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B.TURCQ
ORSTOM, Departamento de Geociências, Universidade de São Paulo, Brazil
R.COE
Departamento de Geoquímica, Universidade Federal Fluminense, Niteroi, Brazil
J.M.FROIDEFOND
Université de Bordeaux I, Département de Géologie & Océanographie, IGBA/CNRS, Talence, France

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Variability of beach ridges on the coast of Maricá (Rio de Janeiro, Brazil)

ABSTRACT

Inventory of morpho-sedimentary units on a 35 km trench of the coastline of the State of Rio de Janeiro allowed the identification of three beach-ridge generations. The first one is characterized by low undulations and medium size well-sorted sands. It was formed during a pleistocene high sea level period which, in contrast to the present, exhibited lower littoral dynamics. The second and third generations are well defined beach ridges separated by a flat trough. They were edificated at 5000 years BP and 3500 years BP respectively, via similar littoral dynamics acting at present. Coalescence of the latter ridges was observed at their eastern premises. This variation of shoreline orientation may be attributed to slight hydrodynamic changes, to wind action and/or to neotectonic movements. The latter seems to be the most pausible process responsible for coalescence.

RESUMO

O estudo das unidades morfo-sedimentares da região de Maricá, no Estado do Rio de Janeiro, possibilitou a identificação de três gerações de cordões arenosos. A primeira geração apresenta-se bastante erodida, com altitudes médias não ultrapassando 4 m. Esses cordões mais antigos são testemunhos de uma transgressão pleistocênica cúja característica reflete uma dinâmica litoral menos intensa do que a atual. A segunda e a terceira gerações são caracterizadas por cordões bem definidos, separados por uma estreita depressão, notadamente na parte oeste. Esses cordões mais recentes foram edificados há 5000 AP e 3500 AP respectivamente, através de uma dinâmica similar à atual. Observa-se no setor leste, uma coalescência desses cordões. A variação de orientação da linha de costa deve-se a pequenas mudanças da hidrodinâmica, a fenômenos eólicos e a

fenômenos neotectônicos, sendo este último, provavelmente, o mais atuante.

INTRODUCTION

Extended sandy coastal plains, named "Restingas", represent about 5000 km of the Brazilian littoral zone (Lacerda et al., 1984). These plains are usually covered by beach ridge, in some cases reworked by sand dunes. These features were the result of the last sea level lowering. This was shown by various systematical studies and also numerous radiocarbon datings which enabled the construction of a detailed pattern of sea level fluctuations since 6000 years BP (Suguio et al.1979, Martin et al., 1980, 1983).

Although the formation of these beach ridges are clearly related to periods of higher sea level and smooth regressions thereafter, little is known about the mechanisms involved in their construction. A recent study has shown that the ridge patterns may reflect a record of past marine hydrodynamical and climatic changes (Martin et al., 1984).

This paper presents a detailed study of a simple small-scale beach ridge system near Rio de Janeiro. The factors responsible for the variability of beach ridges will be discussed in term of temporal and regional changes.

GEOGRAPHICAL AND GEOMORPHOLOGICAL SETTING

The studied area is a 35 km long trench of the coast, 30 km east of Rio de Janeiro, near the city of Maricá, at about 23 Lat. S. and 43.long. E..The morphology of this coastal region is dominated by crystalline massifs. They are remains of the South Atlantic opening and form the typical landscape of Rio de Janeiro (Figure 1). The diagram was constructed by numerical treatment of topographic data according to Froidefond and Berthois (1979). The coastal plains lie at the base of these mounts, formed by fluvial and lagoonal sediments, bordered by beach barriers. The inner shelf is a perfect morphological continuity to the coastal plain.

A more detailed geomorphological description of the studied area is depicted in Figure 2. The crystalline massifs exhibit a SW-NE orientation. They form the landheads of the barrier beaches and inner shelf islands. A hilly lowland extends between the crystalline massifs and the coastal plains. The hills are remnants of dessicated Tertiary erosion surfaces and are, in general, composed of altered gneisses. The beach barrier adopts a tombolo shape in the region close to the Maricá islands.

