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EXCURSION ROUTE ALONG THE COASTAL PLAINS OF THE STATES OF PARANÁ AND SANTA CATARINA

Authors: Louis Martin and Kenitiro Suguio

-1986-

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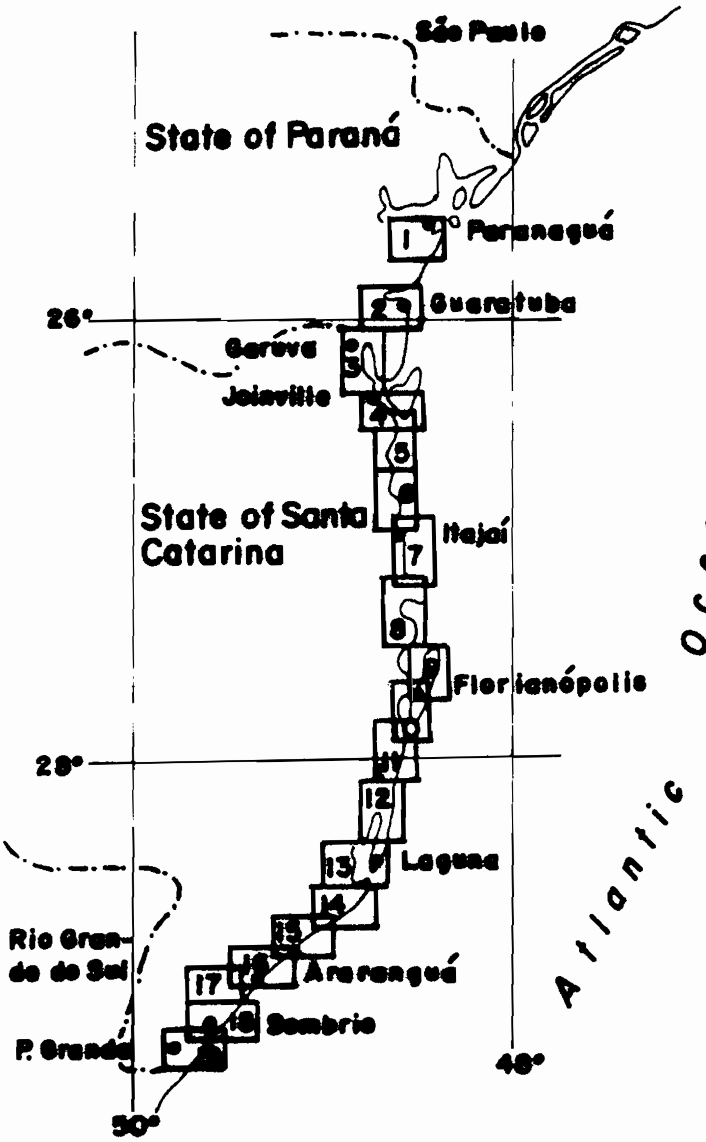

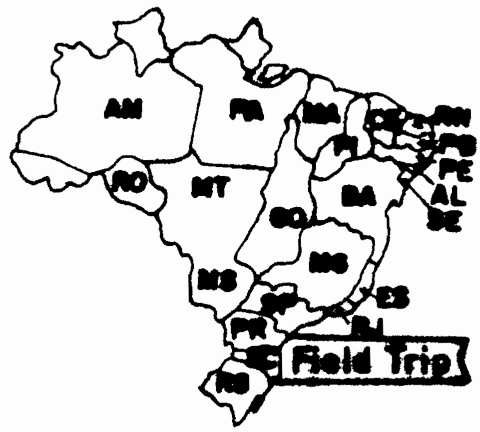

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—— 1986 ——

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P A R T I

BRAZILIAN QUATERNARY SHORELINES

1. RELATIVE SEA-LEVEL CHANGES DURING THE QUATERNARY ALONG THE BRAZILIAN COAST

Until very recently, the ancient shorelines of areas assumed to be very stable, like Brazil, were interpreted as records of world sea-level fluctuations. One of the most important objectives of the Project 61 (The sea-level program: 1974-1982) of the International Geological Correlation Programme was to delineate a world sea-level curve for the Holocene. Nevertheless, field surveys developed throughout the world have immediately shown that this mission was irrealistic and, presently, all experts assume to be impossible to determine a worldwide sea-level fluctuation curve,but only local or regional curves. Then, it is evident that so called eustatic curves, like that of FAIRBRIDGE (1961), cannot be used as sea-level fluctuation model during the last thousands of years. Though Brazil is also insertable within this context, unfortunately until today some researchers insistently use those curves.

1.1 - Complexity of factors influencing relative sea-level changes

The relative sea-level fluctuations are an effect of true sea-level changes (eustasy) and modifications of land-levels (tectonism and isostasy), as shown in the Fig. 1. Therefore, it is evident that the reconstructions of ancient sea-levels represent relative and not absolute positions.

The land-levels are controlled by the following factors:

a) Tectonic movements - Horizontally or vertically oriented movements can affect the earth's crust according to mechanisms whose time delays can be instantaneous (seismic movements) or very long.

b) Isostatic movements - They are related to modifi-

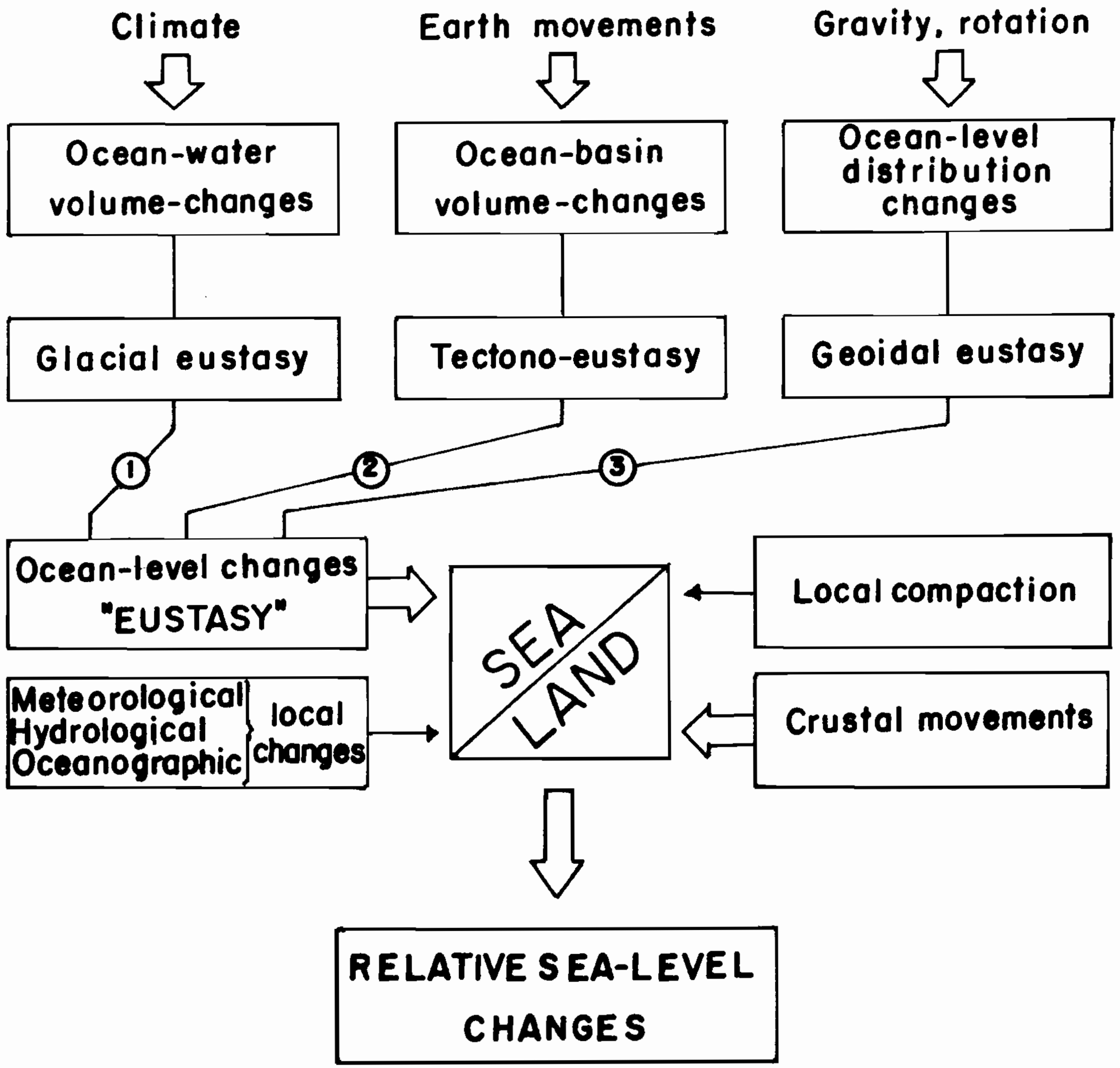


Fig. 1 – Several variables controlling the ocean level and the land level defining the relative sea-level changes

(From MÖRNER, 1979)

cations in the overload as a function of formation or disappearance of ice-caps, erosion of the continents and accumulation of deposits within sedimentary basins and transgressions and regressions on continental shelves (hydroisostasy).

c) Deformations of continental geoid which constitutes our present reference level.

The sea-levels are also controlled by several factors:

a) Modifications of bulk volume of the ocean basins as a consequence of plate tectonics (tectono-eustasy).

b) Changes in water volume of the oceans as a function of the glaciations and deglaciations (glacial-eustasy).

c) Deformations of the oceanic surface.

The height of sea-surface presents an oceanic component and a geophysical component. The oceanographic factors which can influence the sea-level are essentially tides, oceanic currents and associated eddy currents, changes in inclination due to the wind, pressure and water temperature or salinity. The summation of these factors is not more than 1 to 2m, which is small in relation to huge concavities and intumescences of sea-surface due to density differences of interior of the earth. This geophysical component corresponds to geoid and it is confounded with the mean sea-level. Geodetic altimetric measurements have been done from 1975 using artificial satellites as GEOS-3 and SEASAT, which allowed us to measure sea-surface with a great precision. So, it is possible to show the existence of undulations with great wavelength and several tens of meters of amplitude (until about 100m) at south of India. In general, they are attributed to density differences in the lower mantle, or even in the interface core/mantle, due to arguments of MÖRNER (1984) based in the inexistence of correlation between these undulations and the bottom topography besides their amplitude and wavelenghts. When these undulations are characterized by a shorter wavelength the marine geoid exhibits a very changeable specter of anomalies.

The geoid surface corresponds to an equipotential surface of earth gravitational field, being controlled by rotational and gravity forces which act upon the terrestrial globe. These energies, and consequently the geoid shape, change not only according to core and mantle compositions and to relationship between the astenosphere and litosphere, but also as a function of several orbital phenomena and their interactions (MÖRNER, 1980). According to MÖRNER (1984), changes of the geoid surface seem to be very rapid and the rates can reach to 10mm/year with a gradient of several meters by kilometer. A change of 1 miligal in the gravity force would deform the oceanic surface in 3.3m and the continental crust surface in 1.7m.

Therefore, the sea-level measured in a certain point of the coast is the momentary resultant of complex interactions between the sea-surface and land-surface. The changes in volume of oceanic basins (tectono-eustasy) and the changes in volume of the oceans (glacial-eustasy) have a worldwide influence. On the other hand, the modifications of the geoid surface (geoidal-eustasy) and the modifications of the land-level have a local or regional influence.

Then, it is normal to found discrepancies between reconstructions of positions of ancient sea-levels in a certain moment in different places of the world, which is particularly conspicuous during the last 7,000 years. In fact, 7,000 years B. P. (Before Present) the glacio-eustatic rising rate was so rapid that it could conceal the local or regional factors.

1.2 - Relative sea-level fluctuation curves

For reconstruction of an ancient position of relative sea-level is necessary to settle a fluctuation record in space and in time. To locate this record in space is necessary to know its present altitude in relation to its original height, that is, to know its position in relation to the sea-level at the time of its formation or sedimentation. To define the evidence in time is necessary to know the time of its formation or sedimentation, using for this the dating methods (isotopic, archeological, etc.).

After properly placed in time and space the "marker" will supply the position of an ancient sea-level in a certain moment. If we can reconstruct sufficiently numerous ancient sea-levels, well distributed in time, it is possible to outline a curve of relative variations of the mean sea-level. Obviously a homogeneous curve can be derived only by using samples from coastal zones where crustal and eustatic phenomena have been almost the same. Frequently, we must choose among two of the following situations:

a) To construct a curve based on numerous reconstructions covering all the considered time interval, however this will imply in using data from a very long sector of the coast; or

b) To consider a very short segment of the coastline but in this case the reconstructions could be insufficient to allow us to construct complete and relatively accurate curve.

1.3 - Evidence of ancient Quaternary sea-level along the Brazilian coast

1.3.1 - Historic

It has been observed that the sea-level fluctuations during the Quaternary were very important in the evolution of the coastal plains in Brazil. Evidence of these oscillations are known from long ago (HARTT, 1870; BRANNER, 1904; FREITAS, 1951 and BIGARELLA, 1965). Formerly these evidence have been studied exclusively from a geomorphological viewpoint and attributed to the Tertiary, but presently they are ascribed to the Quaternary. Until the decade of 60, geological research on sea-level fluctuations during the Quaternary were very scarce in Brazil (SUGUIO, 1977). One of the first somewhat systematic research, including radiocarbon ages, have been done by VAN ANDEL and LABOREL(1964).

From 1974, sea-level fluctuations during the last 7,000 years have been studied by a group of scientists from the University of São Paulo, Federal University of Bahia and National Observatory in cooperation with O.R.S.T.O.M. (French Institution of Scientific Research for the Development in Cooperation). This team concluded the study of Quaternary formations of the State of São Paulo and southern Rio de Janeiro (MARTIN and SUGUIO, 1975, 1976a, 1976b, 1978; SUGUIO and MARTIN, 1976, 1978a, 1978b, 1982a, 1982b; MARTIN et al., 1979a, 1979b, 1980; SUGUIO et al., 1980), of the States of Bahia, Sergipe and Alagoas (BITTENCOURT et al., 1979a, 1979b, 1982b; MARTIN et al., 1978, 1979b, 1980a, 1980b, 1980c, 1982; VILAS-BOAS et al., 1981; DOMINGUEZ, 1983; DOMINGUEZ et al., 1982), of northern State of Espírito Santo (SUGUIO et al., 1982) and northern State of Rio de Janeiro (MARTIN et al., 1984b). Field surveys related to the coastal plains of the States of Paranã and Santa Catarina have been also concluded. On the other hand, the same group have done systematic research on sedimentary deposits associated with the mouths of Rio Paraíba do Sul, Rio Doce, Rio Jequitinhonha, Rio São Francisco and Rio Parnaíba for the purpose to define the role played by relative sea-level fluctuations during the Quaternary in their evolutionary history (Fig. 2).

1.3.2 - Sedimentologic evidence

Quaternary sand deposits situated above the present sea-level are unquestionable evidence of ancient sea-level higher than today.

Geologic mapping and radiocarbon dating of these deposits permitted the differentiation of two generations of sandy terraces which have been constructed after the maximum levels related to two different transgressive episodes in the Quaternary (MARTIN et al., 1981).

Several outcrops of beach-rocks, trending almost parallel to the present strandline, occur along the coastline of the Northeastern Brazil. It was possible to establish that there are beach-rocks whose sands were deposited in different zones, ranging from offshore to the backshore. A detailed study of the sedimentary structures and grain size of these sandstones can indicate the place where the sands composing them were deposited, and thus define with a precision of $\pm$ 50cm, the position of mean sea-level at the time of deposition (FLEXOR and MARTIN, 1979).

1.3.3 - Biologic evidence

Along almost the entire Brazilian coastline biologic

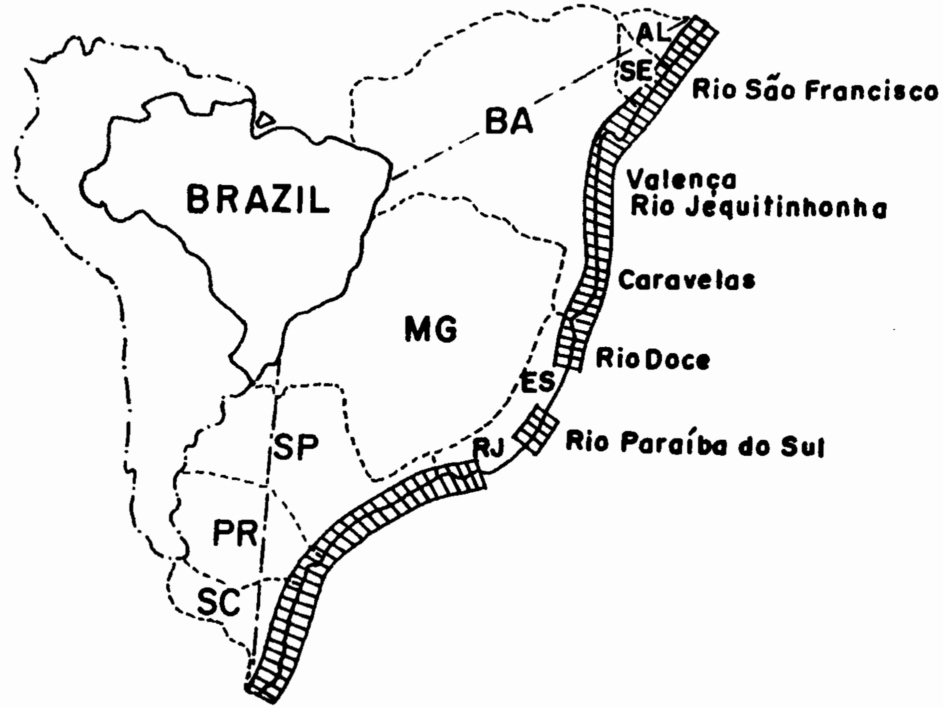


Fig. 2 — Studied sectors of the Brazilian coastal plains including the mouths of the most important rivers flowing to the Atlantic

evidence in the form of numerous Vermetidae (gastropods) and oyster shell incrustations, as well as sea-urchin burrows, which are situated above the present life zone of these animals, is encountered that indicates ancient sea-level higher than the present (LABOREL, 1969 and 1979). Since the vertical range of Vermetidae incrustations is very narrow (ca. 50cm), the occurrence of these fossil organisms permit to have a good reconstruction of ancient position of sea-level in space.

In the northeastern Brazilian coastline there are many reefs, mostly made up of dead corals, whose upper portion testify to an ancient sea-level higher than it is today. Unfortunately the corals supply only with lower limit of the ancient sea-level.

Moreover, Pleistocene and Holocene sandy marine terraces are characterized by numerous fossil Callichirus burrows, as in the Cananéia area (State of São Paulo), situated above the present life zone of this organism (SUGUIO and MARTIN, 1976; SUGUIO et al., 1984; RODRIGUES et al., 1985).

1.3.4 - Pre-historic evidence (shell-middens)

A great number of shell-middens (sambaquis)constructed by ancient indians, are found in the Brazilian coastline sedimentary plains. The position of some of these shell-middens can be explained only by a lagoonal extent clearly larger than it is today and, consequently, by a sea-level higher than the present (MARTIN et al., 1984).

1.3.5 - The oldest high sea-level (older than 120,000 years B.P.)

The oldest Quaternary high sea-level along the Brazilian coastline was evidenced only in the coasts of the States of Bahia and Sergipe, where is known as Ancient Transgression (BITTENCOURT et al., 1979a). It is not a well known event since there are not outcrops which can be certainly attributed to this transgressive episode. The only known evidence are constituted by cliffs carved in Pliocene continental deposits of the Barreiras Formation and probably by a not outcropping coral reef in southern State of Bahia (CARVALHO and GARRIDO, 1966). The summit of this coral reef has been reached and is situated about 11m below the present sea-level, but we do not know certainly if this level has crossed the present level.

1.3.6 - High sea-level of 120,000 years B.P.

The above mentioned Ancient Transgression has been followed by a new transgressive event, when the relative sea-level was 8 ± 2m above the present level about 120,000 years B.P. This age has been established by dating coral samples by the Io/U method (MARTIN et al., 1982).

This transgression is known as Cananéia Transgression in the State of São Paulo coastline (SUGUIO and MARTIN, 1978a)and Penultimate Transgression in the coastal plains of the States of Bahia, Sergipe and Alagoas (BITTENCOURT et al., 1979a).

The testimonies of this high sea-level are constituted by essentially sandy wave-built terraces. The associated sedimentary structures and fossil Callichirus burrows permit to reconstruct the relative sea-level in space, but as there are no datings it is not possible to delineate relative sea-level fluctuation curves for about 120,000 years ago and to compare several reconstructions along the coastline.

1.3.7 - Holocene high sea-level

The more recent high sea-level is well defined as a function of numerous reconstructions of ancient high sea-levels in space and time, which have been done using more than 700 radiocarbon ages.

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

Using all these data it has been possible to delineate complete or parcial 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 80km), with the same geologic framework and sufficiently numerous data, were considered.

1.4 - Relative sea-level fluctuations during the last 7,000 years along the Brazilian coast between Cananéia (SP) and Maceió (AL)

1.4.1 - Northern Salvador sector (State of Bahia)

This segment is about 50km long and about 60 reconstructions of relative sea-levels embracing the last 7,000 years have been done. From these informations it was possible to delineate relatively accurate curve (Fig. 3a), which has shown that:

a) The "zero line" (present mean sea-level) was cut for the first time in the Holocene about 7,100 years B.P.

b) About 5,100 years B.P. the relative sea-level was at the first maximum situated about 4.8 $\pm$ 0.5m above the present level.

c) After this maximum, a very rapid regression took place until about 4,900 years B.P., followed by slower regression until 4,200 years B.P. and again accelerated until about 3,900 years B.P. At that time sea-level was at a minimum situated probably a little bit below it is today.

d) Between 3,900 and 3,600 years B.P. occurred a rapid transgression and about 3,600 years B.P. the relative sea-level was at a second maximum placed about 3.5 $\pm$ 0.5m above the present level.

e) Between 3,600 and 3,000 years B.P. the relative sea-level dropped slowly and regularly. After 3,000 years B.P. it dropped more rapidly and about 2,800 years B.P. the relative sea-level was again slightly below the present level.

f) Between 2,700 and 2,500 years B.P. the relative sea-level raised very rapidly and about 2,500 years B.P. it was in the third maximum situated about 2.5 $\pm$ 0.5m above the present level.

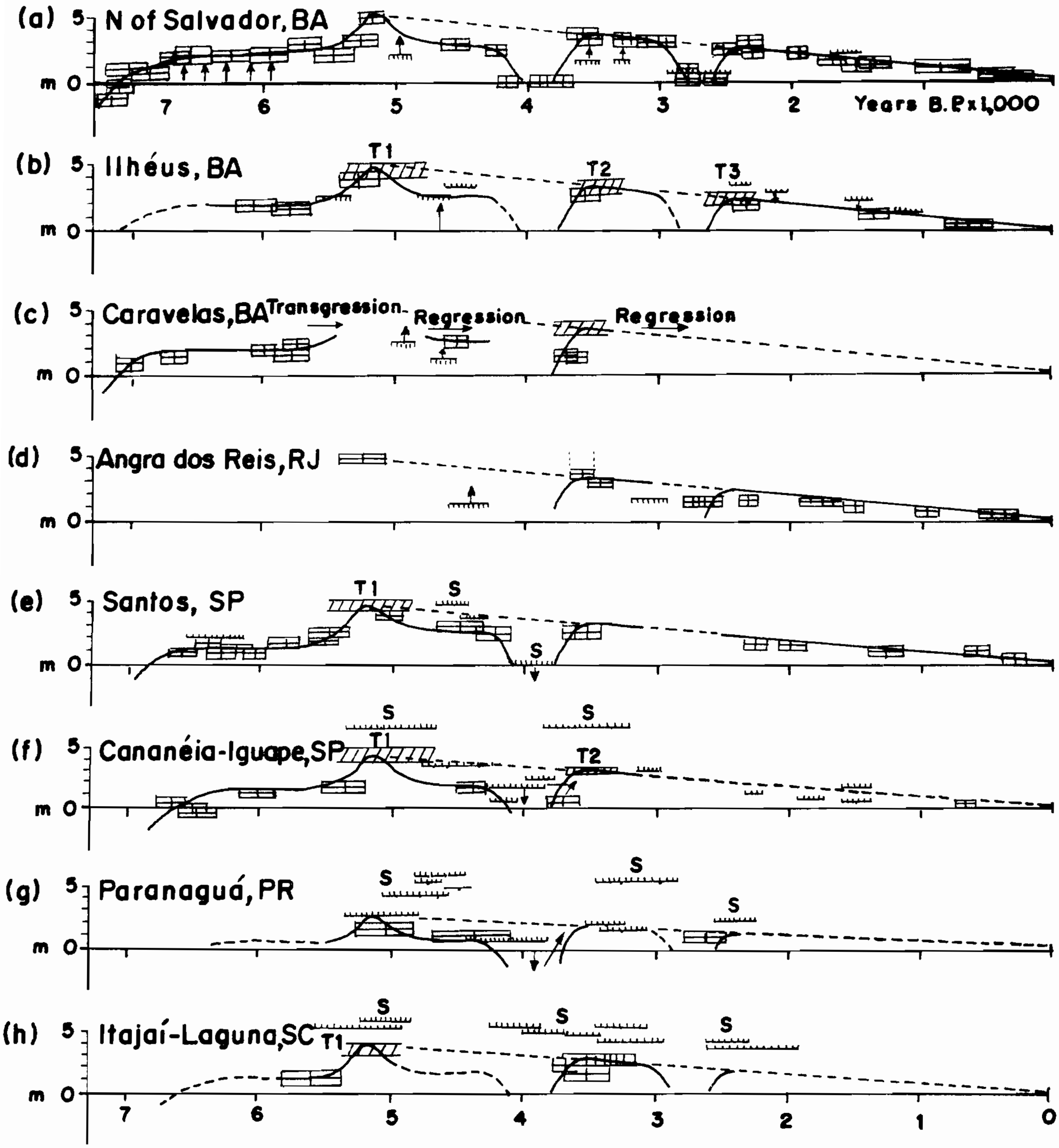


Fig. 3 — Sea-level fluctuation curves during the last 7,000 years for studied sectors of the Brazilian coastline

T1, T2 etc. = wave-built terraces and S = shell-middens

g) After 2,500 years B.P. the relative sea-level was subjected to a regular drop until the present position.

This curve is very well outlined and can be used as reference curve for sectors where reconstructions are insufficient to delineate a complete curve. Then, in these sectors it will be possible to compare the obtained reconstructions with the Salvador curve to test if they are on the curve.

1.4.2 - Sector situated between Itacaré and Ilhéus (State of Bahia)

This sector is about 60km long and ancient sea-level reconstructions were not sufficiently numerous to delineate a complete curve for the last 7,000 years (Fig. 3b). However, the obtained reconstructions are not shifted in relation to the Salvador curve. Three sandy terraces corresponding to three high sea-level periods, situated between 5 to 4m, 4 to 3m and 3 to 2m above the present level, have been revealed. It is logical to imagine that these three terraces correspond to three maximum levels evidenced in the Salvador sector.

1.4.3 - Sector situated between Caravelas and Nova Viçosa (State of Bahia)

This sector is about 30km long and only 11 reconstructions were obtained and, moreover, 7 of them are situated between 7,000 and 5,700 years B.P., then this was the time interval for which the fluctuation curve has been accurately delineated (Fig. 3c). All the obtained data are in accordance with the Salvador curve.

1.4.4 - Sector situated between Angra dos Reis and Parati (State of Rio de Janeiro)

This sector is about 60km long and only 17 ancient relative sea-level positions have been reconstructed. Nevertheless, the portion corresponding to the last 2,500 years was very well established (Fig. 3d). Moreover, there are indications of two maximum levels, the first of about 4.8m occurred 5,200 years B.P.

and the second of about 3m occurred between 3,650 and 3,450 years B.P.

1.4.5 - Sector situated between Bertioga and Santos (State of São Paulo)

About 30 reconstructions have been obtained for this 60km long sector, which allowed us to delineate a very accurate curve (Fig. 3e). It is interesting that in this sector present sea-level has been cut for the first time about 6,000 years B.P., that is, later than in the Salvador curve. Finally, the maximum levels of 5,100 years and 3,600 years B.P. reached, respectively, to 4.5 and 3m above the present level.

1.4.6 - Sector situated between Iguape and Cananéia (State of São Paulo)

In this sector about 100km long, 10 reconstructions of ancient sea-levels have been done. However, 7 reconstructions are related to the interval between 6,650 and 5,300 years B.P., which allowed us to delineate accurately this sector of the curve (Fig. 3f). Moreover, radiocarbon ages and $\delta^{13}C_{(PDB)}$ values of mollusk shells from shell-middens furnished very interesting additional data. Then, it appears that the present sea-level was cut for the first time about 6,600 years B.P. and the maximum level of 5,150 years B.P., whose age has been very accurately established as a function of $\delta^{13}C_{(PDB)}$, was not more than 4m above the present level.

1.4.7 - Coastal plain of the State of Alagoas

It was not possible to construct relative sea-level fluctuation curve for the coastal plain of the State of Alagoas because sufficiently numerous ancient sea-level reconstructions have not been obtained and, moreover, considered sector is too much long. Nevertheless, the obtained data showed a good correlation with the Salvador curve and, then, it is possible to assume that the relative sea-level fluctuations along the State of Alagoas coastline were similar to that of northern Salvador curve.

1.5 - General considerations on the configuration of the curves

Abstracting the variations of second order, which appear in the curves, we can observe that in all the studied sectors the relative sea-level was above it is today, and it rose continuously until about 5,100 years B.P. and, thereafter, came down to the present level. Moreover, they present great resemblance of configuration but they exhibit different vertical amplitudes. Finally, the maximum level of about 5,100 years B.P. appears to be followed by two rapid oscillations of some meters. These oscillations are too much enhanced to be considered of climatic origin.

In Salvador curve, more accurately constructed, 17 reconstructions of ancient sea-levels representing the last 2,500 years are situated on a straight line. Moreover, other 8 reconstructions used to delineate the curve between 3,600 and 3,000 years B.P. are situated in continuity to the above mentioned line. Finally, the prolongation of this straight line until 5.150 years B.P. (Holocene maximum sea-level) will define a sea-level position situated 5m above the present level. On the other hand, based on field informations it was possible to get an ancient relative sea-level situated at 4.8 ± 0.5m about 5,150 ± 111 years B.P. Then, several reconstructions of the last 5,150 years are situated on the same straight line and these data are excessively great to consider them as only fortuitous. Moreover, during some time intervals the experimental curve is more-or-less deviated from the straight line. So, it seems that after 5,150 years B.P. a first phenomenon caused regular drop of relative sea-level and a second phenomenon, superimposed to the first, could provoke very rapid oscillations of same sea-level.

There are no differences of amplitude between the curves of Salvador, Ilhéus and Caravelas, as we can see in the Fig. 3. On the other hand, the curve of Angra dos Reis is slightly shifted downwards. This deviation becomes increasingly accentuated from Santos to the Cananéia curve.

1.6 - Phenomena evidenced by relative sea-level fluctuation curves

In some restricted sectors of the Brazilian coast it was possible to demonstrate that vertical deviations of the Holocene shorelines occurred as a consequence of tectonic movements. Then, for example in the Baîa de Todos os Santos(State of Bahia), situated in the Recôncavo Graben, vertical movements of fault blocks, according to MARTIN et al. (1984a), provoked clearly visible dislocations of Holocene shorelines (Fig. 4). An analogous situation is found in the Guanabara Graben (MARTIN et al.,1980a), and at south of Cabo de São Tomé (MARTIN et al., 1984b), both situated in the State of Rio de Janeiro. It is also possible that some portions of the Brazilian coast have been subjected to continental flexure mechanism, but this phenomenon does not seem to be important in Holocene time scale (MARTIN and SUGUIO, 1976a).

In all the sectors which have been selected for Holocene sea-level studies, excluding the Angra dos Reis sector (State of Rio de Janeiro), records of 120,000 years B.P. marine terraces have been found. Without exception the internal portions of these sectors, presenting about same ages,do not exhibit clear difference of altitude. If the difference of about 2.5m, between the maximum sea-level of 5,150 years B.P. of Salvador and Paranaguá, was of tectonic origin, records of ancient sea-level of about 120,000 years B.P. must be clearly dislocated (until about 60m), but this is not the situation. So, it seems that vertical shifts between certain curves could be attributed to the deformation of geoid surface.

A close examination of geoidal map of Brazil,according to MARTIN et al. (1985), shows that eastern part of Brazil is situated on a geoidal intumescence whose "isoelevation lines" are arranged approximately in N-S direction (Fig. 5). Analogously, it is possible to see that the western portion of Brazil is located on a intumescence centered in Bolivia. Between these two intumescences exists a depression which passes across southeastern and northern coasts of Brazil. The portion of coastline in the State of Bahia, where are located the sectors related to Salvador, Ilhéus and Caravelas curves is trending approximately N-S and

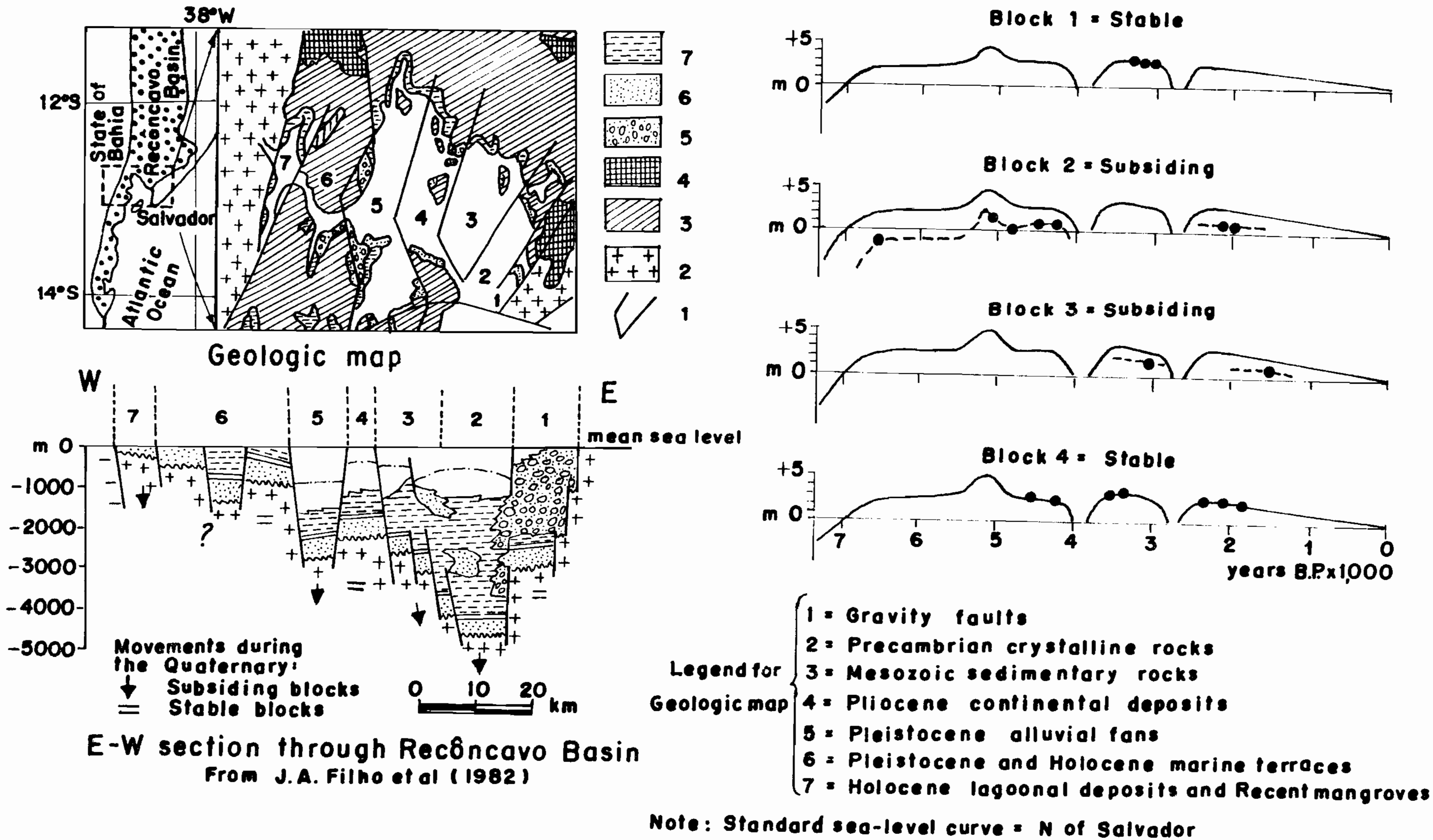


Fig. 4 – Vertical movements along the coastal plain of State of Bahia from 7,000 years B. P. to present.

then it is more-or-less parallel to the "isoelevation lines" of the geoid. On the other hand, the sectors of the coastline related to Angra dos Reis, Santos and Cananéia curves, trending approximately NE-SW, intersect obliquely the "isoelevation lines" of the geoid. Any modification will introduced in the curves of the Fig. 3a to 3c by horizontal shifts of the geoidal relief in N-S or E-W direction, but curves corresponding to other sectors will be deviated.

