes in paleoclimate.

As a consequence of relative youthfulness of tectonic activities and paleoclimatic changes, the Serra do Mar is still a feature which is in disequilibrium with the present environmental conditions which tend towards scarp destruction and a smoothing of relief.

1.4 - EVOLUTIONARY FACTORS

1.4.1 - Lithologies and structures - The Serra do Mar is predominantly composed of granites and gneisses, which are relatively resistent to denudation processes. However, they are very ancient and are intersected by several fault and fracture systems, precipitating their weathering and consequent erosion.

1.4.2 - Climate - The Serra do Mar represents a natural barrier for the atmospheric circulation of southeastern Brazil, directly related to the advances and retreats of Polar Cold Fronts. High humidity of the atmosphere and the barrier effect of the relief provoke the high pluviosity in this area. There are three types of rainfall in the Serra do Mar: (a) frontal rains originated by the collision of different atmospheric systems, that is, the Polar Cold Front and the Atlantic Tropical Mass; (b) orographic rains, originated by a decrease in temperature due to altitude and (c) convective rains, originated by the local condensation of atmospheric high humidity as a consequence of the high evaporation rate.

Due to the combination of these climatic factors, the Serra do Mar is one of the rainiest places in Brazil, being somewhat comparable to the Amazon area, although with more serious consequences because the rains are concentrated in certain periods of the year. They are most frequent from November to March. The mean pluviosity is greater than 2,000 mm/year along the Serra do mar area, and exceeds 3,000 mm/year between Santos and São Sebastião.

1.4.3 - Soils - The climate, especially the high pluviosity, propitiates intensive chemical weathering. Thus, when preserved from erosion, there are thick soils derived from the intense oxidation of mineral with the concentration of iron and aluminum.

1.4.4 - Vegetation cover - The soils in the Serra do Mar, which are poor in nutrients, are in equilibrium with a rich vegetation cover known as the Mata Atlântica (Atlantic forest), which extends from the southern part of the State of Bahia to Rio Grande do Sul State. There is a highly adapted mechanism for nutrient cycling, easily affected by external perturbations.

On the other hand, vegetation cover has an important role as a controlling agent for erosional processes. Besides the role played by roots of trees increasing the physical resistence of the soils, a forest is very important in the interception, retention and elimination (evapotranspiration) of most rain water, avoiding its direct action on soils.

1.5 - ANTHROPIC INFLUENCES

Landslides along the Serra do Mar slopes are not an exception but are a rule, decided by the natural conditions of its evolutionary history. The equilibrium conditions can be disrupted by heavier rainfalls but, even so, anthropic influence has been decisive in the acceleration of such natural processes.

Since the last century man has constructed roads and railways through the Serra do Mar, replacing the ancient pathways used by the jesuits and indians. The railway from Santos to Jundiaí, previously known as the São Paulo railway, was constructed by the English in the middle of the last century, with landslide problems since its construction. However, modern constructions, such as Via Anchieta and Rodovia dos Imigrantes, are also affected by landslides (Table IV - 1).

In addition to this, the Cubatão industries had been discharging tons of polluting wastes daily into the air, the water, and the soil, damaging the entire regional ecosystem. The "chemical soup" they produced had been falling directly upon the vegetation of the Serra do Mar for more than thirty years, inexorably provoking its deterioration. Phytotoxic polluting agents, especially fluorides, were found in abundance in the emissions of local industries and had been causing the progressive destruction of arboreal vegetation. Consequently, the steep mountain slopes had become unstable, particularly in the region behind the industrial park and in the Moji river valley. This was due to winds which had been carrying pollutants from the coast to the plateau during daylight hours.

In such a setting, the rains of 22nd. and 23rd. January, 1985 (380 mm in 48 hours) were enough to cause hundred of mudflows on the slopes. The destruction of the vegetation cover neutralized the normally positive effects which this cover has on the soil. The upper parts of the trees act as a buffer against the rain and their roots act as an anchor, holding the soil in place. As a result of heavy rainfall on those days, hundreds of mudflows and floods occurred throughout an extensive area, including the trouble spot of Vila Parisi. It was there that an ammonia pipeline broke, discharging fifteen tons of ammonia into the atmosphere and forcing a mass evacuation of the population.

This emergency reinforced the diagnosis that the process of deterioration of the Serra do Mar in the Cubatão area was near to the point of no return.

1.6 - CONCLUSIONS

The prospect of tragedies, even greater than that which occurred in January 1985, such as the possibility of mudflows involving the industries and the residential settlements, also loomed ahead. Confronted with this picture the State Government set up the Special Commission for Restoring the Serra do Mar in the Cubatão Region.

One of the first and most important victories attained by this integrated action was a pollution control program, encompassing all 320 sources of pollution in the 23 industrial complexes in Cubatão. Through electrostatic filters it was possible to retain by 1987 more than 85% of the particulate materials previously emitted to the atmosphere.

Presently, besides the construction of protection dams in order to retain the deposits of eventual mudflows, there are programs for restoring the steep mountain slopes through the planting of grasses of the genus Brachiaria, as well as of native species, including arboral vegetation.

TABLE IV - 1: Significant landslides which occurred between 1928 and 1988 in the Serra do Mar

Location	Year	Consequences	Processes
Santos (SP)	1928	80 deaths	Landslides in Monte Serrat involving about 130,000 m^3 of material.
Santos (SP)	1950	3 deaths	Landslides in Monte Serrat.
Santos (SP)	1956	43 deaths	Landslides in Santos and São Vicente.
Caraguatatuba (SP)	1967	120 deaths, several missing and wounded persons.	Mudflows partially reaching to Caraguatatuba.
Serra das Araras (RJ)	1967	1,700 deaths	Mudflows and landslides
Cubatão (SP)	1976	Paralysis of Copebrás, railways and the destruction of viaducts	Landslides on the Serra do Mar steep slopes.
Santos (SP)	1978	100 people injured	Landslides in Monte Serrat and Vila Progresso.
Santos (SP)	1979	11 deaths and several people injured	Landslides at 34 sites in São Vicente and Santos.
Cubatão (SP)	1985	Paralysis of railway and Ultrafértil ammonia pipeline rupture	Widespread landslides in the Serra do Mar.
Santos (SP)	1988	1 death and 166 homeless people	Landslides at 34 sites in São Vicente e Santos.
Cubatão (SP)	1988	10 deaths and closure of Anchieta highway	Landslides and rockslides along Cachoeira Creek.
Ubatuba (SP)	1988	6 deaths and closure of the BR-101 highway, dozens of homeless families, etc.	Landslides along several parts of the BR-101 highway.
Petrópolis (RJ)	1988	171 deaths,600 injured and 4,263 homeless people	Landslides and rockslides.

From: Relatório IPT - Instabilidade da Serra do Mar no Estado de São Paulo - volume 1.

2. A PHYSICAL AND BIOGEOCHEMICAL DESCRIPTION OF THE LAGOA DE GUARAPINA, A SUBTROPICAL BRAZILIAN LAGOON (BASED ON THE ABSTRACT BY KNOPPERS, B.A. & TURCQ, B., 1989)

The Guarapina lagoon (latitude 22°56'S and longitude 42°42'W) lies approximately 50 km east of the city of Rio de Janeiro. It exhibits a surface area of about 6.5 km^2, a mean depth of 1 m and a connection to the sea via 1.4 km long, shallow (0.5 m) and 35 m wide tidal channel. The effective drainage basin of the Guarapina has an area of 59 km^2 and is characterized by a steep relief with a maximum altitude of 879 m and with about half of the total area being less than 25m above mean sea-level. Precambrian biotite granitic gneisses dominate the basin and Quaternary sediments the low level areas. Three small rivers drain the basin and flow in low lying areas across marginal patches of the water reed <u>Typha dominguensis</u> into the lagoon.

The lagoon is separated from the ocean by a long and narrow beach ridge. Littoral transport is extremily active and causes rapid closing of tidal channels. A natural channel between Lagoa de Maricá and the ocean vanished a few decades ago and the man-made channel which was opened in 1951 at Ponta Negra has to be kept opened by frequent dredging. Since the permanent opening of the channel sediment composition clearly changed. The upper sediments show a higher porcentage of carbonate (aragonite) with approximately 4% up to 12 cm depth and 0.3 to 1% below this level. The rate of sediment deposition after 1951 was estimated from these changes as of about 0.3cm/ year.

Although sediment composition may show substantial spacial variability, a general pattern for a large area in the central section of the lagoon may be established. The predominant sediment is organic rich clay at the surface with some sand and silt layers from approximately 40 cm depth onwards. The mineralogy of the sand is mainly quartz, K-feldspar, plagioclase and mica, and the clay consists of kaolinite and illite in almost equal proportions.

Transportation of biogenic elements at the sediment layer interface is highly dynamic and exhibits a substantial spacial and temporal variation. On the other hand, the quantity and chemical composition of suspended matter, and phytoplankton production and succession exhibits marked short term and seasonal variations. The system is mesotrophic in winter and spring and eutrophic in summer and autumn and may be characterized as a quasi-naturally eutrophicated lagoon.

Pollution effects are restricted to some minor atmospheric deposition of lead. Studies conducted on the heavy metal composition of sediments showed the major accumulators Cd, Zn, Cu and Cr are within the lowest levels encountered in comparison to other tropical and temperate systems, which is also the case for organochlorides.

3. RECENT ENVIRONMENTAL CHANGES IN THE SAQUAREMA LAGOON AND ITS WATERSHED (PROJECT OF THE DEPARTMENT OF GEOCHEMISTRY. UNIVERSIDADE FEDERAL FLUMINENSE, COORDINATED BY DR. J.P. CARMOUZE: AGREEMENT ORSTOM/CNPq)

3.1 - INTRODUCTION

The Saquarema lagoon comprises a series of four aligned minor lagoons, named "sacos", which are interconnected and which show a certain symmetry. Two major logoons at the extremities, named Saco de Fora and Saco de Urussanga, are connected through minor lagoons, known as Saco do Boqueirão and Saco do Jardim (Lamego, 1945), Figs. 40 and 41. This association has an area of 23 km^2 and a mean depth of 1m, and has an intermittently active outlet situated in Saco de Fora. Westwards, connected by the Rio Salgado, is the small lake of Jaconé which has little influence at present on Saquarema lagoon.

The hydrographic basin is limited upstream by successive mountain ridges of the Serra de Mato Grosso, the major with the highest altitude (890 m) being in the NW. In general, it is possible to recognize two contrasting geomorphological units: the upper characterized by steep hill slopes and the lower with extensive and flat lowlands. The lagoons are separated from the Atlantic ocean by Quaternary sand bars.

Several rivers flow into the Saquarema lagoon with the Roncador, flowing into the Saco de Urussanga being the most important, with a strongly ramified basin draining the Serra de Mato Grosso, the major orographic barrier in the area. The Jundiá river, crossing extensive lowlands, flows into the same area while other rivers with restricted watersheds flow into other "sacos".

The primitive inhabitants of this area were the Tamoios indians and the town of Saquarema was established in the XVIth century, when the Portuguese promoted the population of the area to avoid of the invasion of foreigners. Until the start of this century, major environmental changes did not occur, beginning with the construction of the RJ-106 highway in 1940. Growth of the urban zones was intensified from 1950 and was accelerated after 1970 with the construction of the Rio-Niterói bridge, when a large number of private properties appeared.

3.2 - ENVIRONMENTAL CHANGES

3.2.1 - In the hydrographic basin - Until the construction of the RJ-016, the hydrographic basin was covered by humid tropical forest typical of the area, known as Mata Atlântica (Atlantic forest), limited only by swampy lowlands bordering the lagoon, which represented about one third of the coastal plains.

Later, a sanitation program was initiated in the area, with the annual dredging of rivers, to reduce the proliferation of malaria vectors. Simultaneously, deforestation of the area began to allow the expansion of sugar cane plantations. This forest was completely eliminated from the coastal plains, being presently restricted to hill slopes. The regional terrestrial fauna was exterminated. Deforestation to enable sugar cane plantations was intensified in the 1950's, with the construction of Usina Santa Luzia situated in Sampaio Correia, when mechanical dredging was introduced, with the consequent acceleration of drainage of the swampy lowlands. The effluent produced by the sugar cane industry known as "vinhoto", was for several years discharged into the Saquarema lagoon, which was certainly an important factor in its eutrophication.

After the 1960's, the sugar cane plantations were replaced by grazings. Sucessive drainage of the area reduced the swampy lowlands to about 15% of their original size. Once, during the Holocene, the aqueous system (lakes, lagoons and associated lowlands) was much more extensive, which explains the presence of peat deposits located to the E and W of the Saquarema lagoon (Martins & Silva, 1982). Due to the lack of any land use planning, some of these peat areas were improperly alloted for urbanization.

3.2.2 - In the lagoonal system - Despite its reduced size, Saquarema lagoon was distinguished by its abundant and diverse aquatic fauna. This was a consequence of its gret environmental complexity. The Saco de Urussanga was associated with a swampy area equivalent to its own dimensions and received a major influx of fluvial freshwater, thus exhibiting low salinities. The intermediate "sacos" Jardim and Boqueirão contained a dense aquatic vegetation, impeding the navigation of even small boats. The Saco de Fora, directly connected with the open sea, showed higher salinities and contained oyster banks. Mangrove swamp extended from the western margin of Saco de Fora as far as Boqueirão (Faria & Magalhães, 1954).

The richness of this ecosystem permitted the development of intensive fishing activities and up until the 1970's, there were about 200 professional fishermen, while presently this number has been reduced to less than 10. This decrease was caused by the reduction of fish productivity provoked by the destruction of a large number of ecological niches, such as: (a) the drastic reduction of swamp areas, as a consequence of drainage, with the extinction of certain fish, such as traíra (Hoplia malabaricus), (b) the disappearance of aquatic vegetation, in the 1970's, from the intermediate "sacos" introducing a reduction in the production of marine species such as corvine (Micropogonias spp.), shrimp (Penaeus spp.),etc.

The disappearance of these macrophytes was apparently an indirect consequence of eutrophication of the Saquarema lagoon, which began in the 1950's by "vinhoto" discharge from the Saco de Urussanga, and which was accelerated by the discharge of domestic wastes in Saco de Fora which began in the 1960's. Due to the increased availability of nutrients, floating marine algae such as Ulva sp., Cladophora sp. and Enteromorpha sp. proliferated excessively, giving rise to compact populations of more than 200 m (Almeida et al., 1986). These populations were displaced by winds as far as the area of macrophytes, reducing sunlight penetration in the water and retarding new germinations. Moreover, these algae would have probably contributed to an increase in the bottom organic matter content, giving rise to anaerobic conditions. This hypothesis is supported by a similar phenomenon which was demonstrated by Uthermohl (1982) in Gosser Ploner lake (West Germany).

3.3. CONCLUSIONS

The above mentioned environmental changes induced very drastic transformations in the structure of the ecosystem, with an accentuated impoverishment of species numbers. The extinction of several oyster banks in Saco de Fora, in the 1950's, was one of the first indications of this (Faria & Magalhães, 1954). The trophic chain became very simple, characterized by compartments of phytoplankton (mostly Cyanophyceae) and heterotrophic microorganisms.

The study presently being undertaken consists of an evaluation of the photosynthetic production rate and of microheterotrophic mineralization, because the evolution of the eutrophication process is a consequence of excessive organic production. The probable factors controlling these processes are being very carefully studied to obtain information which could be used in the restoration of the Saquarema lagoon.

EXCURSION ROUTE ALONG THE BRAZILIAN COAST BETWEEN SANTOS (STATE OF SÃO PAULO) AND CAMPOS (STATE OF RIO DE JANEIRO)

13th May: São Paulo to Rio de Janeiro

14th May: Rio de Janeiro to Arraial do Cabo

15th May: Arraial do Cabo to São Tomé

16th May: São Tomé region

17th May: São Tomé to São Paulo

First day (13th May)

Departure from São Paulo: 07.00 h

Arrival in Rio de Janeiro: 20.00 h

Overnight: Real Palace Hotel
Telephone: (021) 541-4387

Itinerary: Departure from São Paulo towards Santos along the "Imigrantes" express-way, passing initially across the Precambrian plateau (Planalto Atlântico), and descending about 800m as far as the Santos coastal plain. From São Paulo to Rio de Janeiro, about 700 km distant along the coastline route, we shall go through Santos, Caraguatatuba and Ubatuba in the State of São Paulo, followed by Parati, Angra dos Reis and Mangaratiba, etc. in the State of Rio de Janeiro (Fig. 24).

Stop 1/1 (Themes I and IV)

Subjects:
- Panoramic view of Santos coastal plain;
- Instability of steep slopes of Serra do Mar (Coastal Ranges);
- Industrial Pollution in Cubatão.

Location: Serra do Mar (Coastal Ranges).

1. Santos coastal plain (Fig. 25)

1.1 - General characteristics - The Santos coastal plain forms a crescent 40 km long and up to about 15 km wide, which is limited by the Mongaguá mountains to the south and by the rocky portion of the Santo Amaro island to the north. In the central and northeastern parts, the coastal plain is drained by lagoonal and tidal channel systems which isolate the São Vicente and Santo Amaro islands.

Löfgren (1893) noted the presence of 30 shell-middens along this coastal plain, 6 of which have been dated by the

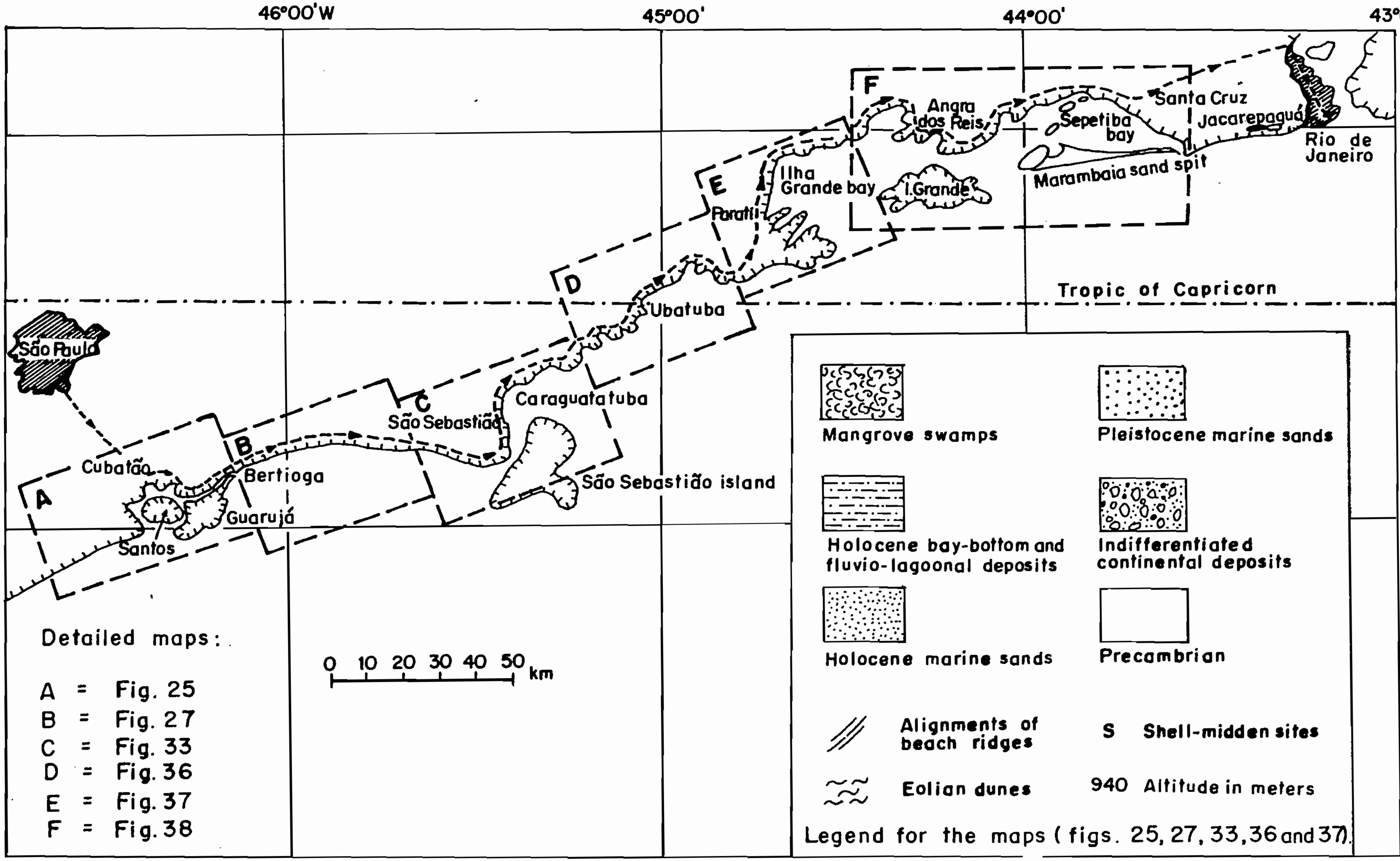

Fig. 24 — Itinerary of the 1st. day : São Paulo to Rio de Janeiro.