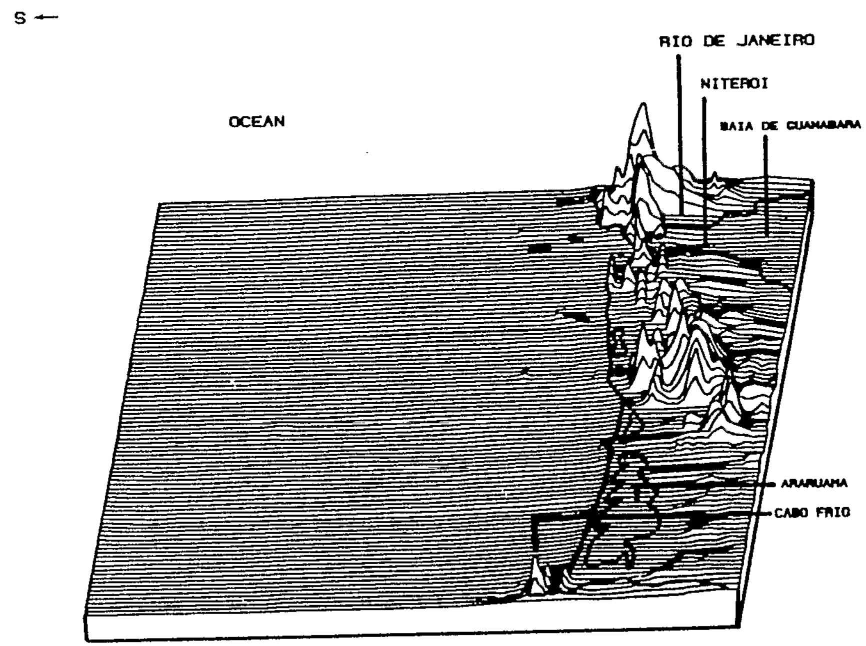

Figure 1. Computer block-diagram showing the topographic features of the Rio de Janeiro area.

MORPHO-SEDIMENTARY UNITS

Aerial photographs at a 1/20 000 scale allow a better definition of the morpho-sedimentary units of the coastal plain (Figure 3). Hills and crystalline massifs are grouped under the term "complex basement".

VALLEY FLATS

The main valleys of the lagoonal tributaries lie between the crystalline massifs. The fluvial deposits formed flat surfaces that were functioning as the flood plains of the rivers and, in part, also of the lagoons. In this last case the high lagoonal levels are well marked on the aerial photographs (Figure 3).