Assuming that Holocene high sea-levels found for the most part of the coast area, at least partially, were produced by regional scale modifications of the geoidal relief, the noticed deviations could be explained, since they were not equal along the whole coastline. For example, it is possible to assume that, submergence period which affected the most part of the Brazilian coast before 5,150 years B.P. was partially due to a temporary elevation of the geoidal relief and that the following emergence, conversely, was due to a lowering of this relief. Moreover, a little eastward deviation of the central depression axis during the geoidal relief lowering, can explain the noticed shift between Angra dos Reis and Cananéia curves. If this hypothesis is correct, Holocene sea-levels of the Paranaguá area (State of Paraná) must be more shifted in relation to corresponding levels of the Salvador curve (Fig. 6). Similarly, Holocene sea-levels of northern Brazil must be equally deviated in relation to corresponding levels of the Salvador area. Unfortunately, numerical informations for this portion of the Brazilian coastline are not yet available. Nevertheless, it is interesting to observe that the coastline between São Luís (State of Maranhão) and Belém (State of Pará) exhibits notorious features of submergence, since the coast is characterized by active scarps carved into the Pliocene continental deposits and downstream portions of river courses have been transformed into "rias".

In conclusion, it seems that Holocene high sea-levels in Brazil, which cannot be attributed to glacial eustasy or tectonism, can be explained, at least partially, by regional rising of the geoidal relief until about 5,150 years B.P., followed by lowering and little eastward horizontal shift. Analogously, a regional lowering of the geoidal relief followed by rising in

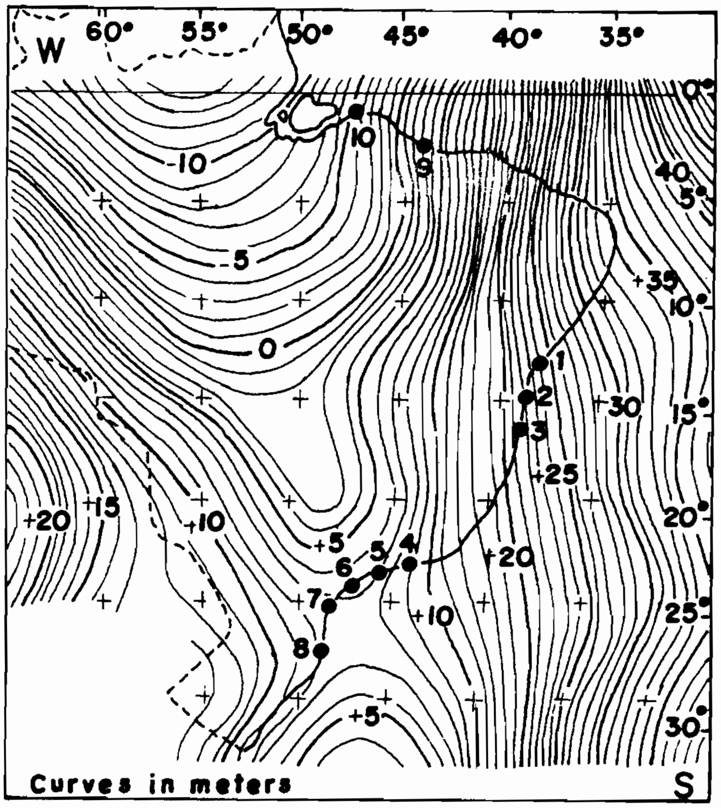


Fig. 5 — Geoidal isoelevation map of Brazil with the approximate positions of the following cities: (1) Salvador, (2) Ilhéus, (3) Caravelas, (4) Angra dos Reis, (5) Santos, (6) Cananéia, (7) Paranaguá, (8) Itajaí, (9) Sao Luís and (10) Belém.

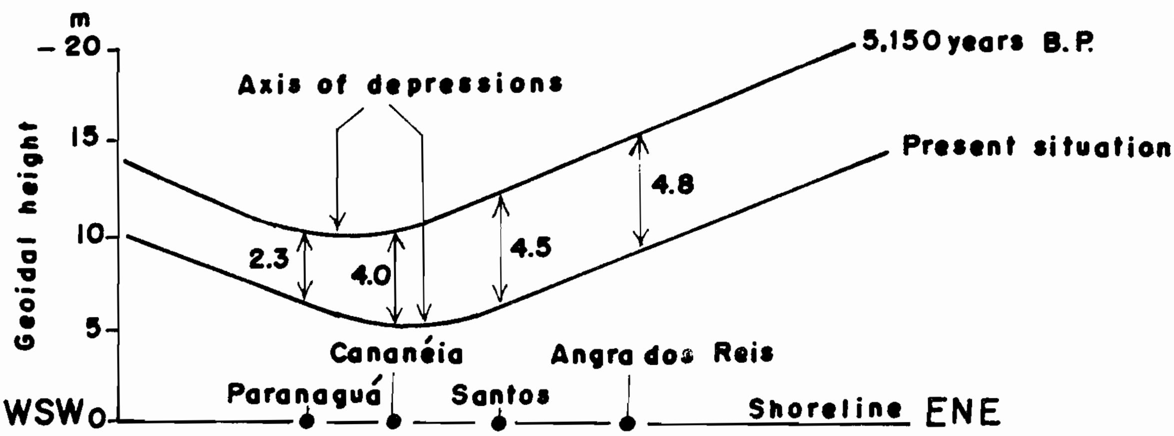


Fig. 6 — Comparison of present geoidal surface with that of 5,150 years B.P between Angra dos Reis and Paranaguá.

hundred years time scale could explain quick oscillations produced after 5,150 years B.P., which also cannot be attributed to glacial-eustasy or to tectono-eustasy.

2. CONSEQUENCE OF RELATIVE SEA-LEVEL FLUCTUATIONS AND LONG-SHORE DRIFT OF SEDIMENT UPON COASTAL SANDY SEDIMENTATION

In summary, regardless of origin, the most part of the Brazilian coast was in submergence until about 5,150 years B.P. followed by emergence until today, abstracting two quick oscillations. This is not a common situation found through the world during this time interval. For example, along the Atlantic coast of the United States, relative sea-level never intercepted present level during the Holocene(Fig. 7). So, evidently coastal evolution during this time interval cannot be the same in the United States and Brazil. The coasts in submergence, like United States, are characterized by barrier islands/lagoonal systems, while coasts in emergence, like Brazil, by extensive beach-ridge plains. A situation equivalent to that presently occurring in the United States could have existed in Brazil about 5,150 years B.P. A paleogeographic reconstruction of Rio Doce mouth coastal plain about 5,150 years B.P. (SUGUIO et al., 1982, 1984a),based on radiocarbon ages, shows a great resemblance with the features presently seen in Cape Hatteras area (Fig. 8).

2.1 - Role played by relative sea-level fluctuation on coastal sandy sedimentation

According to BRUUN (1962), once established the equilibrium profile in a coastal zone, following sea-level rise will disturb this equilibrium, which will be re-established throughout its landward migration. In consequence, beach prism will be eroded and this material will be transported and deposited on foreshore. This process will provoke an elevation of foreshore bottom in equal magnitude to sea-level rise, so water depth will be kept constant.

Field and laboratory experiments accomplished by several authors (SCHWARTZ, 1965, 1967 and DUBOIS, 1976, 1977) ratified the BRUUN (op. cit.) hypothesis. Although this rule has

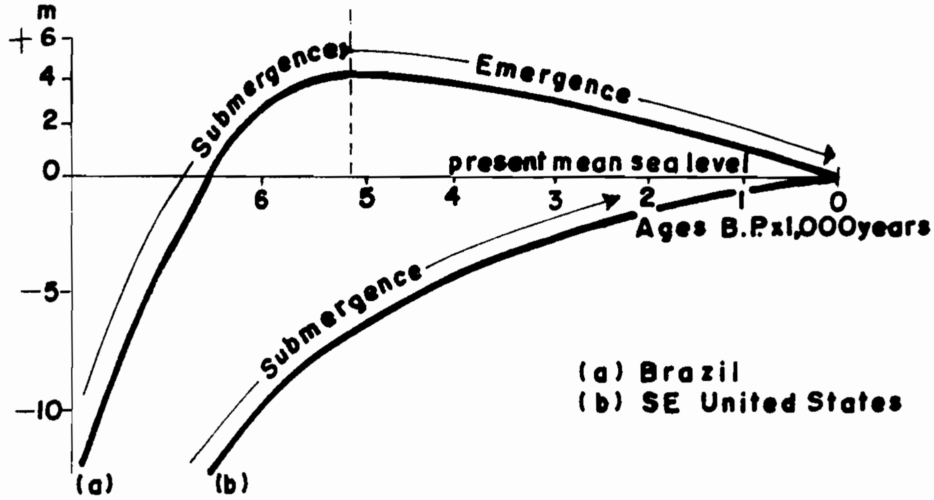


Fig. 7 — Schematic mean curves of sea-level fluctuations along the central portion of Brazilian coastline and south-eastern United States during the last 7,000 years.

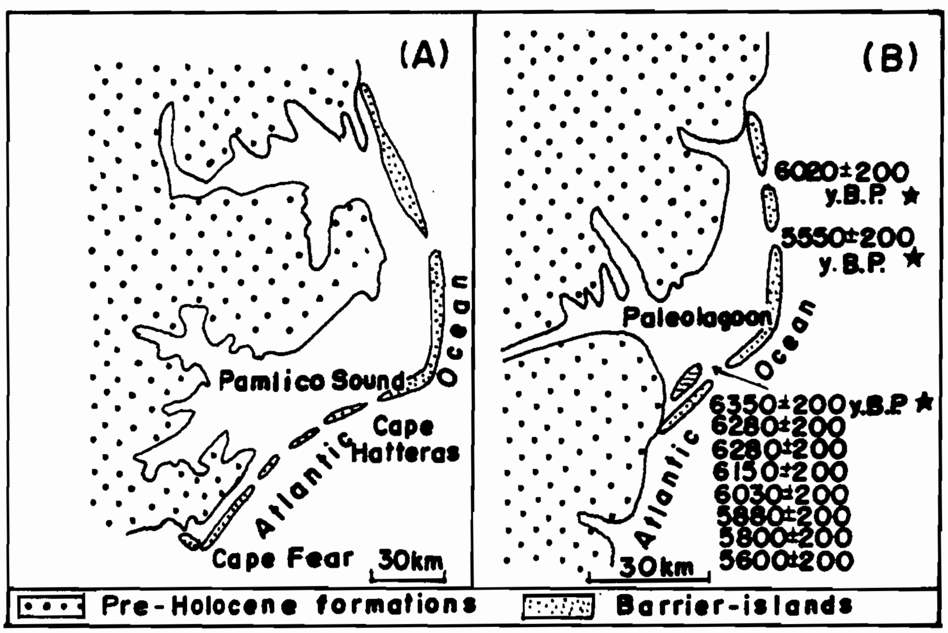


Fig. 8 — Present situation in Cape Hatteras area, United States (A) compared with that of Rio Doce mouth coastal plain about 5,100 years B.P (B).

been developed only for inverse situation, that is relative sea-level rise, the equilibrium destroyed in coastal sedimentation dynamics during sea-level drop also must be restored (Fig.9). In fact, relative sea-level drop, decreasing water depth, will produce desequilibrium in the profile, which will become more aggraded. In consequence, wave will move landward the unconsolidated foreshore sediments, accumulating them in the beach prism and then propitiating coastal progradation. This transference will stop when previously existing water depth is attained. Comparatively, this process is analogous to that when storm beach profile is restored by sediment transfer from foreshore to beach prism in a swell profile, as largely recorded in the literature (DAVIES, 1972; KING, 1972; KOMAR, 1973, 1976; SWIFT, 1976).Analogously, this mechanism can be perfectly observed during a monthly tide cycle. During syzigyal tides, corresponding to a "little transgression", will occur backshore erosion and foreshore deposition and, on the contrary, during quadrature tides, corresponding to a "little regression", will occur backshore deposition and foreshore erosion.

Then, it is obvious that in gentle slope sandy coasts, a relative sea-level drop will induce intensive transportation of sand from the inner continental shelf into the beach. If longshore drift is small or null, shoreline progradation will occur through accrection of successive beach-ridges.

2.2 - Role played by longshore drift of sands on coastal sedimentation

The transportation of sands along a sandy beach is mostly caused by longshore currents generated by the waves. In fact, near to the beaches, the waves do not find sufficient depth to their advancement. This phenomenon is followed by liberation of large amount of energy which will be partially used to put sands in suspension and, in part, to generate longshore currents. Obviously, this phenomenon will occur only when the wave front attains shorelines obliquely.

The velocity of this current is very slow but its influence is very effective where sands were put in suspension by

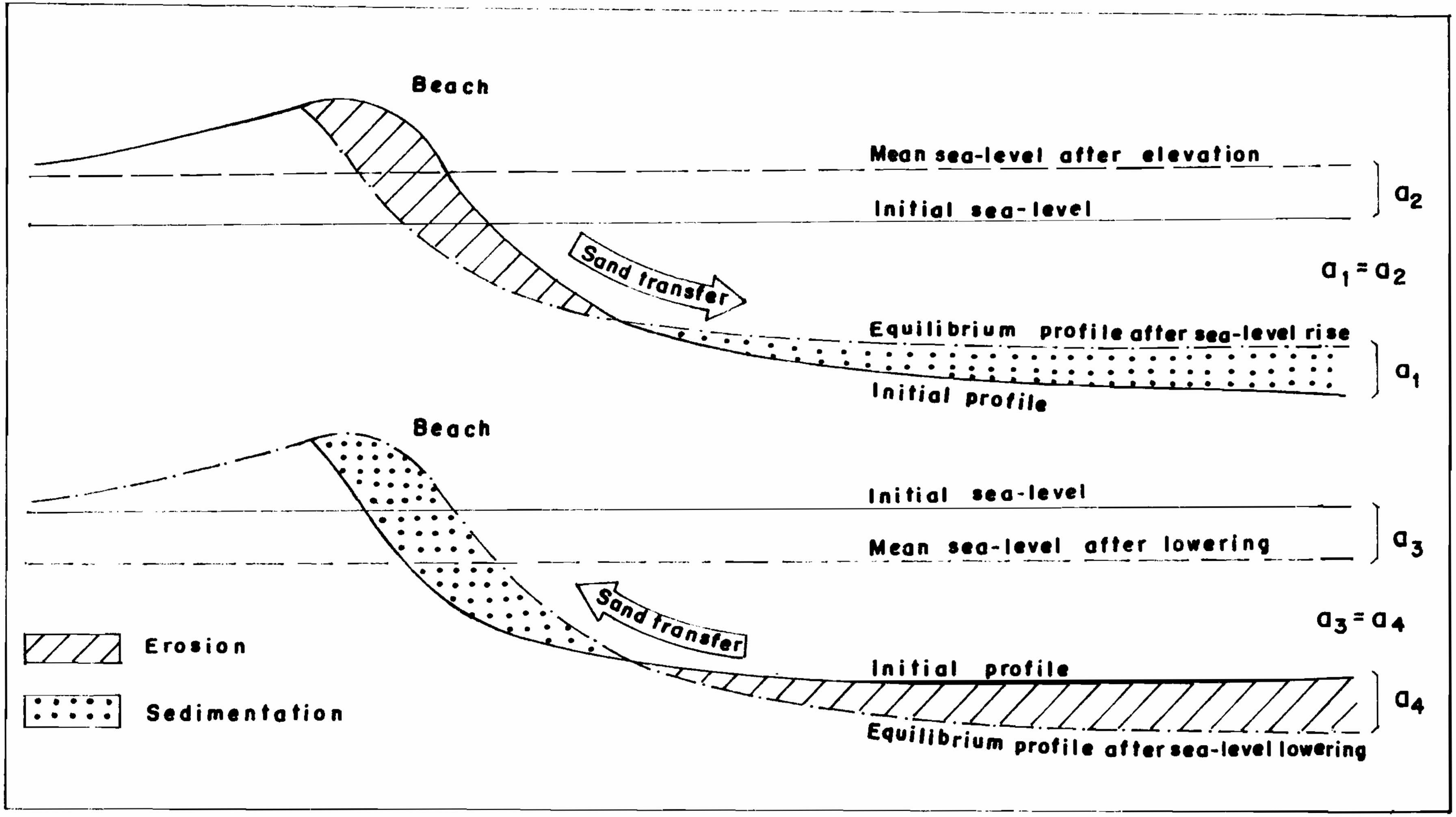


Fig. 9 — A) Behaviour of littoral zone equilibrium profile as a function of sea-level rise (Mod. from BRUUN, 1962); B) Behaviour of littoral equilibrium profile as a function of sea-level drop (DOMINGUEZ, 1982).

wave-break and, therefore, very important volume of sands will be transported in this way. Several calculations have shown that maximum velocity of longshore currents is attained when waves reach the shoreline with inclinations between 46° and 58° (LARRAS, 1981). A combination of spreading effect of broken waves and longshore currents will provoke pulsative transportation of sands. Obviously, direction of transportation will depend on the angle of incidence of wave fronts which reach the shoreline.

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

2.2.1 - Blocking of longshore transportation of sands by a river flow

2.2.1.1 - General statements

In favourable conditions river flow near its mouth will form an obstacle which can block transportation of sands, in a same way as an artificial groyne in the coast. In general, these structures are founded on the land, extending beyond sea after wave breakage, interrupting completely coastal transportation of sediments. As a consequence, the sediments will be retained by the obstacle, in a such way that updrift shoreline will be subjected to a rapid progradation. At the same time, downdrift shoreline will be eroded causing rapid retrogradation (Fig. 10).

KOMAR (1973) simulated the evolution of a delta in a computer model, where the sediments are mostly reworked by wave energy, and called attention to the fact that when the waves form an acute angle, in relation to shoreline, river flow will act as a groyne trapping the longshore drift of sediments. So, deltaic plain would be subjected to a rapid progradation at updrift side of the river mouth, while at downdrift side the sediments will mostly be removed by erosion.

The mechanisms active at river mouth can be explained as follow (Fig. 10):

a) During floods, the river flow acts as a hydraulic jetty, with retention of longshore drift sands in the updrift portion and deposition of fluvial sediments in the downdrift area.

b) On the other hand, the blocking effect of the river flow on longshore sediment transportation will be much less efficient during dry seasons when, partly by erosion of previous deposits, longshore currents will build a sand spit which tends to obstruct the river mouth. If low energy river flow continues, the sand spit will be enlarged to the extent that it will only be partially affected during subsequent periods of high energy. In some cases, only the distal end of the sand spit will be destroyed, the blocking effect of the river flow will be displaced in the direction of the longshore drift, and a new accumulation will occur.

As a consequence of "groyne effect" of the river mouth flow, alternated with low energy conditions, the coastal plain on either side of the river mouth will thus be asymmetric with the updrift portion formed by a series of sandy ridges, and the downdrift portion consisting of alternating sandy ridges and clayey-sandy wetlands. Displacements controlled by the river mouth will be recorded as unconformities in the alignment of sandy ridges.

2.2.1.2 - Example of the Rio Paraîba do Sul mouth

a) Direction of longshore drift

Waves from two different directions are observed at the mouth of Rio Paraîba do Sul. A S-SE direction is related to the penetration of polar air masses through the South American continent and is more frequently observed during autumn and winter. The second comes from the NE and is associated with trade-winds.

The waves from S-SE are much stronger than those from the NE and dominate in the longshore drift of sediment. When NE waves are superimposed on the longwave length S-SE waves, only the latter are active in the longshore drift of sediments.

The S to N longshore transportation of sediments is demonstrated by the geometry of the Holocene beach ridges (DOMINGUEZ et al., 1983), and by the fact that accumulation is occurring to the S (updrift) of the Barra do Furado groyne, while erosion is accelerated to the N (downdrift).

b) Morphological characteristics of the river mouth

The mouth area of the Rio Paraîba do Sul is characterized by the following features (Fig. 11):

- 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.

- The presence of a well-developed sand spit. The construction of this spit was followed by intensive coastal erosion, when many houses were destroyed at Atafona. The coastline of Atafona was displaced in a landward direction about 100m between 1956 and 1976. In February 1976, during a flood of Rio Paraîba do Sul, the sand spit was almost completely destroyed. In February 1981, a 300m-long new sand spit was formed.

- Stepwise unconformities of beach ridge alignments which can be related to the periods following the sand spit formation.

c) Degree of roundness of sands of present beaches around river mouth

If the proposed model is correct, the degree of roundness of sands, on both sides of Rio Paraîba do Sul mouth must be different (SUGUIO et al., 1984). This hypothesis has been tested, using 21 sand samples collected between Macaé (southern limit of the coastal plain) and Guaxindiba (northern limit of the coastal

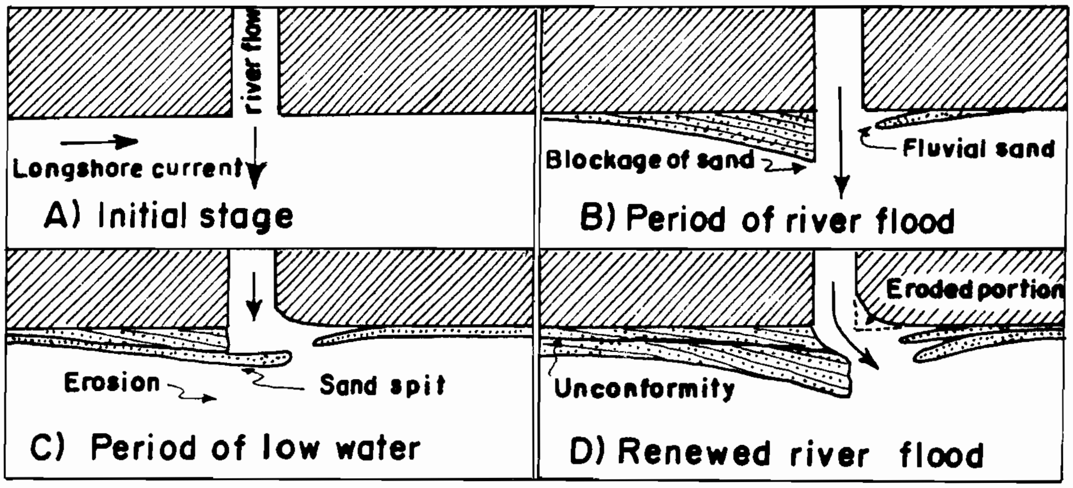


Fig. 10 — Mechanism of blocking of sands supplied by longshore currents around an important river mouth.

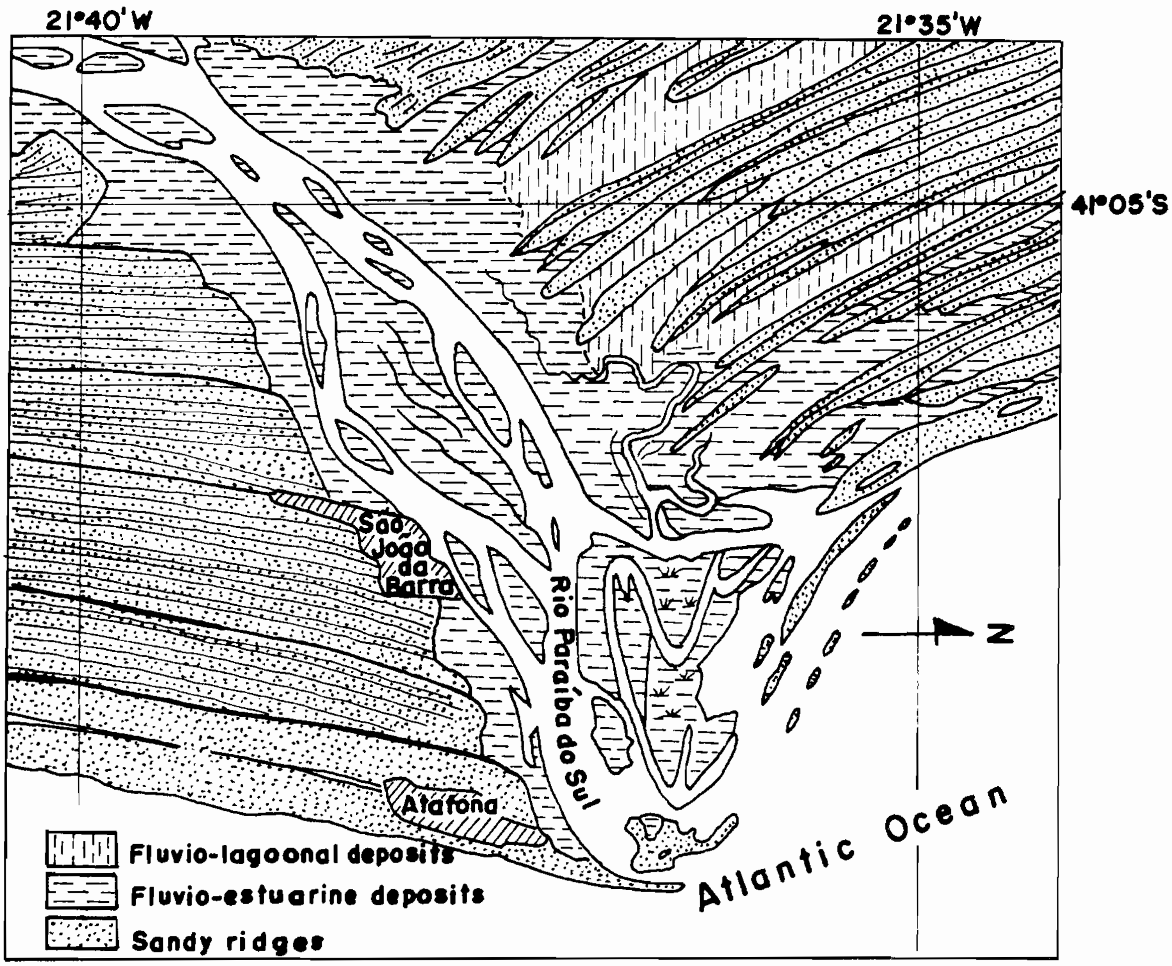


Fig. 11 — Rio Paraíba do Sul mouth showing strong asymmetry between the northern and southern parts of the river.

plain), and 3 samples from the Rio Paraîba do Sul. The degree of roundness of quartz particles was studied in several fractions; following CAILLEUX and TRICART (1959) only the interval 1 to 0.5 mm was considered. Five classes of roundness were established: 1 = angular, 2 = sub-angular, 3 = sub-rounded, 4 = rounded and 5 = very rounded.

Histograms (Fig. 12) show that there are two distinctive types of sands. The sands from Macaé to Grussaî have 20 to 60% of very rounded grains, while the rest is formed by rounded and sub-angular grains. The sands from the northern part (Rio Paraîba do Sul mouth to Guaxindiba) lack very rounded grains and show less than 35% of sub-angular grains. Histograms for these sands are very similar to those for the sands from the Rio Paraîba do Sul. At Atafona, near the river mouth, the sands (samples 70 and 71) exhibit intermediate characteristics probably because sampling was conducted at a time when NE waves were dominant.

A similar pattern emerges when 3 classes of roundness are considered (1 = angular, 2 = sub-angular and sub-rounded, and 3 = rounded and very rounded): dominant classes to the south and north of the river mouth are rounded and very rounded grains, and sub-rounded to sub-angular, respectively (Fig. 13).

These differences in degree of roundness suggest that the river sands are deposited almost entirely to the north of the river mouth.

d) Degree of roundness of sands of Holocene terraces on both sides of river mouth

Histograms of degree of roundness for 12 samples from each side (north and south) of Rio Paraîba do Sul mouth are shown in the Figs. 14 and 15.

All samples from the southern portion of the coastal plain show the same characteristics: a strong dominance of rounded and very rounded grains. The only exceptions are samples 120 and 121 which are characterized by sub-angular and sub-rounded grains. These were collected from near an old river mouth. In contrast, sands from the northern portion of the coastal plain are characterized by large variations in their degree of roundness and two main groups can be identified: sands dominated by

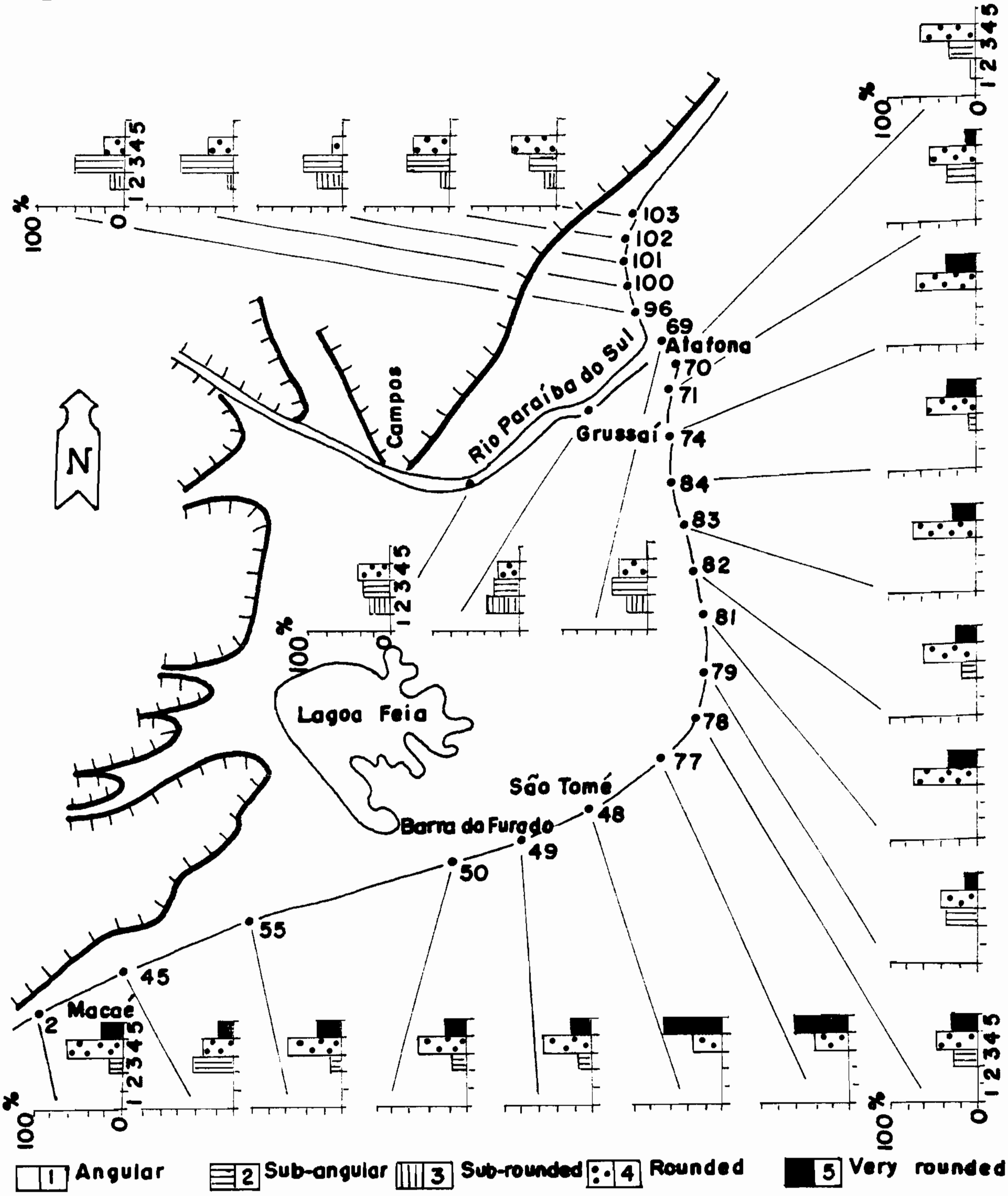


Fig. 12 – Degrees of roundness of sands (5 classes) sampled along the beaches and river bed of the Rio Paraíba do Sul coastal plain.