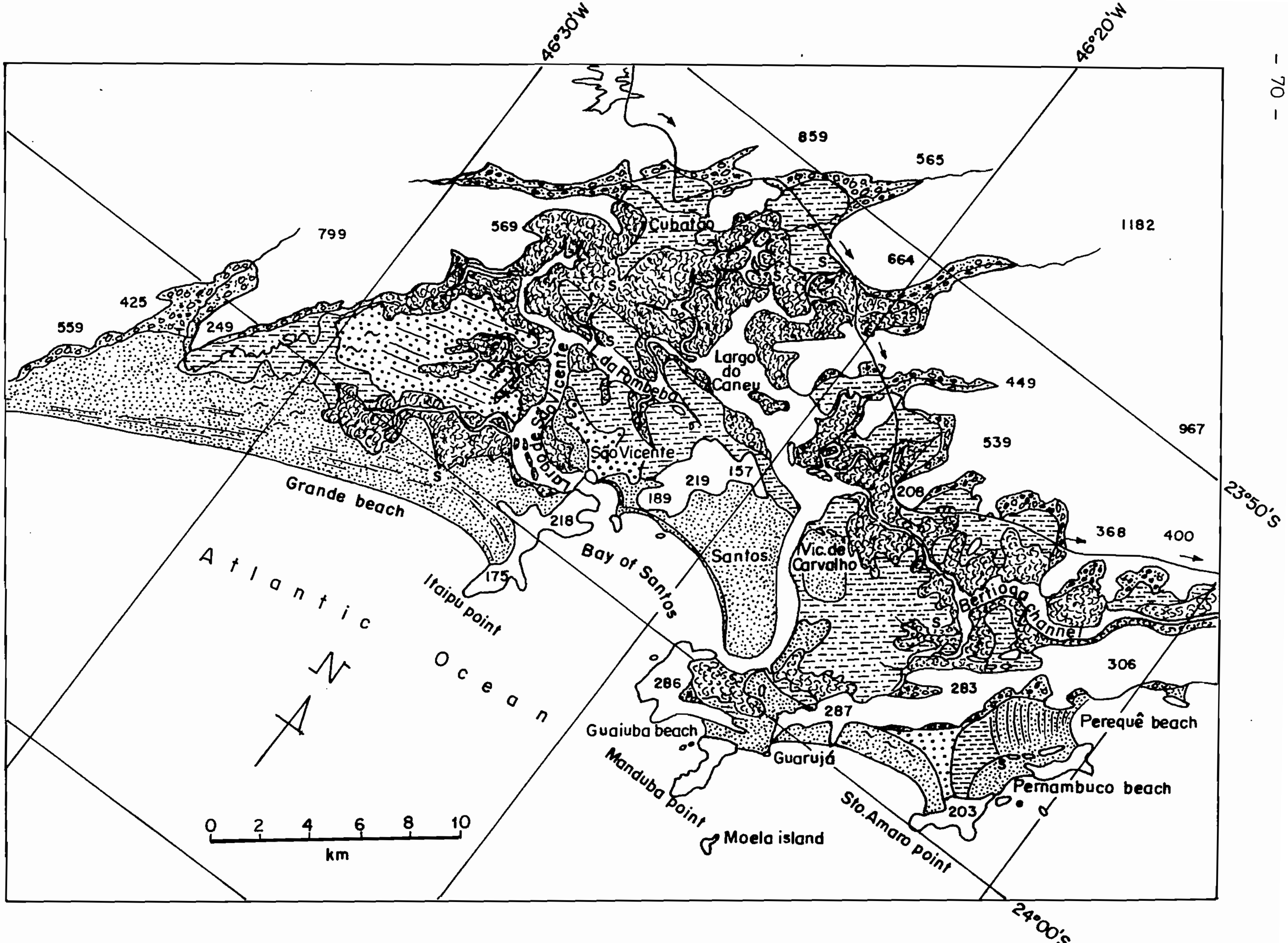

Fig. 25 – Geologic map of the Santos coastal plain (mod. from Suguio & Martin, 1978).

radiocarbon method.

1.2 - Quaternary marine and lagoonal formations

a) Sedimentary deposits related to the Cananéia transgression - In the southwestern part of the coastal plain between the Piaçabuçu and Branco rivers (Samaritá region), there are important outcrops of littoral marine sands characterized by the presence of <u>Callichirus</u> burrows and regressive beach ridges. Frequently, these sedimentary deposits have been superficially reworked by eolian processes and thus exhibit sand dunes on their tops. Along the Mariana river, the upper part of the littoral sands is about 7 m above present high-tide level. Another outcrop of the Cananéia Formation is found in the western part of São Vicente island. Fossil wood from an argillaceous intercalation near the top of these sands, dated at more than 35,000 years B.P., confirms their Pleistocene age. Nowever, similar deposits are not observed in the northeastern part of this coastal plain, with the exception of small outcrops in the Guarujá region.

b) Sedimentary deposits related to the Santos transgression - Sandy littoral marine deposits characterized by <u>Callichirus</u> burrows and regressive beach-ridges comprise a continuous band between Mongaguá and the Itaipu hills. Tree trunks found in their growth positions, covered by these marine sands, have been dated at 6,250 ± 130 years B.P. (Gif - 3845) and 6,480 ± 75 years B.P. (Ba - 327). These ages indicate very well that these deposits were formed during the last transgression. The summits of these marine sandy deposits are about 4.5 to 4.7m above present high-tide level.

Several drillings have shown that the city of Santos lies upon Holocene sands, which in turn is located upon lagoonal clayey-sandy sediments. In the same way, the sea-front of Santo Amaro island is made up of Holocene marine sands abutting against the rocky portion of the island. Their Holocene age is confirmed by the dating of <u>in situ</u> mollusc shells (4,210 ± 145 years B.P. - Ba. 353) from a trench opened in the Acapulco allotment behind Pernambuco beach.

The rest of the coastal plain essentially consists of clayey-sandy, fluviatile-lagoonal, sedimentary deposits.

At the lagoon margins and in the tidal channels, major developments of mangrove swamps occur, which in some places reach the foot of the Serra do Mar.

1.3 - Mechanisms of formation of the Santos coastal plain - At the maximum of the Cananéia transgression the sea reached the foot of the Serra do Mar. Drilling profiles which we have studied suggest that transgressive clayey-sandy sediments were laid down upon continental deposits, probably equivalent to the Pariquera Açu Formation, which in turn rest upon Precambrian crystalline rocks (Fig. 26A). Transgressive sands were deposited on the argillaceous sediments and, during regression, beach-ridges and eolian dunes were formed. It is probable that the southwestern part of the coastal plain was not covered by these regressive sands (Fig. 26B). During the last major regression, when sea-level was -110 m in relation to the present level, the older deposits were partially eroded; in places, even the crystalline basement was eroded down to -50m. When the Santos transgression occurred, the sea entered these low-lying zones and established lagoonal systems in which argillaceous sediments with shell debris and plant fragments were deposited. Several drillings have shown that these lagoonal deposits may be about 50 m thick in certain areas of the coastal plain. At the same time, higher parts of the Pleistocene marine deposits were eroded, thereby providing material for deposition as transgressive Holocene sands. An extensive lagoon formed behind these deposits, which was filled in by sediments and invaded by mangrove vegetation during the return of sea-level to its present position. It has not yet been possible to recognize the occurrence of multiple generations of Holocene beach-ridges. However, the minimum sea-level at 3,800 years B.P. seems to be confirmed by shells of the Maratuá shell-midden dated at 3,865 ± 95 years B.P. (I.9185), according to Garcia (1977), and at 3,935 ± 140 years B.P. (Bah. 382). In fact, the shell-midden substrate is below the present high-tide level (Emperaire & Laming, 1956). Even if the shell-midden substrate has been subjected to some sinking, it is reasonable to suppose that, about 3,800 years ago, sea-level was near to or even below the present level. Vermetidae samples dated at 3,625 ± 100 years B.P. (Bah. 352) indicate an ancient sea-level of +2.5 m. This seems to corroborate the occurrence of a second maximum at about 3,500 years B.P.

Radiocarbon ages of samples from the Santos coastal plain

a) Geological samples

Sample	Nature	Position of ancient sea-level	Age in years B.P.	Laboratory reference	Coordinates
A988	Fossil wood	-11 (± 1m)	7,550 ± 170	Bah. 233	23°52,7'S 46°26.1'W
A272	Fossil wood	+1m (±0.4m)	6,565 ± 115	Bah. 449	24°00.8'S 46°23.3'W
A234	Fossil wood	Below +2m	6,480 ± 75 6,250 ± 130	Bah. 327 Gif.3825	24°00.8'S 46°23.3'W

Sample	Nature	Position of ancient sea-level	Age in years B.P.	Laboratory reference	Coordinates
A238	Fossil wood	+0.8m (± 0.4m)	6,280 ± 130	Gif. 3646	23°57.2'S 46°26.3'W
A271	Fossil wood	+1.2m (± 0.4m)	6,220 ± 125	Bah. 448	24°00.8'S 46°23.3'W
A237	Shell	+1.3m (± 0.4m)	6,200 ± 165	Bah. 329	24°00.8'S 46°23.3'W
A273	Fossil wood	+1.7m (± 0.4m)	5,795 ± 125	Bah. 450	24°00.8'S 46°23.3'W
A232	Fossil wood	+2.4m (± 0.4m)	5,455 ± 170	Bah. 326	24°00.1'S 46°26.3'W
A254	Vermetidae + algae	+3.4m (± 0.4m)	5,010 ± 120	Bah. 354	23°52.3'S 46°50.8'W
Lab.I*	Vermetidae	+3.0m (± 0.4m)	4,480 ± 180	Gif. 2147	23°55.0'S 46°14.0'W
A247	Shell	+2.5m (± 0.5m)	4,210 ± 145	Bah. 353	23°57.8'S 46°12.3'W
A239	Fossil wood	+2.8m (± 0.4m)	4,100 ± 110	Gif. 3847	23°57.2'S 46°26.4'W
A244	Vermetidae	+2,6m (± 0.4m)	3,625 ± 100	Bah. 352	24°00.9'S 46°17.7'W
A249	Vermetidae	+1.4m (± 0.4m)	790 ± 90	Gif. 3848	23°58.4'S 46°11.3'W
A270	Fossil wood	+0.4m (± 0.4m)	530 ± 80	Bah. 354	24°00.8'S 46°23.3'W

b) Shell-middens

Name	Position of ancient sea-level	Ages in years B.P.	Laboratory reference	Coordinates
Piaçagüerea(1)	Above present level	4,930 ± 110	I. 4481	23°51.8'S 46°22.1'W
Mar Casado(2)	Below +3m	4,400 ± 130	Gif.1194	23°57.9'S 46°11.5'W
A229	Below +3.5m (After a maximum)	4,520 ± 150	Bah. 328	24°00.1'S 46°26.2'W
Casqueirinho(3)	Not indicative	4,300 ± 180	SPC-15	23°53.0'S 46°23.0'W
Maratuá(4)	Below 0m	3,935 ± 145 3,865 ± 95	Bah. 382 I. 9185	23°57.0'S 46°15.0'W
A219	Below + 1m	545 ± 90	Bah. 330	23°55.8'S 46°24.8'W

Samples colected by: (*) = J. Laborel, (1) = Caio del Rio Garcia & Dorath P. Uchoa, (2) = Paulo Duarte, (3) = J.A. de Moraes Passos and (4) = J. Emperaire.

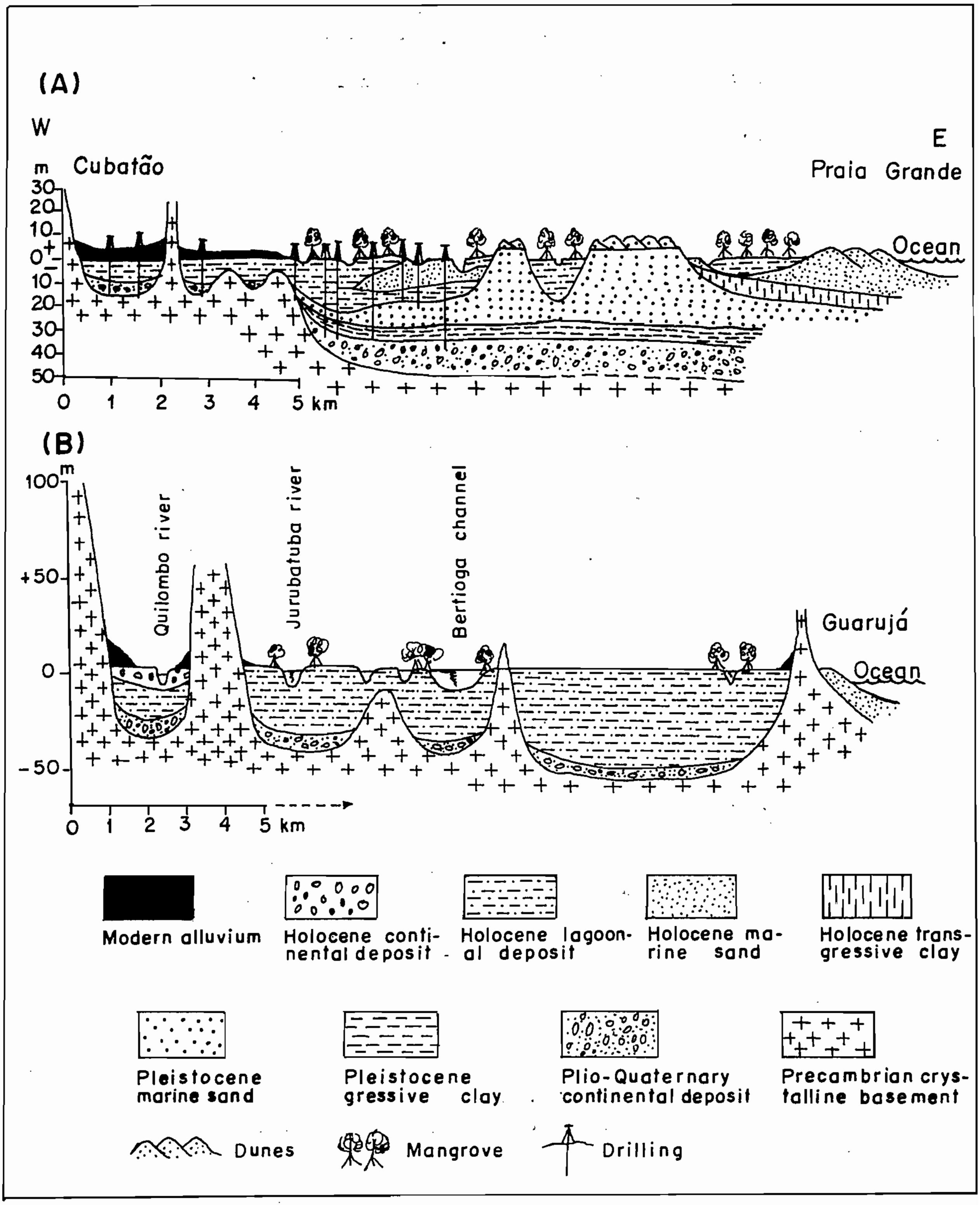

Fig. 26 – Interpretative profiles of the Santos coastal plain: (A) between Cubatão and Praia Grande and (B) between Quilombo river and Guarujá.

2. Bertioga coastal plain (Fig. 27)

2.1 - General Characteristics - The Bertioga sedimentary plain, northeast of the Santos coastal plain, from which it is separated by the Bertioga channel, is about 45 km long and 7 to 8 km wide. There are no lagoons in this region, although three rivers (Itapanhaú, Itaguaré and Guaratuba) drain lowlands composed of ancient lagoonal sediments deposited when the sea-level was higher than present. In front of the Serra do Mar, on the coastal plain, there exist several hills of crystalline rocks recently connected to the continent by tombolos.

Shell-middens have not been found in this region, which may be related to the very restricted development of the lagoonal areas.

2.2 - Quaternary formations of marine and lagoonal origin

a) Sedimentary deposits related to the Cananéia transgression - Between the town of Bertioga and Itapanhaú river a limonitized sandy formation is found which is morphologically distinct from other deposits of the coastal plain. Its top is situated at least 5.5m above present high-tide level. The relationship between marine terraces (Fig. 28) suggests that the limonitized sandy deposits are older than 6,000 years B.P. and were probably deposited during the Cananéia transgression (120,000 years B.P.).

It is possible to cross the coastal plain from Enseada hill as far as the Itaguaré and Una outlets without finding any trace of the Pleistocene marine formation. Nevertheless, it is possible that it may be represented northeast of Itaguá hill.

b) Sedimentary deposits related to the Santos transgression - The majority of the coastal plain is formed of sandy deposits which originated during the last transgressive phase. The above-mentioned age of 6,020 ± 130 years B.P. shows that these sands were partially deposited during the first positive fluctuation of sea-level. Another dating, made on a wood fragment which was also collected from argillaceous sediments covered by sand, gave an age of 3,250 ± 130 years B.P. (Bah.498). These clays and sands abut against the older formation which was deposited during the first fluctuation and thus would have been deposited during the second positive sea-level fluctuation.

Since lagoons are almost absent from the area, mangroves are poorly developed and are restricted to the lower courses of the rivers.

2.3 - Mechanism of formation of the Bertioga coastal plain - During the maximum of the Cananéia transgression, the sea

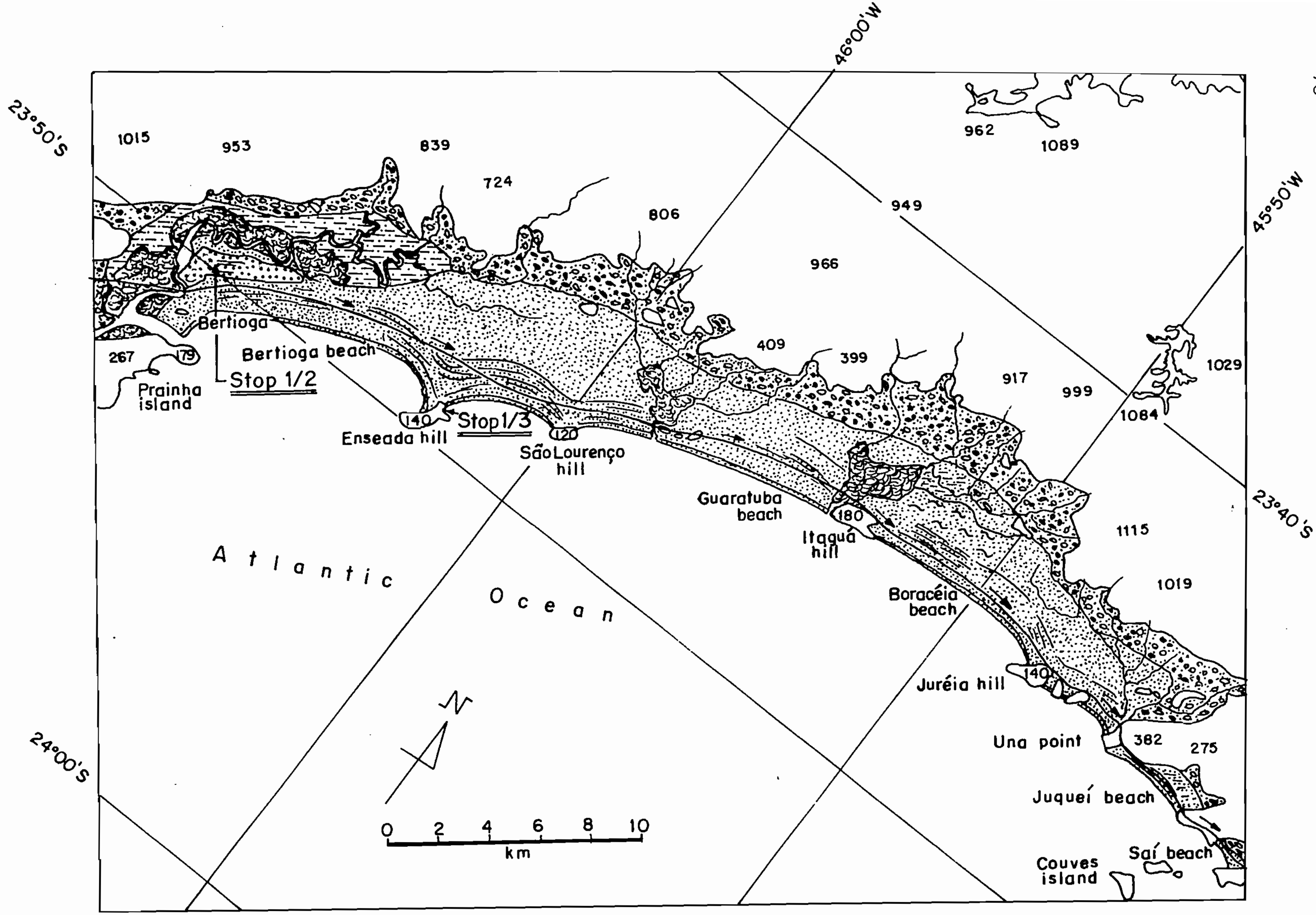

Fig. 27 – Geologic map of the Bertioga coastal plain (mod. from Suguio & Martin, 1978).

reached the foot of the Serra do Mar, and transgressive sands were deposited. During the regression, these sands were covered by beach ridges. When the sea-level was lower than at present, these sands were eroded to varying degrees. The remainder of the sandy deposits were practically destroyed during the last transgressive phase. Pleistocene sands found near Bertioga have been protected from erosive wave action by the extremity of Santo Amaro island.

During the first Holocene maximum, the sea reached the foot of the Serra do Mar twice, depositing marine littoral sands each time. When a minor regression occurred, these deposits were covered by beach-ridges. With the Holocene transgressive episode, the sea encroached upon low-lying zones, depositing clays rich in organic remains and simultaneously destroying part of the previous deposits. The beach-ridges which are so clearly seen on aerial photos, mostly along the external part of the coastal plain, must have formed during the retreat of the sea towards its present level. The Enseada, São Lourenço, Itaguá and Juréia hills may have been connected to the continent during the regression after 5,100 years B.P. Near to the foot of the Serra do Mar, modern alluvium and colluvium covered the marine sediments.

Radiocarbon ages of geological samples from the Bertioga coastal plain.