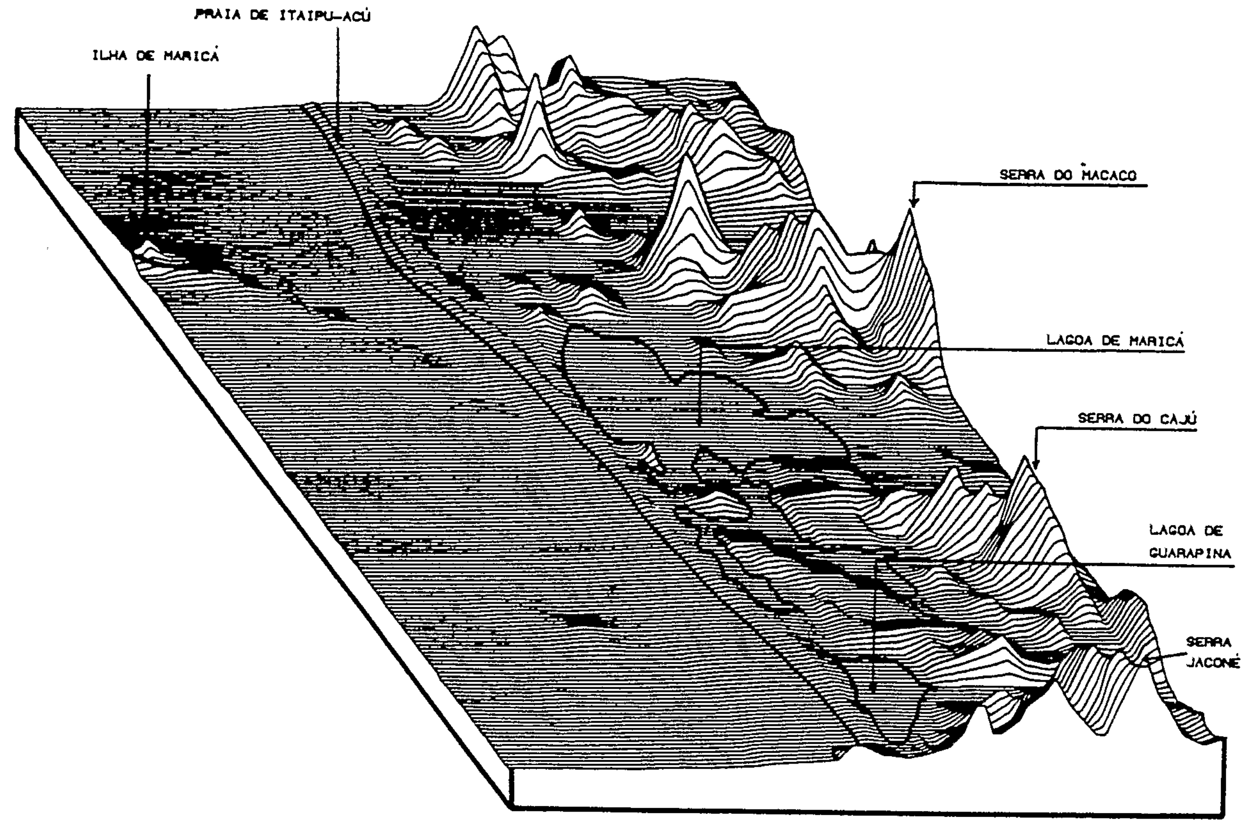

Figure 2. Computer block-diagram depicting geomorphological aspects of Lagõa de Maricá area

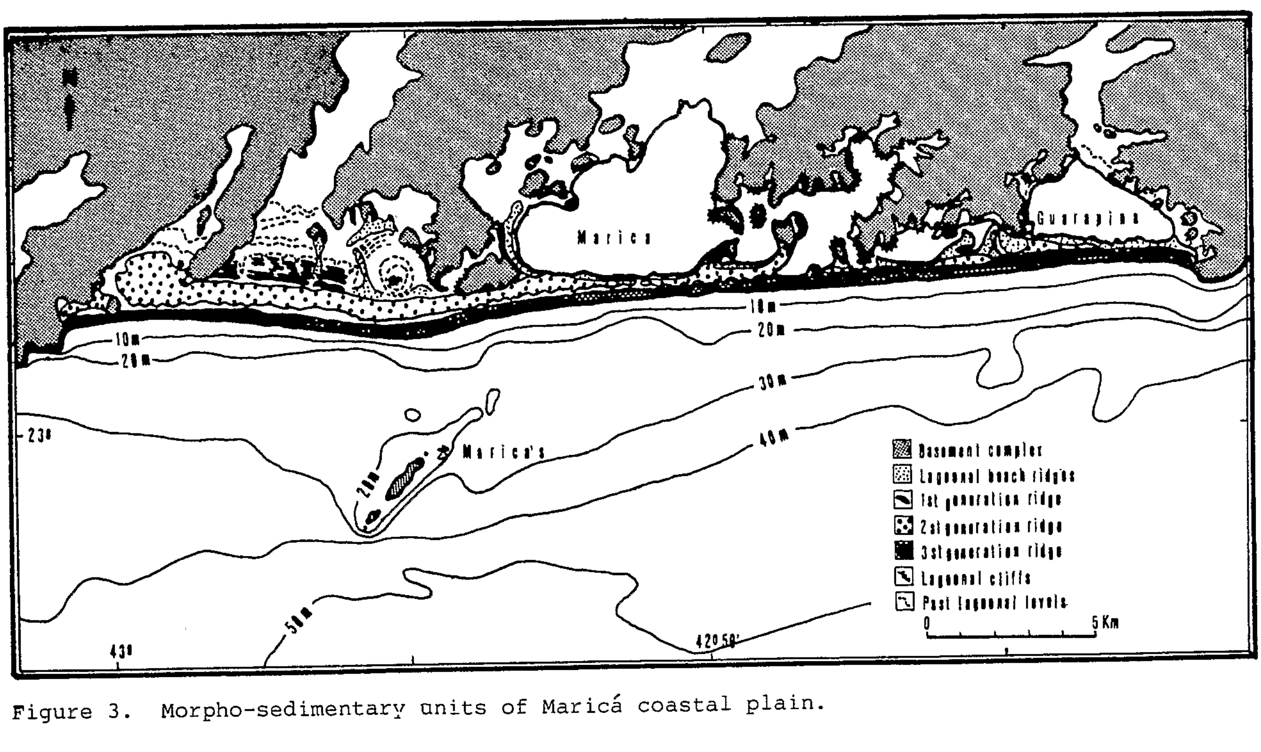

Figure 3. Morpho-sedimentary units of Maricá coastal plain.

LAGOONAL BEACH RIDGES

The formation of small-scale beaches on lagoon shores is a common process. Such beach ridges existed at the periphery of the actual lagoons. They are formed of very well sorted medium sand. Ancient lagoonal beach ridges, with the same morphological and lithological characteristics, were also recognized. This is another indication of the prevailance of higher lagoonal levels in the past. These higher levels are probably related to high sea levels and/or may also be due to the recent draining of this region (Coe et al., 1986).