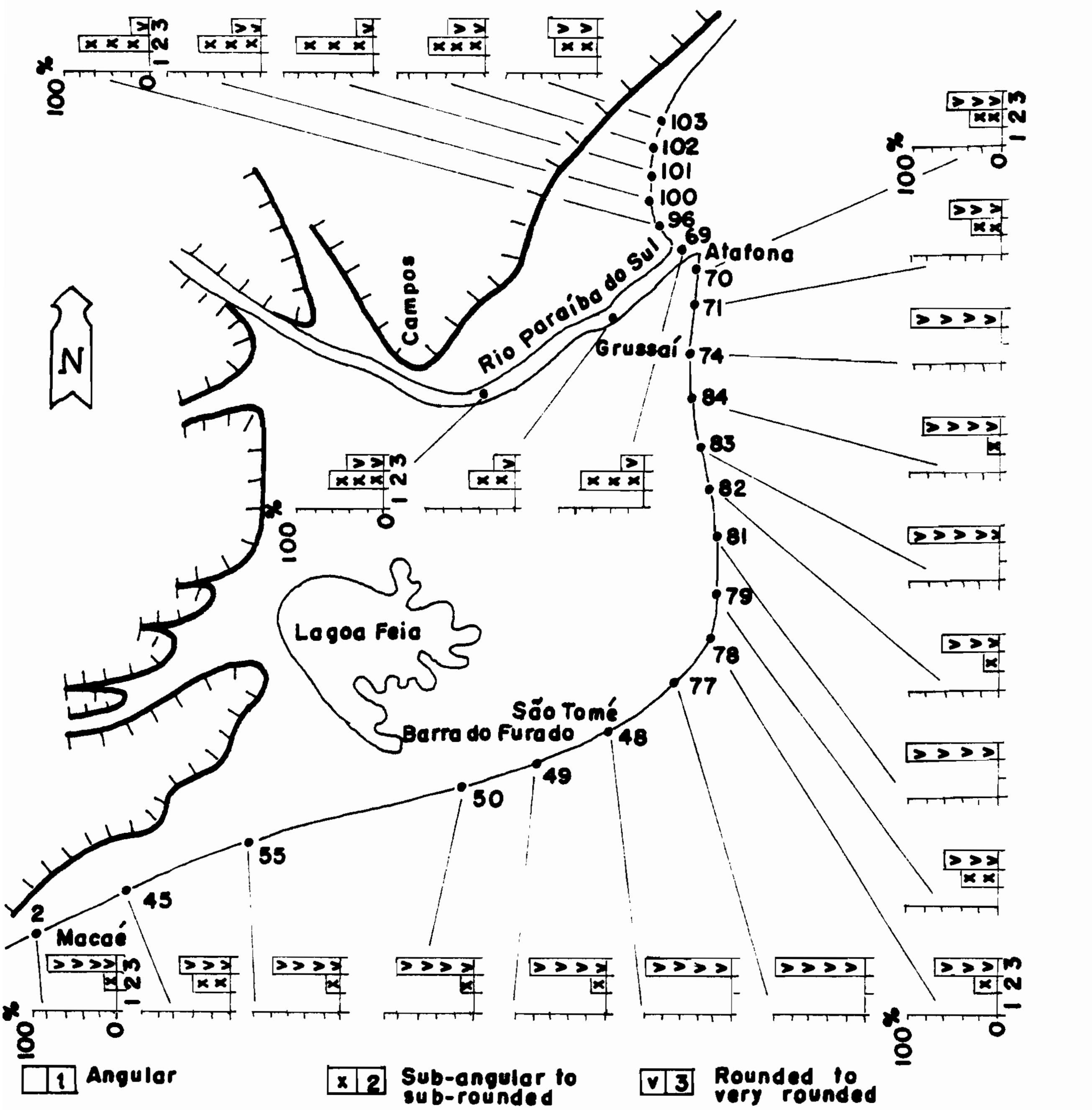


Fig. 13 — Degrees of roundness of sands (3 classes) sampled along the beaches and river bed of the Rio Paraíba do Sul coastal plain.

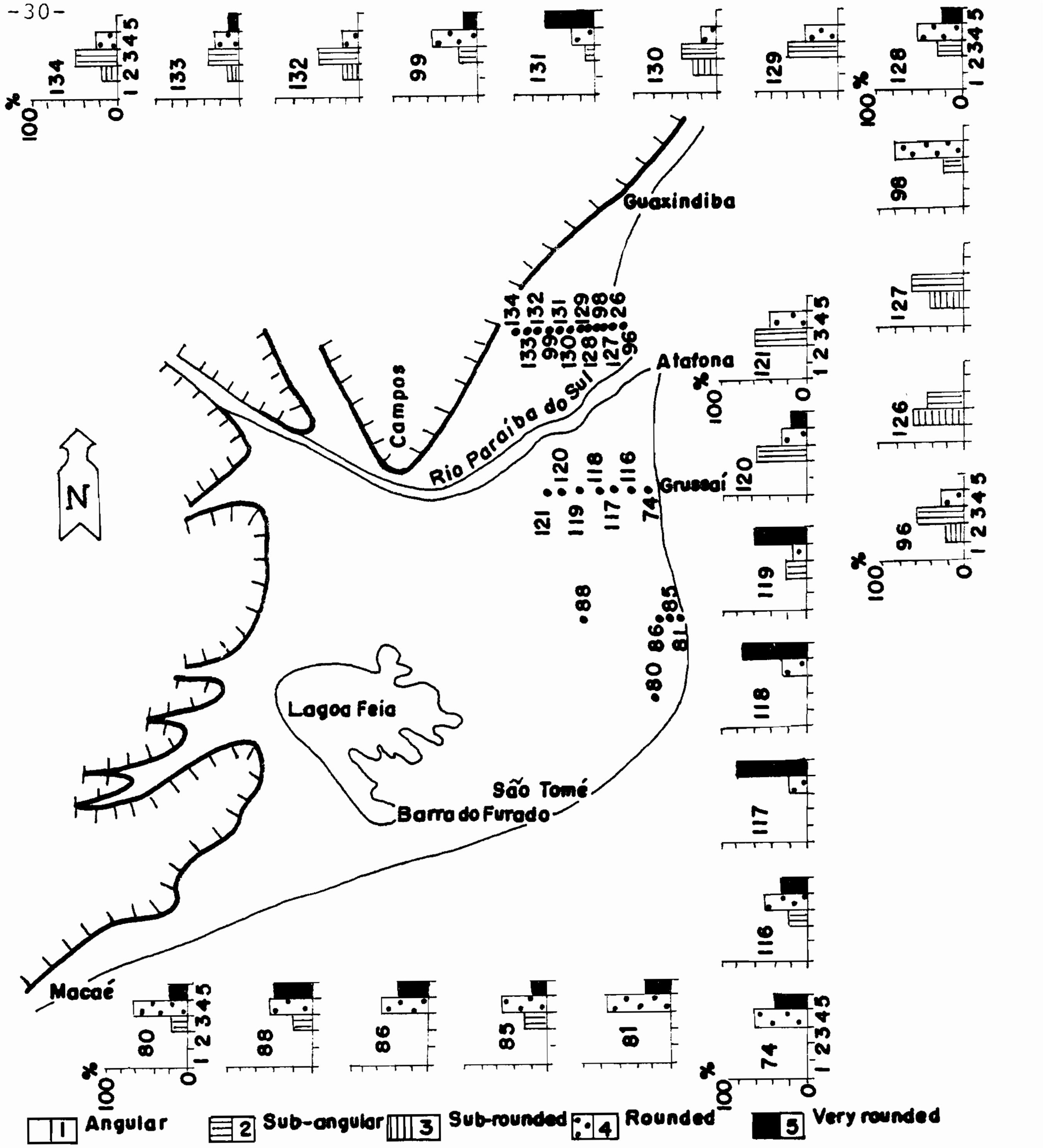


Fig. 14 — Degrees of roundness of sands (5 classes) from Holocene marine terraces of the Rio Paraíba do Sul mouth coastal plain.

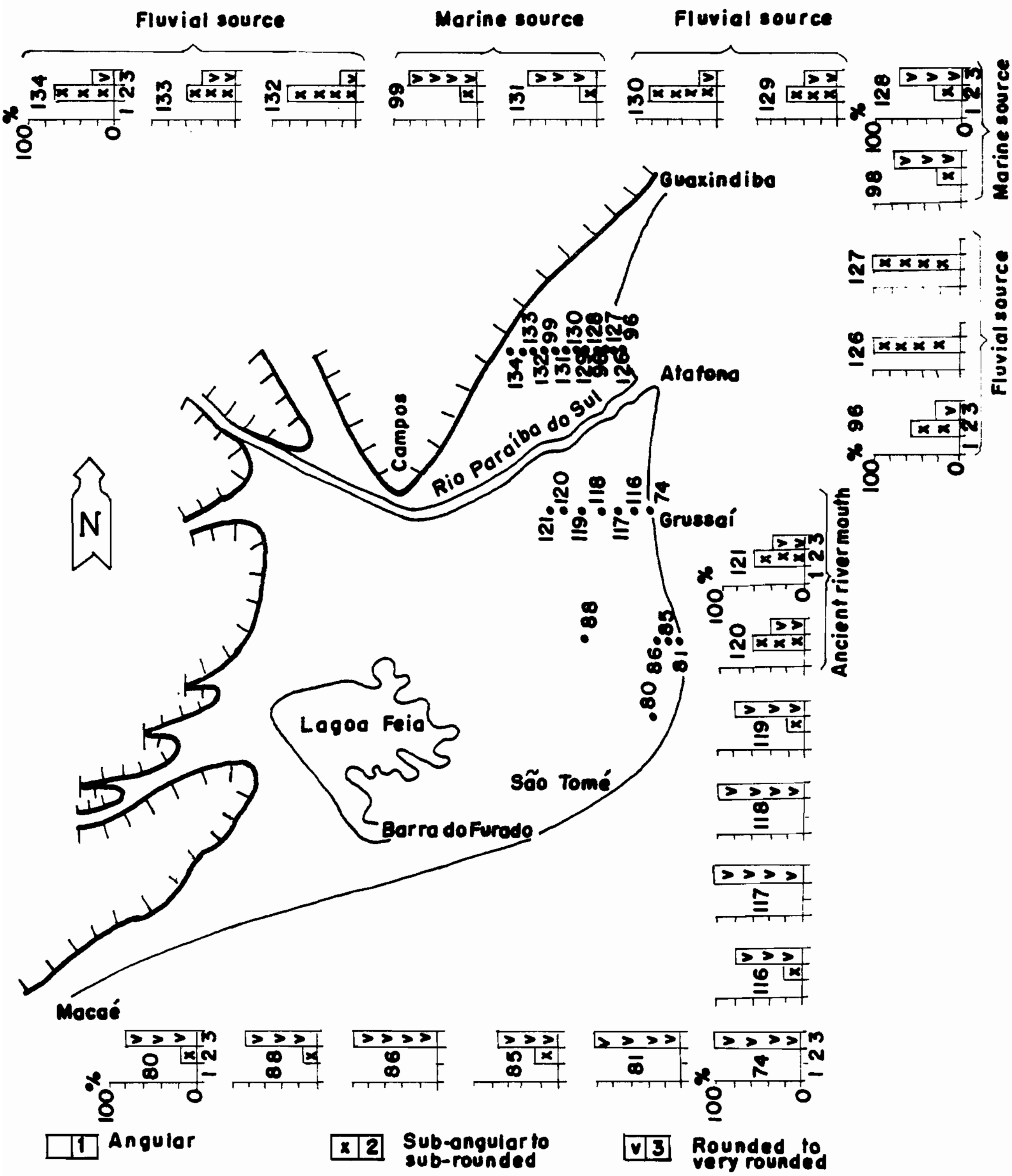


Fig. 15 – Degrees of roundness of sands (3 classes) from Holocene marine terraces of the Rio Paraiba do Sul mouth coastal plain.

sub-angular and sub-rounded grains (as found in the present beach) and sands dominated by rounded and very rounded grains (as found in the southern coastal plain). These data indicate that the northern part of the coastal plain consists of sands deposited by the Rio Paraîba do Sul (type 1), alternating with sands derived from the adjacent inner continental shelf (type 2), and that the supply of either sand types depends upon changes in energy of the Rio Paraîba do Sul. During high energy periods, the river load consists mainly of sands that accumulate in front of river mouth, and then are subsequently reworked by waves and transported northward by longshore currents. During low energy periods, the river load is mainly mud and the sands supplied to the northern part of the coastal plain come mostly from the adjacent inner continental shelf.

2.3 - Main stages of development of the coastal plains between Cananéia (State of São Paulo) and Recife (State of Pernambuco)

Relative sea-level fluctuations, associated with paleoclimatic variations, controlled the origin of the Brazilian coastal plains, whose most complete evolutive model has been established for the coast of State of Bahia (Fig. 16). This model is valid for sector of the coastal plain between Macaé (State of Rio de Janeiro) to Recife (State of Pernambuco) but, in some areas, records corresponding to one or more stages can be absent.

2.3.1 - Evolutive model valid for sector of the coastal plain between Macaé and Recife

a) Stage I: Sedimentation of the Barreiras Formation

Continental deposits of the Barreiras Formation have been deposited during Pliocene, under semiarid paleoclimate and subjected to concentrated and torrential rainfall, originating coalescing alluvial fans which, according to GHIGNONE (1979) filled up extensive segment of the Brazilian coast. During this period, relative sea-level was much lower than it is today and, then, their sediments covered most of the adjacent continental shelf (BIGARELLA

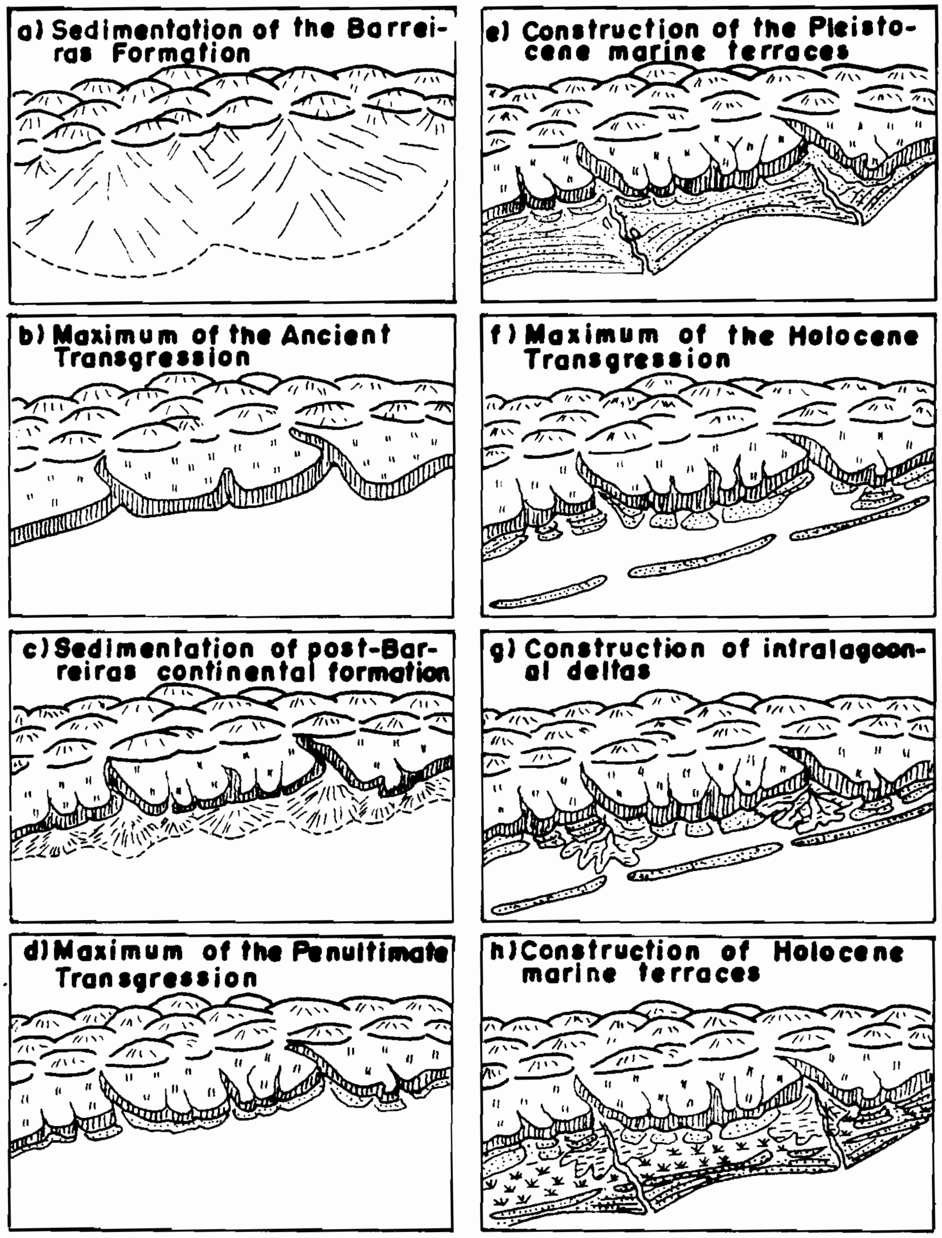


Fig. 16 — Evolutive model during the Neo-Cenozoic valid for sector of the coastal plain between Macaé (State of Rio de Janeiro) and Recife (State of Pernambuco)

and ANDRADE, 1964).

The deposits of the Barreiras Formation occur from State of Rio de Janeiro to the mouth of Rio Amazonas.

b) Stage II: Maximum of the Ancient Transgression (older than 120,000 years B.P.)

According to VILAS-BOAS et al. (1981), the paleoclimate became wetter at the end of sedimentation of the Barreiras Formation then, giving place to Ancient Transgression that originated 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.

c) Stage III: Sedimentation of post-Barreiras continental formation

After the maximum level of the Ancient Transgression and during the following regression, the paleoclimate re-acquired semiarid characteristics, at least in the areas corresponding to the States of Bahia, Sergipe and Alagoas. This turn back 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 the Stage II.

d) Stage IV: Maximum of the Penultimate Transgression (about 120,000 years B.P.)

During this period, corresponding to maximum of the Penultimate Transgression (Cananéia Transgression), sea eroded totally or partially the continental deposits formed during the Stage III. The downstream courses of the rivers were drowned and transformed into estuaries and lagoons and, where the continental deposits of the previous stage were completely eroded the sea reached the cliffs of the Ancient Transgression, which were sometimes entirely eroded.

e) Stage V: Construction of the Pleistocene marine terrace

In this phase occurred the regression which was followed by coastal plain progradation, through successive accretion of sandy ridges, giving rise to extensive coastal plains.

f) Stage VI: 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. Continuously, barrier islands and lagoonal systems have been formed which, in some places, attained huge dimensions. Mollusk shells and wood fragments contained within lagoonal deposits furnished radiocarbon ages of less than 7,000 years B.P., indicating that barrier-islands were formed previously to the maximum level of this transgression.

g) Stage VII: Construction of intralagoonal deltas

Within lagoonal systems formed around the mouths of most important rivers flowing into the Atlantic Ocean, were deposited intralagoonal deltas essentially nourished by fluvial sediments.

h) Stage VIII: Construction of Holocene marine terraces

The relative sea-level drop following the maximum level of 5,150 years B.P. promoted the construction of successive sandy ridges departing from the original barrier-island and forming marine terraces. The sea-level drop, besides the construction of marine terraces, caused gradual transformation of lagoons in lakes, followed by marshes and swamps. Several lakes, as for example Lagoa Bonita in the Rio Doce mouth or Lagoa Feia in the Rio Paraíba do Sul mouth, still occurring in these coastal plains represent vestiges of ancient more extensive lagoons. Small and relatively rapid transgressive episodes of 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 Rio Doce coastal plain, associated with a transgressive event of 3,800 - 3,600 years B.P. (SUGUIO et al., 1982), with construction of new barrier-islands and drowning of lowlands situated between the sand ridges of first generation Holocene terraces. In the Rio Jequitinhonha coastal plain, these transgressive episodes are represented by drowned river mouth associated with shifting of river course by process of avulsion (DOMINGUEZ, 1983).

2.3.2. - Evolutive model valid for the southern half of the State of São Paulo coastal plain

In the southern half of State of São Paulo coastal plain, also exhibiting extensive beach-ridge plains, the general principles of previously presented evolutive model is also valid. The Pariquera-Açu Formation, constituted also by continental deposits, is correlative to the Barreiras Formation, recording semi-arid paleoclimate during the Stage I. Neither evidence of the Ancient Transgression (Stage II), nor post-Barreiras continental formation (Stage III) were found in this portion of the Brazilian coast. Testimonies of Penultimate Transgression (Stage IV) and following regression (Stage V), as well as, records of Holocene Transgression (Stage VI) and following regression (Stage VIII)are very well represented in this region. Nevertheless, as the majority of rivers in the area is flowing to hinterland toward the Rio Paraná, intralagoonal deltas were not developed during Stage VII. Finally, as relative sea-level drop following the Holocene Trangression was less important than previously considered sector, Holocene marine deposits are less developed than in the Macaé-Recife sector.

2.4 - About the validity of the word "delta" to designate coastal plains associated with mouths of the most important rivers of Brazilian eastern and northeastern coasts

Associated with the mouths of the most important Brazilian rivers flowing into the Atlantic Ocean, there are progradation zones, which were classified by BACOCCOLI (1971), based on concepts of SCOTT and FISHER (1969), as "wave-dominated ,highly destructive deltas" (Rios Parnaíba , Jaguaribe, São Francisco, Jequitinhonha, Doce and Paraíba do Sul) and "tide-dominated,highly destructive delta" (Rio Amazonas). Moreover, this author assumed a Holocene age and proposed an evolutive scheme entirely related to Flandrian Transgression, in some cases with an intermediary transition through estuarine phase until constituting more typical deltas, which advanced oceanward causing progradation.

Nevertheless, along the coast of Brazil there are also extensive areas without any relationship with present or past river mouths. The most impressive case is situated near Canavieiras (State of Bahia), where besides fluvial deposits,there are all the types of deposits commonly found in "wave-dominated deltas" of the Brazilian Quaternary coastal plain. For that reason, BACOCCOLI (op. cit.) proposed that this area would represent delta of the ancient Rio Mucuripe, associating it with a negligible river situated there.

The occurrence of such a kind of coastal plain, without any evident association with river mouths, attracted our attention. The classical models of coastal sedimentation, as proposed by FISHER (1969), GALLOWAY (1975), HAYES (1975) and others, emphasize the roles played by wave energy, tidal range, river load,etc., as essential factors but no one mentions the possible influence of relative sea-level fluctuations. In their classical work, COLEMAN and WRIGHT (1975) analysed about 400 parameters which could be active during sedimentation of sandy deltaic deposits, but they also forgot perhaps one of the most important factor, that is, <u>the relative sea-level drop during Holocene</u>. We have seen that sea-level drop promotes sandy transfer from foreshore to beach , which can be partially transported by longshore currents until being trapped by an obstacle, like a river mouth, in a same way as a artificial groyne in the coast. When longshore drift is the dominant process, the fluvial sediments will be accumulated only at downdrift side, since at updrift side will accumulate only marine sands blocked by river flow. On the other hand, only in absence of longshore drift, that is, when the wave front reach parallel to shoreline, the fluvial sediments will be reworked by the waves and deposited on both sides of the river mouth. Detailed surveys accomplished in the coastal plains associated with the mouths of the Rios Paraíba do Sul, Doce, Jequitinhonha and São Francisco showed that the direction of longshore drift has been constant during the last 6 to 7,000 years (BITTENCOURT et al., 1982a; DOMINGUEZ et al., 1981a, 1981b, 1983). As the most important portion of the coastal plains of the mouths of these rivers was not constructed directly by fluvial sediments it is possible to call in question if the word"delta" is the most suitable to designate these progradation features (DOMINGUEZ et al., 1982).

PART II

COASTAL QUATERNARY DEPOSITS OF STATES OF PARANÁ AND SANTA CATARINA

1. INTRODUCTION

The studied area is comprised between the southern extremity of Ilha do Cardoso (southern limit of the State of São Paulo = 25^{o} 13'S) and the town of Torres (northern limit of the State of Rio Grande do Sul = 29^{o} 20'S). Between Paranaguá and the town of Laguna the coastline has a N/S direction which changes to NE/SW direction southward. In some places, as in Paranaguá area, the coastal plain is about 60km-wide but, in other parts Precambrian crystalline rock headlands or Paraná Basin Paleozoic or Mesozoic sedimentary rocks reach the ocean.

1.1 - Geology of the coastal region

In the States of Paraná and Santa Catarina the coastal region is represented by an elongated strip of lowlands, limited eastward by the Atlantic Ocean and westward by the Serra do Mar and Serra Geral. Serra do Mar is usually composed of Precambrian crystalline rocks (gneisses and other metamorphic rocks, granites, etc.) intruded by Mesozoic diabase dikes. The crystalline escarpment of the Serra do Mar disappears south of Laguna (State of Santa Catarina), being replaced by the Serra Geral composed mostly of Mesozoic basaltic lava flows.

Remnants of continental Neocenozoic deposits(Tertiary?) are widespread in these states, being characterized by the general afossiliferous nature and lack of key-beds. They are represented in the State of Paraná by Alexandra Formation (BIGARELLA et al., 1959), and in the State of Santa Catarina by Iquererim Formation (BIGARELLA et al., 1961), Canhanduva sequence (BIGARELLA and SALAMUNI, 1961) and Cachoeira layers (BIGARELLA, 1975).

Quaternary deposits of the coastal region in these states are more-or-less directly related to submergence and emergence periods of Upper Pleistocene and Holocene. Among them, sandy ridges are widespread reaching width of about 15 to 20km, but they are discussed in more detail elsewhere.

1.2 - Physiography of the coastal region

As a function of the physiography, it is possible to divide the coastal region of States of Paraná and Santa Catarina into three sectors:

a) Northern sector - This sector goes from Ilha do Cardoso (25° 13'S) to the town of Barra Velha (26° 40'S), which is characterized by the occurrence of three great bays: Paranaguá, Guaratuba and São Francisco. The coastal plain situated at the foot of the Serra do Mar escarpment presents its greatest development within this sector.

b) Median sector - This sector is limited between the town of Barra Velha and Garopaba area (28° 00'S). This portion of the coastline is characterized by the presence of Precambrian crystalline rocks interrupting Quaternary coastal plains. This sector is also characterized by the Santa Catarina island, where dune fields are for the first time important.

c) Southern sector - This sector is comprised between Garopaba area and the town of Torres (29° 20'S), which is characterized by vast coastal plains with extensive lagoons and paleolagoons. This area is also characterized by frequent and important eolian deposits belonging to several generations.

1.3 - Climate of the coastal region

The States of Paraná and Santa Catarina are almost entirely characterized by a subtropical climate, with cold winter and warm summer. In the tropical areas of Brazil winter is characterized by rainy period and not necessarily by lower temperature. While mean annual temperatures are higher than 20°C in most of the Brazilian territory, in these states they are less than 18°C. The mountainous areas of the Serra do Mar and Serra Geral present the highest precipitation values of Brazil, reaching frequently to maximum precipitation higher than 5,000 mm/year in many places.

2. MARINE AND LAGOONAL DEPOSITS

A detailed study, based on interpretation of aerial photos and field surveys, supported by radiocarbon ages and previous experience obtained studying coastal areas of the States of São Paulo, Rio de Janeiro, Espírito Santo, Bahia, Sergipe and Alagoas, allowed us to distinguish two generations of coastal sandy deposits associated with two periods of high sea-level. The inner deposits began their sedimentation when relative sea-level was about 8m above the present level. Wood fragments sampled from argillaceous deposits at the base of these sands have a minimum age of 35,000 years B.P. (DUARTE, 1981). Though not any dating has been done, we think to be logical to assign an age of about 120,000 years B.P. to this high sea-level in comparison with the corals dated in the State of Bahia. In fact, sandy terraces to which is assignable the high sea-level of 120,000 years B.P.occur almost continuously from the State of Paraíba to Rio Grande do Sul. Thanks to several radiocarbon ages it was possible to assign the outer deposits to the final portion of the last transgressive episode whose maximum level has been attained about 5,100 years B.P. There are also some marine gravel deposits which can be probably correlated with 120,000 years B.P. sandy terraces.

2.1 - Properties and distribution of Pleistocene marine terraces

Presently these sandy deposits are superficially of whitish colour and brownish to blackish at depth. The dark colours can be attributed to the presence of epigenetic organic matter which is impregnating the grains. Shallow marine origin of these deposits can be assured by the presence of Callichirus burrows, which can be attributed to marine arthropods whose life zone is the infratidal zone (SUGUIO and MARTIN, 1976; SUGUIO et al.,1984; RODRIGUES et al., 1984). This origin is also ensured by syngenetic sedimentary structures, like low-angle and harringbone cross-beddings. On the surface of the terraces is possible to distinguish vestiges of alignments of ancient sandy ridges, which are much more dissipated than upon the Holocene terraces. This difference can be easily recognized on aerial photos (MARTIN et al., 1981). At the innermost portions of the coastal plains the altitude of these terraces reach to about 9.5m, and oceanward it declines until to about 2.5m, as in the Paranaguá area near the contact with the Holocene terraces.

Within the northern sector (Ilha do Cardoso - Barra Velha) the Pleistocene marine terraces are very well developed forming about 20km-wide band as in Paranaguá and Joinville regions.

They are much less developed within the median sector (Barra Velha - Garopaba), when they are found only in the protected areas at backside of massives of Precambrian crystalline rocks.

These terraces are once again developed within the southern sector (Garopaba - Torres), giving origin to 8 to 10km-wide band as in São João do Sul area. In this sector they have been superficially reworked by wind and important fossil dune fields exist as in Laguna and Jaguaruna areas. On the other hand, in the Araranguá and São João do Sul regions it is possible to distinguish clearly the alignments of ancient sandy ridges.

2.2 - Properties and distribution of ancient marine gravel deposits

In several places along the coastal plain of the States of Paraná and Santa Catarina there are some remnants of ancient marine gravel deposits. These deposits record ancient sea-levels clearly higher than it is today and they are older than the Holocene. There are no absolute ages of these deposits but it seems that for the most part they could be attributed to high sea-level of 120,000 years B.P.

a) Morro do Sambaqui

In Matinhos area (southern part of the State of Paraná), between the Morro do Escalvado and Morro do Sambaqui, there is a restricted outcrop of ancient marine gravel deposit which probably was originated from incipient reworking by the waves of a colluvial deposit. This deposit is situated between 12 and 13m above present sea-level and was described by BIGARELLA and FREIRE (1960). If the reconstruction of ancient sea-level done by BIGARELLA (1975) is correct, this is a level higher than that of 120,000 years B.P. However, until more detailed study about this problem we prefer to correlate this deposit with the Pleistocene sandy terrace of 120,000 years B.P.

b) Porto da Passagem

At the backside of the Iate Club de Caiobá, there is also a gravel deposit formed through incipient reworking of a colluvial deposit (BIGARELLA, 1975). This deposit is recording an ancient sea-level about 8m above the present level, so in agreement with the altitude of 120,000 years B.P. Perhaps, the difference of altitude between the Morro do Sambaqui and Porto da Passagem gravel deposits could be explained by differences in wave energy!

c) Morro de Itajubá

Between Barra Velha and Piçarras, in northern portion of Morro do Itajubá, there is a gravel terrace originated by parcial reworking of regolith. Also in this case, the gravel deposit could record an ancient sea-level about 8m above the present level (BIGARELLA, 1975).

2.3 - Properties and distribution of Holocene marine terraces

2.3.1 - Sandy deposits

In the outer side of the Pleistocene marine terraces, and very frequently separated from them by swampy lowlands, there are lower sandy terraces commonly containing abundant mollusk shells which can be dated by ^{14}C and, under favourable conditions can give positions of the ancient sea-level. Differently from the Pleistocene marine terraces, these deposits in general are not impregnated by secondary organic matter. Alignments of sandy ridges are very conspicuously visible on aerial photos, mostly in northern and median sectors of the coastal plains, but intensive reworking by wind affected the surface of the terraces in southern sector.

In northern sector the Holocene marine terraces are much less developed than the Pleistocene terraces. They are only 2 to 3km-wide and frequently they can be reduced to a very narrow band as in the region between Ubatuba (Ilha de São Francisco) and the town of Barra Velha. They can be completely absent as in the Piçarras area.

The Holocene marine terraces are very discontinuous within the median sector but locally they can be very well developed like in the Rio Itajaí-Açu valley (about 7km-wide), Tijucas region (about 5km-wide) and Enseada da Pinheira.

In southern sector they have little development until Morro dos Conventos, but they become once more important with 5 to 6km near the town of Sombrio.

2.3.2 - Clayey and/or silty deposits

Around the bays or northern sector (Paranaguá, Guaratuba and São Francisco), as well as in the periphery of lagoons, southward from Ilha de Santa Catarina, there are more-or-less sandy clayey and/or silty deposits, which have been formed during high sea-levels, when the lagoonal extent was greater than today. Very frequently they contain mollusk shells, which are sometimes so abundant, like in Laguna area, being economically exploitable. Similarly, related to the occurrence of paleolagoons and paleobays there are numerous shell-middens, some of them with huge dimensions.

3. RELATIVE SEA-LEVEL CHANGES DURING THE LAST 7,000 YEARS

3.1 - Paraná coastal plain

In straight line the State of Paraná coastal plain is less than 100 km long. The reconstructions of ancient sea-levels for the last 7,000 years were insufficient to delineate a fluctuation curve with the minimum of precision. Nevertheless, some informations allowed us to establish a suitable average curve (Fig. 3g).

3.1.1 - Maximum Holocene high sea-level

In Paranaguá bay the summit of outer portion of Pleistocene marine terrace (Rio do Maciel, Ilha do Mel, etc.) is situated about 2.5m above the present high-tide level. Alignments of sandy ridges are clearly visible on the surface of these terraces and, then, the maximum Holocene high sea-level never has been higher than 2.5m above the present level.

3.1.2 - First episode of high sea-level

In Paranaguá area there are narrow lowlands carved in Pleistocene marine terraces, with the same orientation of ancient sandy ridges , presently drained by tidal channels (Rio Itiberê, Rio dos Almeidas, Rio Guaraguaçu and Rio do Maciel). In these lowlands, carved in Pleistocene terraces, we find paleo-lagoonal deposits with mollusk shells recording ancient high sea-levels above the present level. A sample collected at the border of Rio Guaraguaçu indicated an age of 5,040 ± 230 years B.P.(Bah. 1271). The $\delta^{13}C_{(PDB)}$ value (+ 0.86$^{o}/oo$) of this sample suggests a continental influence practically absent, suggesting that they lived under conditions of high sea-level.

In the Rio Saí-Guaçu area, mollusk shells sampled from paleolagoonal deposits were dated as 5,820±220 years B.P. (Bah. 1279). BIGARELLA (1975) also dated mollusk shells from paleo-lagoonal deposits recording ancient high sea-levels:

	years B.P.
- Guaratuba (sample Bi-5)	5,770 ± 150
- Rio Vermelho (Praia do Leste: Bi-2)....	5,690 ± 200
- Rio Boguaçu (Guaratuba: sample Bi-4)...	4,390 ± 300

These ages suggest that between about 5,800 years B.P. and 4,400 years B.P. the sea-level has been higher than it is today, but not having crossed the level 2.5m above the present.

Numerous shell-middens found in this region supply with some interesting additional informations. Mollusk shells from the shell-midden of Rio Cacatu (nº 17 of BIGARELLA, 1950), the innermost of the Paranaguá region, have been dated as 5,050 ± 220 years B.P. (Bah. 1392). The geographic position of this shell-midden indicates that its construction would have been possible only during the maximum lagoonal extent corresponding to the maximum elevation of the sea-level. As the dated shells were collected near the surface of the shell-midden, probably this age indicates the end of site occupation. Several mollusk shells sampled from different levels of the shell-midden of Rio São João (nº 11 of BIGARELLA, 1950), situated at the margin of ancient Baía de Nhundiaquara, indicated the following ages:

Sampling level in relation to shell-midden's surface	Ages (years B.P.)
125 - 150 cm	4,960 ± 110 (Si. 1022)
150 - 200 cm	4,810 ± 100 (Si. 1023)
175cm	4,670 ± 90 (Si. 1024)
Base	4,890 ± 210 (Bah.1393)

Above listed ages suggest that the site occupation began about 5,000 years B.P. On the other hand, it appears that this site has been abandoned about 4,700 years B.P., when probably the relative sea-level lowered propitiating the desiccation of the lagoon and provoking the migration of the inhabitants.