Sample	Nature	Position of ancient sea-level	Ages in years B.P.	Laboratory reference	Coordinates
A256	Fossil wood	+ 1m (± 0.5m)	6,020 ± 130	Gif. 3850	23°50.5'S 46°08.6'W
A274	Fossil wood	+ 2.5m (±0.5m)	3,520 ± 130	Bah. 498	23°49.8'S 46°08.1'W
A263	Beach rock	+ 1.9m (±0.4m)	5,470 ± 100	Bah. 609	23°49.1'S 46°02.2'W
A266	Vermetidae	+ 1.6m (±0.4m)	2,240 ± 90	Bah. 357	23°47.8'S 45°59.7'W
A267	Vermetidae	± 1.5m (±0.4m)	1,985 ± 120	Bah. 358	23°45.9'S 45°48.1'W
A264	Vermetidae	± 1m (±0.4m)	1,270 ± 130	Bah. 356	23°49.2'S 46°02.2'W

Stop 1/2 (Theme I)

Subject: Pleistocene sandy marine terrace (High sea-level of 120,000 years B.P.)

Location: Jardim Nunes - Bertioga coastal plain (Fig. 27)

Fine to very fine sands partially cemented by humic acids and, probably, iron hydroxides. There are parallel horizontal stratifications, but it is not possible to find Callichirus burrows, these probably being located in deeper zones. Here, the top of the terrace is situated about 5.5 m above present high-tide level.

In the Bertioga coastal plain, only this outcrop can be attributed to the Cananéia Formation. It has probably been protected from the last transgression by the northern extremity of Santo Amaro island.

Stop 1/3 (Theme I)

Subject: Sandstone with shell debris cemented by calcium carbonate

Location: Enseada hill-Bertioga coastal plain (Fig.27)

This is an ancient beach deposit, cemented by calcium carbonate and protected from the erosional action of waves. During its deposition, Enseada hill was probably an island and was later connected to the continent after regression.

This deposit is composed of quartz grains and shell debris. By a comparison of its characteristics with those of equivalent modern sediments, it is possible to conclude that it was deposited within a zone between mean level and low tide (Fig. 29). As the mean level is positioned at +0.8m, the middle point of the equivalent deposit is +0.4 (±0.4m). Nevertheless, part of the deposit may have been eroded, under these conditions, and the present top of this deposit would testify to an ancient sea-level situated at +4.6 (±0.4)m above present level.

The formation does not present any discontinuity and, therefore it was deposited during one transgressive episode. Shell fragments sampled 1.9m above the mid-point of the equivalent deposit have been dated at 5,470 ± 100 years B.P. Thus, it is possible to infer that relative sea-level was about +1.9 (±0,4)m above the present level at that time. Another sample collected at the top was dated at 3,475 ± 70 years B.P. An important negative sea-level oscillation was produced between 5,470 and 3,475 years B.P. (Fig. 5E) and, since the deposit does not show any discontinuities, it is probable that one of these ages is not correct. In fact, an excessively negative (-7.25°/oo) $\delta^{13}C_{(PDB)}$ value suggests that Bah. 355 must correspond to a highly recrystallized, and therefore rejuvenated, sample (Fig. 30), according to Martin et al. (1979).

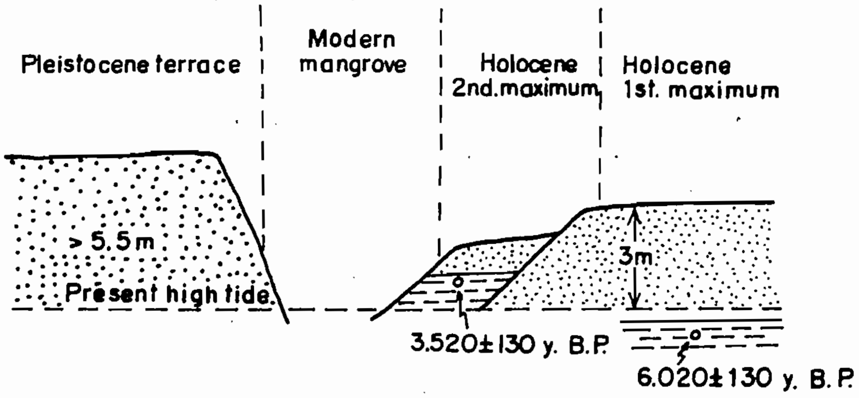

Fig. 28 — Holocene marine terraces and their relation to Pleistocene terrace at the Bertioga coastal plain.

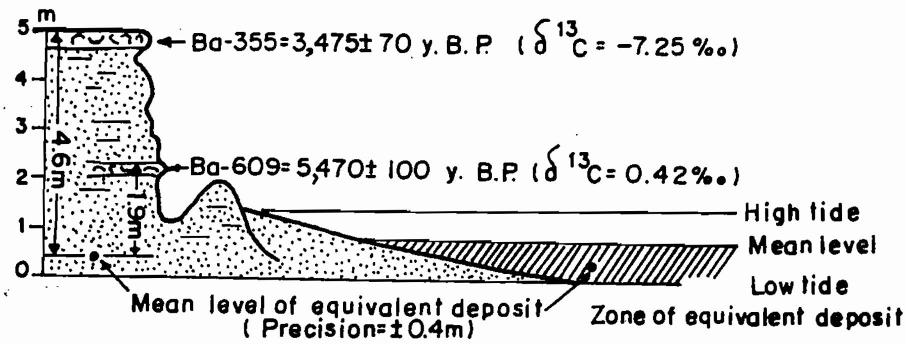

Fig. 29 — Positions of dated samples in relation to present zone of equivalent deposit.

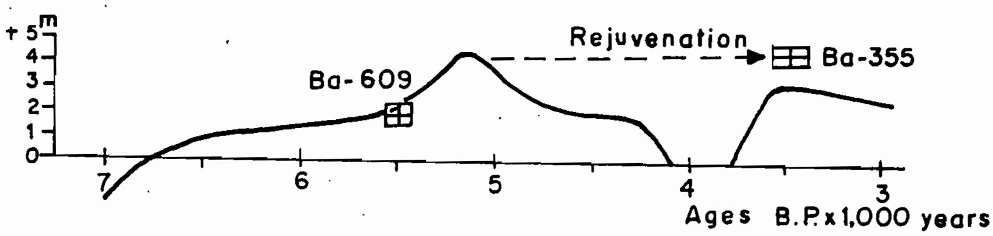

Fig. 30 — Positions of dated samples in relation to the relative sea-level variation curve for the Santos area (mod. from Martin et al, 1979a).

3. Coastal region between the Una outlet and São Sebastião island (Fig. 27, 31 and 32)

In this part of the coastal area, only small sedimentary plains have been developed, which are from W to E: the Juqueí, Saí, Baleia, Camburi, Boiçucanga, Maresia, Paúba, Toque-Toque, Guaecá and Baraqueçaba plains.

Almost without exception, these plains consist of continental sediments in their inland portion and marine sediments in their seaward portion. Sedimentary deposits related to the Cananéia transgression have not been observed. Field observations permit the recognition of two types of coastal plains, which are best represented by the Juqueí and Boiçucanga plains.

3.1 - Juqueí-type coastal plain - In this type, the majority of the plain consists of a lower zone of clayey-sandy sediments which are separated from the sea by a clearly more elevated sandy marine belt (Fig. 31).

The origin of this type of coastal plain can be understood in the following way. After a higher sea-level period, a sand bar, abutting against two Precambrian headlands, formed and subsequently closed an ancient bay occupying the position of the present coastal plain. Behind the sand bar, a lagoon was formed in which clayey-sandy sediments were deposited. When the sea-level returned to its present position, the original sand bar was subjected to enlargement by the lateral accretion of beach-ridges. Simultaneously, the lagoon showed an increasing tendency to fill and dry up. After the disappearance of the lagoon, the lagoonal sediments were partially covered by continental deposits. Some of the coastal plains which formed in this way are those of Baleia and Camburi.

3.2 - Boiçucanga-type coastal plain - In this type, the marine sediments are directly in contact with continental sediments at the foot of the Serra do Mar (Fig. 32). The reason why the formation of this type of coastal plain is not related to a sand bar separating a lagoon can probably be explained by differences in wave and current energy, as well as by the morphology of that part of the coastal plain. The coastal plains of this type are those of Maresia, Paúba, Toque-Toque, Guaecá and Baraqueçaba.

4. Coastal region between São Sebastião island and Parati mountains (Fig. 33 and 36)

This part of the coastal region, which embraces the Caraguatatuba, Ubatuba and Parati regions, is about 100 km long in a straight line and is characterized by having very restricted

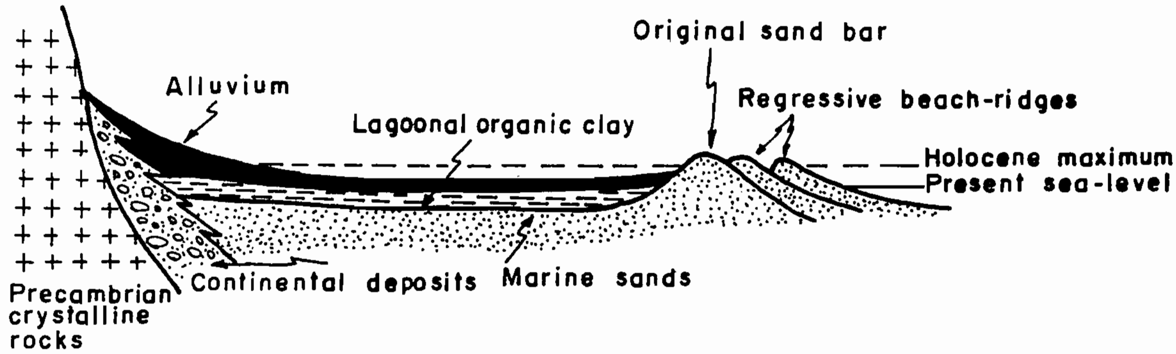

Fig. 31 — Interpretative profile of the Juqueí coastal plain.

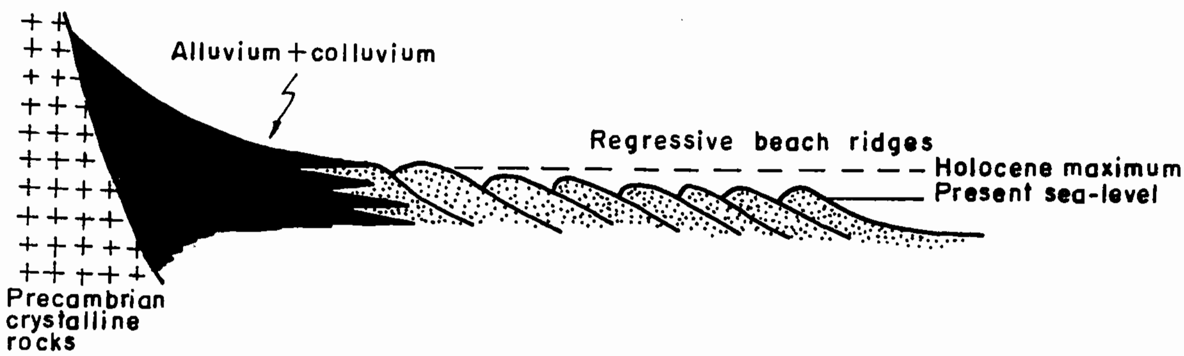

Fig. 32 — Interpretative profile of the Boiçucanga coastal plain.

marine sedimentary deposits. Only the Caraguatatuba coastal plain has significant sedimentary deposits.

Stop 1/4 (Theme I)

Subjects: Pleistocene and Holocene marine terraces

Location: Caraguatatuba coastal plain (Fig. 33)

4.1 - Quaternary formations of marine and lagoonal origin

a) Sedimentary deposits related to the Cananéia transgression - Remains of highly dissected 7 to 8 m high marine terraces are found especially in the northern part of the coastal plain (between Indaiaquara and Empresa hills). Some minor records are found in the central and southern parts. The Pleistocene age of these deposits is suggested by fossil wood fragments which are more than 6,000 years old, found within sandy formations deposited in eroded portions of the older sands. A series of drillings by the Instituto de Pesquisas Tecnológicas S/A permitted the construction of a profile which, shows the relationship between these formations (Fig. 34).

b) Sedimentary deposits related to the Santos transgression - Based upon geomorphological studies, Cruz (op.cit.) recognised two generations of Holocene beach-ridges. Shell samples collected from the zone of second generations (more recent) ridges, near to their contact with first generation beach-ridges, were dated at 2,750 ± 130 years B.P. (Bah. 452). This age places these deposits in a much more recent period than that of the second Holocene maximum. Therefore, it seems logical that the more inland beach-ridges would have been formed soon after the first Holocene maximum.

Behind the older beach-ridges, there is an extensive low-lying zone consisting of clayey deposits. Shells and wood fragments collected from the clays 15 m below the present sea-level indicate ages ranging from 8,030 ± 150 years B.P. (Gif. 3434) to 4,400 ± 110 years B.P. near the surface). Thus, these clay deposits are related to the Santos transgression. Still older deposits, which are also deeper, were deposited in even lower areas which had formed by erosion during the previous regression.

4.2 - Mechanism of formation of the Caraguatatuba coastal plain - The stages which can be associated with the formation of this coastal plain are as follows (Fig. 35):

a) First stage - During the maximum of the Cananéia transgression, the sea encroached over the entire area presently

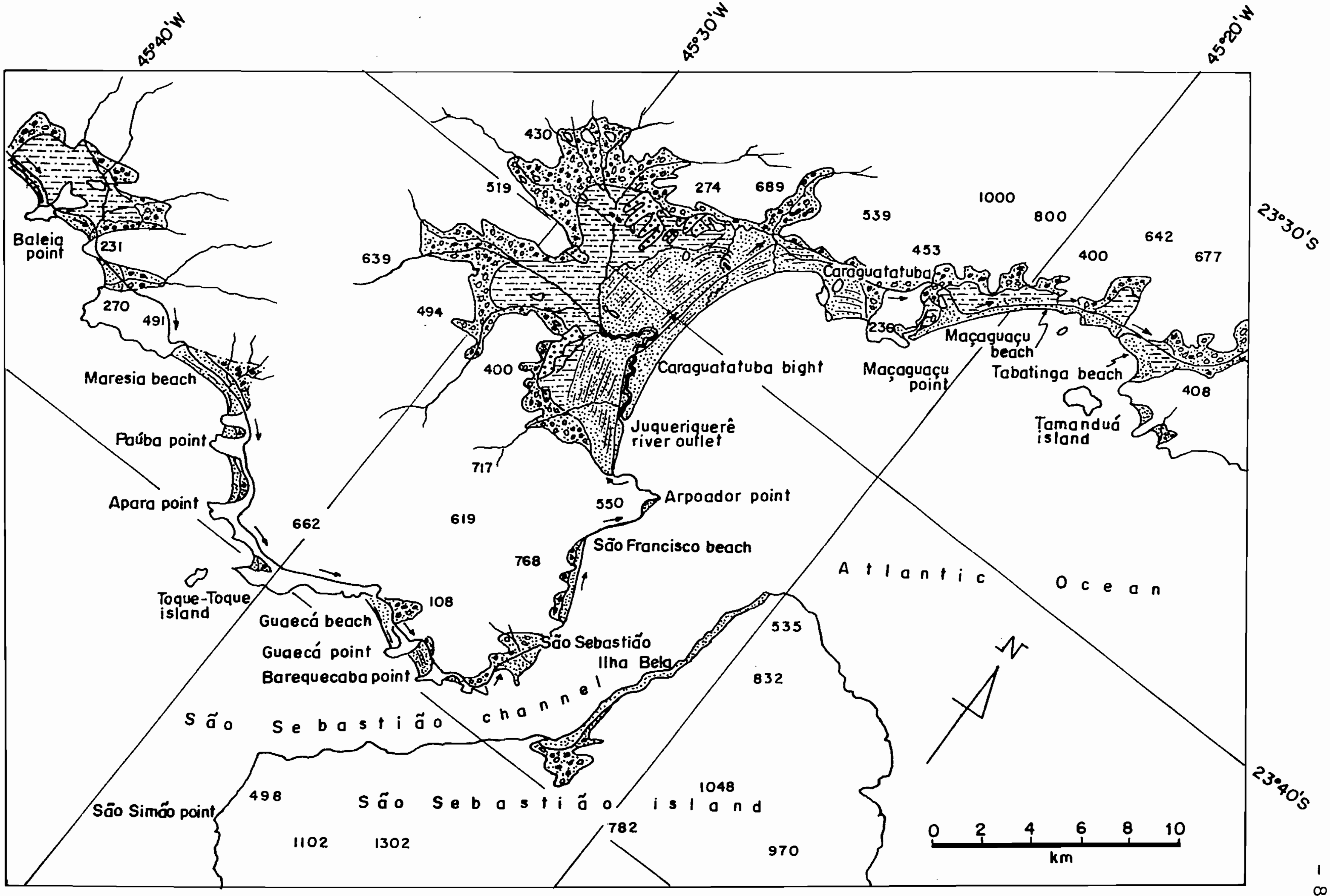

Fig. 33 – Geologic map of the Caraguatatuba coastal plain (mod. from Suguio & Martin, 1978).

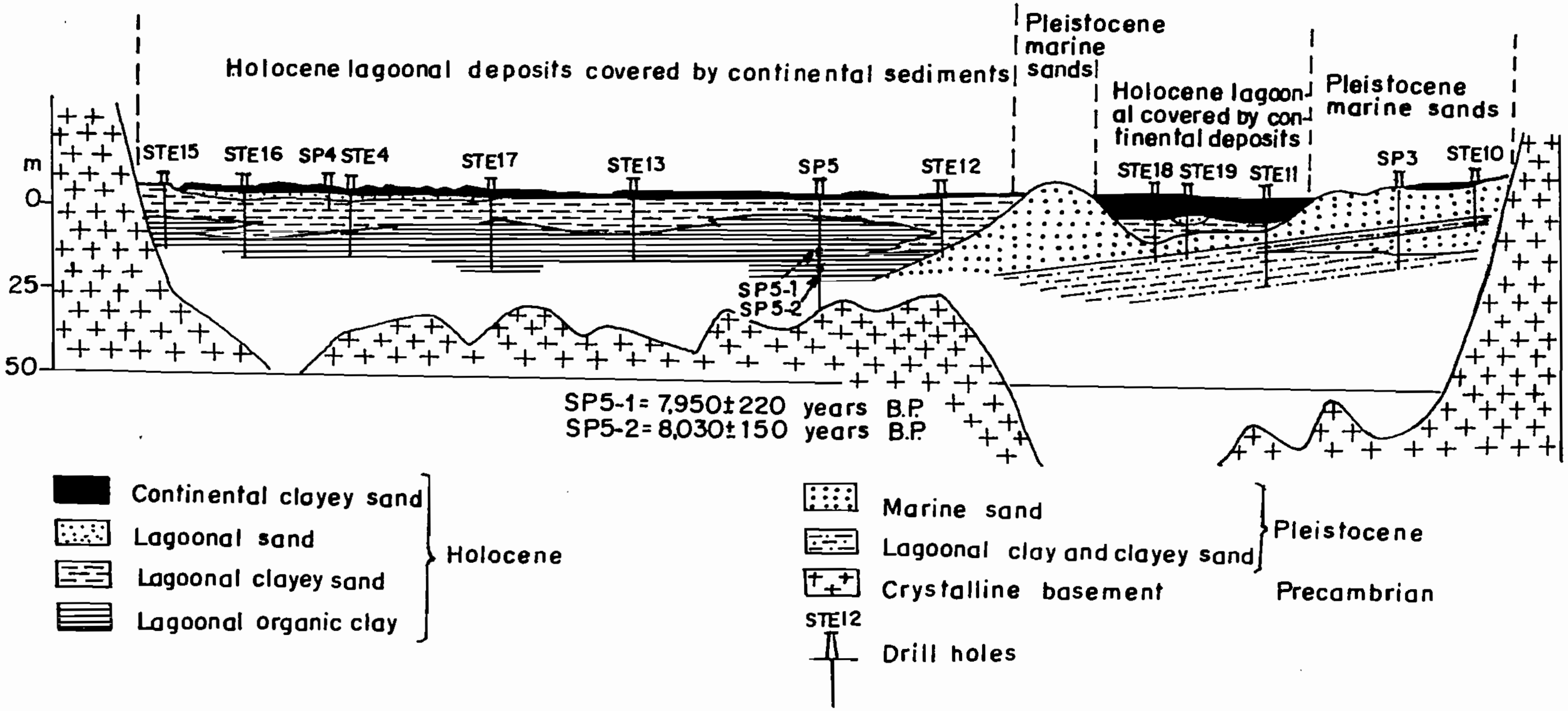

Fig. 34— Profile along the Caxeta line, Caraguatatuba (Mod. from Fulfaro et al., 1976).

occupied by the coastal plain and deposited transgressive marine sands. The base of the sequence is formed by transgressive argillaceous deposits.

b) Second stage - When the maximum transgression occurred, a barrier-island closed the interior of the bay and isolated two lagoonal zones, separated by the Camburu hill. Later, clayey-sandy sediments were deposited in these lagoons.

c) Third stage - During the regressive period, beach-ridges were added to the original sand bar, the lagoons dried up, and the surface of part of these deposits was covered by continental deposits. When the sea-level was lower than at present, the sandy marine formations and the clayey-sandy lagoonal deposits were deeply eroded. Drainage was preferentially established in the zones between beach-ridges.

d) Fourth stage - During the last transgression, the sea invaded the Caraguatatuba coastal plain twice. In the beginning, the invasion occurred preferentially across low-lying zones, with the establishment of lagoonal systems. Two wood fragments collected from old mangrove deposits which attest to ancient sea-levels at -12.5 ± 1 m and -16 ± 1 m were dated as 7,950 ± 220 years B.P. (Gif. 3433) and 8,030 ± 150 years B.P. (Gif. 3434), respectively. During this transgression, the sea partially or almost completely eroded the higher outcrops of the marine Pleistocene formations.

e) Fifth stage - After the maximum at 5,100 years B. P., a new barrier-island formed and a new lagoonal zone was established. Shells collected from clays near the surface were dated as 4,400 ± 110 years B.P. (Bah. 454).

f) Sixth stage - First generation Holocene beach-ridges were added to the barrier-island during the minor regression which followed the maximum at 5,100 years B.P.

g) Seventh stage - During the minor transgressive phase of 3,500 years B.P., the sea invaded the low-lying zones twice and a part of the first generation beach-ridges was eroded.

h) Eighth stage - During the return of sea-level to the present level, the second generation of Holocene beach-ridges was formed.