LAGOONAL CLIFFS

Around the lagoons the hills of alterated rock are cut by cliffs up to 20 m in height. The actual hydrodynamics of the lagoon are not expected to create such cliffs. On the other hand, the gneisses, whose alteration is largely older than the holocene transgression, are not resistant enough to be directly eroded by the sea in such an irregular pattern. These cliffs were probably carved during an older stage of the lagoon by a stronger hydrodynamic forcing than the actual one. This was probably due to a larger access of the lagoon to the open sea (Coe et al., 1986).

FIRST GENERATION BEACH RIDGES

A series of small amplitude beach ridges lies in the western part of the studied area, between a large valley flat and the beach barrier (Figure 3). Their altitude is low (4 m). They are composed of medium sized sand. These ridges are strongly eroded and, at some place, overlain by lagoonal beach ridges.

SECOND AND THIRD GENERATION RIDGES

The beach barrier per se is composed of two well defined beach ridges. They are considered as two distinct beach ridge generations. The second generation ridge (the landward one) adopts a multiple crest pattern in the western part of the studied area. It disappears progressively in the eastern part where the third generation ridge overlies the second. The two beach ridges are composed of coarse sand. The second generation ridge is 9 to 12 m high, the third 4 to 11 m. The ridge elevation is strongly dependant on wind reworking. A flat trough separates the two ridges in the western region. On the northern side, the trough edge is modeled by numerous sand spits (Figure 3). These spits do not prevail on the southern side where a sharp contact between the flat trough and the

steep side of the third generation ridge exists. The shoreward side of this ridge is, in contrast, smooth and prolongated by the actual beach.

GRANULOMETRICAL STUDY

In order to conduct a better characterization of the three ridge generations, we realised samplings along: the two well defined ridges of second and third generation, the best marked crest of the first generation ridges and the berm of the actual beach.

These sediments are dominantly quartzose. Each sample was submitted to granulometrical analyses on a standard US seaving set. Positions of the sampling points and granulometrical results are exposed on Figure 4. Sediments of the second and third generation ridge and of the present berm are well sorted coarse sands. Their mean diameter decreases eastward as also evidenciated by Muehe et al.,(1977) on the present beach. The standard deviation (SD) decreases in the same direction. The skewness (Sk) reaches very high values in the coarse sand zone (3 in millimetric system or -3 in phi system) and faces a marked decrease in the zone located landward of Maricá islands. The granulometry of the second and third generation ridge and of the present berm exhibits very similar patterns.

The first generation ridges are composed of well sorted medium sand and also show high skewness. The short length of these ridges do not allow any identification of granulometrical gradients.

DISCUSSION

1 CHRONOLOGY OF BEACH RIDGE EDIFICATION

The beach barriers of the Rio de Janeiro coast commonly present two well defined beach ridges. Datations realised in Araruama, eastward of the studied area (Coe, 1984) and in Jacarepagua, westward of the studied area (Maia et al., 1984) indicate that these two ridges correspond to the high sea levels of 5000 years BP (second generation ridge) and 3500 years BP (third generation ridge) -see Martin et al., this volume-.

As the second generation ridge corresponds to the higher level of the holocene transgression, the first generation must then be related to an older transgressive event. These ridges, typified by a low relief and an eroded aspect, are similar to those observed in Bahia (Martin et al., 1981) and Santa Catarina States (Suguio et al., this volume). Bahia State ridges were dated at 120 000 years BP (Martin et al., 1982). The great granulometrical difference between the first ridge generation