Shell-middens of Gomes and Saquarema (nº 11 and 10 of BIGARELLA, 1950) also supplied with very interesting data. They are situated one another at very short distance, but they have been constructed under different conditions. The shell-midden of Gomes is situated on Pleistocene sandy terrace at a border of an ancient lagoonal zone. Possibly, at the beginning of installation of the shell-midden the relative sea-level has been above present level and the area in front of it was occupied by a lagoon. Several mollusk shells sampled from different levels have been dated by RAUTH (1968), as follow:

Sampling level in relation to shell-midden's surface	Ages (years B.P.)
25 - 75cm	4,490 ± 140
100 - 150cm	4,490 ± 80
250 - 300cm	4,860 ± 70
Base	4,890 ± 70

These ages suggest that the site occupation began between 5,000 and 4,900 years B.P. It has been abandoned about 4,500 years B. P. as a consequence of relative sea-level drop.

The shell-midden of Saquarema rest on lagoonal deposits situated in front of Pleistocene marine terrace above which was constructed the shell-midden of Gomes. The first idea is that the site of Saquarema has been occupied after that of Gomes. In fact it is possible to think that with sea-level drop the site of Gomes became less interesting and the inhabitants dislocated to stay nearer to the harvesting place of the mollusks which they used for their nourishment. Several samples collected from different levels have been dated by RAUTH (1962), as follow:

Sampling level in relation to shell-midden's surface	Ages (years B.P.)
100 - 150cm	4,060 ± 70
200cm	3,900 ± 70
680cm	4,310 ± 70
800cm	4,070 ± 70
850cm	4,370 ± 70

It seems that the site has been occupied between 4,400 years B.P. (perhaps before this time, because mollusk shells from the basal portion were not dated) and 4,000 years B.P. Similarly, it is possible to think that about 4,000 years B.P., with relative sea-level drop, this site became less interesting and was abandoned.

3.1.3 - Indication of relative sea-level change between 4,000 and 3,600 years B.P.

In the Caiobá area, BIGARELLA (1975) dated mollusk shells sampled from clayey-silty deposits situated below the present sea-level and covered by littoral sands. This sample, contained within a transgressive sequence, was dated as 3,830 ± 120 years B.P. Then, it is possible to assume that about 3,800 years B.P., the relative sea-level was below present sea-level and was rising until reaching to the maximum level. Several other radiocarbon ages obtained near this area supplied with other interesting additional informations.

The shell-midden of João Godo (nº 29 of BIGARELLA, 1950) was studied by RAUTH (1968) by an archeological viewpoint. It is located in Antonina area and was constructed on crystalline rocks surrounded by emerged lagoonal deposits. Several samples collected from different levels were dated as follow:

Sampling level in relation to shell-midden's surface	Ages (years B.P.)
100 - 125 cm	2,980 ± 130 (Si. 1026)

150 - 200 cm	3,000 ± 90 (Si. 1027)
225 - 250 cm	3,360 ± 80 (Si. 1028)
225 - 250 cm	3,300 ± 90 (Si. 1028A)
Interruption	
250 - 300 cm (Base)	4,740 ± 90 (Si. 1029)

As indicated, the radiocarbon ages suggest that occurred an interruption in occupation of the site. In fact, it appears that this site was for the first time occupied about 4,800 years B.P. and reoccupied between 3,300 and 3,000 years B.P. The first abandonment of this site was probably related to sea-level drop, followed by reoccupation after 3,800 years B.P. when the surrounding area was once again drowned, and the second abandonment occurred due to sea-level drop after 3,000 years B.P.

The shell-midden of Macedo (nº 52 of BIGARELLA, 1950) supplied also with interesting data. This shell-midden was studied from an archeological viewpoint by HURT and BLASI (1960). It is located on a sandy terrace whose summit is about 1.6m above the present high-tide level. This terrace is situated in front of Pleistocene marine terrace. Between the Pleistocene terrace and the shell-midden site there are lagoonal deposits formed when the sea-level was higher than it is today. Probably the ancient inhabitants harvested their nourishment from this paleolagoon. Then, the sea-level has been above the present level about 1.6m. Several samples collected from different levels indicated the following ages:

Sampling level in relation to shell-midden's surface	Ages (years B.P.)
75 - 125cm	3,310 ± 60 (P.482)
125 - 225cm	3,340 ± 60 (P.483)
225 - 275cm	3,270 ± 50 (P.485)
275 - 325cm	3,370 ± 60 (P.486)
325 - 400cm	3,280 ± 60 (P.487)
400 - 475cm	3,360 ± 70 (P.488)
475 - 550cm	3,420 ± 60 (P.489)
550 - 650cm	3,500 ± 60 (P.500)
Near the base	3,670 ± 180 (Bah.1265)

These ages suggest that this site has been occupied betwenn 3,600 years B.P. and 3,300 years B.P.

Two shell-middens from Rio Boguaçu (Baía de Guaratuba, State of Paranã), corresponding to nº 50 and 51 of BIGARELLA (1950), supplied with very interesting additional data. The shell-midden nº 51 reposes on an island formed of lagoonal deposits. At the river margin shell-midden has been eroded, showing that in this place its substrate is submerged (is below present sea-level). Mollusk shells collected at present sea-level have been dated as 3,920 ± 190 years B.P. (Bah. 1272). The $\delta^{13}C_{(PDB)}$ value of these shells was - 3.56^{o}/oo. The shell-midden nº 50 is located about 1,200m of nº 51, and is situated on lagoonal deposits whose summit is about 1.3m above the present sea-level. Mollusk shells sampled from the lower portion (not at the base) of the shell-midden were dated as 3,290 ± 190 years B.P. (Bah. 1273), and $\delta^{13}C_{(PDB)}$ value was - 0.6^{o}/oo. This value is clearly less negative than that of nº 51. FLEXOR et al. (1979) demonstrated that $\delta^{13}C_{(PDB)}$ value is a good indicator for lagoonal oscillations and then it is possible to conclude that about 3,300 years B.P. the land influence was much less important than about 3,900 years B.P. and, consequently, the relative sea-level was higher in the former case than in the latter case. So, a sea-level rise was produced between 3,900 and 3,300 years B.P., but this elevation could not be higher than 1.3 m above the present level.

Mollusk shells sampled from lagoonal deposits of a paleolagoonal area occurring at south of the shell-middens nº 50 and 51 have been dated as 3,160 ± 170 years B.P. (Bah. 1277) and 2,970 ± 170 years B.P. (Bah. 1278). As these shells were collected practically from surface levels it is possible to conclude that the paleolagoon was desiccated about 3,000 years B.P. after a relative sea-level drop.

3.1.4 - Indication of relative sea-level change between 3,000 and 2,500 years B.P.

The shell-midden of Ilha das Rosas (Baía de Antonina, State of Paranã) supplied with some informations about this oscillation which has been also evidenced in other sectors of the Brazilian coast. This shell-midden has been studied from an archeological viewpoint by LAMING-EMPERAIRE (1968). Its substrate is a rocky outcrop which is submerged during high-tides and then it is possible that the occupation of this site began during a relative sea-level lower than the present level. Mollusk shells from the base of this shell-midden were dated as 3,150 ± 110 years B.P. (Gif. 1047). This first shell-bed is covered by lagoonal deposits. Then, possibly, after 3,100 years B.P. the relative sea-level rose. These lagoonal deposits were covered by another artificial bed of shells which have been dated as 2,480 ± 110 years B.P. (Gif. 1046). So, it is possible to imagine that the relative sea-level attained a maximum before 2,500 years B.P. followed by relative sea-level drop. Then, we have indication of a relative sea-level change between 3,000 and 2,500 years B.P. It appears that this oscillation occurred here slightly earlier than in other sectors, but we have not sufficient data to be sure of this fact.

Three samples of mollusk shells collected from raised lagoonal deposits of the Baía de Paranaguá, indicative of sea-level higher than it is today, supplied with the following ages:

Samples reference number	Ages (years B.P.)	Laboratory number
PR.06	2,680 ± 240	(Bah.1270)
Bi.01	2,675 ± 150	(BIGARELLA,1975)
PR.04	2,650 ± 170	(Bah.1260)

These three ages ratify the idea that about 2,600 years B.P. the relative sea-level in this region was above the present level.

Based in these informations and in that previously obtained in other sectors of the Brazilian coast it is possible to reconstruct the relative sea-level fluctuations, during the Holocene, along the State of Paranã coastline as follow:

a) The relative sea-level cut the present level for the first time about 6,400 years B.P.

b) This level attained the first maximum not superior to 2.5m above the present level, about 5,100 years B.P.

c) The relative sea-level was above the present level until about 4,100 years B.P.

d) After 3,830 years B.P. the sea-level rose until a maximum of about 1.6m above the present level about 3,600 years B.P.

e) About 3,000 years B.P. the sea-level drop to a minimum probably below the present level between 3,000 and 2,500 years B.P.

f) A third elevation was produced before 2,500 years B.P.

3.2 - Santa Catarina coastal plain

Ancient sea-level reconstructions during the last 7,000 years for the State of Santa Catarina coastal plain were insufficient to delineate a fluctuation curve for several sectors of restricted dimensions. Nevertheless, we obtained a certain number of informations which allowed us to have a good knowledge of the relative sea-level changes for the last 7,000 years in this sector of the Brazilian coast.

3.2.1 - First episode of high sea-level

The downstream portion of the Rio Itajaí-Açu valley is occupied by a sandy marine terrace presenting conspicuous alignments of ancient beach-ridges. Within inner portion of this terrace, at the margin of the river, we studied an outcrop which furnished very important data. At the base of the outcrop there are lagoonal or bay bottom clayey deposits. Mollusk shells sampled from these sediments have been dated as 5,580 ± 240 years B.P. (Bah. 1290). These lagoonal deposits are covered by shallow marine sands. The lower portion of this terrace corresponds to a transgressive phase and the upper part with the sandy ridges to a regressive phase. Between these two phases the relative sea-level was at a maximum. The lagoonal deposits record an ancient sea-level situated about 1.0 ± 0.5m above the present level. After 5,580 years B.P. the rising sea-level was at a maximum at least 3.0m above the present level. This level +3m is indicated by the summit of this outcrop, but during the maximum it is possible that this level was slightly higher because this outcrop is not at the innermost portion of this sandy marine coastal plain.

Two shell-middens presently located about 30 and 22km from the shoreline, within Rio Itajaí-Açu valley, supplied with very interesting informations about the period of maximum level. In fact, due to their geographical positions, their construction could have been possible only during the maximum lagoonal extent, during the Holocene. At this epoch, the Rio Itajaí-Açu valley was a vast "ria". The shell-midden of Gaspar, situated about 30km from the present shoreline, was studied from an archeological viewpoint by PIAZZA (1960), who obtained the following ages:

5,320 $\pm$ 350 years B.P. (Si. 362c)
5,270 $\pm$ 300 years B.P. (Si. 362a)

We visited another shell-midden situated about 8km downstream from Gaspar, at left margin of the Rio Itajaí-Açu near Ilhota village. This shell-midden is situated on ancient fluvial deposit (Pleistocene?) at the margin of presently swampy lowland, probably representing an ancient lagoonal zone. Sample SC-16 collected from this shell-midden was dated as 5,340 $\pm$ 210 years B.P. (Bah. 1357).

Therefore, it seems logical to think that also in this area the Holocene maximum, as in other sectors of the Brazilian coast, was produced about 5,100 years B.P.

3.2.2 - Second and third episodes of high sea-levels

Near Barra Velha, at the margin of the Rio Itapocu, we found a very interesting outcrop. The lower portion of this outcrop, slightly above the present sea-level, is constituted by clay deposits, which are covered by shallow marine sands. The lower portion represents a transgressive phase while the upper part corresponds to regressive phase, and the maximum level is situated between them. Wood fragment sampled from the clay has been dated as 3,520 $\pm$ 180 years B.P., when the relative sea-level was about 1.5 $\pm$ 0.5m above the present level. In comparison with other areas, it is possible to think that the maximum was produced about 3,600 years B.P.

The shell-midden of Ponta das Almas, situated at the margin of Lagoa da Conceição (Ilha de Santa Catarina), was studied by PIAZZA (1966) and HURT (1974), both from an archeological viewpoint. It is constituted by a little shell-midden "B" abutted against the principal shell-midden "A". Several trenches opened during the archeological researches allowed us to obtain a parcial profile of the shell-midden "A" and complete profiles of the shell-midden "B" and of terrace situated between this shell-midden and the present lagoon. This shell-midden is situated partially on blocks of crystalline rocks and partially on compacted reddish coloured eolian sands. The most ancient age obtained by PIAZZA is 4,290 ± 400 years B.P. (Si.222). A trench revealed occurrence of a notch carved in eolian sands at the southern margin of the shell-midden "A". The summit of this notch is situated about 2.6m above the present lagoonal high-tide. Mollusk shells sampled from an ancient beach, in front of the notch, were dated as 3,620 ± 100 years B.P. (I.2627), according to HURT (1974). A second dating accomplished by PIAZZA on shells of the shell-midden "A" indicated an age of 3,690 ± 100 years B.P. (Si. ?). The mollusk shells sampled from the ancient beach could have two origins: (a) They could have been reworked from the shell-midden "A" during high sea-level which carved the notch in the eolian sand. In this case, this high sea-level could not be that of 3,600 years B.P. but of 2,500 years B.P. (b) They could have been originated from the area where the ancient inhabitants harvested their nourishment. This area would have been emerged during low-tides and part of shells have been transported and deposited on the beaches. This could explain similar ages indicated by the shells of the shell-midden "A" (3,690 ± 100 years B.P.) and of the ancient beach (3,620 ± 100 years B. P.). In this case the erosional notch could have been carved in eolian sands during high sea-level of 3,600 years B.P. This hypothesis was reinforced by the fact that HURT evidenced the existence of another high sea-level period after that of notch erosion, when relative sea-level was about 2.0 ± 0.5m above the present level. This high sea-level occurred before 2,400 ± 250 years B.P. (Si. 111). In fact, this age could correspond to the site reoccupation.

In summary, it is possible to think that:

a) About 4,300 years B.P. the site was already occupied.

b) The lagoonal level (=sea-level) was at a maximum situated 2.6 ± 0.5m above the present level about 3,600 years B.P.

c) The shell-midden site was abandoned, for the first time, during a certain unknown epoch, probably due to relative sea-level drop.

d) Before 2,400 ± 250 years B.P. the lagoonal level was once again elevated until a maximum situated 2.0 ± 0.5m above the present level, when this site was reoccupied.

The shell-midden of Carniça, studied by an archeological viewpoint by HURT (1974), is constituted by two joined shell-middens. The most important of them was named Carniça "I" and the subsidiary one was designated Carniça "IA". They have been established upon lagoonal deposits partially covered by eolian sands. In areas not covered by eolian sands it is possible to see some alignments of sandy ridges on aerial photos, which probably correspond to ancient lagoonal shorelines.

The excavations accomplished by HURT (1974) showed that the lagoonal sediments situated below the shell-midden contain bank of shells some in life position (closed valves). Three radiocarbon ages of these shells indicated the following:

3,300 ± 150 years B.P. (L.1164B)
3,350 ± 110 years B.P. (I.2620)
3,400 ± 150 years B.P. (L.1164)

Mollusk shells and charcoals sampled from different levels of the same profile supplied with the following ages:

Height above the shell-midden's base	Ages (years B.P.)
530cm	3,210 ± 150 (A.917) shell
380cm	3,370 ± 150 (A.918) charcoal
380cm	3,370 ± 100 (A.919) shell
60cm	3,310 ± 150 (A.912) shell

Another sample collected 0.5m below the surface of another profile has dated as 3,040 ± 50 years B.P. (A.883/2). It appears that the site began to be occupied about 3,300 years B.P.; was interrupted about 3,000 years B.P. probably as a consequence of accentuated relative sea-level drop. Similarly, it seems that the lagoonal deposits which constitutes the shell-midden's substrate, have been eroded during a new period of relative sea-level elevation. The principal shell-midden was partially eroded and the collapsed shells were spreaded on the beach surface by the waves. During the maximum of high sea-level period the lagoonal level was situated about 0.5m below the preceding high-level period. Mollusk shells sampled from a hearth-stone directly upon the lagoonal terrace within the shell-midden "IA" were dated as 2,460 ± 110 years B.P. (A.959). It seems that this site was reoccupied after this epoch which must correspond approximately to the maximum of the last high sea-level. Another sample collected from near the top of the principal shell-midden indicated an age of 2,250 ± 100 years B.P. (A.914).

Finally, near this place, there is a terrace very rich in mollusk shells whose summit is situated below the terrace upon which the shell-middens were constructed. Sample collected from near the top of this terrace was dated as 2,500 ± 170 years B.P. (Bah. 1380). At this moment the sea-level must be situated 2.0 ± 0.5m above the present level.

In summary, it is possible to think that:

a) About 3,400 ± 150 years B.P. the sea-level was dropping and was situated 2.5 ± 0.5m above the present level.

b) The first occupation of the Carniça occurred between 3,300 and 3,000 years B.P. It would seem that this site was then abandoned as a consequence of important relative sea-level drop.

c) At about 2,500 years B.P., once again the relative sea-level rose and that time it was situated 2.0 ± 0.5m above the present level, propitiating the reoccupation of the site.

Based on these informations and in that previously obtained in other sectors of the Brazilian coast it is possible to reconstruct the relative sea-level fluctuations, during the Holocene, along the State of Santa Catarina coastline as follow (Fig. 3h):

a) The relative sea-level cut the present level for the first time about 6,500 years B.P..

b) About 5,100 years B.P. the relative sea-level was at the first maximum situated probably 3.5m above the present level.

c) Between 4,100 and 3,800 years B.P. the sea-level was probably below the present level.

d) About 3,600 years B.P. the relative sea-level was at the second maximum situated about 2.5 ± 0.5m above the present level.

e) Between 2,900 and 2,700 years B.P. the relative sea-level was probably below the present level.

f) The relative sea-level was probably at the third maximum situated 2.0 ± 0.5m above the present level about 2,500 years B.P.

4. CHARACTERISTICS AND DISTRIBUTION OF MANGROVES AND COASTAL MARSHES

Around protected margins of tidal channels and bays, where the tidal action is very conspicuous, there are mangroves and coastal marshes constituted dominantly by clayey silty sediments very rich in organic matter.

The southernmost limit of occurrence of mangrove swamps along the Brazilian coast is located at the southern extremity of the Ilha de Santa Catarina. Northward of this point,at the margins of the baías of Paranaguá, Guaratuba and São Francisco and around the Ilha de Santa Catarina there are more-or-less developed mangroves. Southward the typical mangrove trees are replaced almost entirely by grasses like Spartinia.

5. QUATERNARY CONTINENTAL DEPOSITS OF THE STATES OF PARANÁ AND SANTA CATARINA

5.1 - Colluvio-alluvial deposits

The States of Paraná and Santa Catarina coastal plains are also characterized by extensive continental deposits, essentially terrigenous of different origin and age. At the foot of the Serra do Mar escarpment there are colluvial ramps representing episodes of generalized mass-movement phenomena. The alluvial deposits are formed of gravels and clayey-silty sediments. In general, the coarse alluvial deposits are older than the fine alluvial deposits. Former deposits correspond to semiarid paleoclimatic conditions while the latter have been formed under present conditions. In certain areas, like Garuva, Joinville, Turvo and Praia Grande, these colluvio-alluvial deposits are particularly well developed and may be more ancient than the Quaternary.

5.2 - Eolian deposits

The coastal dunes are very well developed within the southern half of the State of Santa Catarina, mostly from the Ilha de Santa Catarina southward. It is possible to distinguish at least three generations of coastal dunes: (a) ancient dunes, (b) Holocene dunes fixed by vegetation and (c) active dunes.

a) Ancient dunes

They are mostly constituted by reddish coloured sands, covered by more-or-less dense vegetation and subjected to intensive pedogenetic processes. In some places it is possible to recognize the nature of the substrate, formed of Pleistocene marine sands. Obviously, they are more recent than 120,000 years B.P. In other places, it is possible to conclude that their deposition occurred when sea-level was much lower than today. Then, they are older than 7,000 years B.P.

b) Holocene dunes fixed by vegetation

These sands are composed by whitish to yellowish coloured sands. They rest upon Pleistocene or Holocene marine terraces, ancient dunes and ancient lagoonal deposits as,for example, in Lagoa da Conceição, Paulo Lopes and Garopaba do Sul areas.They are covered by vegetation and their migration stopped but they can be activated by antropic influence.

c) Active dunes

They are formed only of whitish coloured sands and represents the outermost band of eolian deposits existing in the coastal plains.

5.3 - Fluvio-lagoonal deposits

When a river flows into a lagoon the fluvial sediments will form an intralagoonal delta. Thus, the Rio Tubarão constructed during the past thousands of years an intralagoonal delta with a considerable area, which partially filled the vast lagoon situated at south of Laguna (State of Santa Catarina). This delta is still active.

5.4 - Peat deposits

Total or parcial desiccation of ancient lagoonal areas as a consequence of relative sea-level drop gave origin to swampy lowlands favourable to form peat deposits. Similarly, some badly drained lowlands gave origin to peat deposits. Neither of them resulted in thicky deposits because vertical movements are practically null within Holocene time scale in these areas. Between Joinville and Itapocu, for example, occur extensive peat deposits presently covered by forest.

6. EXCURSION ROUTE ALONG THE STATES OF PARANÁ AND SANTA CATARINA COASTAL PLAINS

July 10: São Paulo to Curitiba

July 11: Curitiba to Barra Velha

July 12: Barra Velha to Florianópolis

July 13: Florianópolis to Laguna

July 14: Laguna to Laguna

July 10 (First day)

Departure from São Paulo: 12.00 h
Arrival in Curitiba: ca. 18.00 h

From São Paulo to Curitiba, we shall travel through BR 116 road. There is no stop between São Paulo and Curitiba. Geologically, this portion of Brazil is formed dominantly of Precambrian crystalline rocks and only near Registro (about 190km from São Paulo) and Jacupiranga we can see some continental deposits of the Pariquera-Açu Formation. This formation can be correlated with Barreiras Formation that occurs northward, from Rio de Janeiro to Rio Amazonas mouth area. The Pariquera-Açu Formation was probably deposited under semiarid paleoclimate during the Pliocene (SUNDARAM and SUGUIO, 1983). The site of Curitiba (capital of State of Paranã) is occupied by a little Tertiary sedimentary basin filled by continental deposits.

Stop overnight: Park Motor Hotel (Curitiba, State of Paranã)

July 11 (Second day)

Departure from Curitiba: 07.30 h

Itinerary: Curitiba to Barra Velha

- BR 116 toward São Paulo until bifurcation of the Estrada da Graciosa;
- Through Estrada da Graciosa until bifurcation of BR 277 road (Curitiba to Paranaguã);
- BR 277 to Paranaguã;
- Paranaguã to Caiobã by BR 53 road;
- Passage by ferry-boat between Porto da Passagem and town of Guaratuba (Baía de Guaratuba);
- Guaratuba to village of Garuva by PR 54 road;
- Garuva to town of Barra Velha by BR 101 road.

Estrada da Graciosa

The Serra do Mar in Southern Brazil is not only an escarpment, but in part as well is constituted by a system of block mountains. The summit areas above the plateau level are remnants of old erosion surface. On the very steep forested slopes of the Serra do Mar, after a long period of rainfall, landslides may occur in which the sliding is usually the limit between the weathered mantle and the fresh rock. This phenomenon caused many scars in the steep slopes of Serra do Mar. Its occurrence is not very frequent being restricted to exceptionally humid years and very steep slopes. Landslides may also occur after the anthropologically originated removal of the forest on slopes of smaller gradient, being in this case a mere reactivation of the mass movement.

Mass movement processes were generalized. Deep chemical weathering is conspicuous originating a regolith cover more than 15m thick. The area has a very humid climate. Rainfall in Serra do Mar reaches 3,000 to 5,000 mm/year. Elluvium and colluvium are present. The colluvium of fine grained matrix has enclosed coarser material of pebble to boulder sizes. The coarser material tends to be concentrated in the bottom of the sliding mass as well as in its edges. Nevertheless the greatest rudaceous material concentration is located where the running water flows. The lithologic composition of the slided material depends on the composition of the present rocks.

The inspection of the structure of numerous cuts in southern Brazil indicates that solifluction processes in sub-actual or more remote epochs were of great importance in the development of many characteristics found in the present day landscape morphology. Nowadays the slope movement caused by gravity action is extremily slow and frequently unnoticed (BIGARELLA, 1975).

Coastal plain of Paranaguá

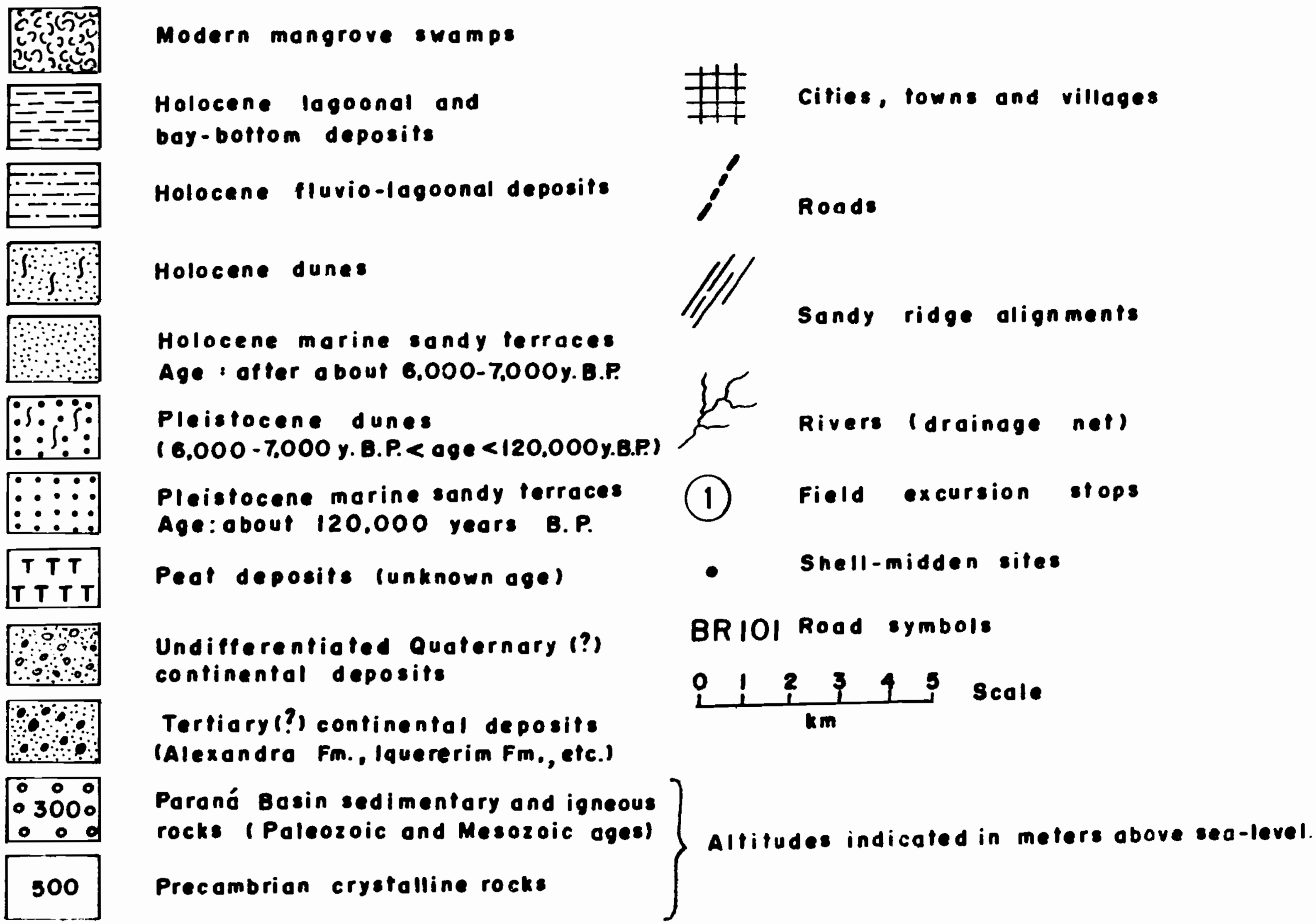
Its relief is very smooth, with slight undulations which are, in general, only some meters above present sea-level. Headlands and isolated hills of Precambrian crystalline rocks are markedly conspicuous giving rise to little massive mountains throughout sedimentary coastal plain. Between isolated blocks there are pediment levels abutted against wide and irregular alveolus which represent extensive intermountain pedimentation during some epochs of the Quaternary. These surfaces are gently plunged eastward and sunk under recent deposits that fulfilled the baía de Paranaguá area. Several levels of wave-built terraces are the dominant feature of eastern portion of the coastal plain but the western part is mainly constituted by terrigenous fluvial deposits with many gravel beds and colluvial deposits (CORDANI and GIRARDI, 1967).

In Morretes region the coastal plain of Paranaguá has its maximum width of about 45km.

Stop 1: Continental deposits of Alexandra Formation

Location: BR 277, km 13.1 (Figs. 17 and 18) - 5 minutes

FIG.17 — LEGEND FOR GEOLOGIC MAPS



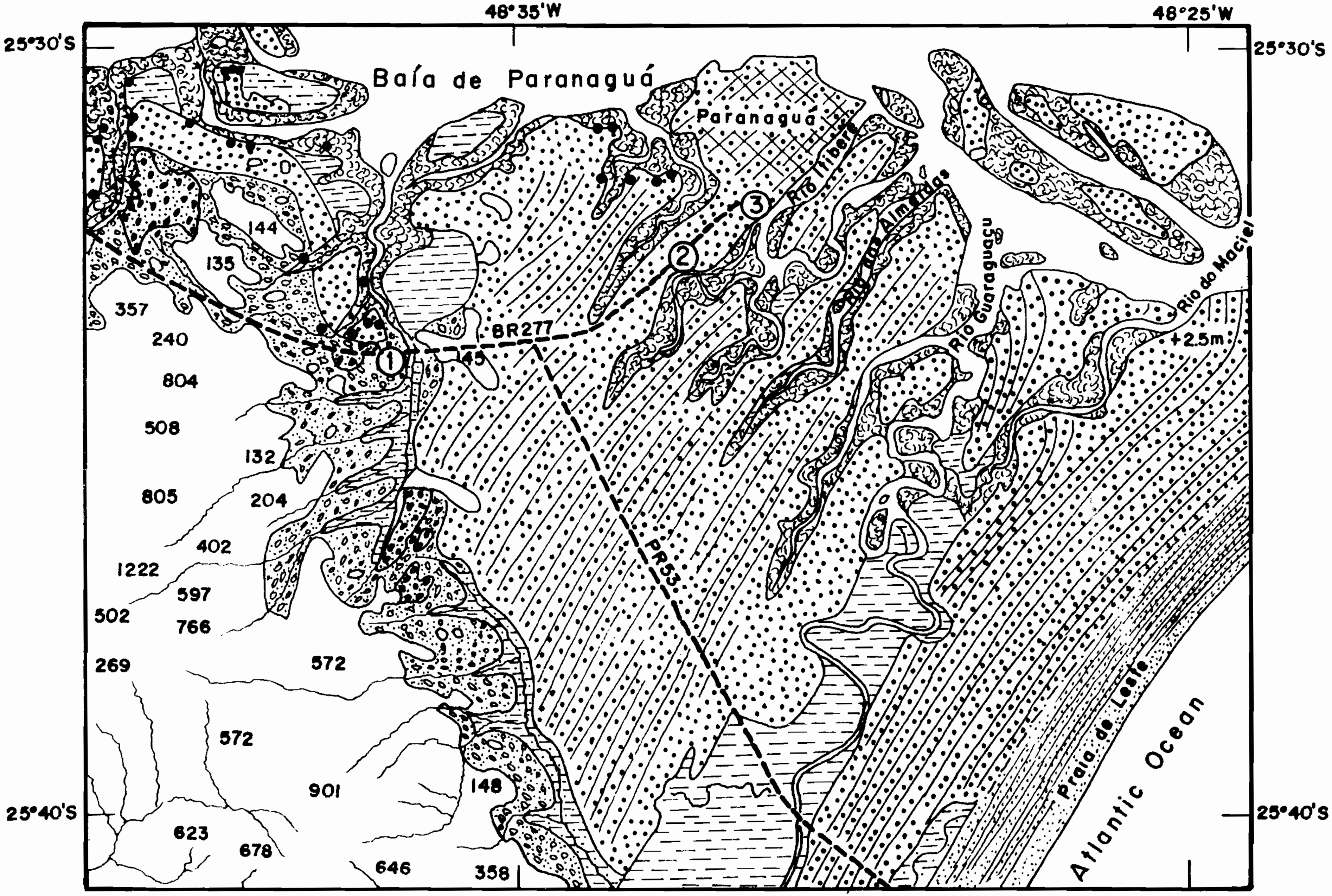


Fig. 18 — Geologic map of the Paranaguá region — Stops 1, 2 and 3 (2nd. day).

This formation was described by BIGARELLA et al.(1959), who considered it as Tertiary. It is assumed to be correlative of Barreiras and Pariquera-Açu Formations. An erosive unconformity separates these deposits from the Precambrian basement.

According to BIGARELLA (1975), "the lower section is composed mostly by arkosic coarse-grained sands and some rudaceous sediments, upward there is a predominance of silty-clayey deposits. In subsurface near the coastline it occurs down to 100m below the present sea-level indicating a lower sea-level stand more than 100m below the present one. The sediments were laid down under severe climatic conditions in a bajada environment, in large extent playa lakes. The sedimentary sequence show the action of sheet transport without the development of definite channels".

Stop 2: Pleistocene marine deposits
Location: Entrance of Paranaguá city at Rio Itiberê border (Fig. 18) - 10 minutes

A "river" named Itiberê, in reality a tidal channel, is located within a lowland carved in a Pleistocene marine terrace. There are several tidal channels like this in Paranaguá area, constituting the Rio dos Almeidas, Rio Guaraguaçu and Rio do Maciel. These channels are arranged with the same orientation of the present shoreline and ancient sandy ridges which are clearly distinguishable on aerial photos. Obviously these lowlands have been carved during low sea-level period and were drowned with Holocene high sea-level. This marine terrace was eroded within a meander of the Rio Itiberê allowing us to have an idea of its characteristics. Other features, like hydrodynamic structures and Callichirus burrows which characterize these deposits, were observed in other places of Paranaguá area. The summit of the marine terrace is flat, gently sloping seaward, and is about 8 to 9m above the present sea-level.

Stop 3: Raised lagoonal deposits
Location: Entrance of Paranaguá city at Rio Itiberê border (Fig. 18) - 10 minutes

In some places of Rio Itiberê lowlands, there are remnants of raised lagoonal deposits recording ancient sea-levels higher than it is today. In this place there are lagoonal bottom deposits with the upper part constituted dominantly by 50cm-thick shell bed. Closed bivalve shells have been found,indicating that they are, at least partially, in life position. These shells were dated as 2,650 ± 170 years B.P. (Bah. 1269), which corresponds to the last Holocene high sea-level. A boring accomplished here cut 5.7m-thick clayey deposits (Fig. 19).