5. Coastal plains of restricted extent

5.1 - Maçaguaçu, Mococa, Tabatinga, Maranduba and Lagoinha coastal plains - These plains were formed in the same way as the Juqueí coastal plains. Sandy ridges enclosed small bays; subsequently, lagoons formed and were filled by organic and argillaceous sediments. After these lagoons dried up, continental

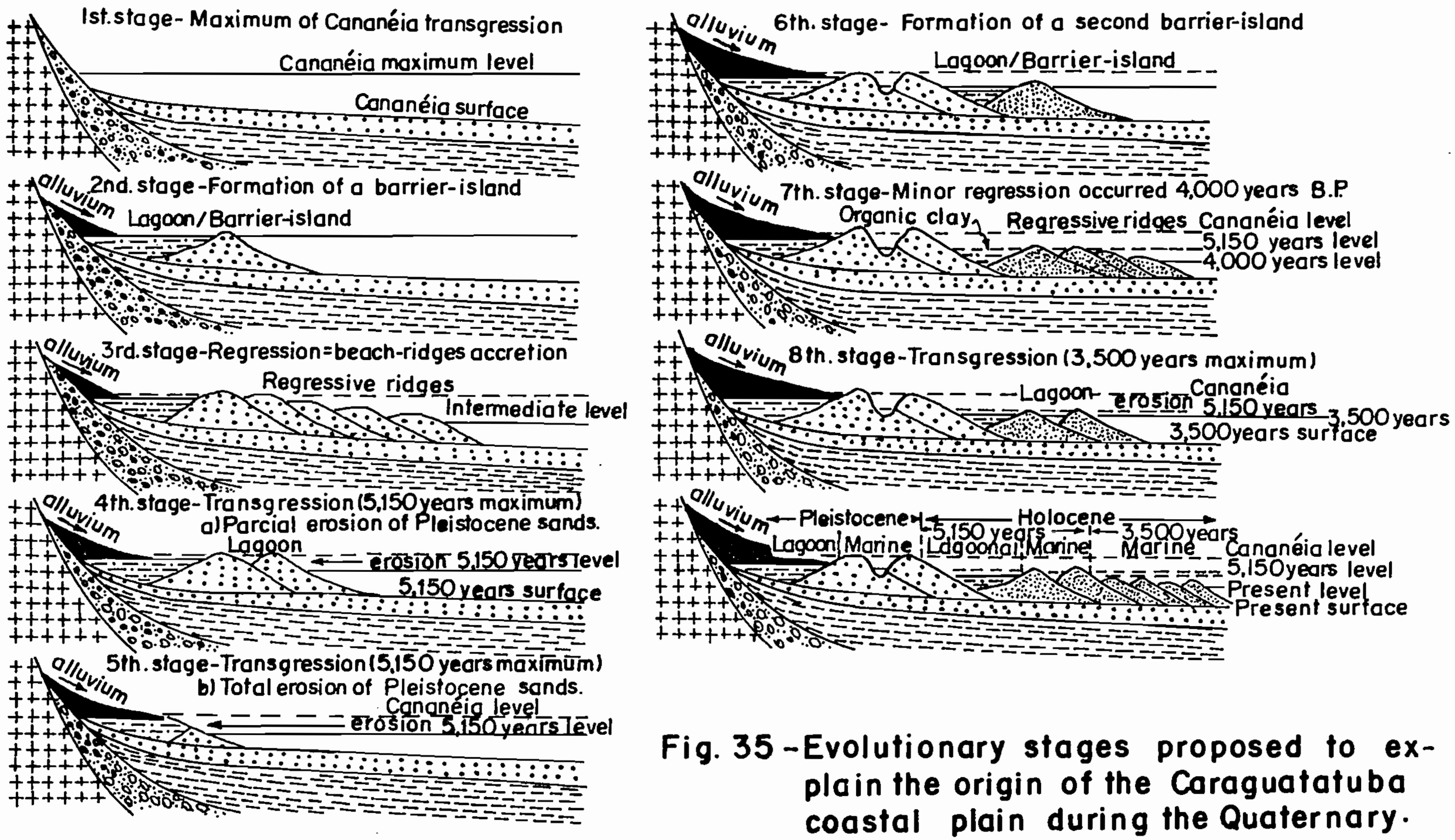

Fig. 35 - Evolutionary stages proposed to explain the origin of the Caraguatatuba coastal plain during the Quaternary.

Martin & Suguio (1978)

sediments partially covered their deposits.

It should be noted that the sands in these coastal plains are coarser than those in the south and that they can be built up to higher altitudes (5 to 6m above sea-level) during strong storms.

Records which can be correlated with the Cananéia transgression have not been found in these coastal plains.

5.2 - Fortaleza, Flamento, Toninhas, Praia Grande and Ubatuba coastal plains - These plains are of the Boiçucanga type; that is, marine sediments are in direct contact with continental deposits. Beach-ridges are well developed here (Fig. 36).

5.3 - Praia Vermelha do Norte coastal plain - In the northern part of Ubatuba, there exists small coastal plain which was closed by a high beach-ridge. Due to a drainage trench which has been excavated there, we could observe that this ridge is limonitized and fairly ancient. Its top is situated about 4m above the upper limit of the present beach. Very clear bedding planes, some dipping towards the continent, others dipping seawards, can be observed. This shows that the ridge was slightly submerged but was still separated from the open sea by a lagoonal zone.

No material which could be dated has been founded in this area. It is possible that this ridge is evidence of the Cananéia transgression, but it could also be evidence of the first Holocene maximum. The absence of shells may be one argument for a Pleistocene age. In fact, shells have never been found in Pleistocene sandy formations, apparently because they have been dissolved, whereas they are frequently observed in great abundance in Holocene deposits.

5.4 - Itamambuca, Puruba, Ubatumirim and Picinguaba coastal plains - These coastal plains are of the Boiçucanga type, with beach-ridges clearly visible on aerial photos. Two varieties of beach-ridges may be observed on aerial photos of the Puruba coastal plain, although this difference could not be verified in the field.

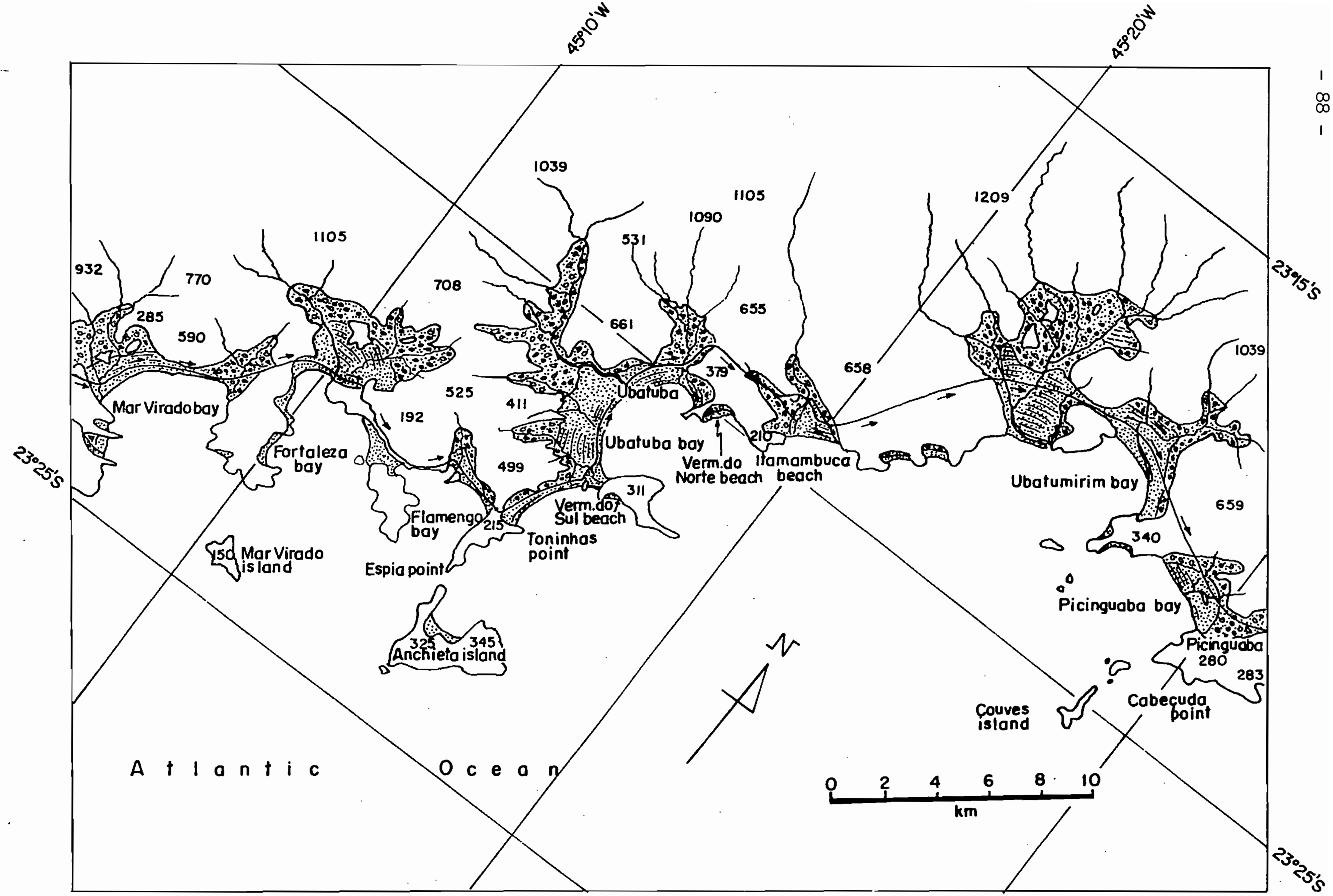

Fig. 36 – Geologic map of the Ubatuba and neighboring coastal plains (mod. from Suguio & Martin, 1978).

Radiocarbon ages of geological samples from coastal plains of restricted extent.

Sample	Nature	Position of ancient sea-level	Ages in years B.P.	Laboratory reference	Coordinates
SP05-2	Fossil wood	-16.5m (± 1m)	8,030 ± 150	Gif. 3434	23°39.3'S 45°29.0'W
SP05-2	Fossil wood	-12.5m (± 1m)	7,950 ± 220	Gif. 3433	23°39.3'S 45°29.0'W
A300	Shell	Near the present level	6,905 ± 185	Bah. 455	23°40.6'S 45°28.6'W
A302	Shell	Near the present level	6,890 ± 175	Bah. 456	23°41.3'S 45°28.8'W
A282	Oyster in situ	Above + 1.6m	4,605 ± 150	Bah. 462	23°44.9'S 45°28.8'W
A281	Vermetidae	+ 1.9m (0.4m)	4,455 ± 145	Bah. 461	23°44.9'S 45°20.8'W
A293	Shell	Above the present level, after a maximum	4,405 ± 110	Bah. 454	23°38.8'S 45°27.2'W
A290	Shell	Above the present level, after 2nd maximum	2,750 ± 130	Bah. 452	23°38.5'S 45°26.1'W
A280	Vermetidae	+0.8m (±0.4 m)	2,665 ± 130	Bah. 460	23°44.9'S 45°20.8'W
A309	Vermetidae	+1.2m (±0.4 m)	2,530 ± 130	Bah. 469	23°29.6'S 45°05.9'W
A307	Shell	+1.5m (±0.4 m)	2,085 ± 140	Bah. 457	23°34.4'S 45°17.5'W
A308	Vermetidae	+1.2m (±0.4 m)	1,840 ± 120	Bah. 468	23°30.0'S 45°08.5'W
A325	Vermetidae	+1.0m (±0.4 m)	1,490 ± 80	Bah. 482	23°14.8'S 44°37.6'W
A291	Shell	Above the present level	885 ± 115	Bah. 453	23°38.5'S 45°26.1'W
A305	Vermetidae	+1.0m (± 0.4 m)	865 ± 90	Bah. 463	23°37.9'S 45°23.4'W
A312	Vermetidae	+0.4m(± 0.4 m)	620 ± 120	Bah. 487	23°22,6'S 45°50.4'W

6. Ilha Grande bay region (Figs. 37 and 38)

Based upon geomorphological and structural features, due to the presence of the Guanabara graben, this unit can be subdivided into three parts.

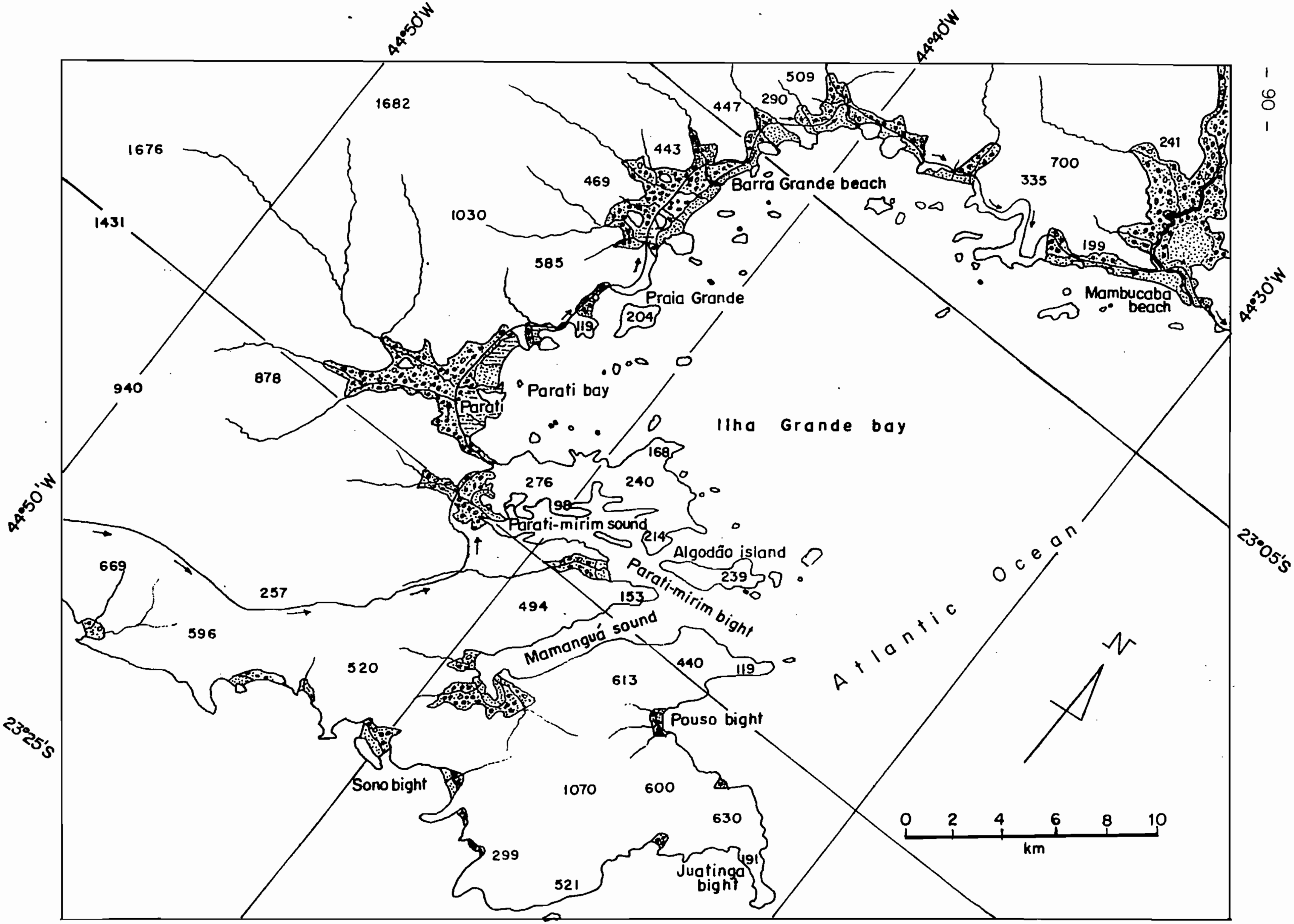

Fig. 37 – Geologic map of the Parati and neighboring coastal plains (mod. from Suguio & Martin, 1978).

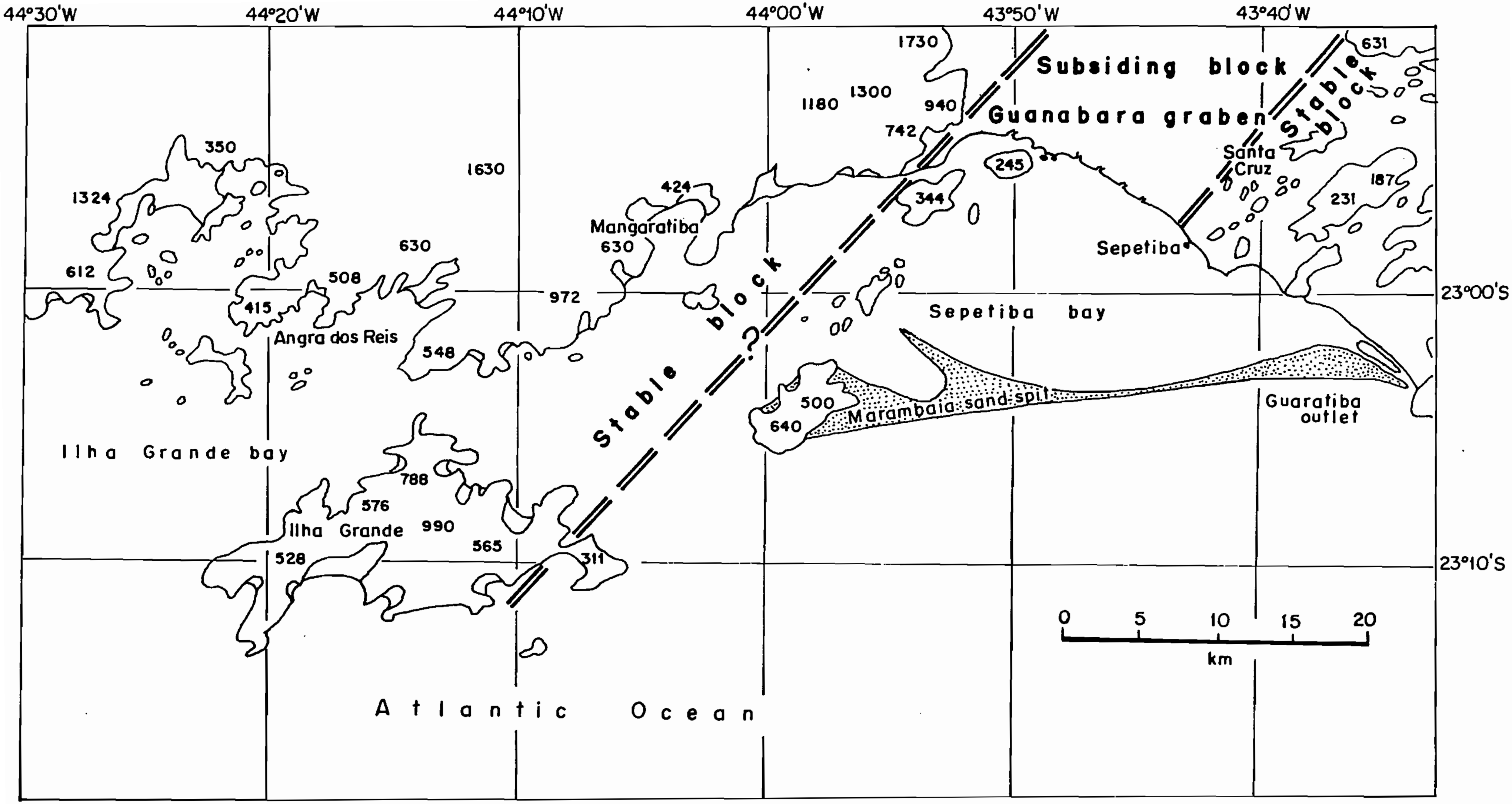

Fig. 38 – Schematic map of the Ilha Grande bay and its neighbors showing the possible structural framework affecting this area during the Cenozoic and still active.

6.1 - Part of the coastal plain region between Parati and Mangaratiba - This portion is situated on the western side of the Guanabara graben. Quaternary sedimentary deposits are very poorly developed. This region exhibits an irregular coastline which is characterized by a typical submersion morphology with several "rias", mostly in the Parati region (Mamanguá and Parati Mirim sounds). There are several islands of Precambrian rocks and the coastline is very indented. Sedimentary deposits related to the Cananéia transgressive phase have not been observed. There are several vermetidae and oyster incrustations on the rocky surfaces above the present life zones of these animals. Curray (oral communication) has dated in situ oysters 4.8 m above the present sea-level as 5,200 ± 200 years old (LJ.1364). It has not been possible to find the location of Curray's sample, which was collected during the construction of the BR-101 highway.

6.2 - Part of the coastal region at the southern extremity of the Guanabara graben - In this part, the coastal plain is low-lying, although marine deposits have not been found in surface outcrops. Possible lagoonal deposits with shell debris, found in drillings, were mentioned by Ponçano (1976).

6.3 - Part of the coastal region east of Sepetiba - Marine deposits situated above present sea-level are again observed when we leave the Guanabara graben. Near to the place named Pedra, an approximately 20-cm-thick shell bed lying upon a weathered crystalline surface is exposed. These shells indicate an ancient sea-level at least 2.5 m above the present level. Between Pedra and Guaratiba, a very flat low-lying sedimentary plain, which is superficially similar to that of the graben area, extends between the crystalline rocks and the ocean. However, in this case, we have a sandy-clayey deposit which is very rich in shell beds.

A strong contrast can be noted between the last two above-mentioned parts, even although they are morphologically similar. At the surface, in the area of the graben, only continental deposits are observed whereas East of Sepetiba well-developed marine beds occur above the present sea-level. Thus, sedimentary deposits related to ancient sea-levels which were higher than at present are evident on both sides of the Guanabara graben, although they are absent in the interior of the graben. However, before postulating Quaternary graben activity in order to explain these features, it will be necessary to date shell samples from the lagoonal deposits mentioned by Ponçano (op.cit.), in order both to define their position in time and space and to correlate their ages with sedimentary deposits located outwith the graben area.

Radiocarbon ages of geological samples from the Ilha Grande bay region.

Sample	Nature	Position of ancient sea-level	Ages in years B.P.	Laboratory reference	Coordinates
Curray I	Oyster in situ	+4.8 m (±?)	5,200 ± 200	LJ. 1364	22°57.0'S 44°25.6'W
A333	Shell	Above or equal to present level	4,900 ± 120	Bah. 492	23°01.0'S 43°36.0'W
Curray II	Oyster in situ	+4.8m (±?)	4,800 ± 200	LJ. 970	22°57.0'S 44°25.6'W
A340	Shell	More then +1.8m	4,395 ± 140	Bah. 631	22°58.7'S 44°27.0'W
A332	Shell	Above + 2.5m	3,550 ± 105	Bah. 492	22°59.8'S 43°39.0'W
Laborel II	Vermetidae	+3,0m (± 0.4m)	3,420 ± 110	Gif.1059	23°00.0'S 45°00.0'W
A327	Vermetidae	+1.7m (± 0.4m)	3,255 ± 100	Bah. 472	22°57.8'S 44°02.6'W
A330	Oyster in situ	More than +1,6m	3,055 ± 140	Bah. 474	22°55.7'S 43°50.6'W
A321	Vermetidae	+1.5m (± 0.4m)	2,695 ± 130	Bah. 465	22°58.7'S 44°26.3'W
A329	Vermetidae	+1.6m (± 0.4m)	2,595 ± 132	Bah. 473	22°55.7'S 43°50.6'W
A322	Oyster in situ	More than + 1.5m	2,510 ± 125	Bah. 466	22°58.7'S 44°26.3'W
A178	Shell	More than + 1.5m	2,390 ± 100	Gif.3647	23°08.2'S 44°42.3'W
A316	Vermetidae	+1.4m (± 0.4m)	2,300 ± 85	Bah. 470	23°09.2'S 43°41.8'W
A315	Oyster in situ	+1,7m	2,300 ± 95	Bah. 464	23°14.0'S 44°42.0'W
A320	Vermetidae	+1.5m	1,840 ± 90	Bah. 471	23°09.2'S 42°41.8'W
Laborel III	Vermetidae	+1.5m (± 0.4m)	1,670 ± 100	Gif.1060	23°00.0'S 45°00.0'W
A328	Vermetidae	+0.8m (± 0.4m)	1,630 ± 65	Bah. 499	22°58.2'S 44°02.8'W
A318	Vermetidae	+0.7m (± 0.4m)	975 ± 80	Bah. 478	23°02.9'S 47°36.7'W
A314	Oyster in situ	More than +0.9m	960 ± 110	Bah. 467	23°14.4'S 44°37.9'W
Laborel II	Vermetidae	+0.5m (± 0.4m)	380 ± 90	Gif.1061	23°00.0'S 45°00.0'W
A326	Vermetidae	+0.5m '± 0.4m)	230 ± 60	Bah. 483	23°01.0'S 44°13.3'W

The samples Curray I and II were collected by F. Danciger (DER-Rio de Janeiro) and dated by J. Curray.

The samples Laborel II, III and IV were collected by J.Laborel (Station Marine d'Endoume - France).

Second day (14th May)

Departure from Rio de Janeiro: 07,00 h

Arrival in Cabo Frio (RJ): 18,00 h

Overnight: Hotel Acapulco
Telephone: (0246) 43-0202

Itinerary: Departure from Rio de Janeiro towards Cabo Frio, passing by several coastal lagoons (Fig. 39) and, after travelling about 250 km we shall arrive at Hotel Acapulco in Cabo Frio to pass the night.

Departure from Rio de Janeiro towards Niterói, crossing Guanabara bay, and then to Cabo Frio along the RJ-106 highway.

The Rio de Janeiro State coastal plain, between Niterói and Cabo Frio, is characterized by the occurrence of two lagoonal systems. The inner one is composed of major lagoons (Maricá, Guarapina, Saquarema and Araruama). These lagoons are separated from the ocean by two systems of beach-ridges with different ages. Between these beach-ridges there is a lower zone, which is desiccated in certain sectors, although between Saquarema and Cabo Frio (Figs. 41 and 42) the depression is occupied by a rosary of small lagoons and lakes, the largest being the Lagoa Vermelha (about 2 km^2). The major lagoons exhibit a gradient of salinity, which increases from W to E (Maricá = 15°/oo, Guarapina = 20°/oo and Araruama = 58°/oo).

Some evidence suggests that, at least at Saquarema and Cabo Frio, the inner beach-ridges (separating the two generations of lagoons) are Pleistocene in age and were probably formed during a sea-level high about 120,000 years B.P. If this is true, then the major lagoons would be installed within low zones existing behind the Pleistocene sandy terrace, as in the Santa Catarina (Martin & Suguio, 1987) or Rio Grande do Sul (Villwock et al., 1987) coastal plains. Thus, the Holocene sandy deposits are restricted to an outer beach-ridge system. Their poor development could be explained by a strong declination of the foreshore, perhaps due to a tectonic influence. It is interesting to observe that modern beach sands present an exceptional degree of roundness, which is probably due to intensive reworking by waves over a long time interval.

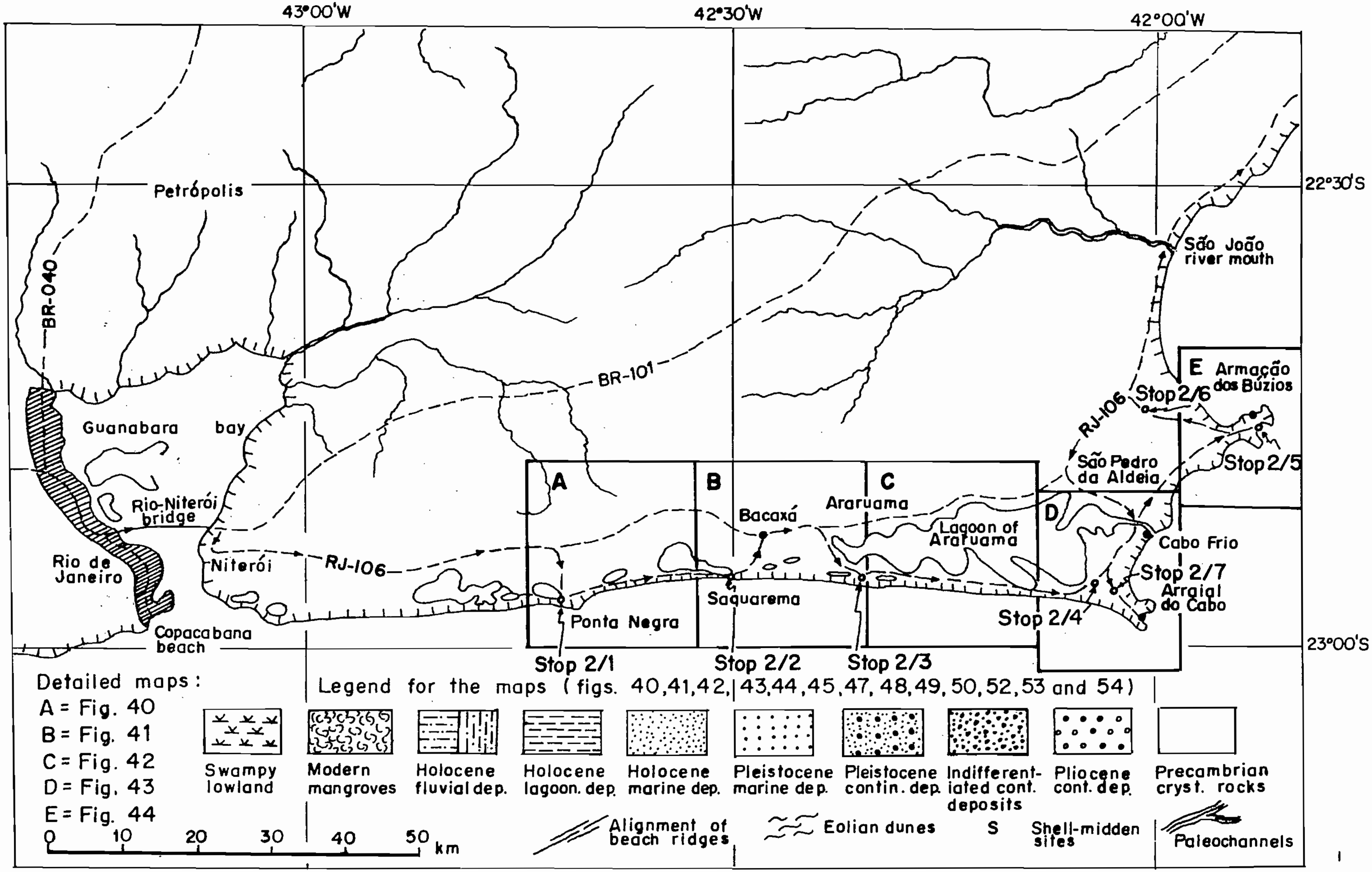

Fig. 39 — Itinerary of the 2nd. day : Rio de Janeiro to Arraial do Cabo.

Stop 2/1 (Theme IV)

Subject: Changes in natural environments (Project of the Department of Geochemistry, Universidade Federal Fluminense)

Location: Guarapina lagoon in Ponta Negra (Fig. 40).

From here, we shall go towards Saquarema lagoon, along a road situated upon a Holocene sand bar (Figs. 40 and 41), passing by Jaconé lake, presently isolated from the ocean.

Stop 2/2 (Theme IV)

Subject: Changes in natural environments (Project of the Department of Geochemistry, Universidade Federal Fluminense, coordinated by Dr. J. P. Carmouze: Agreement ORSTOM/CNPq).

Location: Saquarema lagoon.

The church of Saquarema (Fig. 41) is situated upon an ancient island composed of Precambrian crystalline rocks. Beneath the church, there are numerous shells representing the remains of a shell-midden which was constructed by ancient indians. Its situation is not suitable to supply us with any information about ancient sea-level changes (Martin et al., 1986e).

Departure from Saquarema towards Bacaxá along the RJ-106 highway, which must be left after about 10 km, heading towards Praia Seca and Araruama lagoon.

Stop 2/3 (Theme III)

Subject: Changes in carbonate and organic sedimentation as a consequence of modifications in microclimate in the Cabo Frio region.

Location: Lagoa Vermelha (Fig. 41).

A small core will be obtained, during the excursion, to show the rythmic alternations of carbonate and organic matter.

The route from Lagoa Vermelha to Cabo Frio will be along the Araruama lagoon margin (Figs. 42 and 43). The road has been constructed at the foot of or upon the inner sand bar, which is probably of Pleistocene age since it is situated at the margin of a Holocene bar. It is interesting to observe the abundant occurrence of salt marshes, related to the semiarid microclimate and hypersalinity of the Araruama lagoon due to the upwelling in Cabo Frio.

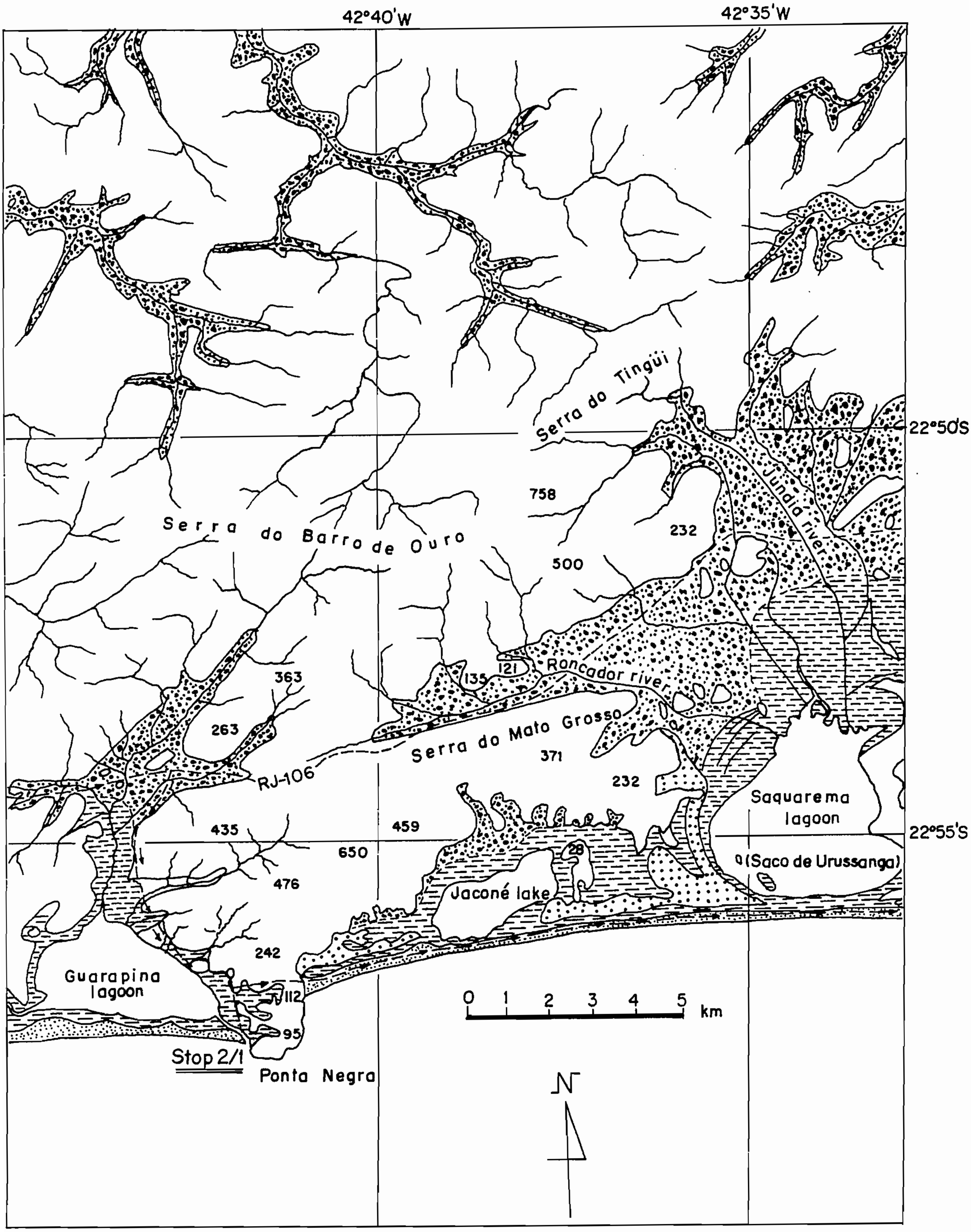

Fig. 40 – Geologic map of the Ponta Negra and its neighbors.

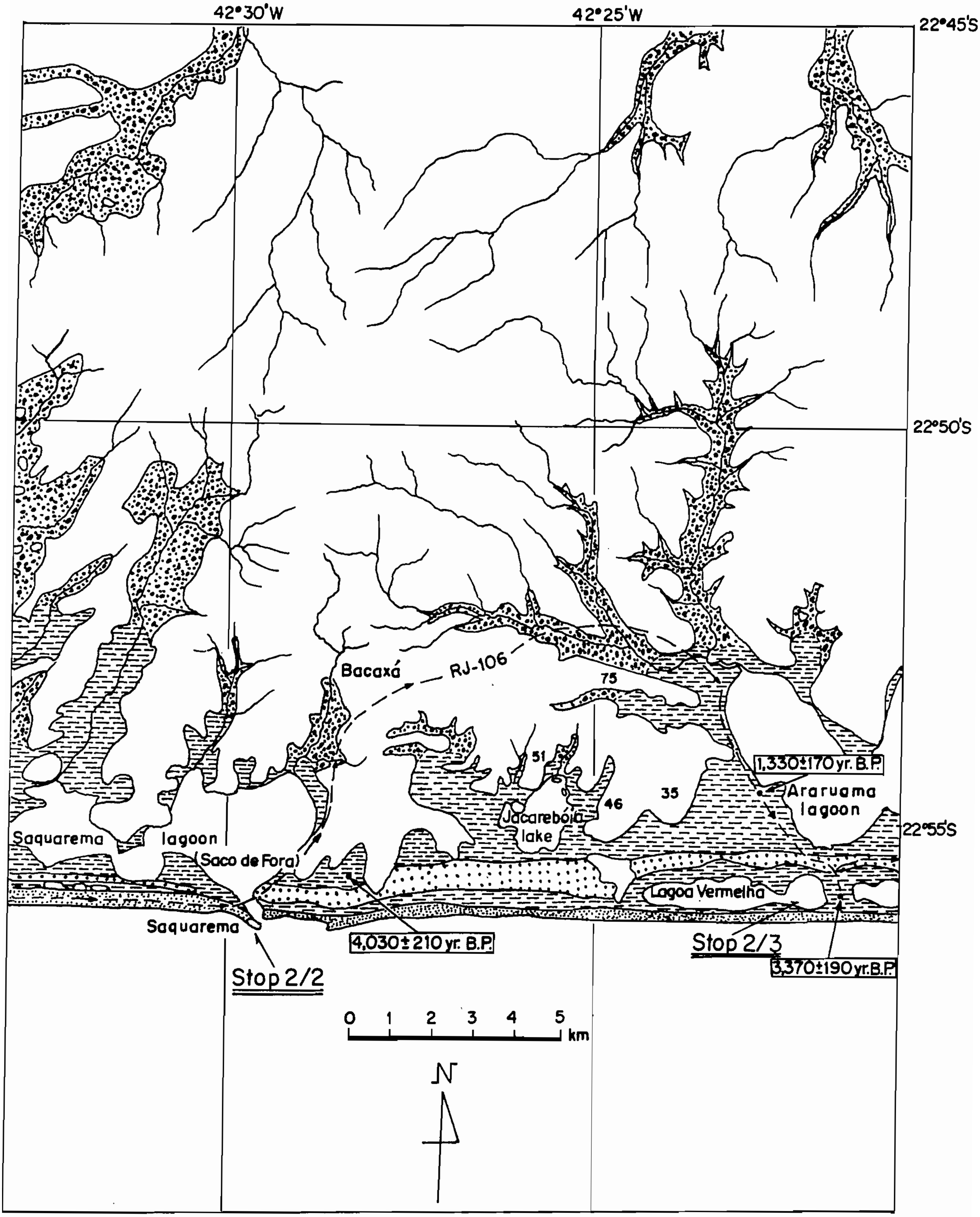

Fig. 41 — Geologic map of the Saquarema lagoon and Lagoa Vermelha.

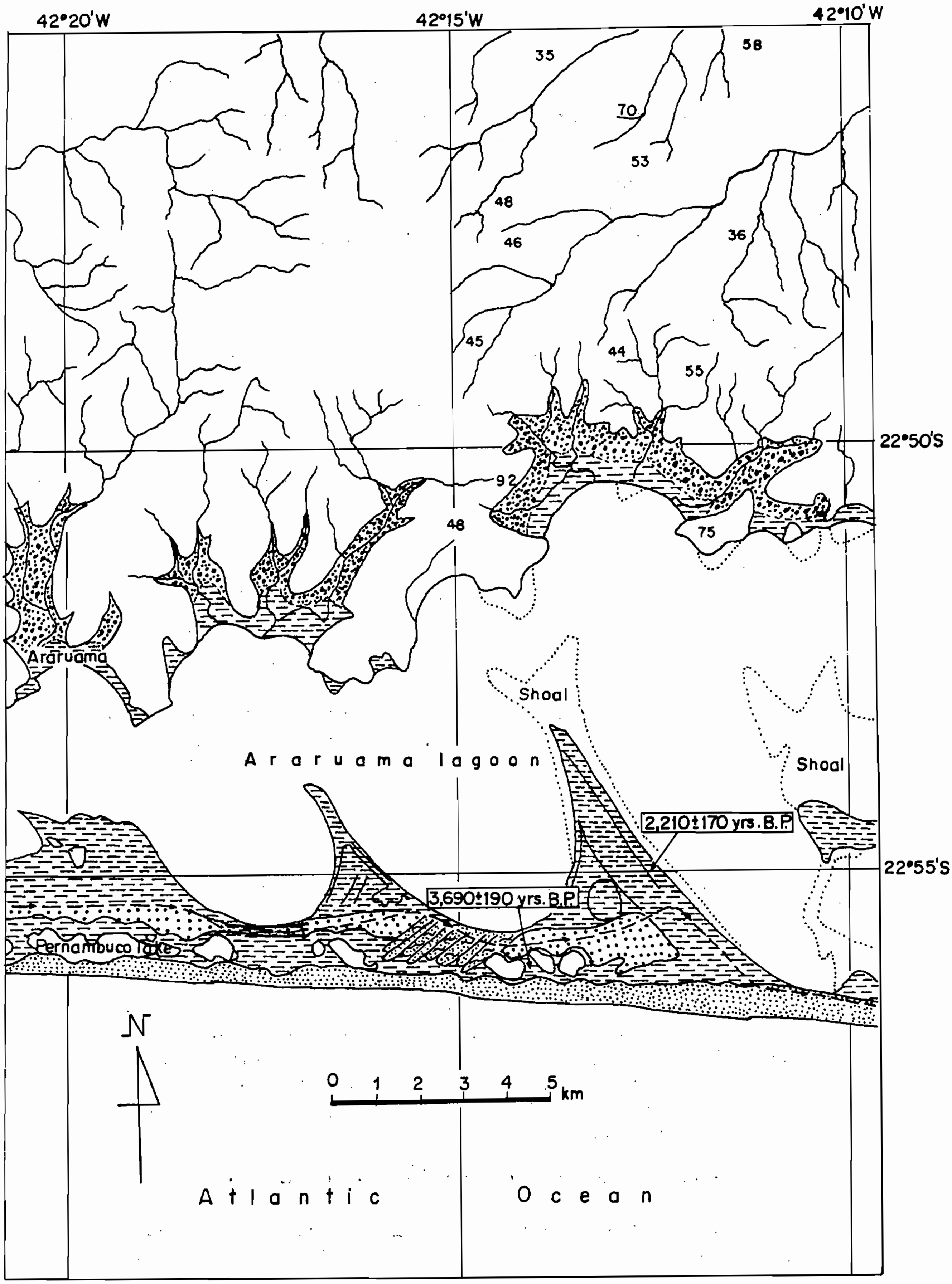

Fig. 42 — Geologic map of part of the Araruama lagoon.