Sector to be run through PR 53 road, from BR 277 road to Praia de Leste (Fig. 20)

We shall cross through about 20km of an extensive sandy coastal plain whose altitude diminishes gently seaward(Fig. 20). The most of this coastal plain is formed of Pleistocene marine sands. Only after crossing the Rio Perry there are Holocene marine sands. Topographic accident is absent in the transition zone between Pleistocene and Holocene marine terraces, making difficult the distinction between them. In the lowland drained by Rio do Maciel, in this coastal plain, the summit of the Pleistocene terrace does not exceed 2.5m above present high-tide level.Beach-ridge alignments upon surface of these Pleistocene terraces indicate that they have not been submerged during the Holocene high sea-levels, and, consequently they were not higher than 2.5m above present sea-level. On the other hand, altitudes ranging between 8 and 9m at Paranaguá to less than 2.5m near the Holocene transition do not imply that there are several generations of Pleistocene terraces. They represent two different moments during the regressive phase, which followed the 120,000 years B.P. maximum. Modifications in Pleistocene terrace declivities found by PEDRO LAGO MARQUES (BIGARELLA, 1975), could be explained by sea-level oscillations after the 120,000 years B.P. maximum, like that produced after the 5,100 years B.P. maximum.

Sector to be run through PR 53 road, from Praia de Leste to town of Caiobá (Fig. 21)

The PR 53 road is parallel to present shoreline and is entirely situated on Holocene terrace. One of the most striking feature of this sector is represented by the Tombolo of Caiobá (Fig. 22), which is constituted by sandy deposits of two differ-

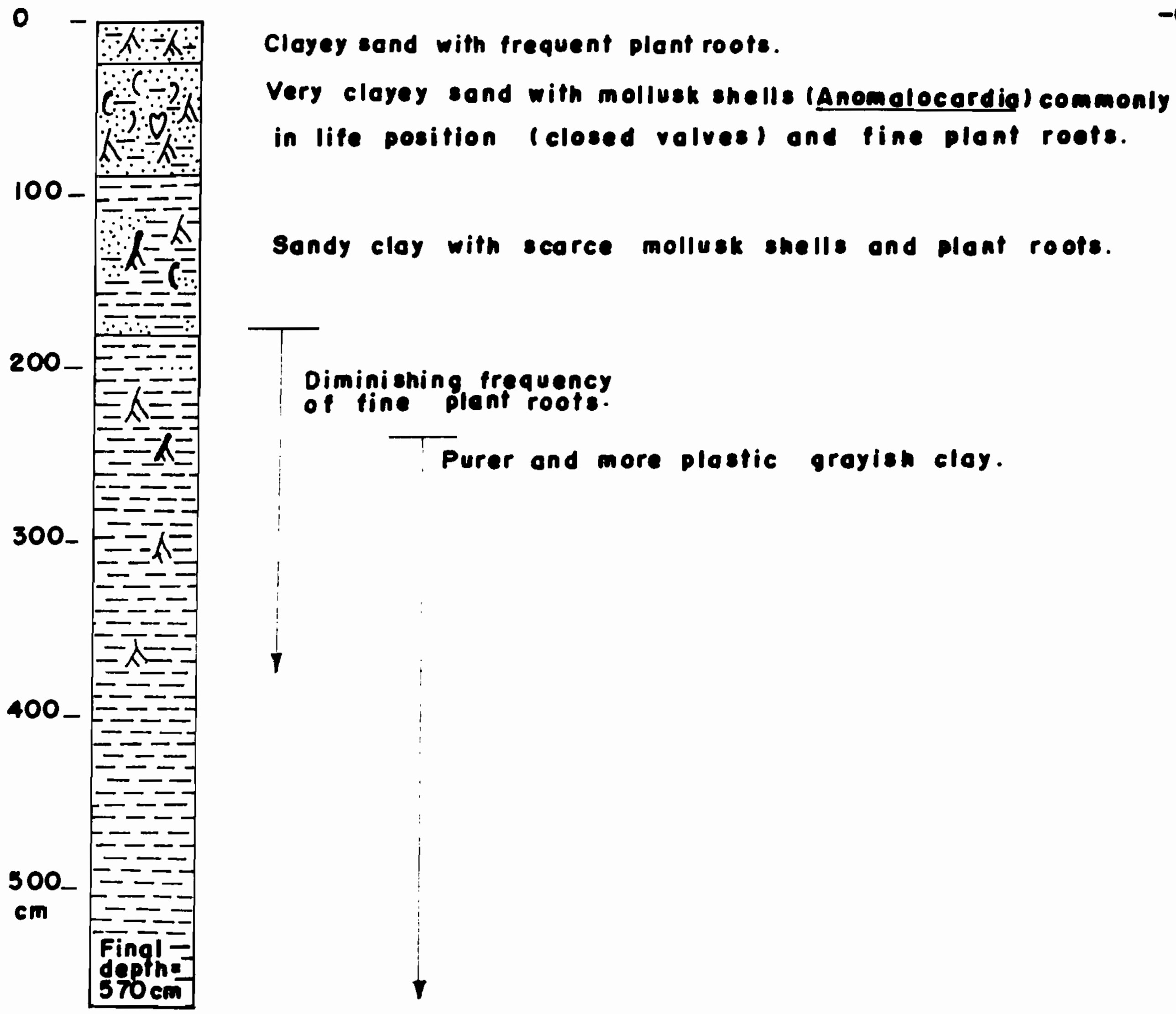


Fig. 19 — Sequence of paleolagoonal deposits drilled at stop 3 of 2nd. day (Rio Itiberê margin).

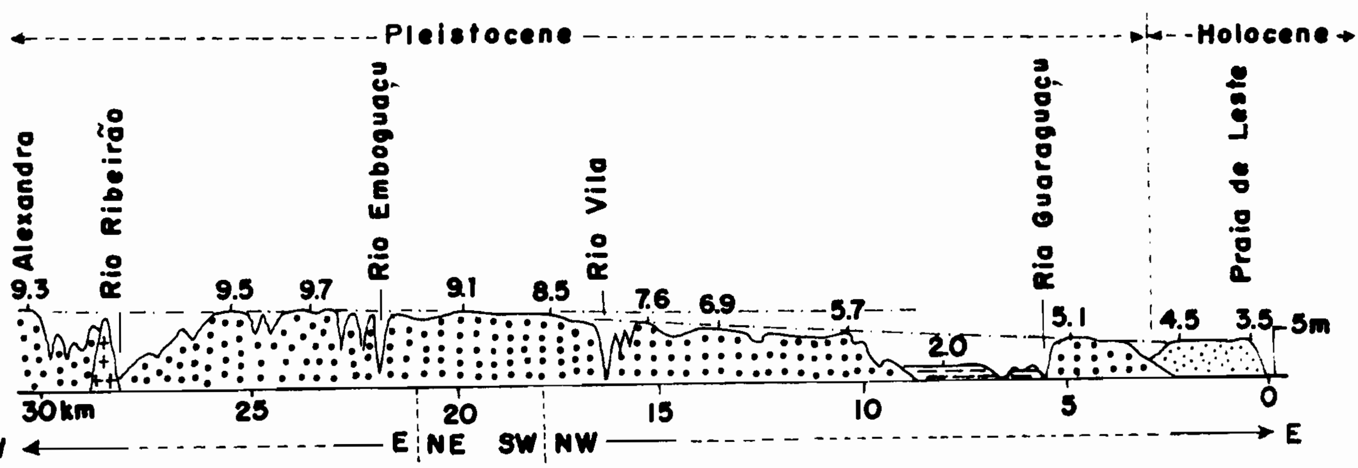


Fig. 20 — Profile through sand ridges of the Paraná coastal plain between Alexandra village and Praia de Leste

Based in P.L.MARQUES FILHO (BIGARELLA, 1975)

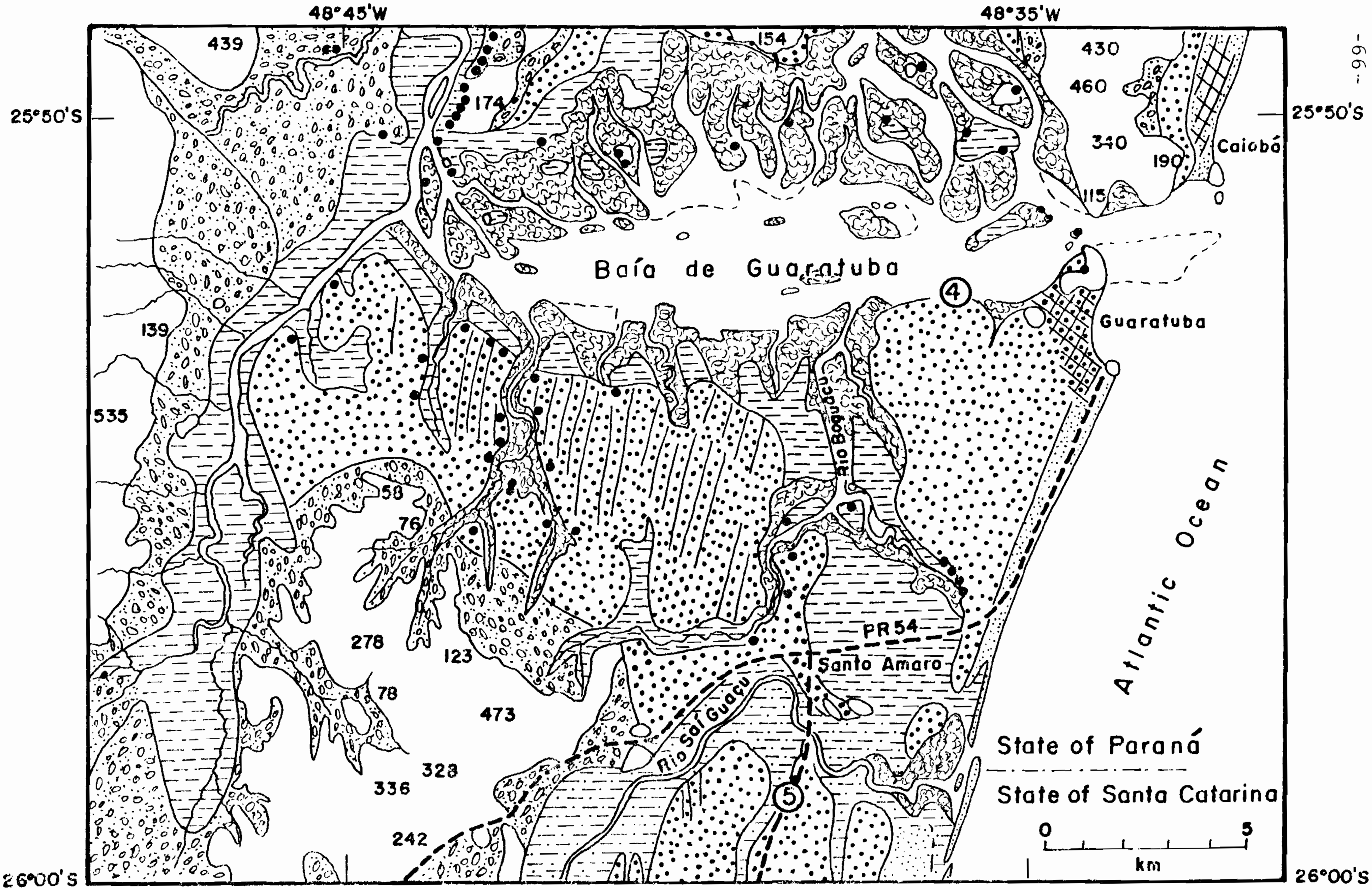


Fig. 21 — Geologic map of the Guaratuba region — Stops 4 and 5 (2nd day).

ent ages. The western portion, near Serra da Prata is formed of Pleistocene sands and the eastern part, near Morro de Caiobá is constituted by Holocene sands. The latter sands were laid down on clayey-silty deposits containing shells which have been dated by BIGARELLA (1975) as 3,830 ± 120 years B.P. The dated sample comes from a depth of about 3m below the present mean sea-level. According to our sea-level curves, after 3,800 years B.P. relative sea-level has been subjected to a maximum followed by a lowering period.

The coastal plain around the town of Guaratuba(Fig.21)

The greatest part of the town of Guaratuba is situated on Holocene terrace. The transition zone between Pleistocene and Holocene terraces does not exhibit any topographic accident, making difficult to establish with precision the contact between them. Nevertheless, we can assume that Holocene marine terrace is rather developed (Fig. 21).

Stop 4: Pleistocene marine terrace
Location: Baía de Guaratuba, near the fish shop Espíndola (Fig. 21) - 30 minutes

There are beautiful outcrops of Pleistocene marine deposits exhibiting conspicuous bedding planes and some <u>Callichirus</u> burrows. The summit of this terrace is not so high (about 3m).

Sector to be run through PR 54 road, from the town of Guaratuba to Santo Amaro village (Fig. 21)

Going out from the town of Guaratuba, PR 54 road follows parallel to shoreline about 6km and then changes to E/W direction crossing a 3.5km-wide paleolagoon situated within Pleistocene sandy terrace. Mollusk shells sampled near the surface have been dated as 3,160 ± 170 years B.P. (Bah. 1277) and 2,970 ± 170 years B.P. (Bah. 1278). There are many shell-middens at the border of this paleolagoonal area. As the dated shells came from the superficial levels it is possible that the lagoon desiccated about 3,000 years B.P. A boring carried out in this area cut only laminated sands with thin clayey intercalations (Fig. 23).

After the paleolagoonal area the road goes back to

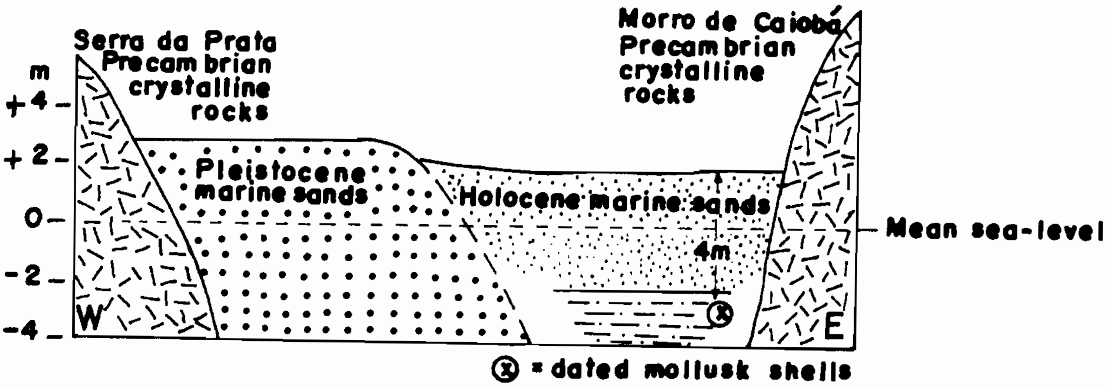


Fig. 22 — Geologic section in the tombolo of Caiobá with indication of a dated sample (about 3,830 years B.P.).

(From BIGARELLA, 1975)

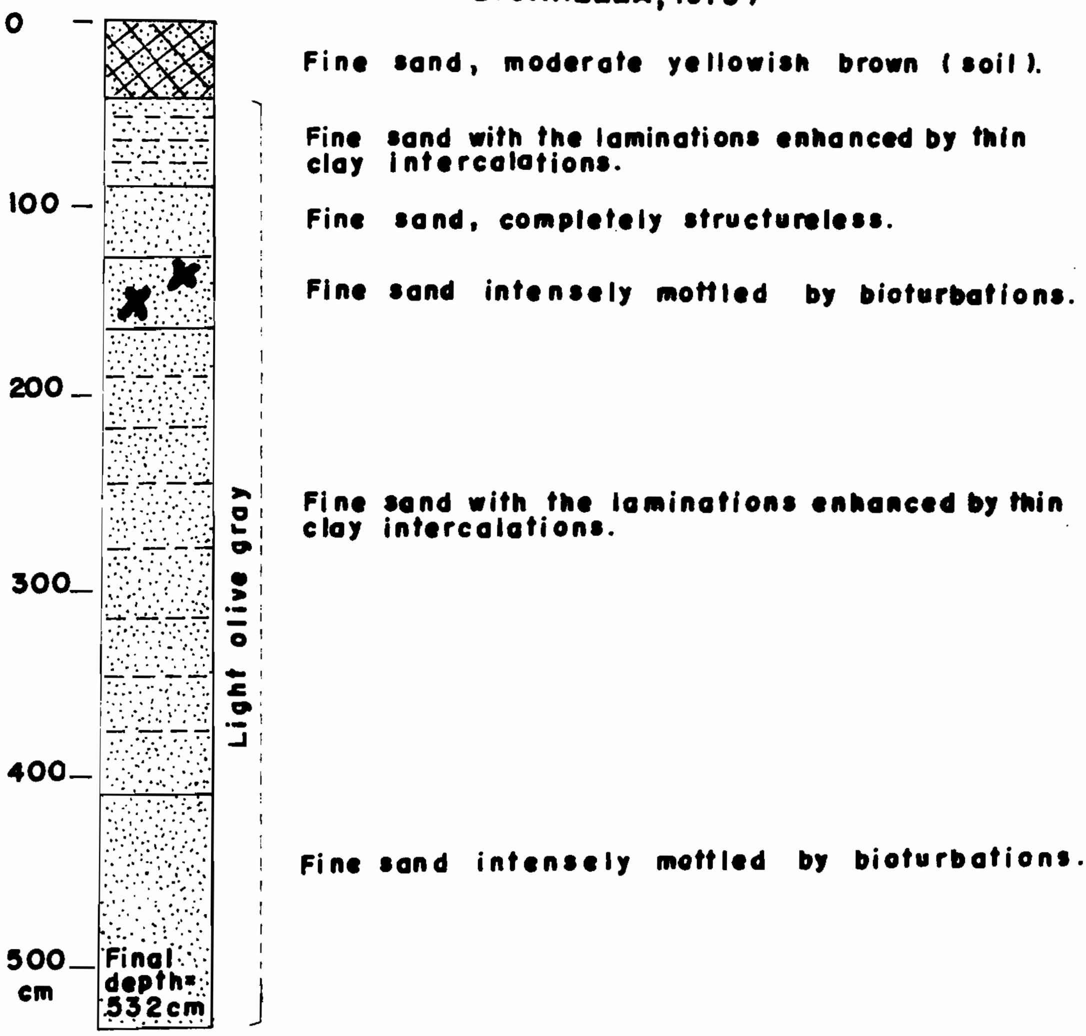


Fig. 23 — Sequence of paleolagoonal deposits drilled beside PR 54 road in the area of town of Guaratuba.

cross Pleistocene sandy terrace.

Sector to be run from Santo Amaro village to Itapoã beach (Fig. 21)

A little way off paleolagoonal zone, we shall leave the PR 54 road to take a secondary road, at the left, toward Saí-Guaçu outlet. At the beginning this road is situated on Pleistocene marine terrace, then lies along hills of crystalline rocks and finally crosses the paleolagoonal zone presently drained by Rio Saí-Guaçu. Mollusk shells sampled from these paleolagoonal deposits were dated as 5,820 ± 220 years B.P. (Bah. 1279). After the river the road goes back to cross Pleistocene marine terrace with some outcrops of crystalline rocks. About 1.5km after the bridge there is a partially destroyed shell-midden.

Stop 5: Shell-midden of Rio Saí-Guaçu
Location: road to Saí-Guaçu outlet (Fig.21)-15 minutes

This shell-midden lies on Pleistocene marine terrace and is situated at margin of a lowland anciently occupied by a lagoonal branch. Due to its geographic position this shell-midden could have been constructed only during the Holocene maximum lagoonal extent, which corresponds to a high sea-level period. Mollusk shells from this shell-midden have been dated as 5,040 ± 210 years B.P., which is in perfect agreement with the maximum sea-level of 5,100 years B.P.

Sector to be run through PR 54 road, from the locality of Santo Amaro to Garuva village (Fig. 21 and 24)

At the beginning the road is situated on Pleistocene marine terrace, followed by a zone dominated by crystalline rocks and finally about 10km-wide lowland drained by the Rio Palmital. It is not a true "river" but the margin of the Baía de São Francisco mangrove swamp. It is interesting that until today ancient lagoonal or marine deposits have not been noticed here, and the present mangrove swamp is directly in contact with continental deposits of different origin and age. BIGARELLA (1975) studied an outcrop of alluvial deposits of the Rio Pirabeiraba, a tributary of Rio Palmital, which is formed of two sequences (Fig. 25). The

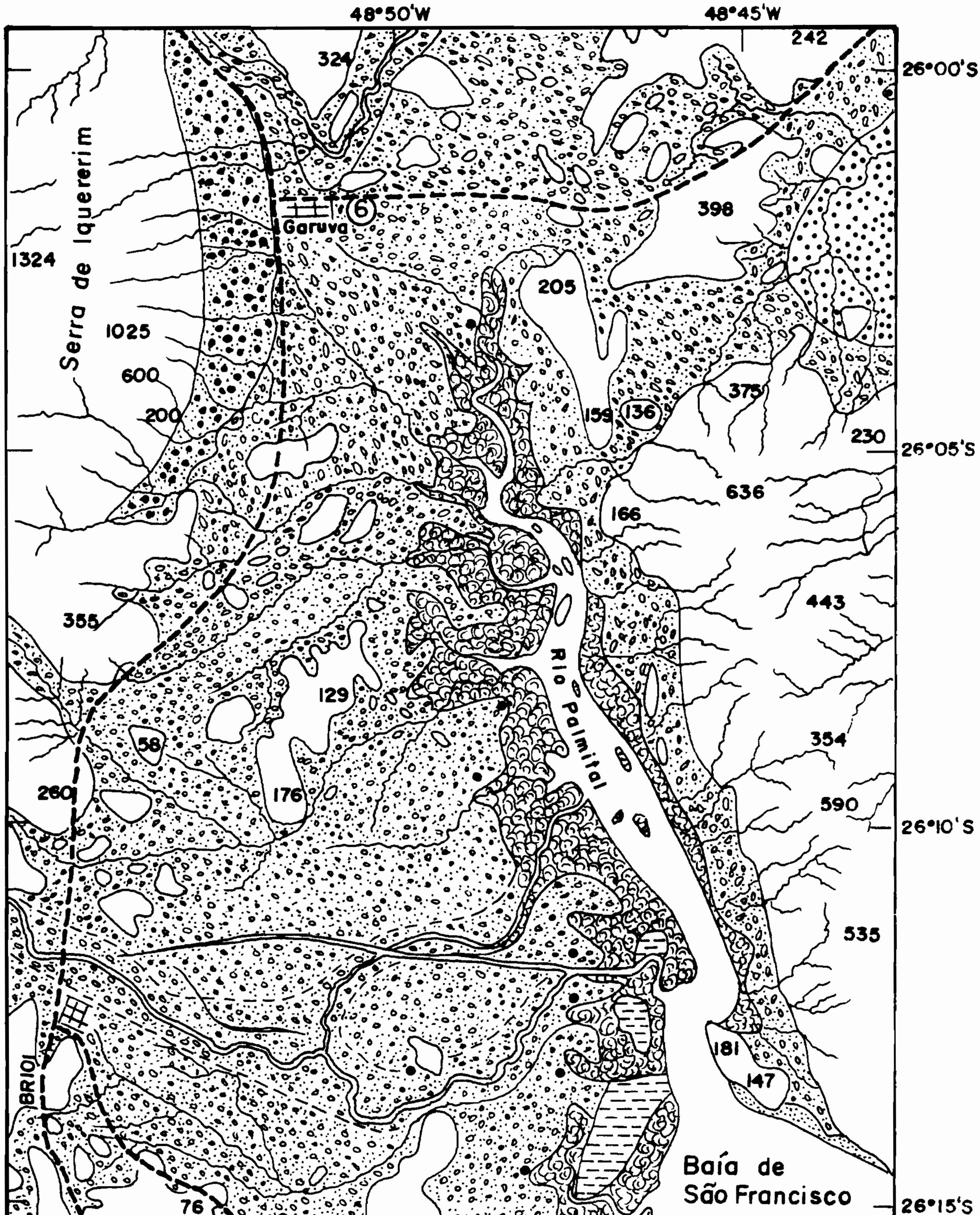


Fig. 24 — Geologic map of the Garuva region — Stop 6 (2nd. day).

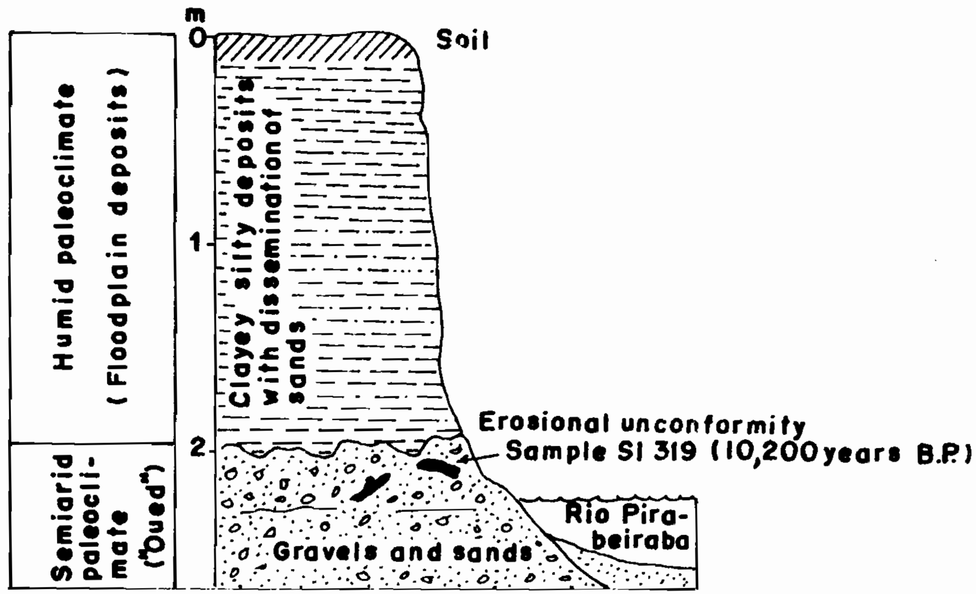


Fig. 25 — Geologic section of floodplain terrace of the Rio Pirabeiraba, near the locality of Rio Bonito. The dated sample indicates the Pleistocene/Holocene boundary.

(From BIGARELLA, 1975)

lower sequence is constituted by a conglomerate which is in erosional contact with the upper clayey-silty sequence. A fossilized wood fragment sampled from the lower sequence was dated as 10,200 ± 100 years B.P.

Stop 6: Iquererim Formation (BIGARELLA, 1975)
Location: Near Garuva village (Fig.24) - 5 minutes

According to BIGARELLA (1975), "the sediments of this formation constitute the detrital pediments developped at the foot of the Iquererim mountains (local name for the Serra do Mar). In Garuva the rudaceous sediments of the Iquererim Formation rest with an erosive unconformity on a very irregular surface cut in Precambrian rocks. The rudaceous sequence does not present stratification. The thickness of the deposit ranges from few meters up to more than 12m. The phenoclasts are usually very coarse and range from pebbles to huge blocks up to 4m-in-diameter. They are mostly composed of granite and gneiss, being the ones of diabase less frequent. The matrix has a colluvial nature (sandy-silty-clayey)".

Sector to be run through SC 301 and BR 280 roads, from Garuva village to Araquari village (Figs. 24 and 26)

From Garuva village to bifurcation to the town of São Francisco do Sul, the roads cross hills of crystalline rocks and lowlands occupied by undifferentiated continental deposits. Some kilometers after the bifurcation we shall enter the coastal plain, mostly formed of Pleistocene marine terraces.

Stop 7: Pleistocene marine terrace (Figs. 24 and 26)
Location: Araquari village (Fig. 26) - 15 minutes

At the margin of Rio Parati, there is an outcrop of the Pleistocene marine terrace, exhibiting an upper sandy sequence and lower sandy-clayey deposits.

Stop 8: Shell-midden on a crystalline rock substrate
Location: Linguado island (Fig.26) - 15 minutes

Linguado island is situated at the middle of the homo-

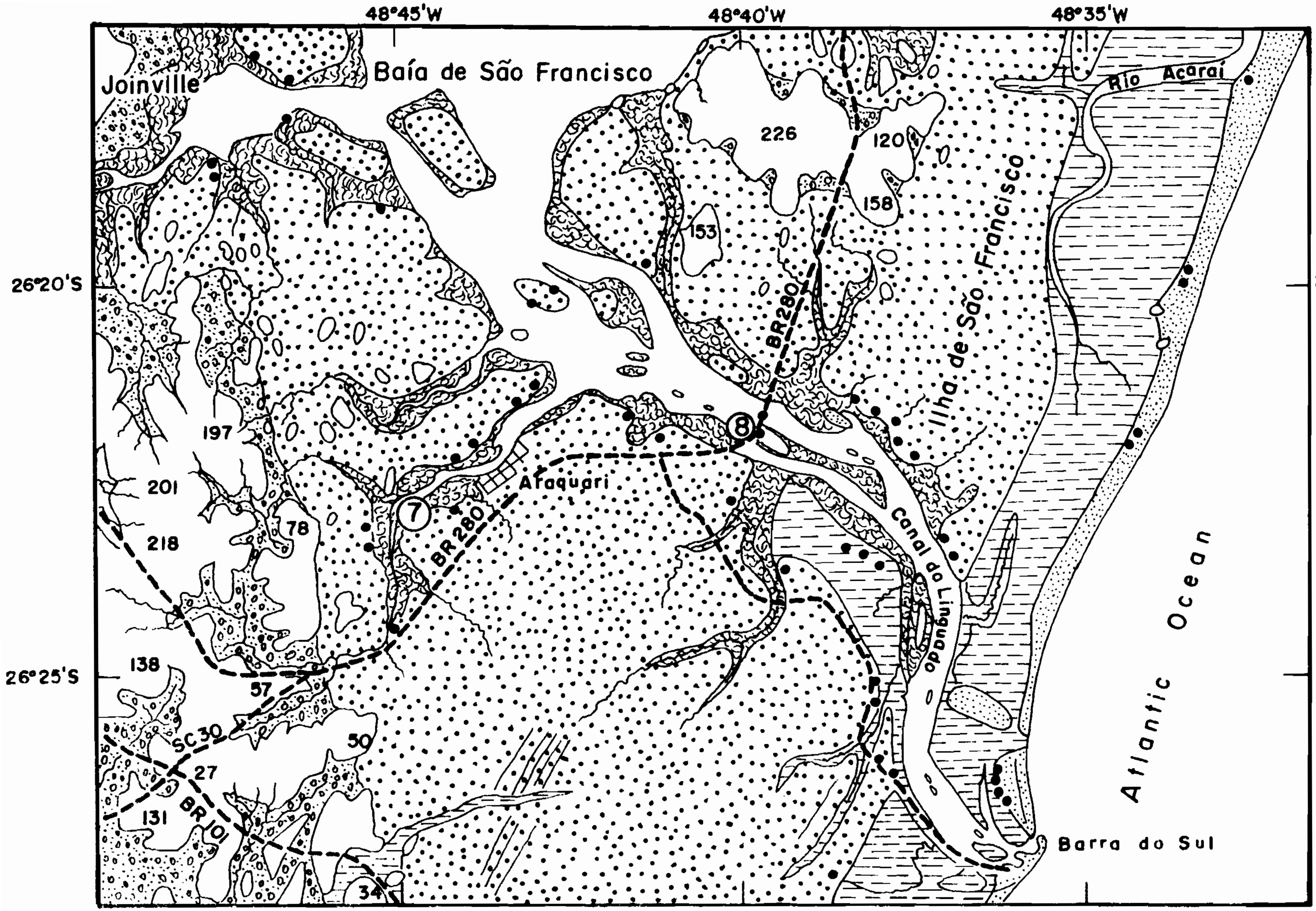


Fig. 26 — Geologic map of the Araquari region — Stops 7 and 8 (2nd. day).

nimous channel separating continent from Ilha de São Francisco. In this island there is a shell-midden on a hill of crystalline rocks. As it is located at the border of present lagoonal zone,this shell-midden does not supply with any information on ancient high sea-levels.

We shall not visit the Ilha de São Francisco but it is formed mostly of crystalline rocks besides Pleistocene marine terraces and a narrow band of Holocene sands seaward. Between these two sandy zones there is an ancient lagoonal area presently drained by the Rio Acaraí. At the inner margin of Holocene terrace there are many shell-middens. Mollusk shells sampled from the top, indicating the end of site occupation, of one of these shell-middens furnished an age of about 4,000 years B.P. (3,850 ± 200 years B.P. = Bah. 1287). Mollusk shells from the base, indicating the beginning of site occupation, of another shell-midden supplied with an age of 3,600 ± 180 years B.P. (Bah. 1288). These two ages agree with the sea-level curves mostly with the low sea-level period about 3,900 to 3,800 years B.P.

Sector to be run between the town of São Francisco do Sul and Barra Velha (Fig. 26 and 27)

At the beginning the road crosses a sequence of hills of crystalline rocks and lowlands filled up by undifferentiated Quaternary continental deposits and then the coastal plain formed of Pleistocene marine sands appears.

Stop 9: Pleistocene marine sands
Location: BR 101 road, km 68 (Fig. 27) - 15 minutes

This is a good outcrop of Pleistocene marine sands showing incipient stratifications (probably destroyed during pedogenesis) and some sparse Callichirus burrows.

Stop 10: Cenozoic continental deposits
Location: BR 101 entrance of Barra Velha (Fig. 27) - 10 minutes

Outcrop of rudaceous continental deposits, which can be probably correlated with the Barreiras Formation.