Stop 2/4 (Theme I)

Subject: Evidence of Quaternary sea-level change.

Location: Channel connecting Araruama lagoon to the factory of Companhia Nacional de Álcalis.

This channel was opened to allow the passage of pontoons transporting shells dredged from the bottom of Araruama lagoon, which are used along with salt, in the fabrication of Kali (Na_2CO_3).

The outcrop is represented by a lagoonal terrace with abundant shells. The top of this terrace is situated about 1 m above the present mean lagoonal level. These shells have been dated at 2,640 ± 190 years B.P. (Bah. 1297). Certainly, relative sea-level was higher than today at that time.

This channel has been excavated within lagoonal deposits situated between a Pleistocene terrace and a Holocene sandy bar (Fig. 43).

The route from here to Cabo Frio will be upon a Pleistocene sandy terrace in part covered by salt marshes whose water is being elevated by eolian energy (Fig.43).

After travelling through the town of Cabo Frio and across the Itapuru channel, which is the only connection of Araruama lagoon with the sea, we shall head towards the famous Balneal Station of Armação dos Búzios, which was an island latterly connected to the continent during the last transgressive episode, after the formation of a double tombolo (Fig. 44).

Stop 2/5 (Theme I)

Subject: Biological (Vermetidae) evidence of relative sea-level higher than present.

Location: Ferradura beach, Armação dos Búzios (Fig.44).

A Vermetidae sample has been dated at 3,350 ± 180 years B.P. (Bah. 1306), indicating an ancient sea-level situated 1.8 ± 0.4m above the present level. Another sample collected from João Fernandes beach (Fig. 44) was dated at 3.420 ± 190 years B.P., indicating an ancient level situated 2.1 ± 0.4 m above the present level.

Armação dos Búzios to São Pedro da Aldeia (Figs. 44, 45 and 43)

Within the Manguinhos bight area (Fig. **44**), a marina was constructed in a paleolagoonal zone formed by a double

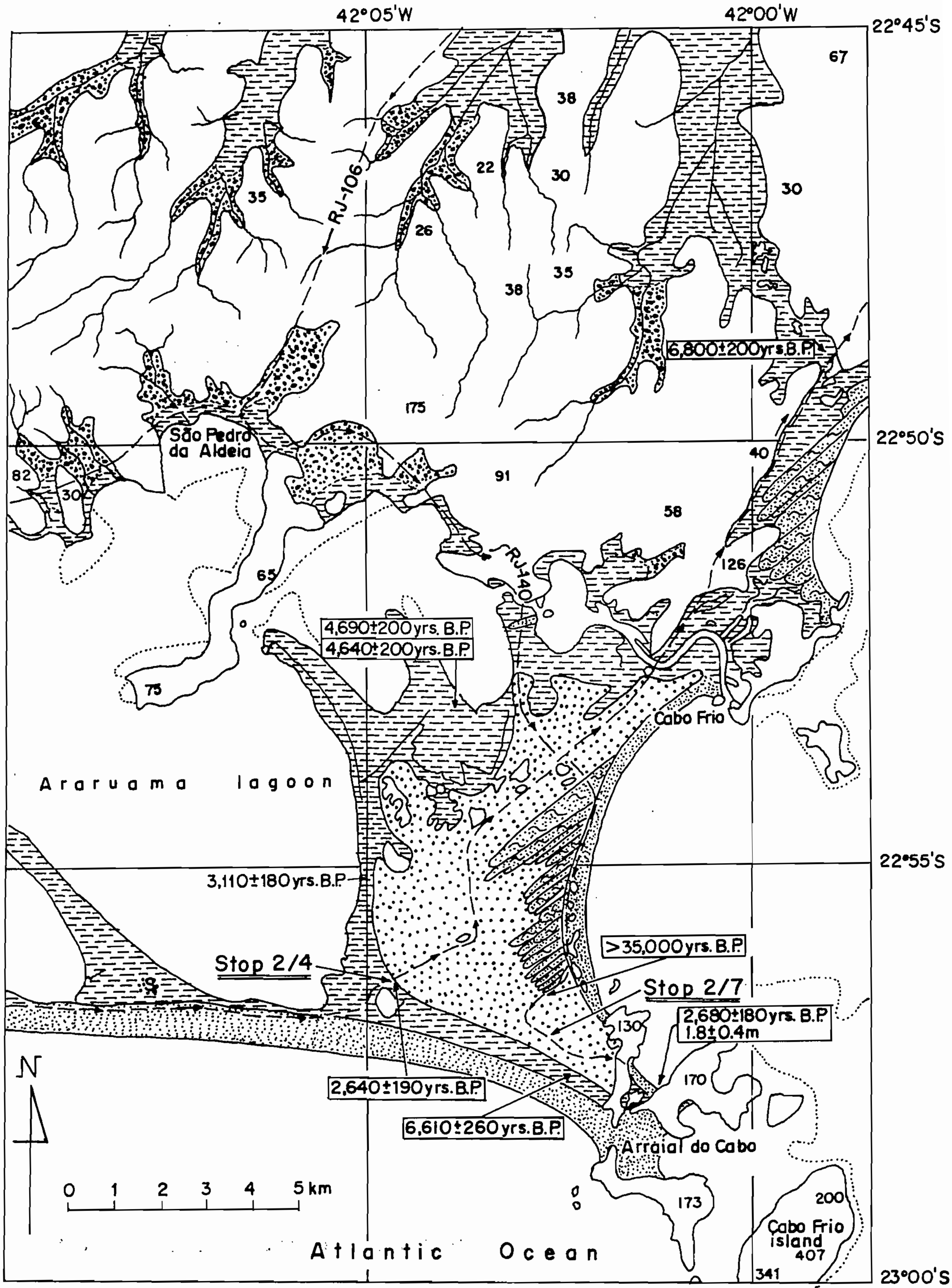

Fig. 43 – Geologic map of the Cabo Frio and its neighbors.

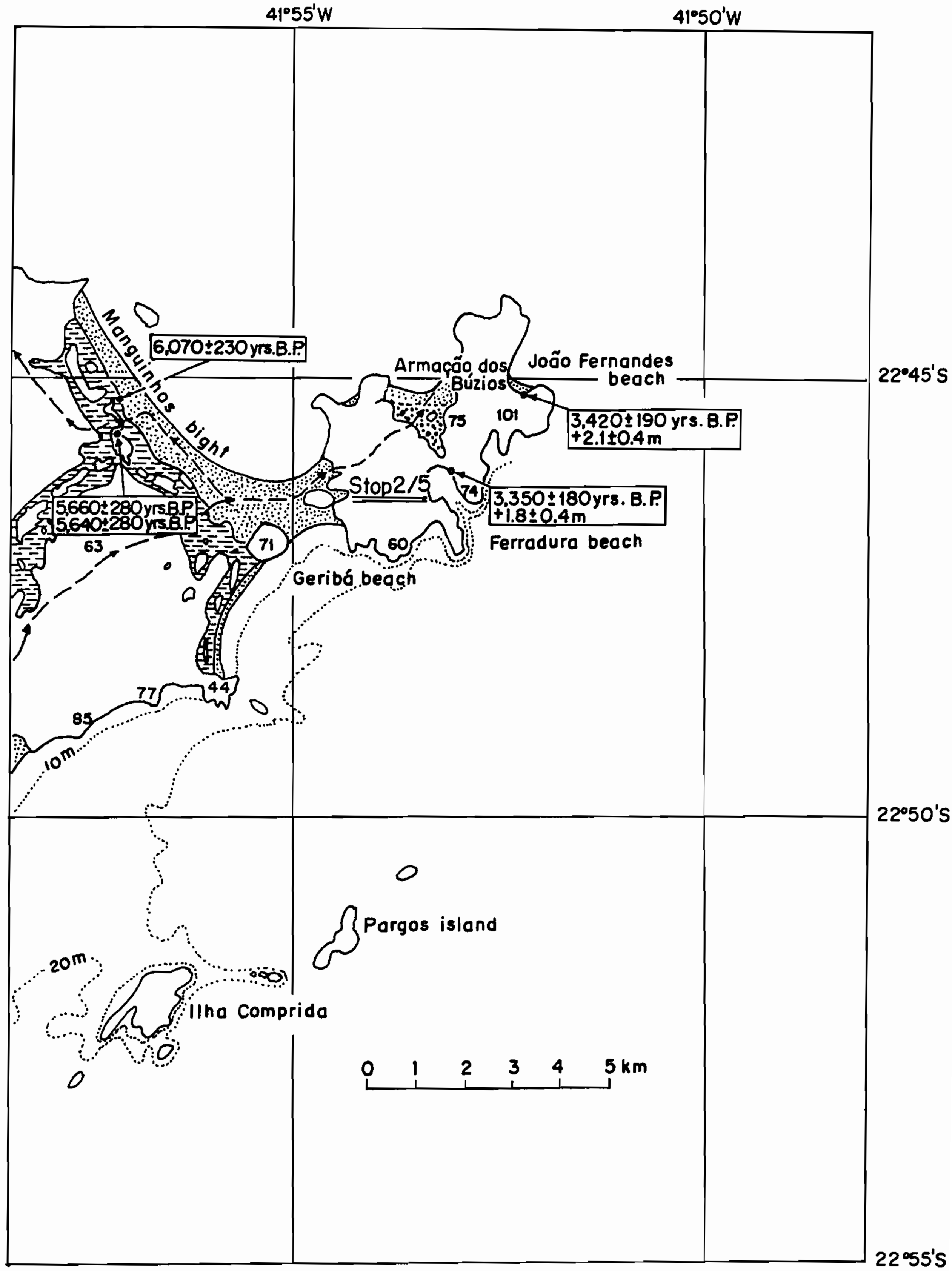

Fig. 44 - Geologic map of the Armação dos Búzios and its neighbors.

tombolo which connected Búzios island to the continent. Shells of Anomalocardia brasiliana and Lucina jamaicensis collected from paleolagoonal deposits have yielded the following ages:

Sample	Ages in years B.P.	Laboratory reference
RJ-02	6,070 ± 230	Bah. 1137
RJ-14	5,600 ± 240	Bah. 1302
RJ-15	5,660 ± 240	Bah. 1303

Stop 2/6 (Theme I)

Subject: Paleolagoonal deposits indicating a relative sea-level higher than the present.

Location: Pântano da Malhada (Fig. 45).

It is possible to observe abundant mollusc shells within excavation debris.

São Pedro da Aldeia to Arraial do Cabo along the RJ-140 highway (Fig. 43).

Stop 2/7 (Theme I)

Subject: Pleistocene sandy terrace.

Location: Between Cabo Frio and Arraial do Cabo.

It is possible to observe an outcrop of probable Pleistocene sandy terrace within a drainage channel. The cohesion and color of these sands can be explained by secondary impregnation by humic acids. A sample of a wood fragment collected from similar sands found in another drainage channel has yielded an age of > 30,000 years (Bah. 1135). This age confirms that this terrace is older than the Holocene.

Arraial do Cabo: Proposed visit to the Instituto Nacional do Mar Almirante Paulo Moreira.

Sample	Nature	Position of ancient sea-level	Age in years B.P.	Laboratory reference	Coordinates
RJ-04	Lagoonal wood	> 0 m	1,880 ± 150	Bah.1292	22°57.5'S 42°41.8'W
RJ-05	Lagoonal shell	> 0 m	4,030 ± 210	Bah.1293	22°55.7'S 42°28.3'W
RJ-06	Lagoonal shell	> 0 m	1,330 ± 170	Bah.1294	22°54.5'S 42°22.8'W
RJ-07	Lagoonal shell	> 0 m	3,370 ± 190	Bah.1295	22°55.7'S 42°21.7'W
RJ-30	Lagoonal shell	> 0 m	3,690 ± 190	Bah.1399	22°56.2'S 42°14.8'W

Sample	Nature	Position of ancient sea-level	Age in years B.P.	Laboratory reference	Coordinates
RJ-08	Lagoonal shell	> 0 m	2,210 ± 190	Bah.1296	22°55.0'S 42°12.5'W
RJ-09	Lagoonal shell	> 0 m	2,640 ± 190	Bah.1297	22°56.3'S 42°04.5'W
RJ-10	Vermetidae	+1.8 ± 0.4 m	2,680 ± 180	Bah.1298	22°56.7'S 42°01.2'W
RJ-11	Lagoonal shell	> 0 m	6,610 ± 260	Bah.1299	22°57.6'S 42°02.3'W
RJ-12	Lagoonal shell	> 0 m	4,640 ± 200	Bah.1301	22°53.3'S 42°03.3'W
RJ-13	Lagoonal shell	> 0 m	4,690 ± 200	Bah.1300	22°53.3'S 42°03.3'W
RJ-01	Wood		⩾ 30,000	Bah.1136	22°56.6'S 42°02.7'W
RJ-29	Lagoonal shell	> 0 m	3,110 ± 180	Bah.1399	22°55.4'S 42°04.9'W
RJ-19	Lagoonal wood	> 0 m	6,800 ± 280	Bah.1307	22°49.0'S 41°58.4'W
RJ-18	Vermetidae	+1.8 ± 0.4m	3,360 ± 180	Bah.1306	22°46.2'S 41°53.0'W
RJ-16	Vermetidae	+2.1 ± 0.4m	3,420 ± 180	Bah.1304	22°44.3'S 41°51.3'W
RJ-17	Algae + Barnacle	+1.6 ± 0.4m	2,010 ± 160	Bah.1305	22°44.3'S 41°51.3'W
RJ-02	Lagoonal shell	> 0 m	6,070 ± 230	Bah.1137	22°45.2'S 41°57.3'W
RJ-14	Lagoonal shell	> 0 m	5,600 ± 240	Bah.1302	22°45.4'S 41°57.6'W
RJ-15	Lagoonal shell	> 0 m	5,660 ± 240	Bah. 1303	22°45.7'S 41°57.4'W

Thirdy day (15th May)

Departure from Arraial do Cabo: 07,30 h

Arrival in São Tomé: 18,00 h

Overnight: Hotel Garoupas
Telephone: 101/227 or 255

Itinerary: Departure from Arraial do Cabo towards São Tomé passing by São Pedro da Aldeia, Barra de São João, Rio das Ostras, Macaé, Campos, Travessão, Ponta do Retiro and Gargaú, travelling about 450 km (Fig. 46). The route from Arraial do Cabo to São Pedro da Aldeia will be along the RJ-140 highway (Fig. 43), and from São Pedro da Aldeia, Barra de São João, Rio das Ostras and Macaé along the RJ-106 highway (Figs. 43, 45 and 47).

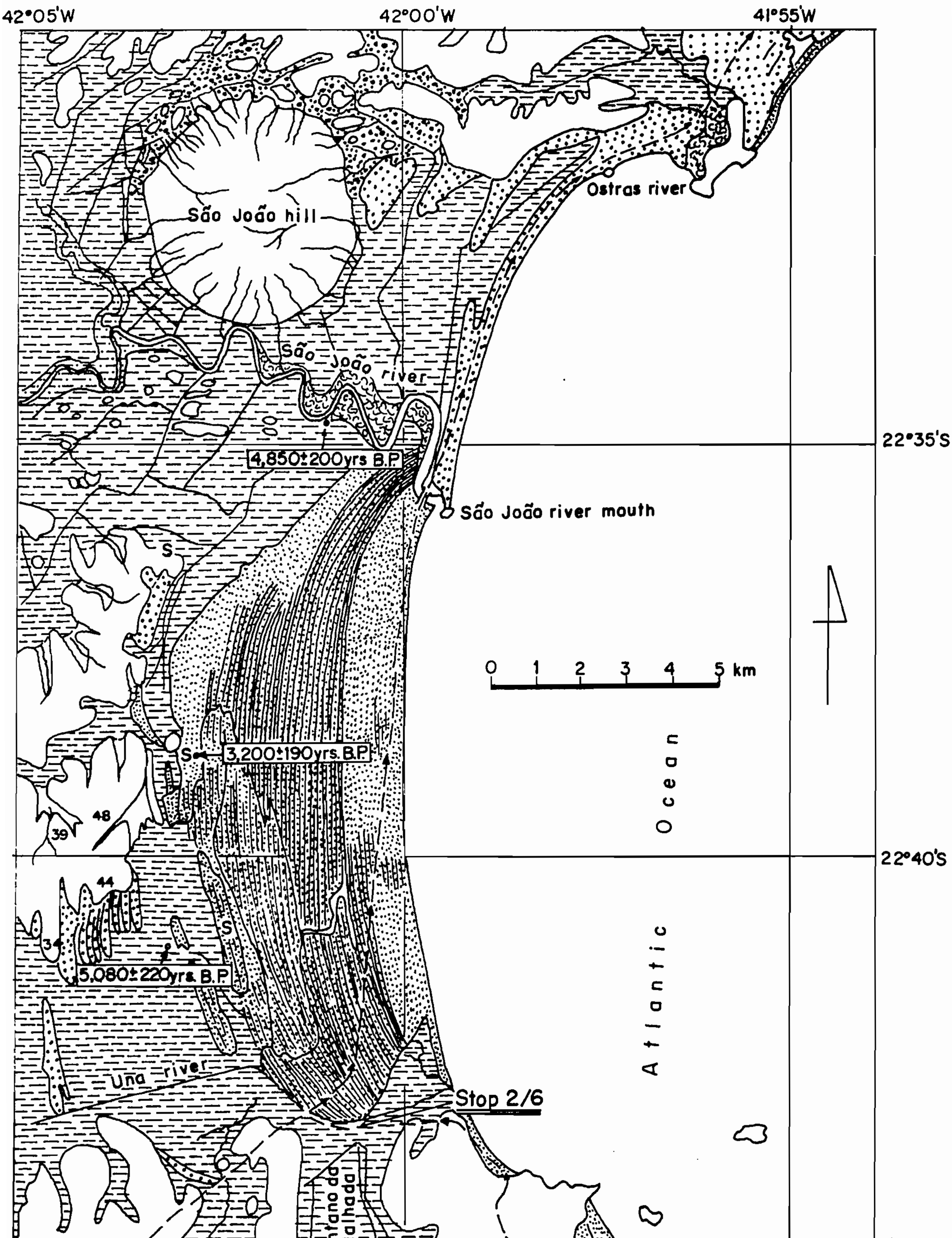

Fig. 45- Geologic map of the São João river mouth coastal plain.

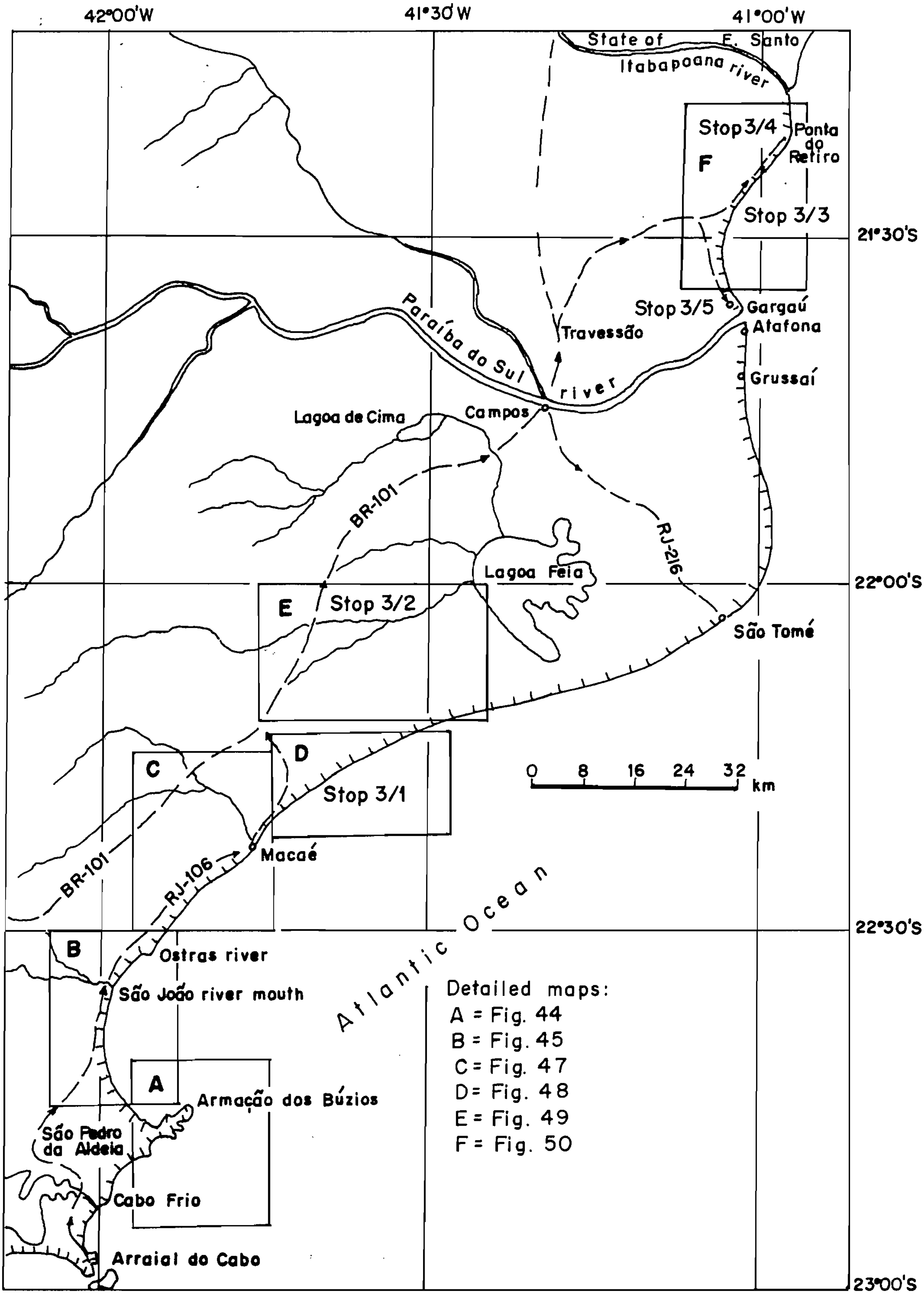

Fig. 46 – Itinerary of the 3rd. day: Arraial do Cabo to São Tomé.