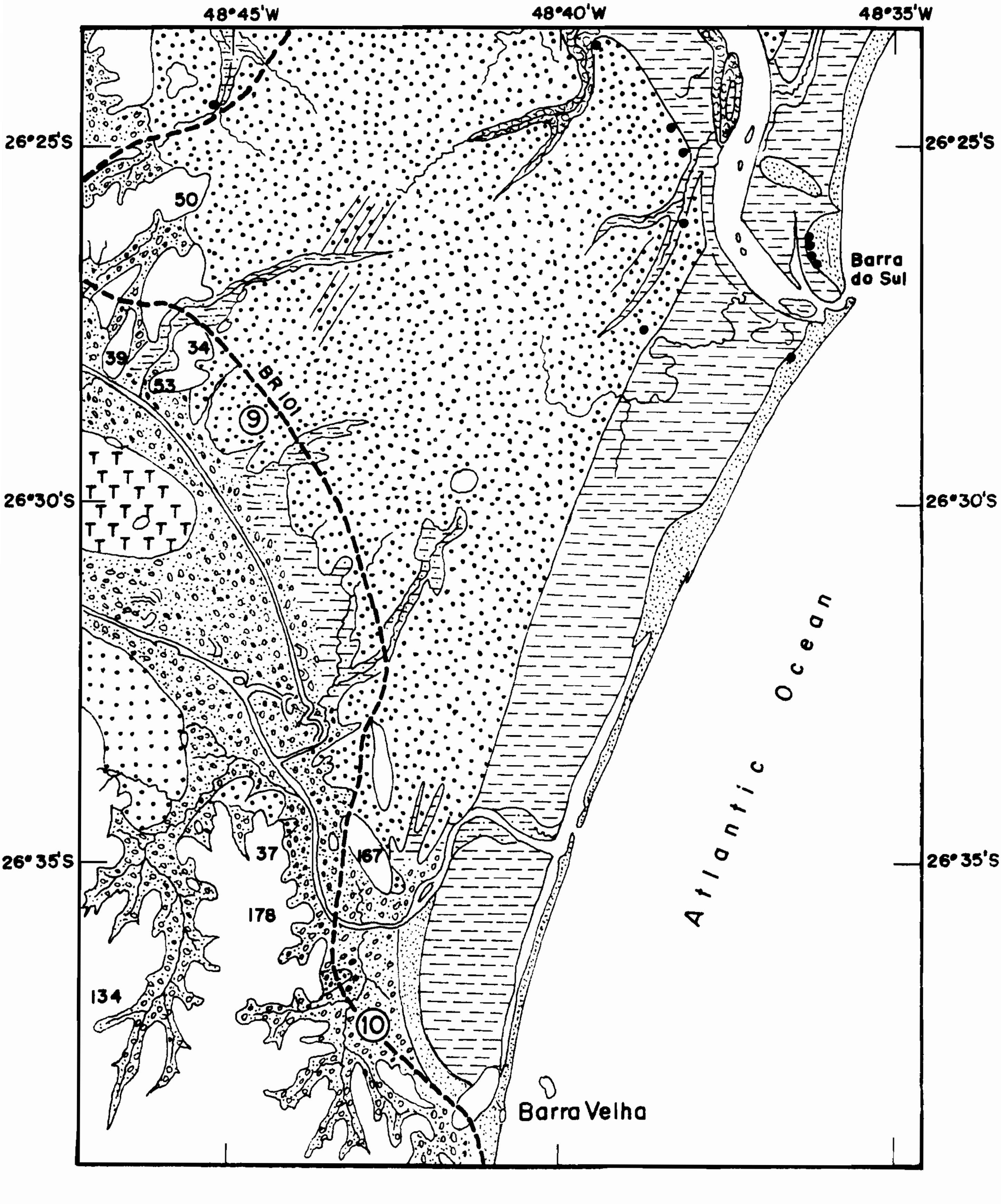


Fig. 27 — Geologic map of the Barra Velha region — Stops 9 and 10 (2nd. day)

Stop overnight: Hotel Bela Vista (town of Barra Velha, State of Santa Catarina).

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July 12 (Third day)

Departure from Barra Velha: 07.30 h

Itinerary: Barra Velha to Florianópolis

- BR 101: Barra Velha to Areia Branca;
- SC 414: Areia Branca - Itajubá - Piçarras and Penha;
- BR 101: Itajaí - Camboriú - Itapema - Tijucas - bifurcation to Governador Celso Ramos - Biguaçu - Florianópolis;
- SC 401 and 403: Florianópolis - Canasvieiras - Ingleses do Rio Vermelho - São João do Rio Vermelho;
- SC 406: São João do Rio Vermelho - Barra da Lagoa - Lagoa.

Sector to be run through BR 101 and SC 414 roads, from the town of Barra Velha to Penha village (Fig. 28)

Between Barra Velha and Areia Branca the road is located on a narrow band of Pleistocene marine sands. The Holocene deposits are almost practically absent or limited to the present beach. The Pleistocene marine sands reach the present beach where form several-meters-high cliffs. The declivity of these terraces is well-defined seaward, suggesting that they never had a great lateral development.

Stop 1: Pleistocene marine terrace
Location: Town of Piçarras (Fig. 28) - 10 minutes

Here the Pleistocene marine terrace reaches practically present shoreline.

Sector to be run through SC 414 and BR 101 roads, from Penha village to Rio Itajaí-Açu

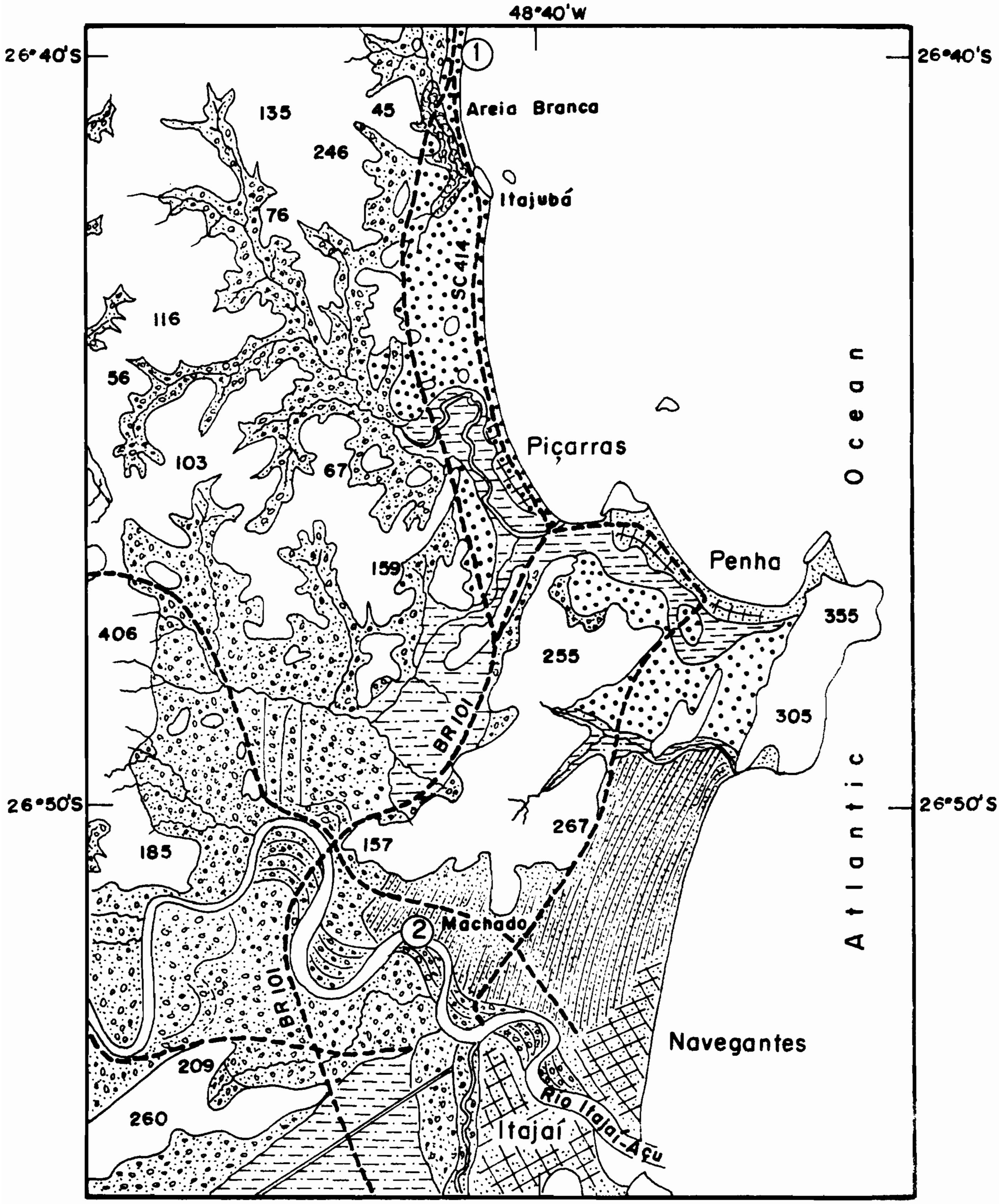

Fig. 28 — Geologic map of Piçarras-Itajaí region — Stops 1 and 2 (3rd. day)

The Rio Itajaí-Açu valley is presently occupied by fluvial deposits excepting by its downstream portion where is more than 7km-wide band of Holocene sandy ridges, conspicuously visible on aerial photos.

During Holocene high sea-level periods, the Rio Itajaí-Açu valley has been drowned forming an extensive "ria". This ancient situation is confirmed by shell-middens located at a great distance from the present shoreline. For example, the distance of shell-midden of Gaspar village to the present shoreline is about 30 km. PIAZZA (1966) studied this shell-midden and furnished two radiocarbon ages: 5,270 ± 300 years B.P. (Si.362-c) and 5,230 ± 350 years B.P. (Si. 362-a). Mollusk shells from another shell-midden situated at left margin, upstream of Ilhota village has been dated as 5,340 ± 210 years B.P.(Bah.1352). These two shell-middens, due to their geographic situations, could have been constructed only during a high sea-level period. These ages are in perfect agreement with the maximum of 5,100 years B.P.

Stop 2: Holocene marine terrace
Location: Machado village, Rio Itajaí-Açu left margin (Fig. 28) - 30 minutes

An outcrop exhibiting the upper portion of Holocene marine terrace is found in a meander of the Rio Itajaí-Açu margin. The outcrop is formed, from top to bottom, of the following sequence:

a) 150 cm - Fine to medium sand, whitish colour, horizontal and low-angle cross bedding;

b) 15 cm - Clay, dark gray, very rich in organic matter, eroded locally forming angular blocks;

c) 10 cm - Fine sand, brownish colour (epigenetic?), wavy bedding;

d) 18 cm - Sandy clay, dark gray, purer to the top;

e) 5 to 30 cm - Coarse sand (basal portion) with abundant shell fragments and medium to fine sand without shell fragments at the top, trough cross bedding;

f) 40 cm - Medium to fine sand with incipient horizontal bedding and cut-and-fill structure associated to coarse sand;

g) 15 cm - Medium sand, blackish colour with millimetric fragments of shells concentrated in horizontal laminations;

h) 40 cm - Medium sand, grayish colour,with millimetric fragments of shells.

The lower portion could represent a transgressive phase and the upper portion (outcropping) corresponds to regressive sandy ridges. Mollusk shells sampled slightly above present high-tide level have been dated as 5,580 ± 240 years B.P. (Bah. 1290). During their deposition the relative sea-level was higher than today. After 5,580 ± years B.P. relative sea-level attained a maximum situated at least 3m above the present level. This +3m high sea-level is indicated by the summit of the Holocene marine terrace, but during the maximum sea-level it was probably higher than 3m, since the studied outcrop is not the innermost portion of the Holocene terrace, which corresponds approximately to the period of maximum level. A drilling carried out here cut about 5m of Holocene deposits (Fig. 29) situated below the base of the outcrop.

Sector to be run through BR 101 road, from Rio Itajaí-Açu to Florianópolis (Fig. 30 and 31)

Stop 3: Continental deposits of the Canhanduva sequence
Location: BR 101 road (Fig. 30) - 5 minutes

BIGARELLA and SALAMUNI (1961) described the stratigraphic sequence of this outcrop, from bottom to top, as follows: (a) Precambrian metamorphic rocks, (b) erosive unconformity forming an irregular surface, (c) Pre-Canhanduva layers and (d) Canhanduva layers.

According to BIGARELLA (1975), "before the deposition of the Pre-Canhanduva layers, a humid climate conditioned the formation of a thick regolith and promoted the dissection which gave origin to the erosive unconformity separating the basement

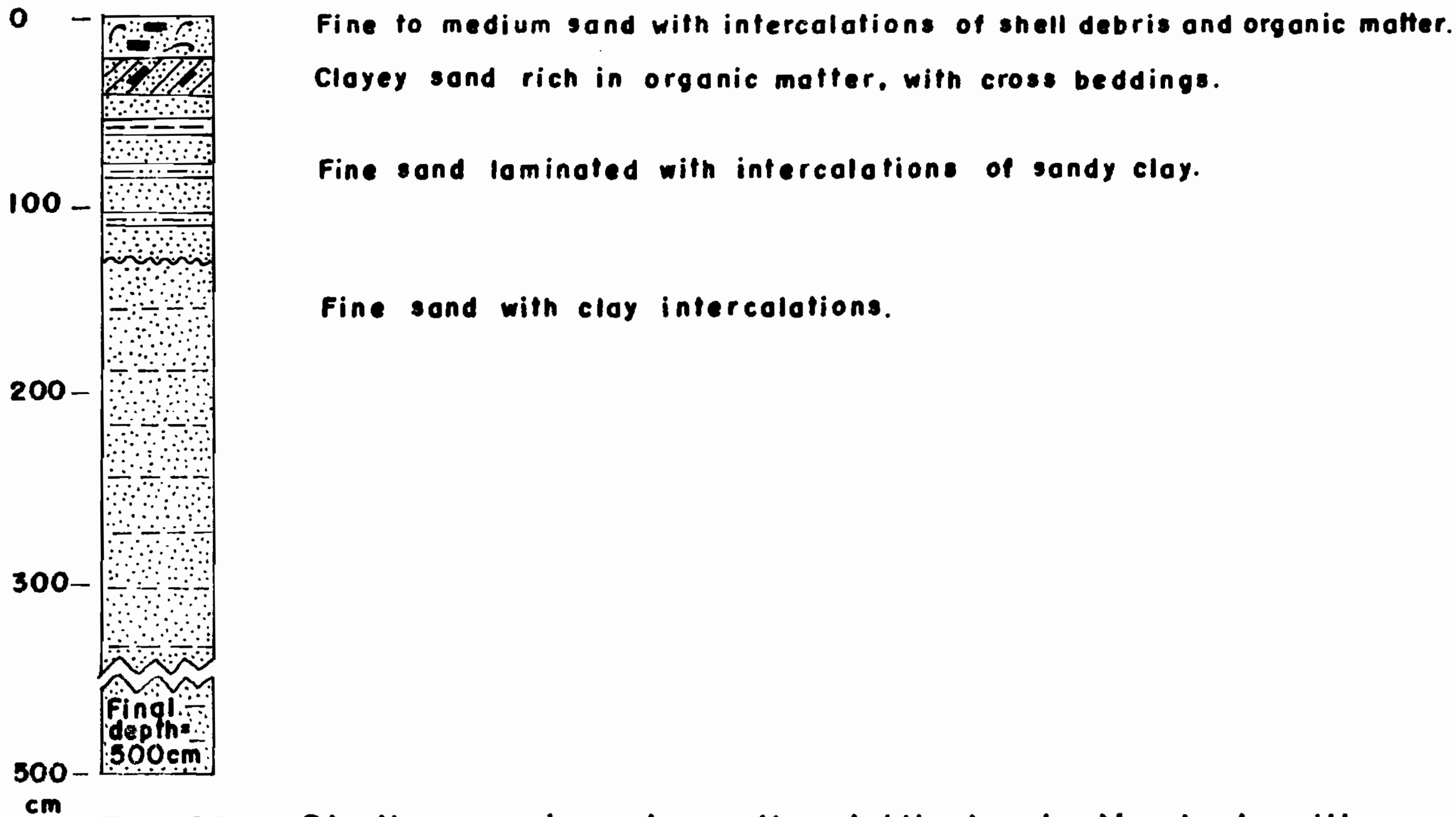

Fig. 29 - Shallow marine deposits drilled at Machado village, left margin of Rio Itajaí-Açu (State of Santa Catarina).

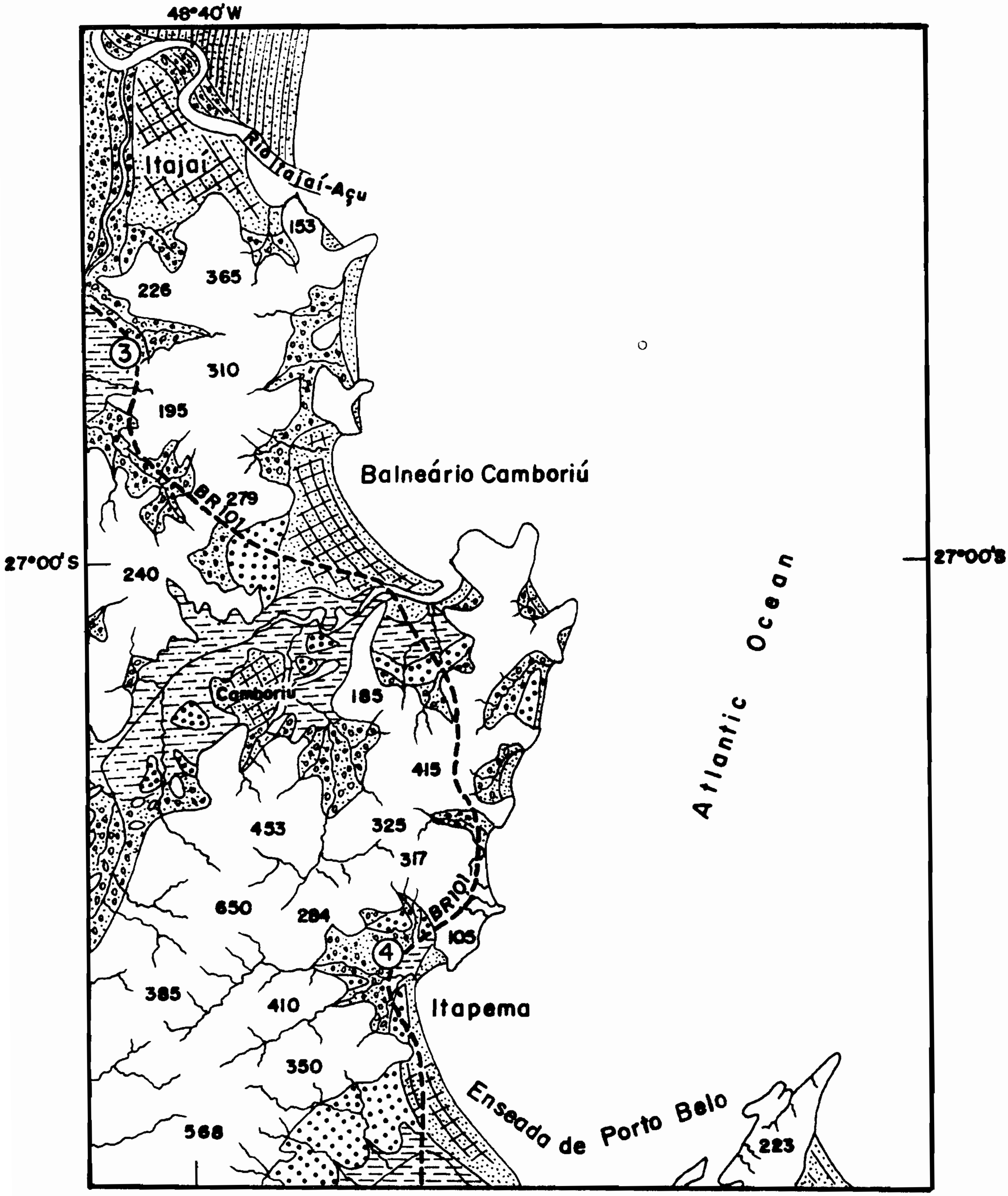

Fig. 30– Geologic map of the Balneário Camboriú-Itapema region — Stops 3 and 4 (3rd. day).

from the Pre-Canhanduva layers. When the climate changed progressively from humid to semiarid the loss of vegetation facilitated the erosion of the slopes. The weathering mantle was then removed to the lower parts of the basin, filling the depressions mostly through mass movements. This sedimentation of variable thickness, originated the Pre-Canhanduva sequence, which is light gray in colour. The sediments are predominantly fine-grained, unsorted and rich in sparse pebbles and blocks of quartzite, quartz and phyllite, which may be concentrated in some places. The Pre-Canhanduva layers document the climatic transition from humidity to semiaridity. The Canhanduva layers represent the subsequent epoch of mechanical morphogenesis related to the development of pediment. They are about 7.5m-thick and made-up of relatively coarse rudaceous reddish brown deposit. High density flows originated a succession of 50 to 70cm thick beds showing incipient stratification. Angular pebbles of quartz and phyllite are inbedded in a sandy-clayey matrix. The abundance of pebbles and especially the great number of phyllite phenoclasts (easily weathered under humid conditions) confirm the prevalence of mechanical morphogenesis during their deposition. The same does not occur in the Pre-Canhanduva layers. There are sparse quartz and quartzite pebbles representing residual elements of a previous chemically weathered regolith".

Stop 4: Pleistocene marine terrace
Location: BR 101 road, town of Itapema(Fig.30) - 5 minutes

Remnant of a sandy terrace whose summit is situated 13.9m above present sea-level (BIGARELLA, 1975). This altitude is clearly higher than all remnants of Pleistocene marine terraces found in other places. BIGARELLA (op. cit.)interpreted as a record related to the most ancient interglacial period but it is very strange so it was not identified in other places. It is possible that the upper portion of this terrace has been reworked by eolian processes which could have increased its altitude.

Going out from the town of Itapema, we shall cross a Pleistocene tombolo, situated between Porto Belo and Tijucas bays (Fig. 31), which shows conspicuous sandy ridges on aerial photos.

At the Holocene time the Pleistocene terrace has been almost entirely eroded, and only the central portion situated between two massives of crystalline rocks has been preserved, giving origin to a "erosional tombolo".

Stop 5: Contact between Pleistocene and Holocene marine terraces
Location: BR 101 road (Fig. 31) - 5 minutes

Clearly visible contact between Pleistocene and Holocene marine terraces marked by a contrast of altitude of some meters.

Sector to be run through BR 101 road in the area neighbouring the Tijucas coastal plain

The northern half of the Tijucas coastal plain is constituted by Holocene sandy ridges conspicuously visible on aerial photos, while its southern half is formed of clayey sands.

Stop 6: Tijucas coastal plain panoramic view
Location: Road to Governador Celso Ramos village (Fig. 31) - 10 minutes

Panoramic view of the Tijucas coastal plain.

Stop 7: Continental deposits of the Cachoeira Formation
Location: BR 101 road (Fig. 31) - 5 minutes

Following BIGARELLA (1975), "the sequence consists of an alternation of clay and arkosic sand layers without clear stratification. The sediments are filling a N-S elongated depression, possibly of tectonic origin, located between two crystalline granite massives. The remnants of the surface which was originated at the end of the sedimentation seem to dip toward the center of the basin. The geomorphic feature, together with sedimentologic aspects, suggests a bajada environment developed under semiarid conditions.

Ilha de Santa Catarina: Sector Florianópolis to Ponta

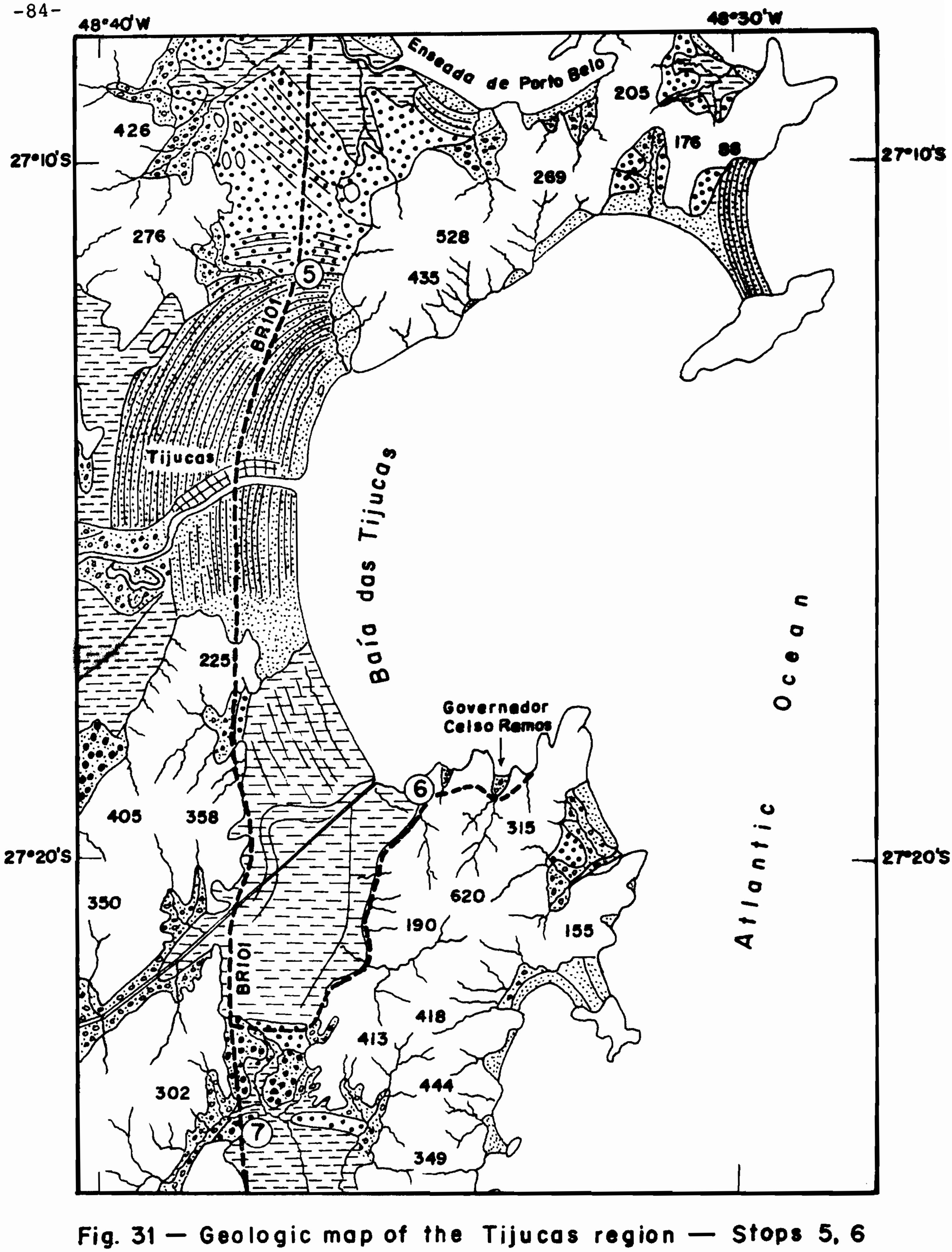

Fig. 31 — Geologic map of the Tijucas region — Stops 5, 6 and 7 (3rd. day).

das Canas (Fig. 32)

The northern part of the Santa Catarina island is formed of: (a) Remnants of Pleistocene marine terraces abutted against crystalline rock massives, (b) Paleolagoonal deposits,(c) Holocene sandy ridges, and (d) mangrove swamps. Around the paleo-lagoons there are several shell-middens.

Stop 8: Pleistocene marine terrace
Location: Santo Antônio de Lisboa locality (Fig. 32)

Pleistocene marine terrace exhibiting unusual characteristic associated with very coarse sands, originated from surrounding granitic rocks, slightly reworked under low energy conditions. In some places, there are incipient parallel beddings.

Stop 9: Papaquara paleolagoonal deposits
Location: Road to Ponta das Canas village (Fig.32)- 10 minutes

There is a 30cm-thick mollusk shell bed outcropping in both margins of a drainage channel. Several bivalve shells are closed indicating that they are in life position. These shells have been dated as 2,260 ± 160 years B.P. (Bah. 1362). As the shell bank is situated near the surface it is possible to infer that the paleolagoon desiccated about 2,000 years B.P. A drilling carried out in this paleolagoonal deposits penetrated 5.20m (Fig. 33).

Stop 10: Pleistocene marine terrace ("erosional tombolo")
Location: Ponta das Canas, Ilha de Santa Catarina(Fig. 32) - 5 minutes

Remanat of Pleistocene marine terrace has been preserved from erosion during Holocene transgression giving origin to a "erosional tombolo" situated between two massives of crystalline rocks.

Ilha de Santa Catarina: Sector Ponta das Canas to Lagoa

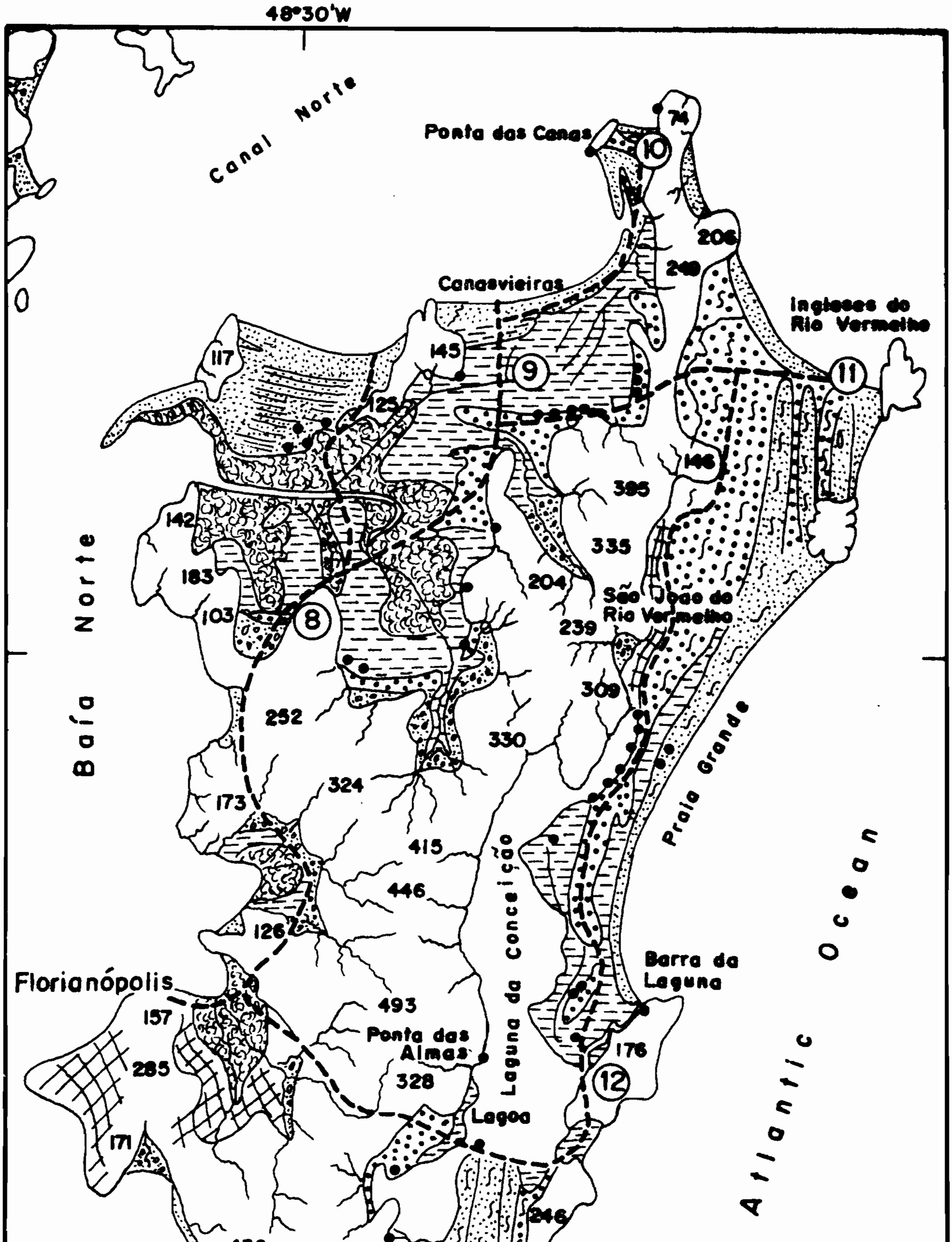

Fig. 32 — Geologic map of northern part of the Ilha de Santa Catarina — Stops 8, 9, 10, 11 and 12 (3rd. day).

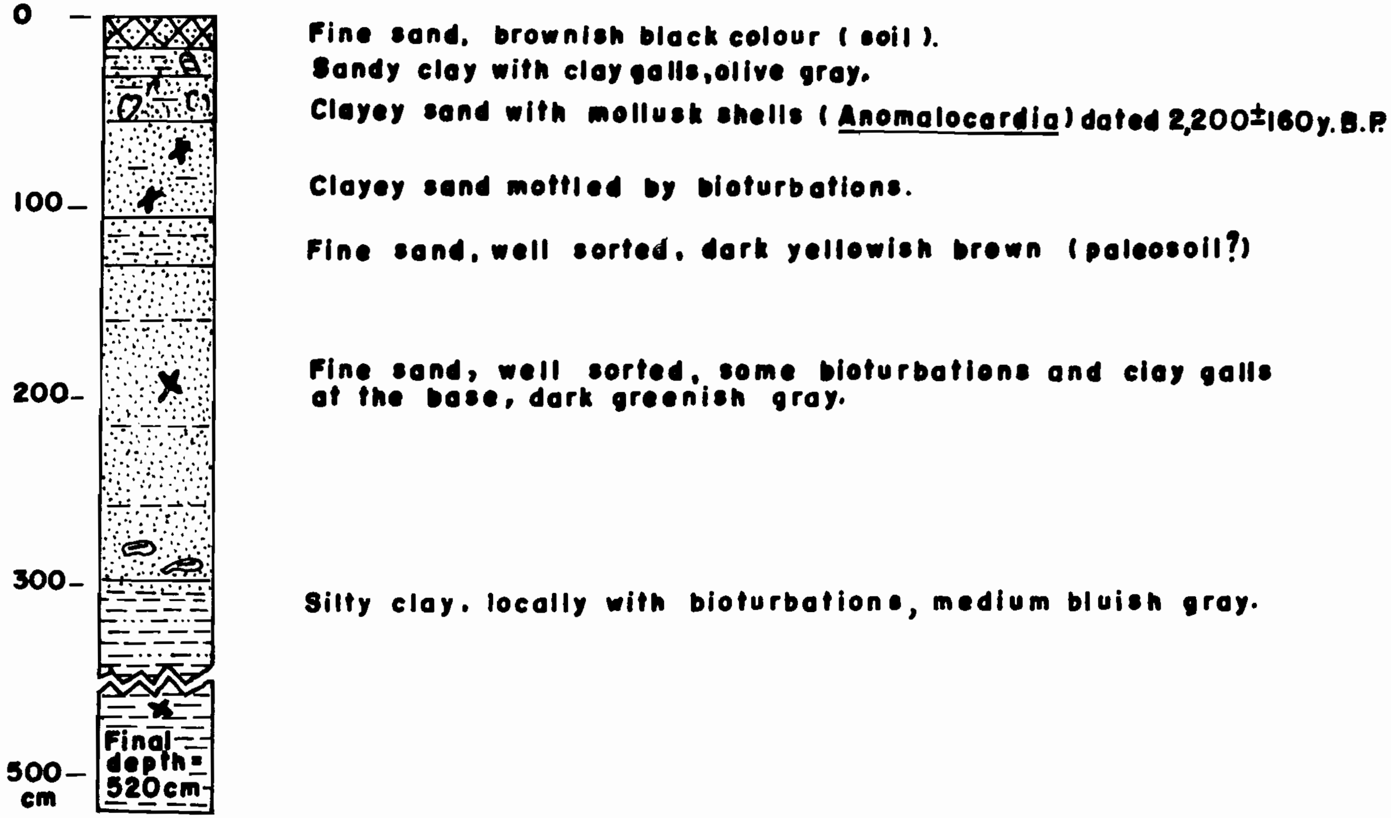

Fig. 33 — Sequence of sediments drilled at Papaquara paleolagoon.

The northeastern portion of Ilha de Santa Catarina is separated from the northwestern part by a massif of crystalline rocks being formed in greatest part of Pleistocene marine sands reworked superficially by the wind. Holocene marine sands are less important. In the Ingleses do Rio Vermelho village, Pleistocene marine terraces have been reworked by the wind and were covered by three bands of parabolic dunes: (a) a band of ancient reddish coloured sand dunes completely fixed by vegetation, (b) a band of Holocene whitish coloured sand dunes fixed by vegetation, and (c) a band of active dunes.

Stop 11: Ancient reddish coloured sand dunes
Location: Ingleses do Rio Vermelho village (Fig. 32)- 10 minutes

Outcrop of reddish coloured sand dunes without visible sedimentary structures.

Between São João do Rio Vermelho village and Barra da Lagoa (outlet), the Laguna da Conceição is separated from the open-sea by remnant outcrops of Pleistocene marine deposits filled by Holocene lagoonal or marine deposits. Remnant of Pleistocene marine terrace was outcropping within an excavation made for road construction.

Stop 12: Ancient reddish coloured sand dunes
Location: Morro da Galheta (Fig. 32) - 10 minutes

Ancient dunes partially covering Morro da Galheta and the panoramic view of the area.

Stop overnight: Chalés da Lagoa (Ilha de Santa Catarina, State of Santa Catarina)

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July 13 (Fourth day)

Departure from Ilha de Santa Catarina (hotel): 07.30h
Itinerary: Lagoa (Ilha de Santa Catarina) to Laguna

- SC 404: Lagoa to Florianópolis;
- BR 101: Florianópolis to Paulo Lopes;
- SC 434: Paulo Lopes - Garopaba - Araçatuba;
- BR 101: Araçatuba - bifurcation to Imbituba;
- SC 437: toward Imaruí village;
- SC 437: toward town of Imbituba;
- SC 437: Imbituba to Vila Nova;
- BR 101: Vila Nova to Laguna
- Laguna to Laguna de Santa Marta (ferry-boat).

Stop 1: Several generations of dunes
Location: Lagoa (Fig. 34) - 10 minutes

There are ancient reddish coloured dunes covered by Holocene parabolic dunes fixed by vegetation which is in turn being covered by presently active dunes. It is clearly visible that the dunes situated between Praia da Joaquina and Lagoa village invaded the Laguna da Conceição dividing it in two lagoons.

Stop 2: Shell-midden of Ponta das Almas
Location: Ponta das Almas, Lagoa village (Fig. 35)- 15 minutes

The shell-midden of Ponta das Almas was studied by PIAZZA (1966) and HURT (1974). Nevertheless, its geographic situation, in a lagoonal margin, is not so interesting for sea-level studies, some detailed research done by archeologists supplied with very important data.

In this site, we have a small shell-midden "B" abutted against the most important shell-midden "A". Several trenches excavated during the archeological researches allowed us to obtain a profile of half of the shell-midden "A", of half of the shell-midden "B" and of totality of the terrace occurring between the shell-midden and the present lagoon. The shell-midden substrate is constituted by blocks of crystalline rocks and reddish coloured (Probably of Pleistocene age) sands. A trench has shown

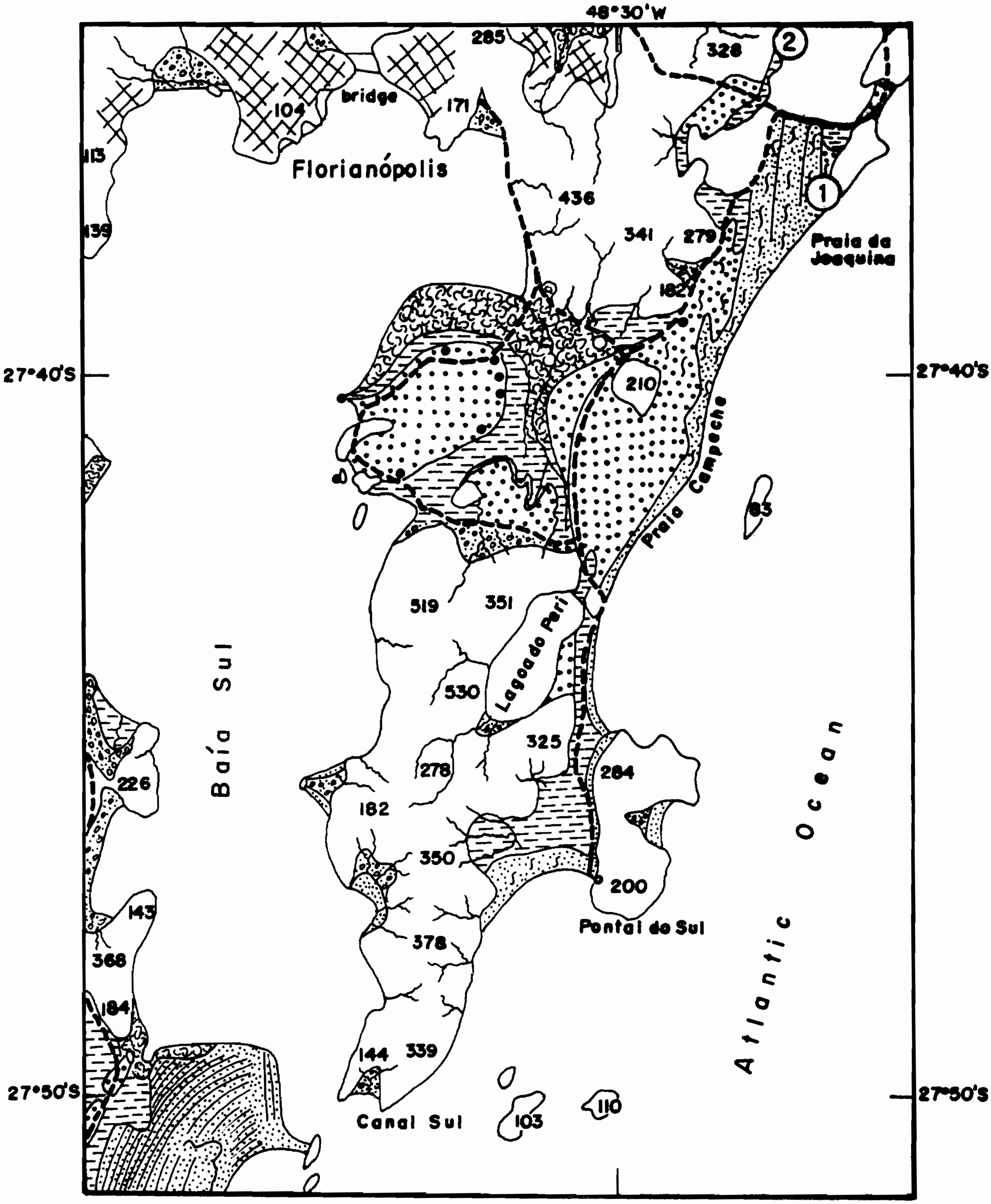

Fig. 34 — Geologic map of southern part of the Ilha de Santa Catarina — Stops 1 and 2 (4th. day).

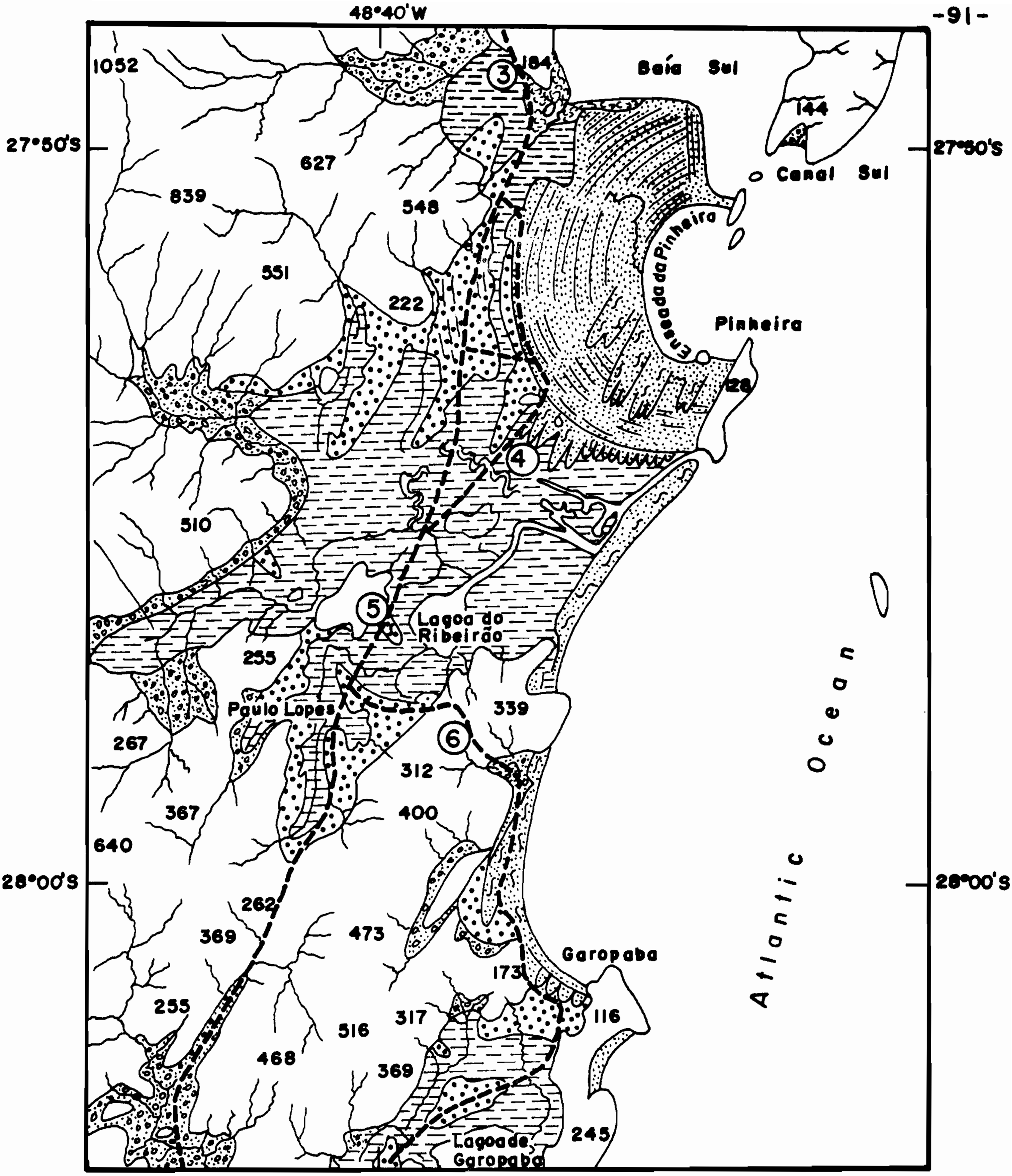

Fig. 35 — Geologic map of the Paulo Lopes region — Stops 3, 4, 5 and 6 (4th. day).

that, at the border of the shell-midden "A", there is a erosion notch cut on reddish coloured sands. The bottom of this notch is about 2.6m above present lagoonal high-tide level. Mollusk shells sampled by HURT (op. cit.) from an ancient beach in front of the notch were dated as 3,620 ± 150 years B.P. (Io. 2627). PIAZZA (op. cit.) obtained two ages for mollusk shells of the shell-midden: 4,280 ± 400 years B.P. (Si. 222) and 3,690 ± 100 years B. P. (Si. ?). The shells sampled from the fossil beach in front of the notch could have two origins: (a) They could have been reworked from a shell-midden previously existing for the time of notch formation. In this case, the high sea-level that gave origin to the notch was not of 3,600 years B.P. but a high sea-level after that time. (b) Their source could be related to the site from which the paleoindians were obtaining the mollusks for nourishment. The source area could be near the shell-midden and they have been transported by the waves. In this case, the notch could have been cut during the high sea-level of 3,600 years B.P. The second hypothesis was reinforced when HURT (op. cit.) discovered the existence of a new high sea-level after that of the notch formation. During this period the relative sea-level was about 2.0 ± 0.5m above the present level. This high sea-level occurred about 2.400 years B.P., time which seems to correspond to a new occupation of this site.

Sector to be run through BR 101 road, from Florianópolis city to Paulo Lopes village

Stop 3: Mangrove swamp
Location: Rio Maciambu (Fig. 35) - 5 minutes

This place represents almost the southernmost limit of mangrove swamp occurrence, today in Brazilian coastline.

Stop 4: Dunes advancing upon paleolagoonal deposits
Location: Enseada da Pinheira (Fig. 35) - 15 minutes

There are arcuate sandy ridges forming a coastal plain partially covered by active dunes. Southward, there are, in the inner portion of marine terraces, parabolic dunes which advanced upon paleolagoonal deposits. These dunes were originated when the shoreline occupied the innermost portion. In fact, these dunes do not advanced upon the sandy ridge terrace because their alignments are very well preserved and there are not any trace indicating this migration of the dunes through the terrace.

Stop 5: Frontal portion of an ancient dune
Location: BR 101 road, 2km before Paulo Lopes village (Fig. 35) - 5 minutes

This outcrop corresponds to the frontal portion of an ancient parabolic dune, which was formed when the present paleolagoonal site, on behind, was occupied by a coastal plain supplying eolian sands.

Sector to be run from Paulo Lopes village to Garopaba and then to Araçatuba and the town of Imbituba (Fig.35 and 36)

Stop 6: Panoramic view of the Garopaba area
Location: Road to Garopaba (Fig. 35) - 5 minutes

This area is formed of remnants of Pleistocene marine terraces and ancient dunes. Between Garopaba and Araçatuba the road is situated on Pleistocene marine terrace (without dunes), which borders a paleolagoon where Lagoa de Garopaba constitutes the last visible trace. Between Araçatuba and the bifurcation between BR 101 and SC 437, the road is situated upon Pleistocene marine terrace whose surface was reworked by the wind. Landward this terrace is limited by an ancient lagoonal zone which is today drained by the Rio Una, forming a continuation of the Laguna Mirim.

Stop 7: Raised lagoonal terrace
Location: SC 437 road to Imaruí village (Fig. 36) - 15 minutes

This raised lagoonal terrace is very rich in mollusk shells which are being exploited economically. On the lagoonal terrace, slightly in front of Pleistocene marine terrace, there

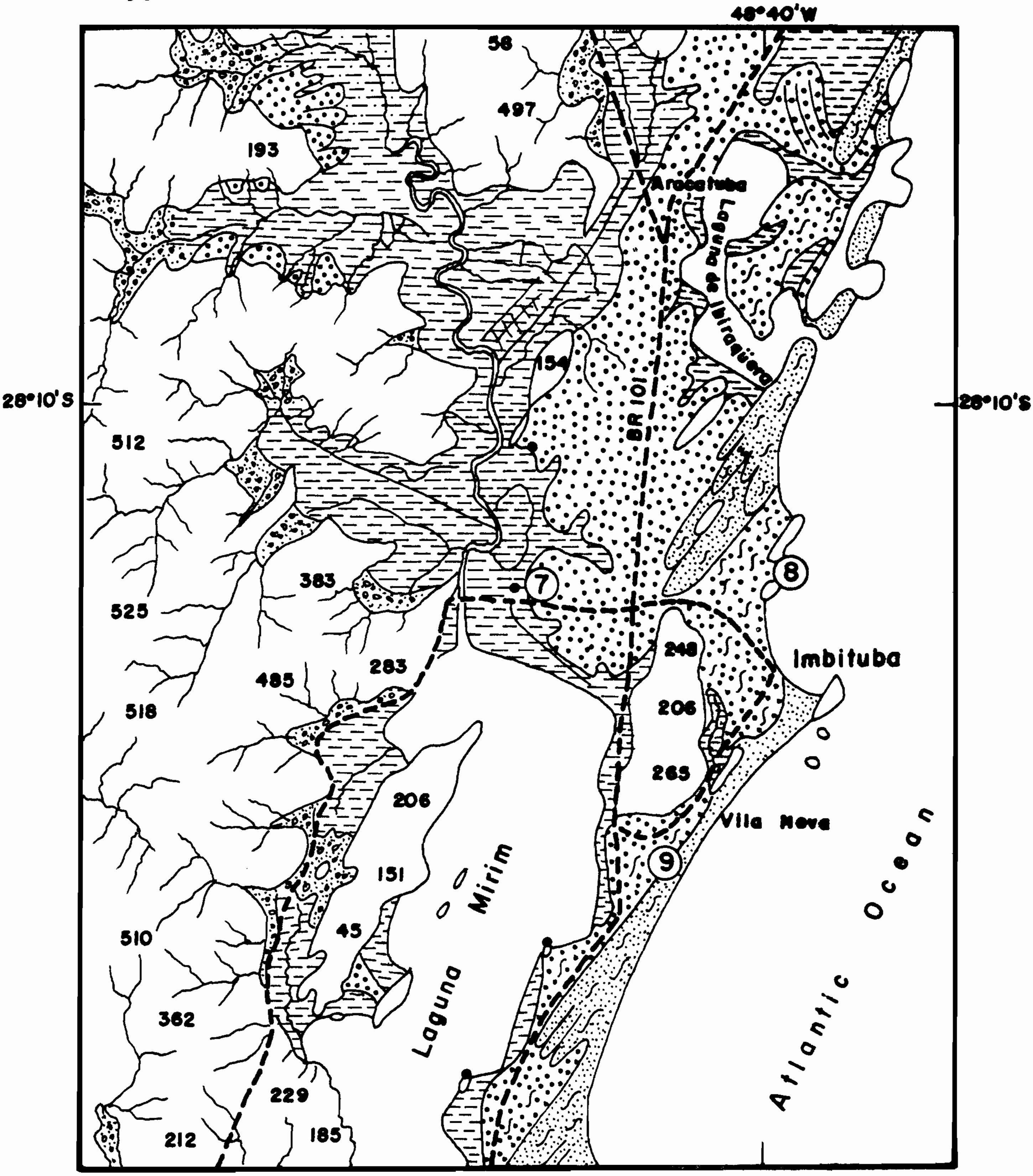

Fig. 36 — Geologic map of the Imbituba region — Stops 7, 8 and 9 (4th. day).

is a shell-midden. Mollusk shells from the surface of the lagoonal terrace have been dated as 4,490 ± 200 years B.P. (Bah. 1395), while those sampled from the shell-midden have been dated as 3,990 ± 200 years B.P. (Bah. 1394). Based on these two ages we can think that between 4,500 and 4,000 years B.P. the relative sea-level of the lagoon dropped, since the lagoonal deposits have been emerged and then were used as substrate for shell-midden's construction.

Stop 8: Ancient dunes on a coastal cliff
Location: Praia de Muita Água, town of Imbituba (Fig. 36) - 15 minutes

The Imbituba area is characterized by the occurrence of three generations of dunes: (a) ancient reddish coloured dunes, (b) Holocene whitish dunes fixed by vegetation and (c) modern, active dunes. These dunes of different generations can be observed between bifurcation to Imbituba from BR 101 road.

In the place named Praia de Muita Água, north of Imbituba, there is a beautiful outcrop of the ancient reddish coloured dunes. Certainly they are older than 7,000 years B.P. because after this epoch, characterized by relative sea - level higher than is today, there are no conditions to be formed. On the other hand, they have less than 120,000 years B.P., since Pleistocene marine terrace of this age is partially covered by them.

Sector to be run between Imbituba and Laguna

The origin of Laguna Mirim and Laguna Imaruí is not related to a Holocene sand bar, which formed a barrier against their direct contact with the open-sea, but they have been established in a lowland between Pleistocene marine terrace and the massives of crystalline rocks. Holocene marine sands, frequently reworked by the wind, are being deposited only on the outer side of the Pleistocene marine terrace.

Stop 9: Contact between Pleistocene and Holocene marine terraces

Location: Vila Nova village (Fig. 36) - 10 minutes

We can see a small cliff (topographic accident) in the contact between Pleistocene and Holocene marine terraces. Southward this contact disappears because it is covered by Holocene dunes but it reappears near Itapirubá and in the Laguna area.

Stop 10: Raised lagoonal terrace with shell bank
Location: Perrexil (Fig. 37) - 15 minutes

Mollusk shells sampled near the surface of the lagoonal terrace gave a radiocarbon age of 4,240 $\pm$ 200 years B.P. (Bah. 1374). They are being exploited economically. There are a contact between the Pleistocene marine terrace and the Holocene lagoonal terrace.

Sector to be run between the town of Laguna and the Cabo de Santa Marta Grande (Fig. 38)

Stop 11: Shell-middens of Carniça
Location: North of Laguna de Santa Marta (Fig. 38) - 15 minutes

One of these shell-midden sites was studied, from an archeological viewpoint, by HURT (1974). The information of HURT allowed us to get very interesting data on relative sea-level fluctuations during the Holocene in the area.

The studied site is, in reality, constituted by two joined shell-middens. The most important of them was designated Carniça "I" and the subsidiary one has been named Carniça "IA". They have been established upon Holocene lagoonal deposits partially covered by dunes. When an area is not covered by eolian sands it is possible to see some alignments on aerial photos, which probably represent the ancient lagoonal shorelines. The excavations accomplished by HURT (op. cit.) have shown that the lagoonal deposits, upon which shell-middens were established, contain bank of shells mostly in life position (closed valves). Three radiocarbon ages on mollusk shells indicated:

3,300 $\pm$ 150 years B.P. (L.1164B)
3,350 $\pm$ 110 years B.P. (Io.2620)

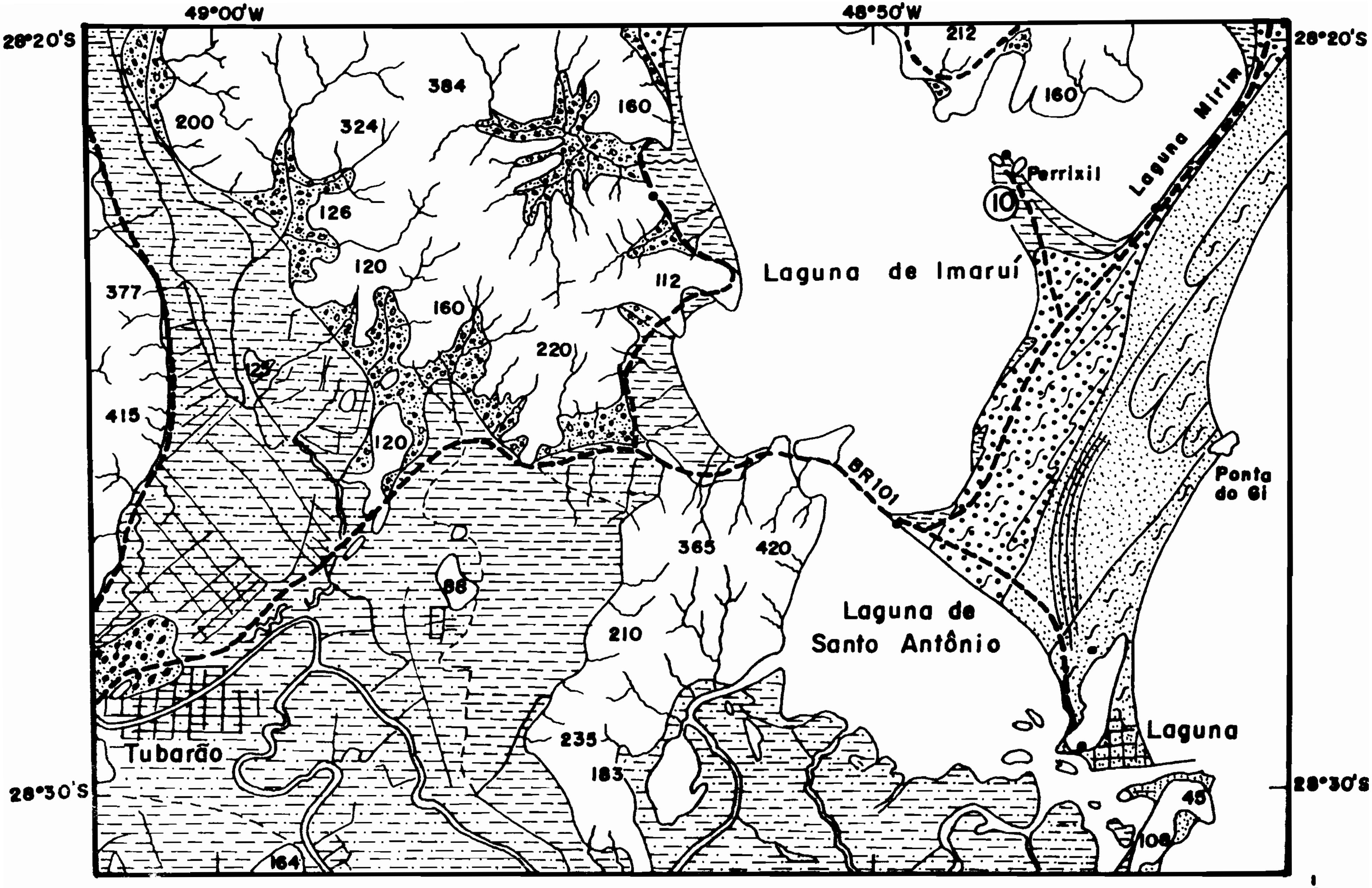

Fig. 37 — Geologic map of the Laguna-Tubarão region — Stop 10 (4th. day).

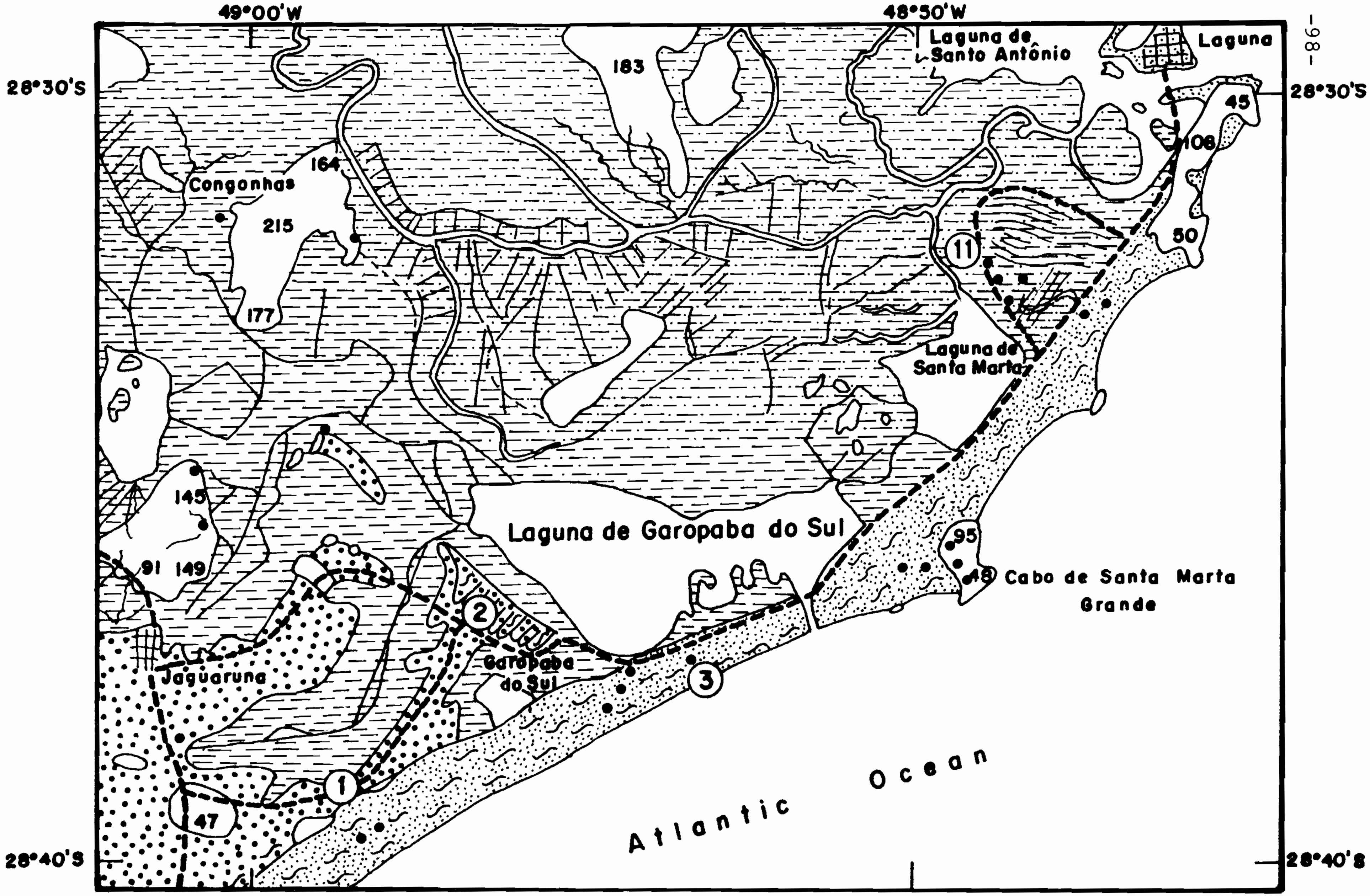

Fig. 38 — Geologic map of the Jaguaruna-Garopaba do Sul region — Stop 11 (4th. day) and stops 1, 2 and 3 (5th. day).

3,400 ± 150 years B.P. (L.1164)

Mollusk shells and charcoals sampled from several levels between the base and the summit of shell-midden Carniça "I" furnished the following ages:

3,210 ± 150 years B.P. (A.917)
3,370 ± 150 years B.P. (A.918)
3,370 ± 100 years B.P. (A.919)
3,310 ± 150 years B.P. (A.912)

Another sample collected near the surface indicated an age of 3,030 ± 50 years B.P. (A. 883-2). Then, it seems that about 3,450 years B.P. the lagoonal level was clearly higher than it is today but was dropping since the lagoonal deposits were subsequently e-merged and shell-middens were established upon them. This site was probably once abandoned about 3,000 years B.P. The trenches excavated by HURT (op. cit.) showed that the lagoonal deposits, upon which the shell-middens have been established, were eroded during a new high lagoonal level period. As a consequence, the shell-midden Carniça "I" was partially eroded and the tumbled shells were dispersed upon the lagoonal beach. During the maximum of this new high level period, the lagoonal level was situated about 0.5m lower than during the previous high level period. Mollusk shells sampled from a hearth-stone directly upon the lagoonal terrace within the shell-midden "IA" indicated an age of 2,460 ± 110 years B.P. (A.959). Then, it seems that this site was reoccupied about 2,500 years B.P., when probably occurred the last high lagoonal level. Another sample collected near the shell-midden summit was dated as 2,550 ± 100 years B.P. (A.914). Finally, near this place there is a terrace very rich in mollusk shells whose summit is situated below the terrace upon which the shell-middens were constructed. Sample collected near the top of this terrace was dated as 2,500 ± 170 years B.P. (Bah. 1380).

Stop overnight: Lagoa Hotel (town of Laguna, State of Santa Catarina).

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July 14 (Fifth day)

Departure from the town of Laguna: 07.30 h
Itinerary: Laguna returning to Laguna

- BR 101: Laguna - Tubarão - Jaguaruna;
- Jaguaruna to Garopaba do Sul;
- BR 101: Jaguaruna to Vila Nova;
- Vila Nova to Lagoa dos Esteves (Rincão);
- BR 101: Vila Nova to Araranguá
- Araranguá to Morro dos Conventos;
- BR 101 and SC 448 roads: Araranguá - Ermo - Sombrio;
- Sombrio to Praia Gaivota;
- BR 101 and SC 450: Sombrio to Praia Grande.

Sector to be run through BR 101 road, from the town of Laguna to the town of Jaguaruna (Fig. 37 and 38)

After crossing the Laguna de Imaruí, followed by an area dominated by crystalline rocks, the road continues at the border of a huge paleolagoon, which is partially occupied by the intralagoonal delta of the Rio Tubarão. The town of Jaguaruna is situated upon Pleistocene marine terrace on border of an ancient paleolagoon. Many shell-middens are known in this area and between them the shell-midden of Congonhas was dated as 3,270 ± 200 years B.P.

Sector to be run through a secondary road, from the town of Jaguaruna to Garopaba do Sul village (Fig.37 and 38)

Stop 1: Shell-middens surrounded by active dunes
Location: Lagoa Figueirinha (Fig. 38) - 5 minutes

There are two huge shell-middens presently surrounded by active dunes. Originally these shell-middens were located on the border of a lagoon which has been mostly filled by eolian sands. Lagoa de Figueirinha and Lagoa de Gregório Bento are small remnants of the original lagoon. Mollusk shells sampled near the summit (end of site occupation) were dated as 4,240 ± 190 years B.P. (Bah. 1378). It is possible that these shell-middens have been established on a Holocene sandy barrier which separated the lagoon from the open-sea.

Stop 2: Ancient dune field
Location: Road to Garopaba do Sul village (Fig. 38) - 5 minutes

This area represents the frontal portion of an extensive dune field established on Pleistocene marine terrace. The backside portion of these dunes has been destroyed and replaced by the Laguna Garopaba do Sul. These dunes, like that of Imbituba, are more recent than 120,000 years B.P. and more ancient than 7,000 years B.P.

Stop 3: Giant shell-midden
Location: Garopaba do Sul village (Fig. 38) - 30 minutes

Northward of Garopaba do Sul village there are remnants of a huge shell-midden, which is probably the greatest in Brazil. It was constructed on a Holocene sandy barrier bar which separated the lagoon from the open-sea. Mollusk shells from this shell-midden have been dated as 3,450 ± 170 years B.P. (Bah. 1379). Nevertheless this age is not so significant since the great size allow us to imagine a long period of site occupation. Then, the evolutionary history could be established only after a systematical study accompanied by numerous radiocarbon ages.

Sector to be run through BR 101, from Jaguaruna to Vila Nova (Fig. 39)

At Esplanada we can see the contact between Precambrian crystalline rocks and the Paranā Basin sedimentary rocks: (a) at the road-side before the village entrance we have the last outcrop of crystalline rocks, and (b) at the road-side near Morro da Fumaça village we have the first outcrop of sedimentary rocks.