Radiocarbon datings of samples collected between Armação dos Búzios and Macaé

Sample	Nature	Position of ancient sea-level	Age in years B.P.	Laboratory reference	Coordinates
RJ-21	Shell from Shell-midden	> 0 m	3,200 ± 190	Bah.1309	22°38.8'S 42°02.8'W
RJ-22	Lagoonal shell	> 0 m	5,080 ± 220	Bah.1310	22°41.4'S 42°03.0'W
RJ-23	Lagoonal shell	> 0 m	4,850 ± 220	Bah.1311	22°34.8'S 42°01.0'W
RJ-24	Lagoonal shell	> 0 m	5,280 ± 230	Bah.1312	22°29.9'S 41°55.8'W
RJ-25	Lagoonal shell	> 0 m	5,900 ± 230	Bah.1313	22°20.8'S 41°46.0'W
RJ-26	Lagoonal shell	> 0 m	5,820 ± 230	Bah.1314	22°18.4'S 41°46.1'W
RJ-27	Lagoonal shell	> 0 m	6,370 ± 250	Bah.1396	22°21.3'S 41°49.5'W

Stop 3/1 (Themes I and II)

Subject: Pleistocene marine terrace

Location: Southernmost extremity of the Paraíba do Sul river coastal plain (N of Macaé)

Pleistocene marine terrace, composed of white sands, is being eroded and covered by a Holocene sand bar, composed of yellow beach sands.

Northwards, where there is an ancient lagoonal lowland between the Pleistocene terrace and the Holocene sand bar, the landwards displacement of this bar is demonstrated by the fact that paleolagoonal deposits are outcropping on the present beach in front of the sand bar. <u>Lucina jamaicensis</u> shells from these paleolagoonal deposits have yielded the following ages:

6,620 ± 240 years B.P. (Bah. 1107)
6,000 ± 230 years B.P. (Bah. 1108)

This region exhibits characteristics of a submergence zone, as the consequence of a subsidence mechanism, which apparently confirms the Bouguer map pattern (Fig. 19). The route from Macaé to Campos will be along the RJ-106 and BR-101 highways (Figs. 47, 48 and 49).

Stop 3/2 (Themes I and II)

Subject: Pleistocene fluvial terrace

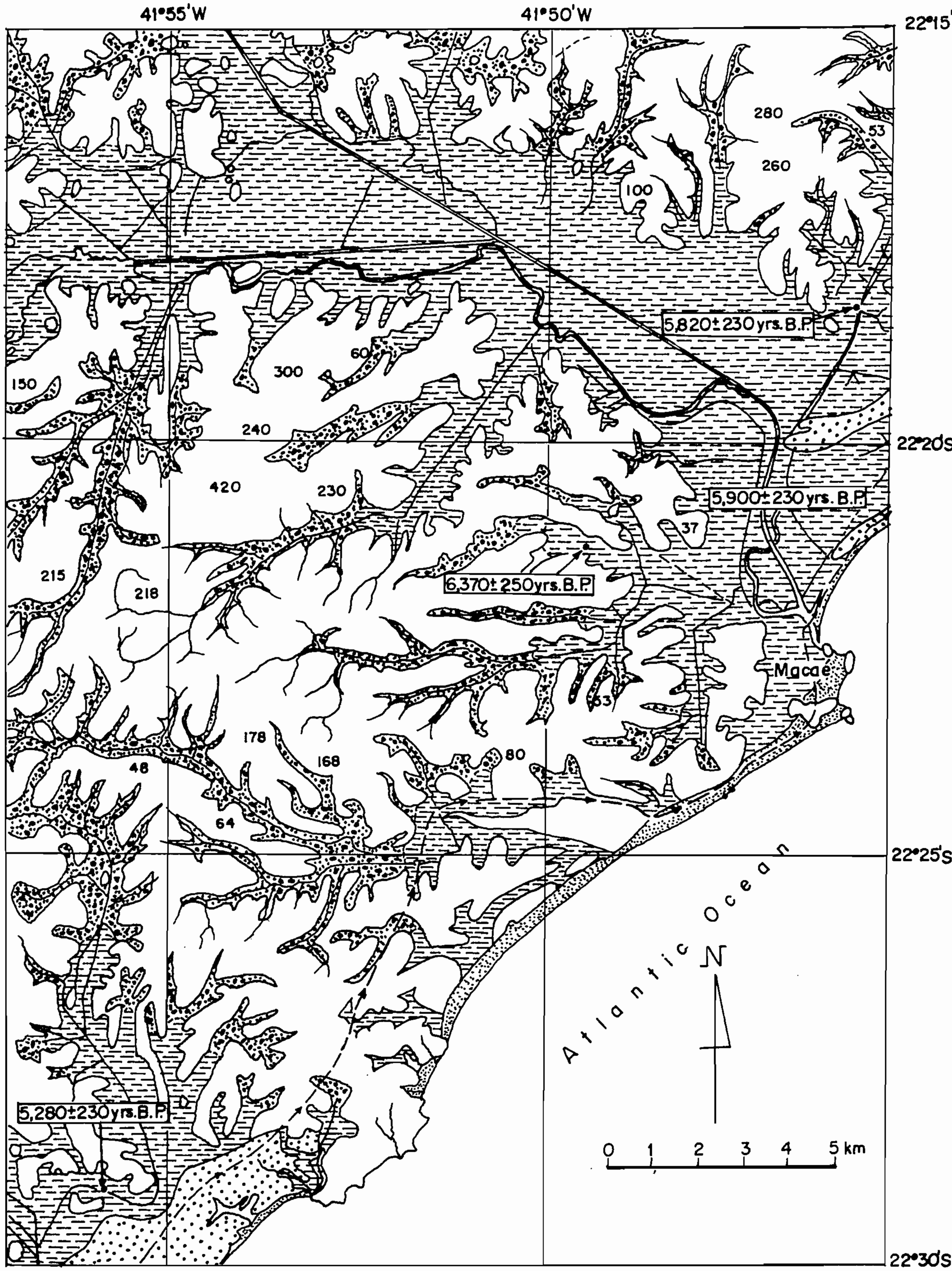

Fig. 47— Geologic map of the town of Macaé and adjacencies.

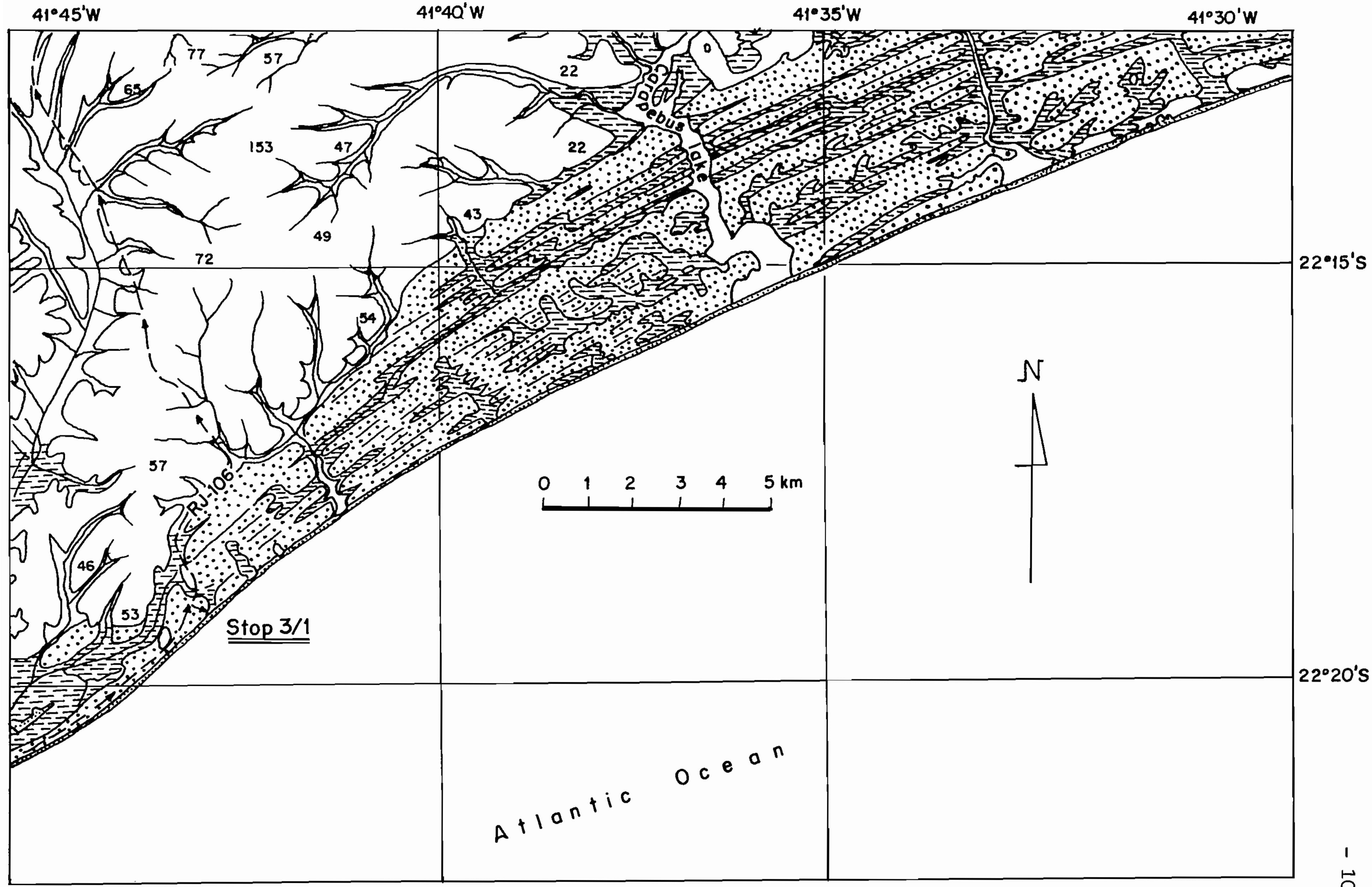

Fig. 48 – Geologic map of southern extremity of the Paraíba do Sul river coastal plain.

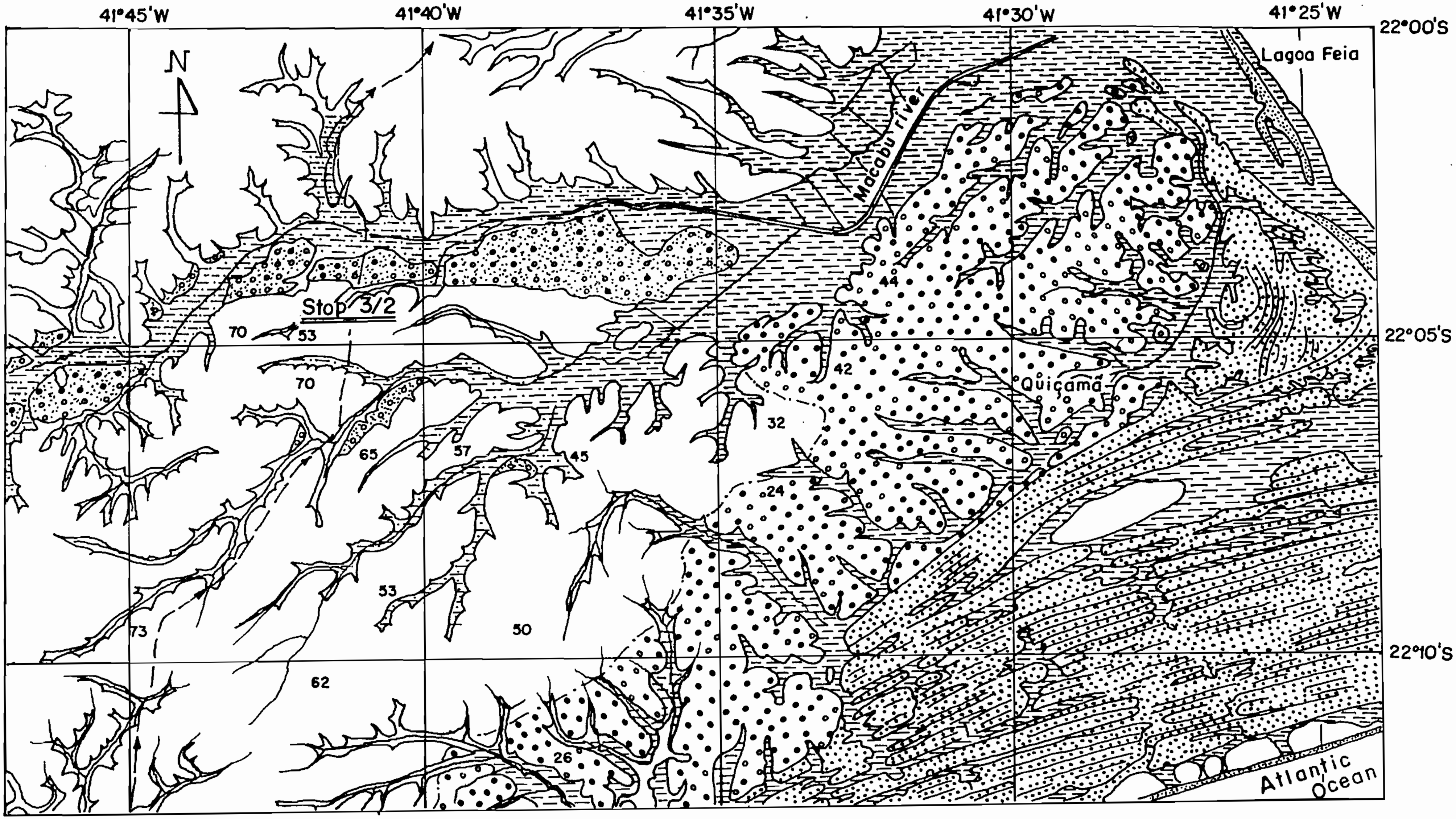

Fig. 49 — Geologic map of the Quiçamã village region showing Pleistocene (?) fluvial terraces.

Location: Macabu river valley, presently flowing to Lagoa Feia

Apparently, this fluvial terrace corresponds to a base level above the present one, associated with a sea-level, and consequently a lake level, above that of the present.

It is also interesting to observe that this Pleistocene terrace is composed of sands, which indicates that Macabu river was probably characterized by different hydrodynamical conditions and was thus submitted to different paleoclimatical conditions.

The area between stops 3/2 and 3/3 is characterized by extensive sugar cane plantations. Campos has long been an area for these plantations, but they have expanded since the Brazilian Government Proalcohol Program, as a consequence of the oil shock. This program can be considered as being technically successful, although the present oil price fall has made it economically less interesting.

In Campos we shall cross the Paraíba do Sul river and after this town the route will take us Barreiras Formation continental deposits, characterized by a flat surface carved by wide valleys whose downstream portions have been frequently invaded by the sea during periods of high sea-levels.

Stop 3/3 (Themes I and II)

Subject: Beach-rock within Holocene deposits.

Location: Northern extremity of the Paraíba river coastal plain.

A Holocene marine terrace is exposed here, closing a wide valley carved within Barreiras Formation deposits. Presently, this valley is occupied by a swampy lowland and it was invaded by the sea during the final part of the last transgression.

Within the drainage channel of Brejo do Espiador, which crosses the Holocene sandy terrace, there is a beach-rock outcrop. In its lower portion it is possible to observe stratifications dipping oceanwards. There are many shell fragments, which have been dated at 3,850 ± 200 years B.P. (Bah. 1102). It is evident that, subsequently, the sea-level passed through a maximum.

Between stops 3/3 and 3/4 the road is situated more-or-less at the foot of an ancient cliff carved within Barreiras Formation deposits, and Holocene sandy deposits show a slight development. Monazite concentrations are being exploited in a place known as Ponta Buena.

Stop 3/4 (Theme I)

Subject: Abrasion platforms on Barreiras Formation deposits.

Location: Ponta do Retiro (Fig. 50).

Outcrop of Barreiras Formation deposits, with several abrasion platforms, covered by Holocene marine and eolian sands. On the highest abrasion platform there are vermetidae and oyster incrustations, as well as, some isolated corals in life position. A sample of vermetidae has been dated at 3,620 ± 150 years B.P. (Bah. 1008), indicating an ancient sea-level situated 3.0 ± 0.4m above the present level.

The journey towards Gargaú will be made partially upon a Holocene sandy terrace (Fig. 50), where it is possible to observe beach-ridge alignments.

Stop 3/5 (Theme II)

Subject: Present and past dynamics in the Paraíba do Sul river mouth northern margin.

Location: Gargaú region (Fig. 50)

A rapid glance at Fig. 54 allows us to see the occurrence of a strong asymmetry the two margins of the river mouth.

On the northern margin of the river mouth it is possible to find an important influence of the Paraíba do Sul river, mostly upon the supplied very angular sands. There are also sand bars in front of the present beach.

The journey from Gargaú to Campos will be in the same direction as previously and, after Campos, the route as far as São Tomé will be along the RJ-216 highway, firstly upon fluvial deposits of the intralagoonal delta (with sugar cane plantations), and then upon paleolagoonal deposits. The village of São Tomé is situated on a Holocene sand bar.

Fourth day (16th May)

Departure from São Tomé: 07,30 h

Arrival in São Tomé: 18,00 h

Overnight: Hotel Garoupas
Telephone: 101/227 or 255

Itinerary: Departing from São Tomé and returning there after travelling about 200 km. Departure from São Tomé to Barra do

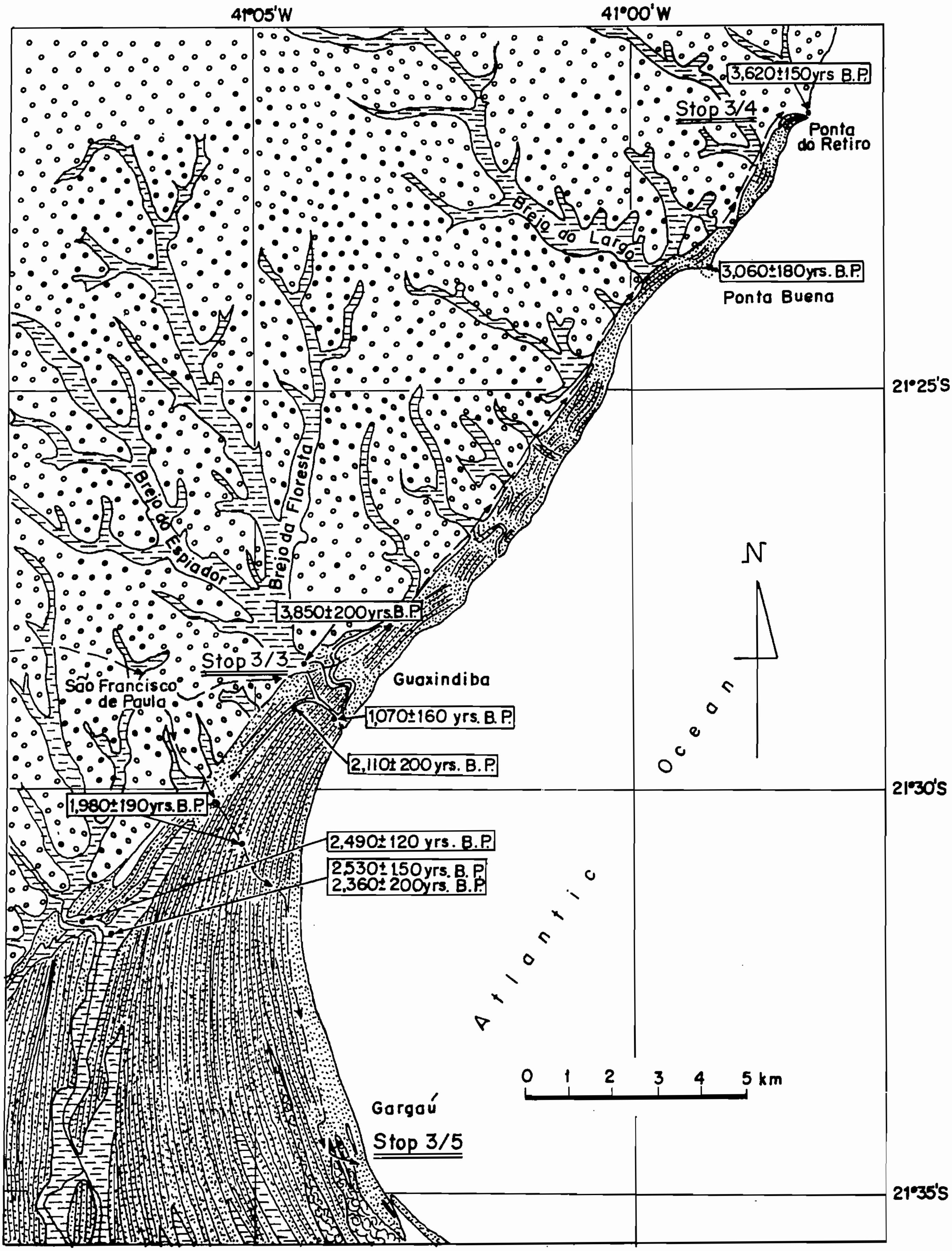

Fig. 50 — Geologic map of northern extremity of the Paraíba do Sul river coastal plain.