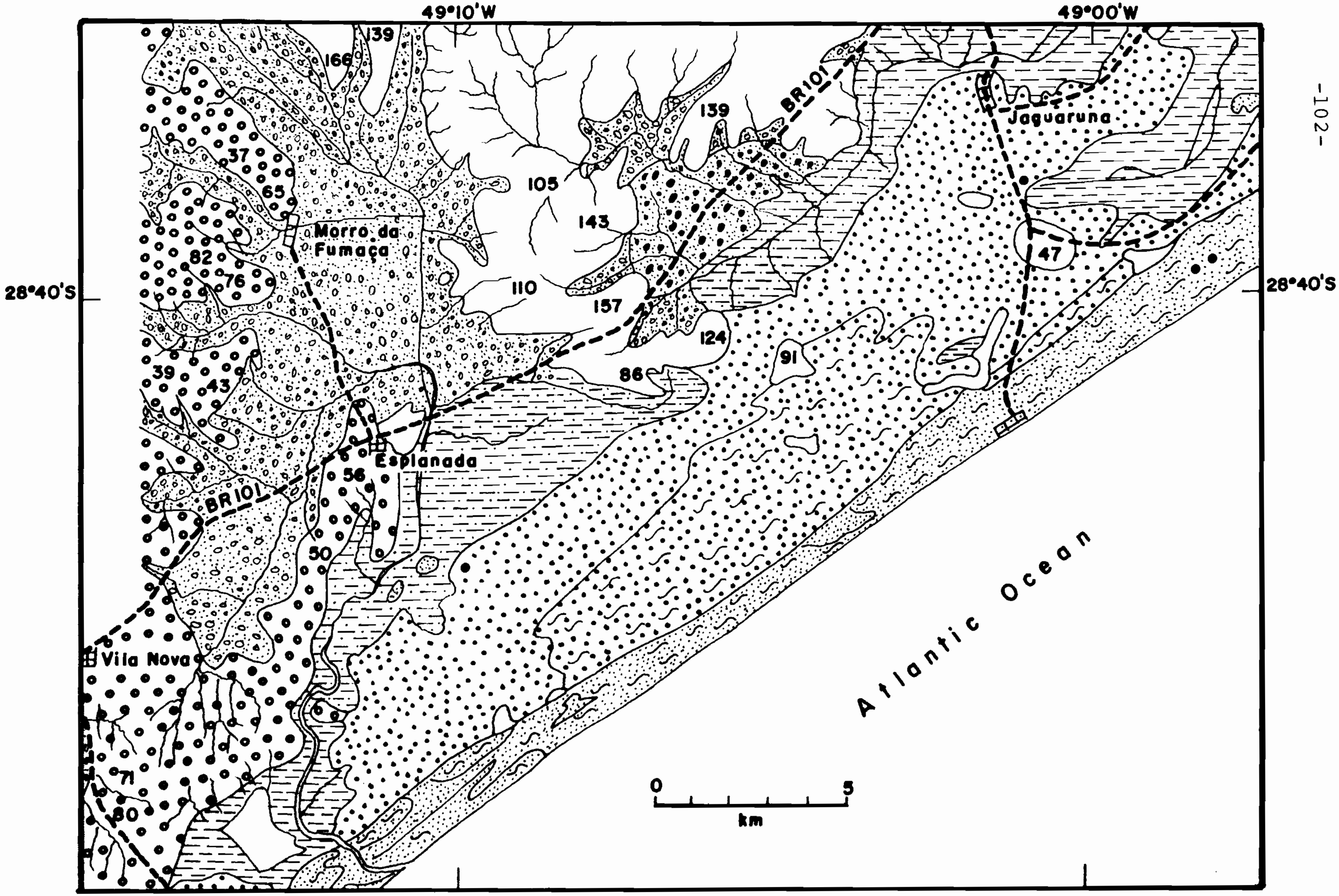

Fig. 39 — Geologic map of the Jaguaruna-Vila Nova region (5th. day).

Sector to be run through a secondary road, from Vila Nova to Lagoa dos Esteves (Fig. 39 and 40)

The Pleistocene marine terrace is abutted against Paranã Basin sedimentary rocks, which can be covered partially by ancient dunes. The Lagoa da Mãe Luzia, Lagoa dos Esteves and Lagoa do Faxinal are surrounded by Pleistocene marine terraces.This situation is very frequently observed from Florianópolis to this place but it will disappear southward when more extensive lagoons and lakes will be separated from the open-sea by Holocene sandy barrier bars.

Sector to be run through BR 101 road, from Vila Nova to Araranguá (Fig. 40)

Between Maracajá village and the town of Araranguá the road will cross Pleistocene marine terrace with arcuate sandy ridges clearly distinguisable on aerial photos. The town of Araranguá is situated upon Pleistocene marine terrace.

Sector to be run through a secondary road, from Araranguá to Morro dos Conventos (Fig. 40)

The Morro dos Conventos is a remnant (dead cliff) of the Paraná Basin sedimentary rocks (Paleozoic), which reach practically the present shoreline. At backside of the Morro dos Conventos there is a rest of Pleistocene marine terrace which was preserved by the hill during the Holocene high sea-level period.

Sector to be run through BR 101 road, from Araranguá to Sombrio (Fig. 40 and 42)

Between the towns of Araranguá and Sombrio the road crosses Pleistocene marine terrace.

Stop 4: Fluvial deposits
Location: Rio Itoupava, near Ermo village (Fig. 41) - 15 minutes

At the border of the Rio Itoupava there are gravel

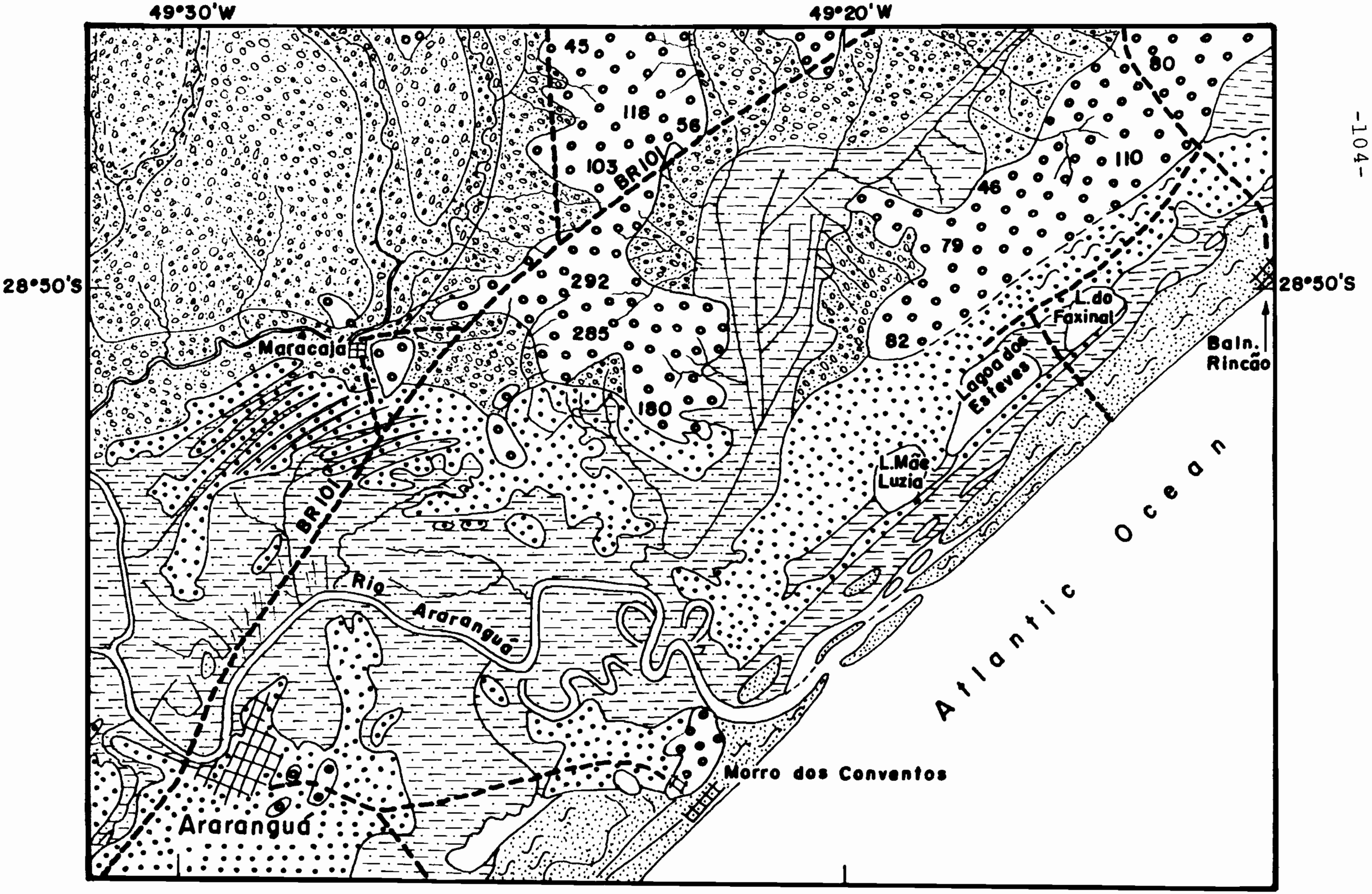

Fig. 40 — Geologic map of the Araranguá region (5th. day).

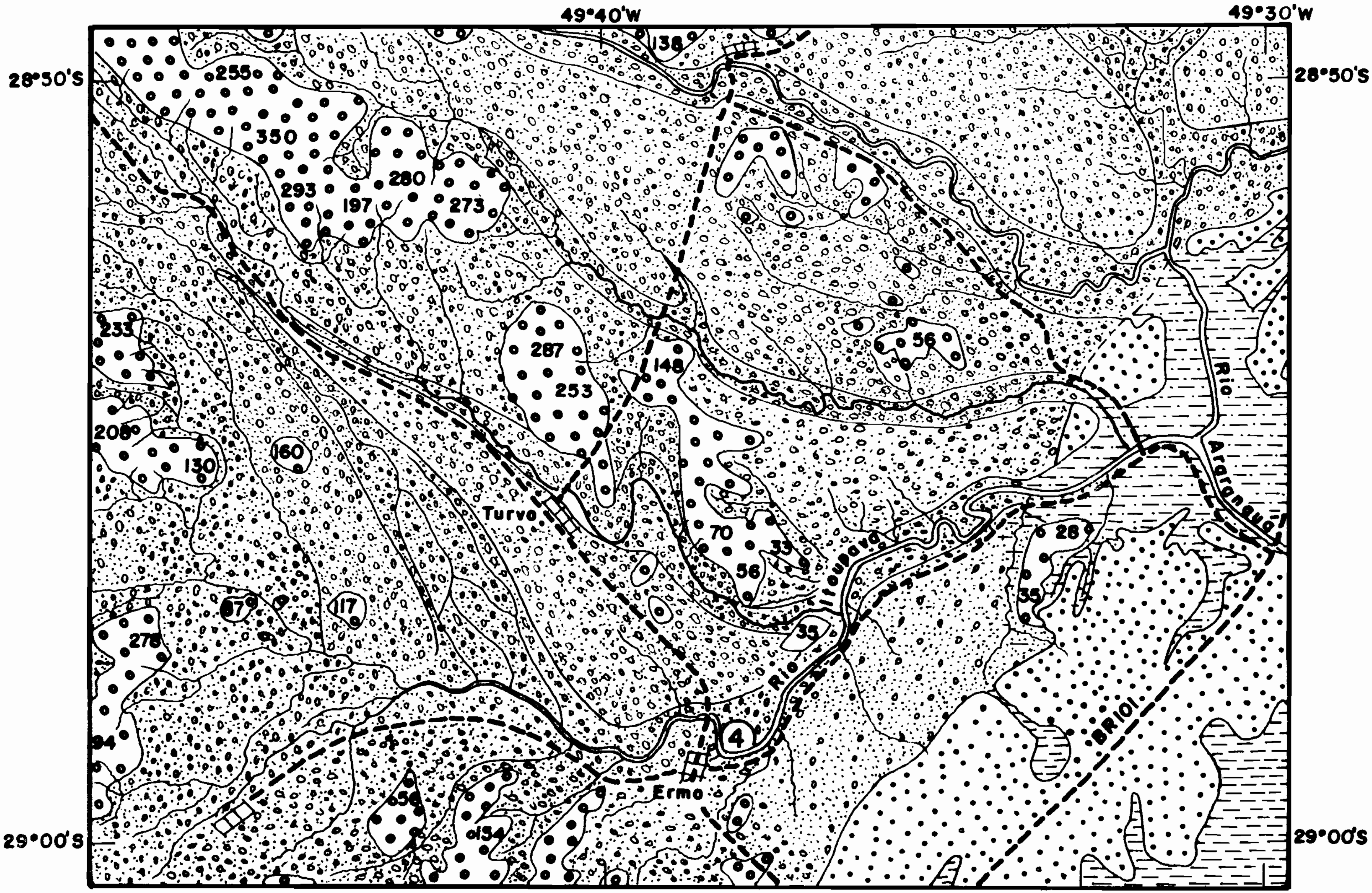

Fig. 41 — Geologic map of the Ermo–Turvo region — Stop 4 (5th. day).

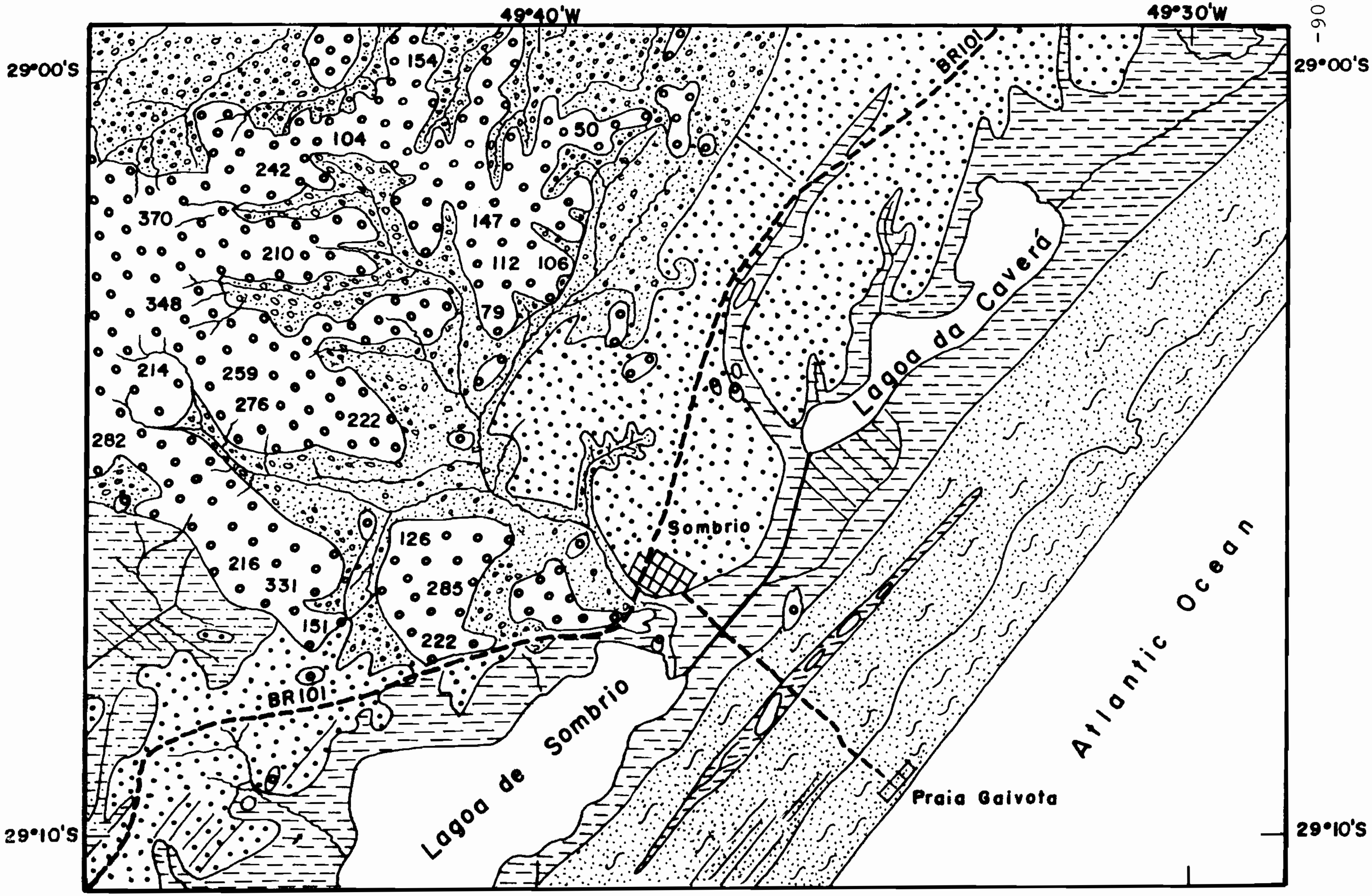

Fig. 42 — Geologic map of the Sombrio region (5th. day).

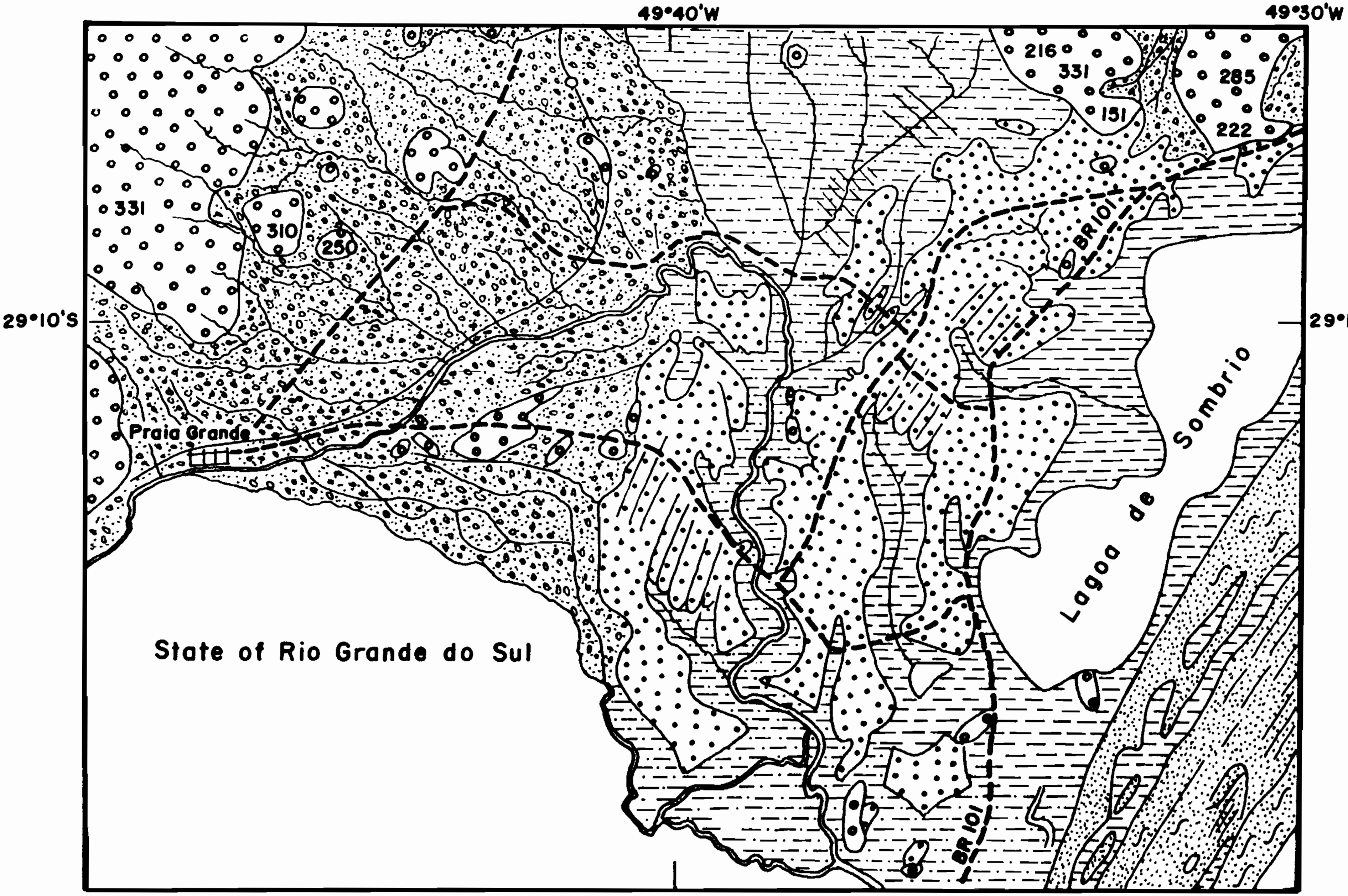

Fig. 43 — Geologic map of the Praia Grande region (5th. day).

deposits covered by fluvial sediments. In the contact we can see clayey-sandy deposits very rich in organic remains (wood fragments, etc.)

Sector to be run through a secondary road, from the town of Sombrio to Praia da Gaivota (Fig. 42)

Departing from Sombrio, situated upon Pleistocene marine terrace, we shall cross a lagoonal lowland followed by about 5km-wide Holocene marine sands more-or-less covered by dunes. In this case, the extensive paleolagoon, presently represented by the vestigial Lagoa de Sombrio e Lagoa de Caverá, was separated from the open-sea by a Holocene sandy barrier bar.

Sector to be run through a secondary road, from the town of Sombrio to Praia Grande village (Fig. 43)

The Pleistocene marine terrace intensely dissected by erosion has a great development. It is still possible to distinguish the alignments of ancient sandy ridges on aerial photos. Between the Pleistocene marine terrace and the counterforts of the Serra Geral there is an extensive area of continental deposits probably of Pleistocene age.

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Table I - Radiocarbon ages of mollusk shells and wood fragments sampled from coastal deposits of the State of Paraná.

Sample number	Name of the topo - graphic map	Coordinate	Nature of the sample	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
PR.16	Guaratuba	25°58.0'S 48°38.5'W	Shells	5,820±220	+0.06	Bah.1279	>0m
Bi.05	Guaratuba	----------	Shells	5,770±150	-----	--------	>0m
Bi.02	Ilha do Mel	Praia de Leste	------	5,690±200	-----	--------	>0m
PR.07	Ilha do Mel	25°35.0'S 48°29.6'W	Shells	5,040±230	+0.87	Bah.1271	>+ 1.5m
Bi.04	Guaratuba	Rio Boguaçu	Shells	4,390±300	-----	--------	+ 1.0±0.5m
Bi.03	Guaratuba	25°50.7'S 48°32.4'W	Shells	3,830±120	-----	--------	<0m (transgression)
PR.14	Guaratuba	25°56.9'S 48°36.2'W	Shells	3,160±170	-0.21	Bah.1277	>+ 1.0m
PR.15	Guaratuba	25°57.0'S 48°36.8'W	Shells	2,970±150	-0.44	Bah.1278	>+ 1.0m
Bi.01		Saco da Tam burutaca	Shells	2,670±150	-----	--------	+ 1.5±0.5m
PR.06	Ilha do Mel	25°33.2'S 48°27.9'W	Shells	2,680±240	-0.89	Bah.1270	+ 1.0±0.5m
PR.04	Paranaguá	25°32.5'S 48°31.5'W	Shells	2,650±170	-0.39	Bah.1269	+ 1.0±0.5m
PR.17	Guaraqueçaba	25°22.4'S 48°18.9'W	Wood	1,100±150	-24.33	Bah.1388	>0m

Table II - Radiocarbon ages of lagoonal and marine mollusk shells and charcoals sampled from shell-middens of the State of Paraná coastal plain.

Sample number	Name of the shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$	Laboratory number	Position of sea-level
PR.21	Cacatu	17	25°19.6'S 48°45.3'W	Shells	Surface (end of occupation)	5,050±220	-4.10	Bah. 1392	> 0m (max.)
PR.22	São João	03	25°27.3'S 48°45.3'W	Shells	Base (beginning of occupation)	4,890±210	-3.03	Bah. 1393	> 0m
Rauth 1	"	"	"	"	"	4,810±100	-----	Si. 1023	
" 2	"	"	"	"	"	4,960±110	-----	Si. 1022	
" 3	"	"	"	"	Near surface	4,070±100	-----	Si. 1021	
Rauth 4	Gomes	11	25°31.0'S 48°41.5'W	Shells	Base (beginning of occupation)	4,890±70	-----	P. 543	> 0m
" 5	"	"	"	"	"	4,870±70	-----	P. 542	
" 6	"	"	"	"	"	4,490±180	-----	P. 541	
" 7	"	"	"	"	Surface (end of occupation)	4,490±140	-----	P. 540	
Rauth 8	Pto.Maurício	43	25°31.3'S 48°38.8'W	Shells	Surface (end of occupation)	4,760±80	-----	Si. 508	
" 9	"	"		"	"	4,540±90	-----	Si. 507	
" 10	"	"		"	"	4,740±90	-----	Si. 506	
" 11	"	"		"	"	4,620±100	-----	Si. 505	
" 12	"	"		"	"	4,640±80	-----	Si. 504	
Rauth 13	Godo	29	25°25.0'S 48°44.6'W	Shells	Base (beginning of occupation)	4,740±90	-----	Si.1029	> 0m
PR.12		10	25°54.0'S 48°42.2'W	Shells	Base (beginning of occupation)	4,500±190	-1.98	Bah.1275	> 0m

Table II (Continuation 1)

Sample number	Name of the Shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
Rauth 14	Saquarema	10	25°30.9'S 48°41.2'W	------	Near base (beginning of occupation)	4,370±70	------	p. 588	+1.0m
" 15	"	"	"	------	"	4,300±70	------	p. 587	
" 16	"	"	"	------	"	3,900±70	------	p. 586	
" 17	"	"	"	------	"	4,050±70	------	p. 536	
	Guaraguaçu		Guaratuba	Charcoal	Near surface (end of occupation)	4,120±130	------	Gif.79	0m
PR.09		51	25°55.2'S 48°37.7'W	Shells	Near base	3,920±190	-3.56	Bah.1272	0m
PR.19			25°21.9'S 48°25.2'W	Shells	Surface	3,830±190	+0.78	Bah.1390	+1.0m
PR.20			25°19.9'S 48°25.1'W	Shells	Base	3,800±190	-2.30	Bah.1391	+1.5m
PR.01	Macedo	17	25°33.0'S 48°37.3'W	Shells	Base (beginning of occupation)	3,670±180	-0.11	Bah.1265	+1.6m
Hurt 01	"	"	"	"	"	3,500±60	------	P.500	
Hurt 02	"	"	"	"	"	3,420±60	------	P.489	
" 03	"	"	"	"	"	3,360±70	------	P.488	
" 04	"	"	"	"	"	3,280±60	------	P.487	
" 05	"	"	"	"	"	3,370±60	------	P.486	
" 06	"	"	"	"	"	3,270±50	------	P.485	
" 07	"	"	"	"	"	3,240±60	------	P.483	
" 08	"	"	"	"	Near surface (end of occupation)	3,310±60	------	P.482	

Table II (Continuation 2)

Sample number	Name of the shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
PR.10		50	25°55.4'S 48°38.3'W	Shells	---------	3,290±190	-0.27	Bah.1273	<+1.3m
Rauth 18	Godo (2nd.phase)	29	25°25.0'S 48°44.6'W	Shells	---------	3,300±90	-----	Si. 1028A	
" 19	"	"	"	"	---------	3,360±80	-----	Si. 1028	
" 20	"	"	"	"	---------	3,000±90	-----	Si. 1027	
" 21	"	"	"	"	Near surface (end of occupation)	2,980±130	-----	Si. 1026	
PR.13		22	25°50.7'S 48°43.5'W	Shells	Base (beginning of occupation)	2,420±170	-1.98	Bah.1276	>0m
PR.18	Guapicu		25°22.4'S 48°18.9'W	Shells	Base	1,250±150	-3.40	Bah.1389	<+0.5m

Table III- Radiocarbon ages of mollusk shells and wood fragments sampled from coastal deposits of the State of Santa Catarina

Sample number	Name of the topographic map	Coordinate	Nature of the sample	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
SC.03	São Francisco do Sul	26°10.6'S 48°37.1'W	Shells	6,080±250	-7.28	Bah. 1280	>0m
SC.18	Tijucas	27°14.0'S 48°43.0'W	Wood	5,870±240	-26.83	Bah. 1359	>0m
SC.41	Jaguaruna	28°43.5'S 49°10.7'W	Shells	5,710±200	-4.77	Bah. 1382	>0m
SC.14	Itajaí	26°51.9'S 48°41.3'W	Shells	5,580±240	-0.21	Bah. 1290	+1.0±0.5m
SC.44	Imbituba	28°12.7'S 48°43.7'W	Shells	4,490±200	+0.94	Bah. 1395	>0m
SC.33	Laguna	28°22.1'S 48°17.7'W	Shells	4,240±200	+1.08	Bah. 1374	+1.5±0.5m
SC.28	Imbituba	28°02.8'S 48°37.6'W	Shells	4,080±200	-0.25	Bah. 1369	>0m
SC.27	Paulo Lopes	27°46.1'S 48°30.5'W	Shells	4,070±190	+1.36	Bah. 1368	>0m
SC.29	Imbituba	28°07.0'S 48°42.0'W	Shells	3,960±200	+0.42	Bah. 1370	>0m
SC.09	Araquari	26°17.4'S	Shells	3,920±190	-0.49	Bah. 1286	>0m
SC.40	Garopaba do Sul	28°35.6'S 48°58.1'W	Shells	3,830±180	-0.33	Bah. 1381	>0m

Table III - (Continuation I)

Sample number	Name of the topographic map	Coordinate	Nature of the sample	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
P.d.A.	Lagoa	27°35.8'S 48°27.5'W	Shells	3,620±100	------	Io.2627	+2.6m
SC.12	Barra Velha	26°35.5'S 48°42.2'W	Wood	3,520±180	-26.41	Bah.1289	+1.5±0.5m
SC.31	Vila Nova	28°17.5'S 48°43.2'W	Shells	3,460±200	+1.13	Bah.1372	+1m
Carniça "a"	Garopaba do Sul	28°33.9'S 48°48.5'W	Shells	3,400±150	------	L.1164B	+2.5±0.5m
Carniça "b"	Garopaba do Sul	28°33.9'S 48°48.5'W	"	3,350±150	------	Io.2620	+2.5±0.5m
Carniça "c"	Garopaba do Sul	28°33.9'S 48°48.5'W	"	3,300±150	------	L.1164	+2.5±0.5m
SC.39	Garopaba do Sul	28°33.3'S 48°48.3'W	Shells	2,500±170		Bah.1380	+2.0±0.5m
SC.36	Laguna	28°21.6'S 48°53.4'W	Shells	2,450±170	+0.19	Bah.1377	+1m
SC.19	Biguaçu	27°20.7'S 48°37.8'W	Shells	2,420±160	+2.13	Bah.1360	>0m
SC.21	Canasvieiras	27°26.6'S 48°27.4'W	Shells	2,220±160	+0.16	Bah.1362	+1.5±0.5m
SC.24	Lagoa	27°31.4'S 48°26.4'W	Wood	1,860±160	-25.93	Bah.1365	+1m
SC.17	Tijucas	27°12.9'S 48°37.5'W	Shells	1,700±160	+0.16	Bah.1358	>0m

Table IV - Radiocarbon ages of lagoonal and marine mollusk shells and charcoals sampled from shell-middens of the State of Santa Catarina coastal plain.

Sample number	Name of the shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
SC.04		02	26°04.4'S 48°48.8'W	Shells	Base (beginning of occupation)	5,420±230	-1.56	Bah.1282	Max. heigh
SC.16			26°53.4'S 48°51.6'W	Shells	Surface	5,340±210	-3.29	Bah.1357	Max. heigh
Piazza 01	Gaspar		26°51.1'S 48°55.5'W	------	--------	5,270±300	-----	Si.362-C	Max. heigh
" 02	"		"	------	--------	5,230±350	-----	Si.362-o	Max. heigh
SC.01		01	25°58.9'S 48°38.5'W	Shells	Base (beginning of occupation)	5,040±210	-7.28	Bah.1280	Heigh
Piazza 01	Ponta das Almas		27°35.8'S 48°27.5'W	Shells	Base (beginning of occupation)	4,280±400	-----	Si.222	Indifferent
	Ratones		27°30.0'S 48°27.0'W	Shells	--------	4,260±210	+0.10	Bah.1329	>Present
SC.37			28°40.0'S 48°58.7'W	Shells	Surface (end of occupation)	4,240±190	+0.58	Bah.1378	>Present
	Cabeçudas		28°26.4'S 48°49.6'W	------	--------	4,120±220	-----	Hv. 167	>Present
	Conquista		26°23.0'S 48°40.0'W	------	--------	4,070±220	-----	--------	>Present
SC.43			28°12.7'S 48°43.7'W	Shells	Surface (end of occupation)	3,990±200	+0.85	Bah.1287	<+1.0m
SC.10			26°22.1'S 48°34.5'W	Shells	Surface (end of occupation)	3,850±200	-1.63	Bah.1286(?)	

Table IV - (Continuation 1)

Sample number	Name of the shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
SC.35			28°19.3'S 48°52.9'W	Shells	Base (beginning of occupation)	3,690±190	+1.38	Bah.1376	Indifferent
SC.11			26°17.3'S 48°32.8'W	Shells	"	3,600±180	-0.98	Bah.1288	>Present
SC.30			28°10.7'S 48°43.4'W	Shells	"	3,520±180	+0.33	Bah.1371	High
SC.38			28°37.5'S 48°53.5'W	Shells	-----------	3,450±170	-0.05	Bah.1370 (?)	Indifferent
Hurt 01	Carniça (1st.phase)		28°32.9'S 48°48.5'W	Charcoal	Base (beginning of occupation)	3,310±150	-----	A.912	>+2.5m
" 02	"		"	Shells		3,370±100	-----	A.919	
" 03	"		"	Charcoal		3,370±150	-----	A.918	
" 04	"		"	Charcoal		3,270±120	-----	A.956	
" 05	"		"	Shells		3,210±150	-----	A.017	
" 06	"		"	Shells	Surface (end of occupation)	3,040±50	-----	A.888	
	Congonhas		28°31.4'S 49°00.5'W	--------	------------	3,270±200	-----		> Present
	Caieira		28°27.0'S 48°46.3'W	Charcoal	------------.	3,230±150	-----	Io.2628c	
Piazza 03	Espinheiros		26°17.2'S 48°47.0'W	Charcoal		2,920±100	-----	Si.	Indifferent

Table IV (Continuation 2)

Sample number	Name of the shell-midden	Reference number	Coordinate	Nature of the sample	Sample position in shell-midden	Age B.P.	$\delta^{13}C_{(PDB)}$ o/oo	Laboratory number	Position of sea-level
Piazza 04	Espinheiros	"	"	Charcoal	----------	2,870±100	-------	Si.	Indifferent
SC.7			26°27.9'S 48°38.8'W			2,760±180		Bah.1284	> 0m
	Ratones		27°30.0'S 48°27.8'W	Shells	----------	2,640±180	+0.63	Bah.1327	Present
Hurt 07	Carniça (2nd phase)		28°32.9'S 48°48.5'W	Shells		2,550±100	-------	A.914	> +2.0±0.5m
" 08	"		"	Shells	Base (beginning of reoccupation)	2,460±110	-------	A.959	
" 09	"		"	Charcoal		2,400±110	-------	A.884	
Piazza 05	Ponta das Almas		27°35.8'S 49°27.5'W	Shells	----------	2,400±250	-------	Si.111	> +2.0±0.5m
	Jurerê III		27°27.5'S 48°30.3'W	Shells	----------	2,380±130		-------	
	Barra do Sambaqui		27°34.0'S 48°31.0'W	Shells	----------	2,370±100	-------	Bah.	----------
	Ratones		27°30.0'S 48°27.0'W	Shells	----------	2,340±120	-------	Bah.	> Present
Piazza 06	Espinheiros		26°17.2'S 48°47.0'W	Charcoal	Surface	2,220±210	-------	Si.	Indifferent
SC.26	Tavares III		27°39.7'S 48°30.1'W	Shells	Base	2,170±170	+0.19	Bah.1367	> Present

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