Furado, where the road is situated on a Holocene sandy bar separating the paleolagoon from the ocean (Fig. 51).

Stop 4/1 (Themes II and IV)

Subject: Anthropic influence.

Location: Furado outlet (Fig. 52)

The construction of breakwaters has blocked the littoral drift of sands and destroyed the previous dynamic equilibrium, giving rise to an intensive sedimentation on the updrift side and accelerated erosion on the downdrift side of the Furado outlet.

Stop 4/2 (Themes I and II)

Subject: Paleolagoonal deposits

Location: Near to Furado outlet (Fig. 52)

Paleolagoonal deposits of barrier-island/lagoonal systems with abundant mollusc shells.

Stop 4/3 (Themes II and IV)

Subject: Anthropic influence

Location: Southern breakwater of the Furado outlet (Fig. 52)

There is a blockage of the littoral drift of sands and, consequently, a major accumulation on the updrift side of the southern breakwater. It is also possible to observe that accelerated erosion on the downdrift side of the northern breakwater is almost separating it from the continent. In this situation, the entry and departure of small fishing boats through the Furado outlet became very dangerous and some of them are retained on São Tomé beach. Here we have evidence that littoral transportation is being carried out from south to north, in connection with polar cold fronts.

Stop 4/4 (Themes I and II)

Subject: Paleolagoonal deposits

Location: South of the Furado outlet (Fig. 52)

This locality corresponds to the northern extremity of the Pleistocene terrace whose southern extremity was visited at **Stop 3/1** (Fig. 48).

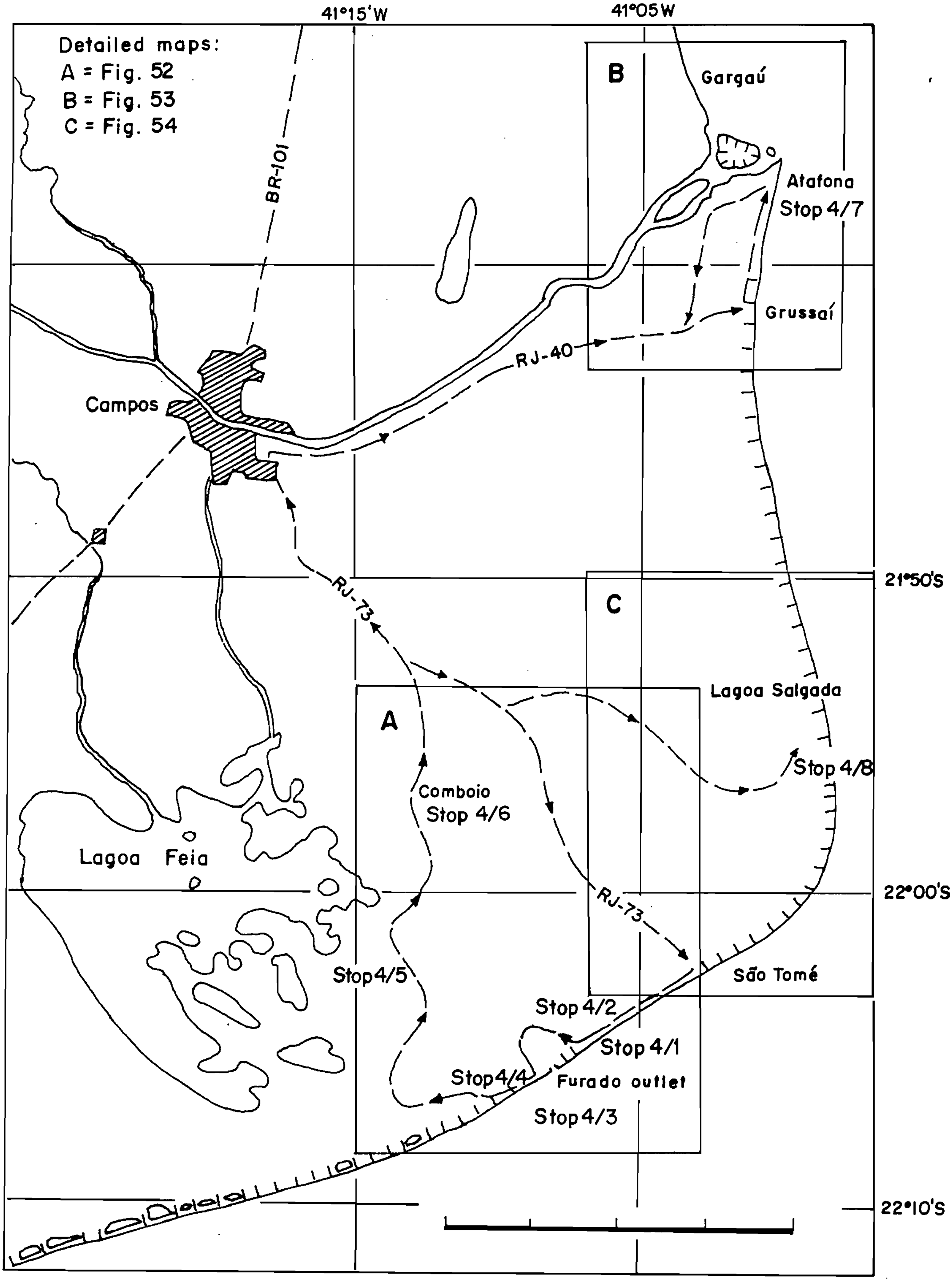

Fig. 51 — Itinerary of 4th. day : São Tomé returning to São Tomé.

An ancient lagoonal lowland exists between the Pleistocene terrace and the Holocene sand bar. Mollusc shells sampled from paleolagoonal deposits have yielded the following ages:

6,590 ± 250 years B.P. (Bah. 1105)
5,930 ± 240 years B.P. (Bah. 1106)

It is possible to observe that the top of the Holocene bar is higher than the Pleistocene terrace.

Stop 4/5 (Themes I and II)

Subject: Lagoa Feia

Location: Beside Furado channel

Lagoa Feia is the remnant vestige of a large paleo-lagoon which existed during the Holocene maximum sea-level,about 5,000 to 6,000 years B.P., constituting a barrier-island/lagoonal system (Fig. 12). The study of a drill core from Lagoa Feia showed its evolutionary history from salt water to freshwater environments.

Quantitative and qualitative changes of foraminiferal assemblages were observed along this core. The most abundant form is Ammonia beccarii, while the frequency of Miliolidae diminishes from the bottom to the top. These changes reflect salinity variations which are related to sea-level changes through time.

Stop 4/6 (Themes I and II)

Subject: Pleistocene sandy terrace

Location: Comboios region (Fig. 52)

This shows the remains of a Pleistocene terrace isolated within Holocene deposits of the Paraíba do Sul river coastal plain. The lowlands between beach-ridges have been more deeply excavated during low sea-level before the last maximum, being subsequently invaded by seawaters during the last transgression. Clayey deposits with oyster shells have yielded the following ages:

6,590 ± 200 years B.P. (Bah. 1004)
6,000 ± 200 years B.P. (Bah. 1003)

The journey between stops 4/6 and 4/7 (Fig. 51) is carried out upon fluvial deposits of the intralagoonal delta, with sugar cane plantations, along the RJ-73 highway (connecting Campos to São Tomé), frequently sited upon paleochannel deposits of the ancient intralagoonal delta.

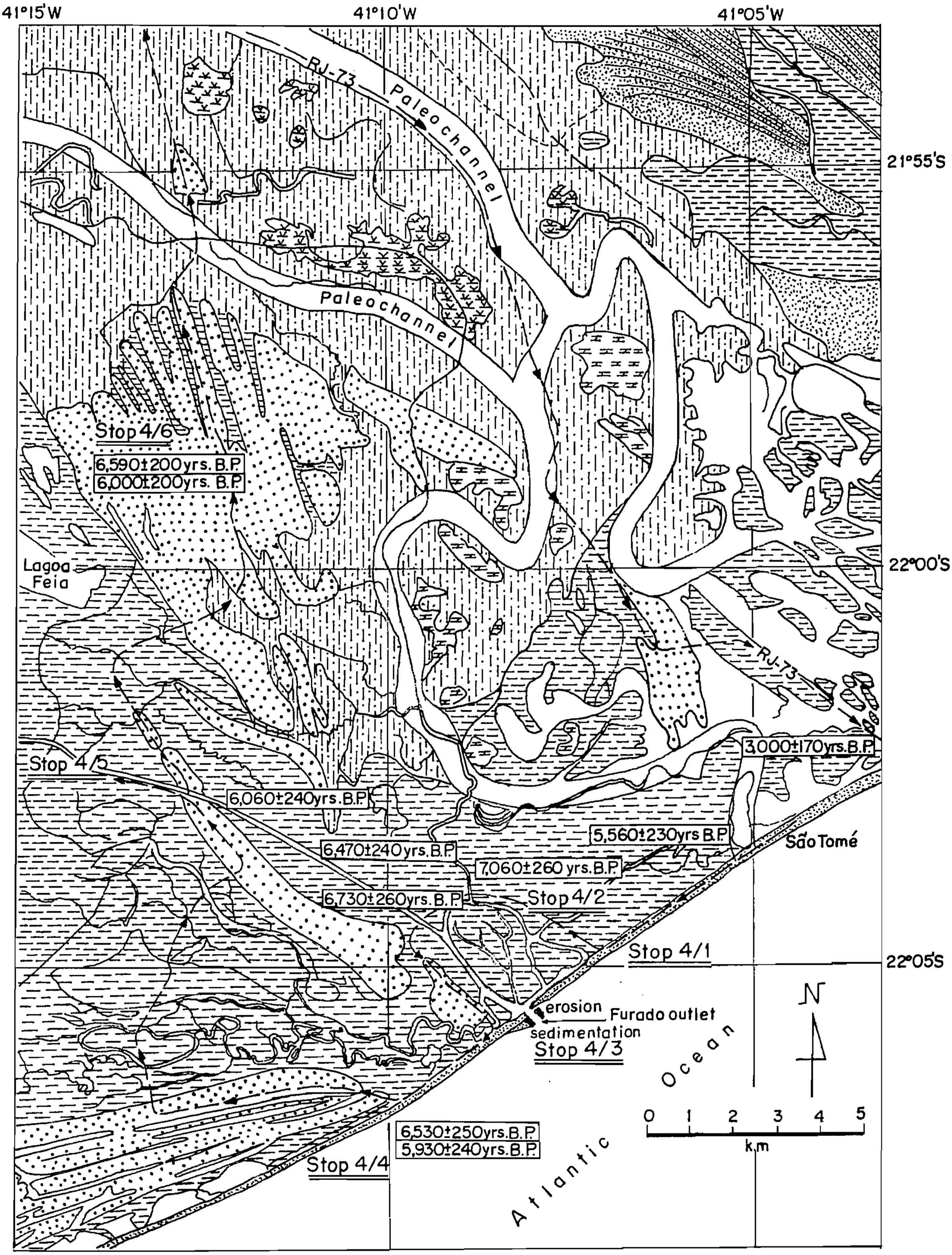

Fig. 52 – Geologic map of the Paraíba do Sul river coastal plain in the São Tomé region

Between Campos and Grussaí, the RJ-40 highway runs first along the intralagoonal delta and later upon the Holocene sandy terrace, covered by beach-ridges which are perpendicularly cut by the road.

Between Grussaí and Atafona, the road runs parallel to the beach. In Grussaí the degree of roundness of sand grains is very high, suggesting that the sands supplied by the Paraíba do Sul river are mostly transported norhtwards (Fig. 17).

Stop 4/7 (Theme II)

Subject: Paraíba do Sul river mouth, southern margin

Location: Atafona village (Fig. 53)

This margin is quite different from the northern margin (Stop 3/5) and sedimentation dynamics here can be understood through figures 15, 16 and 17.

From here we shall return towards Campos, arriving in Barra do Açu, which is on the way to São Tomé.

Stop 4/8 (Theme I)

Subject: Lagoa Salgada and other dried paleolagoons

Location: NNE of São Tomé (Fig. 54)

At the southern extremity of the Holocene sandy terrace there are four paleolagoons; only Lagoa Salgada permanently retains water. Mollusc shells sampled at the surface have yielded the following ages:

3,060 ± 150 years B.P. (Bah. 1002)
2,930 ± 180 years B.P. (Bah. 1114)

The geometry of the beach-ridges indicates that the Lagoa Salgada was the last to be formed, behind a hooked spit. Continuous progradation closed its outlet and the lagoon became isolated within sandy deposits. Since the surface mollusc shells have furnished ages of about 3,000 years B.P., the above mentioned outlet was probably closed at that time, which correspond to the beginning of the second period of rapid fall of relative sea-level (3,000 - 2,800 years B.P.). This sea-level fall certainly accelerated the progradation.

After its isolation, the surface diminished as a consequence of evaporation also increasing its salinity, with stromatolite formations developing upon surface shell beds. One of these incrustations has been dated at 2,130 ± 180 years B.P. (Bah. 1113).

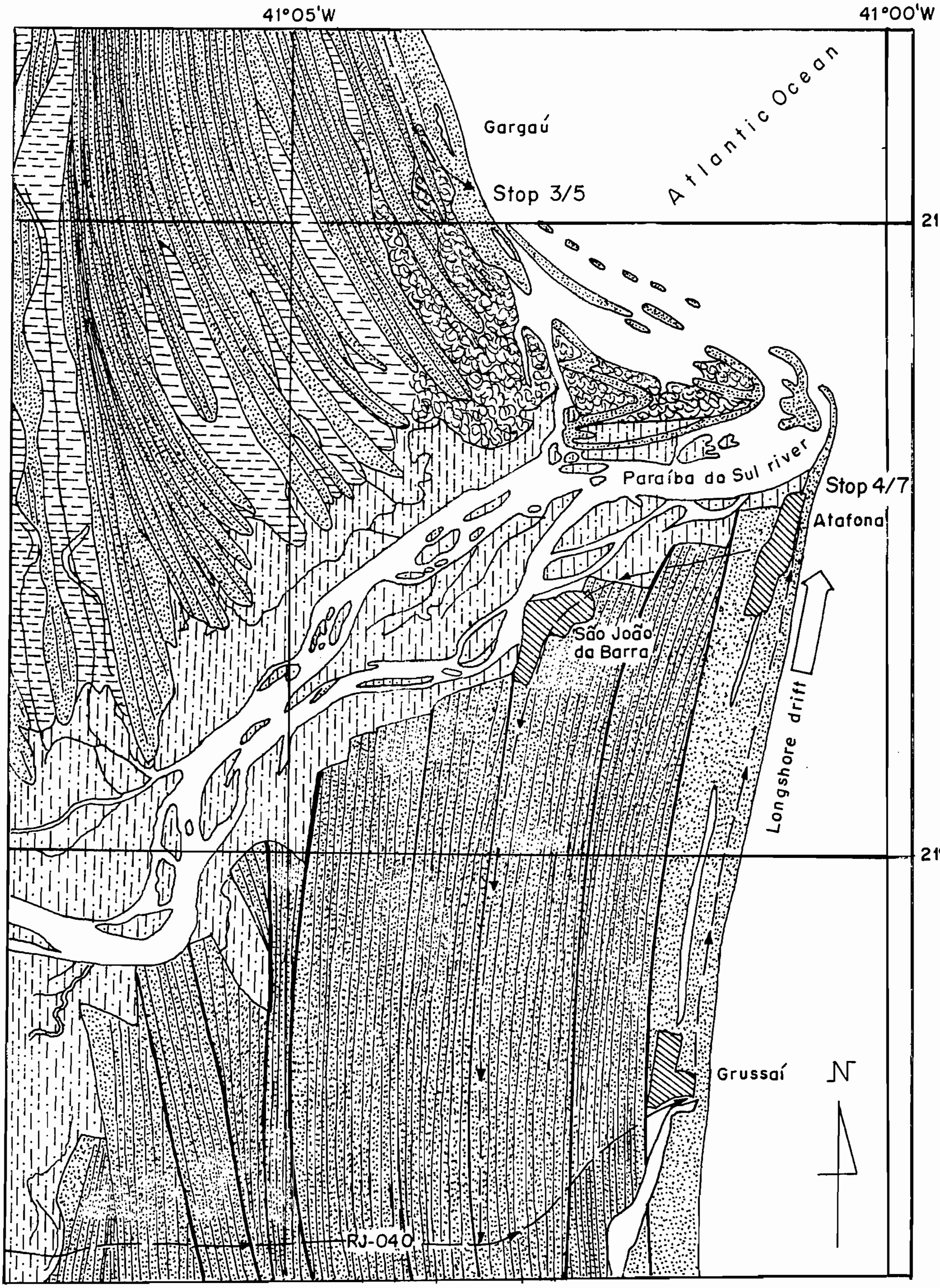

Fig. 53 – Geologic map of the present Paraíba do Sul river mouth.

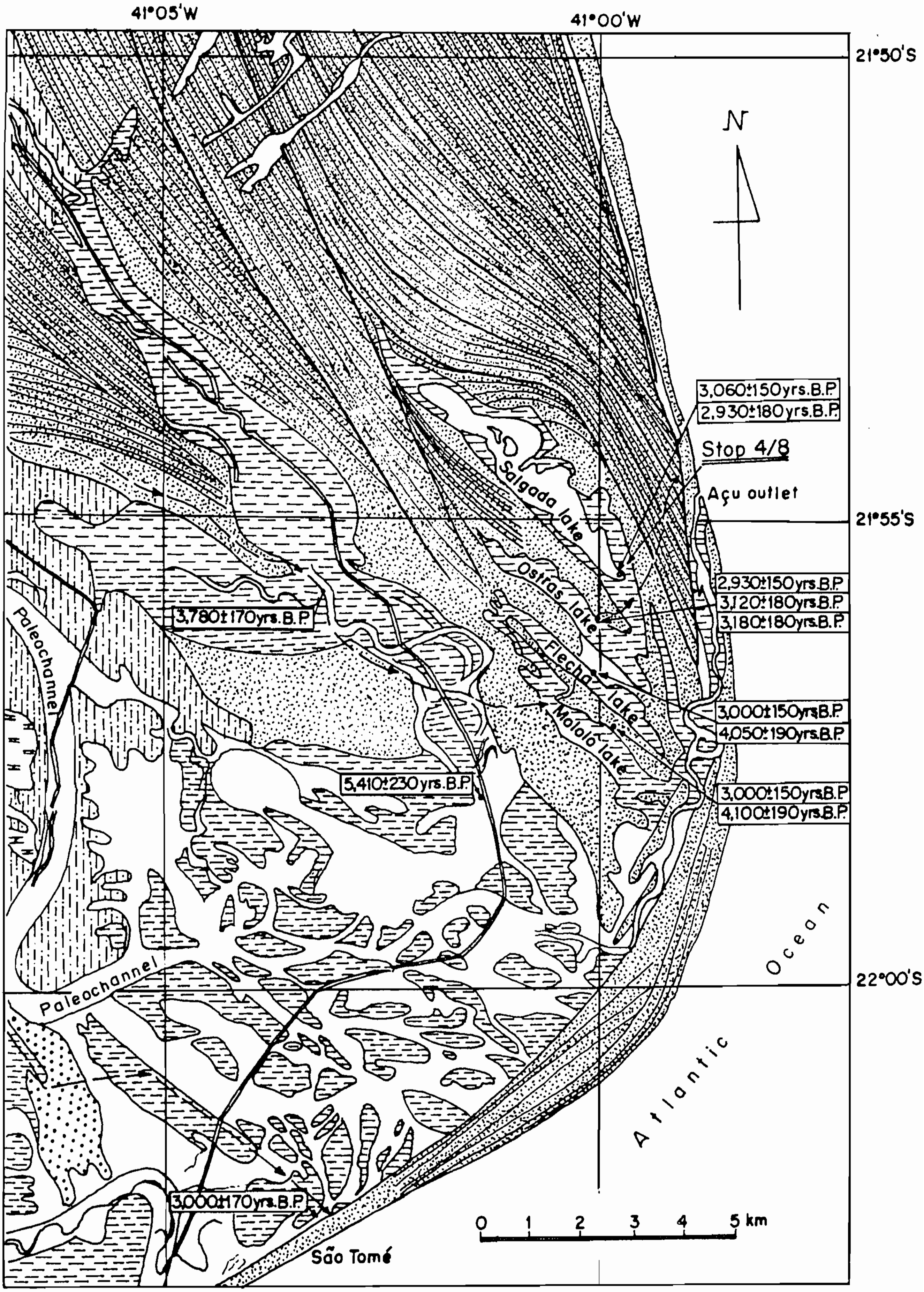

Fig. 54 — Geologic map of the Paraíba do Sul river coastal plain in the Salgada lake region.

The Lagoa das Ostras was formed through the same mechanism. On the other hand, the lagoas do Mololô and da Flecha have yielded two groups of ages, of around 4,000 and 3,000 years B.P.

Fifth day (17th May)

Return from São Tomé (RJ) to São Paulo (SP) via Rio de Janeiro (RJ), along the BR-101 (about 300 km) and then the BR-116 (about 400 km) highways. It is possible for participants to leave this excursion in Rio de Janeiro.

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