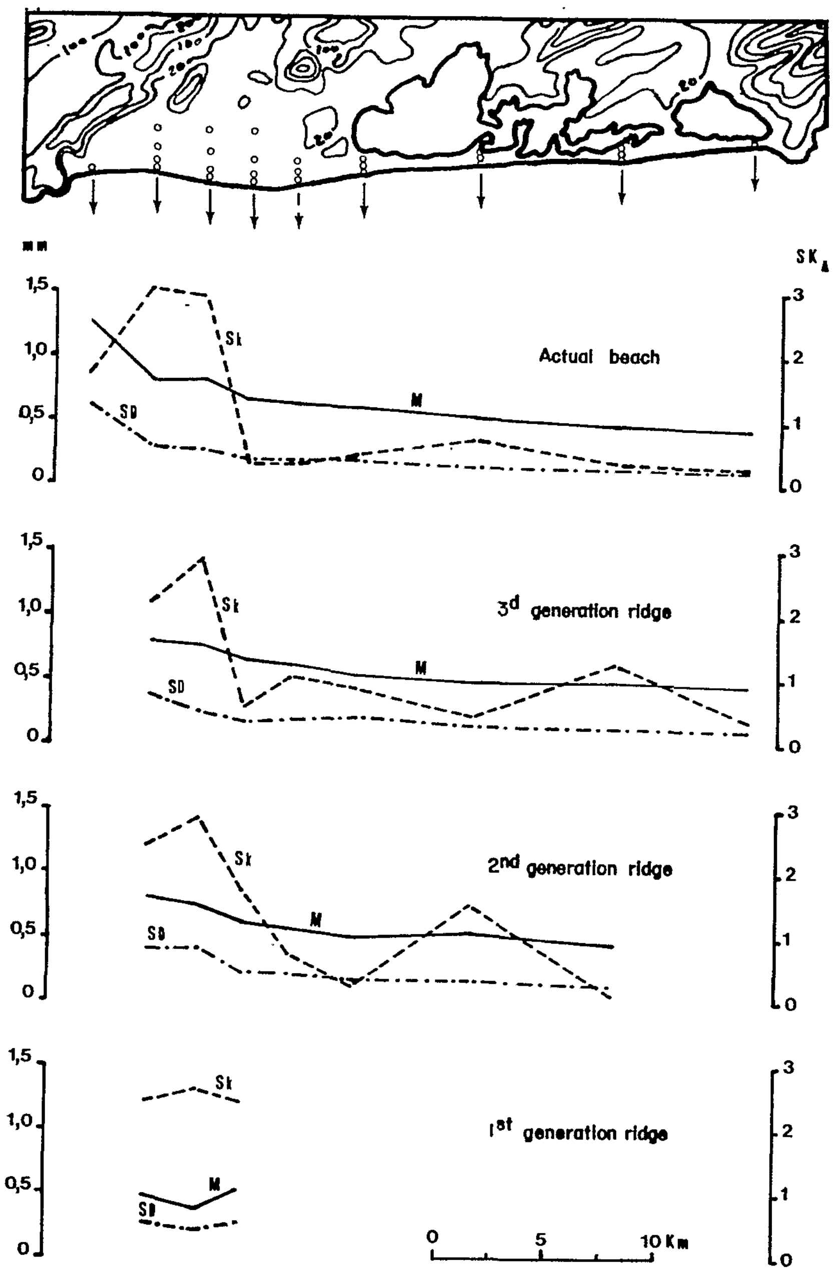

Figure 4. Granulometrical characteristics of beach ridges in Maricá.

and the others shows that the pleistocenic swells from southwest to southeast were consistently weaker than the present ones.

2 THE LAST TRANSGRESSIVE MIGRATION

Muehe (1984) proposed the existence of a last transgressive event in this region. His main argument is supported by the past existence of a lagoon in the flat trough between second and third generation ridges. The sand spit observed on the shoreward face of the second generation ridge seems to be lagoonal cuspate spits (Zenkovitch, 1959). Such morphology is observed in lagoons between the two holocenic beach ridges in other regions of the Rio de Janeiro State (Coe, 1984; Maia et al., 1984). The presence of lagoonal organic mud under a 20 cm thick sand layer in the flat trough south of Maricá lagoon (Lacerda personal communication) corroborates Muehe's hypothesis. In this case, sand spits are expected to occur also on the third generation ridge edge, facing symmetrically the cuspate spits of the second generation ridge. The lack of these spits is interpreted as the result of recent transgressive migration of the third generation ridge.

The second and third generation ridges observed in the whole studied area (Figure 3) present different orientations, the second generation being progressively overlain by the third in an eastward direction. This implies a past variation of the shoreline orientation. In the eastern part of the studied area, close to Guarapina lagoon, the third generation beach ridge also overlies lagoonal mud of this lagoon. This fact fits in with a reorientation of the coast and with a possible transgressive dislocation of the third generation ridge between 3500 years BP and present.

3 FACTORS OF BEACH RIDGE MIGRATION

Several mechanisms may explain the variations of shore orientation. The most likely are:

1. A variation of the dominant swell orientation,
2. An effect of wind which would thrust the third generation ridge over the second one (this translation could be higher in the east zone where the sand is finer) and,
3. An effect of neotectonism.

The pattern of swell formation in this part of the South Atlantic Ocean is little known. Some visual observations (Muehe, 1979) reveal that swells from south (44%) and southwest (39%) are dominant. These swells are initiated by the strong winds resulting from the passage of polar fronts. The influence of the southerly swells can be seen on the present beach, through the great frequency of beach cusp occurrence,

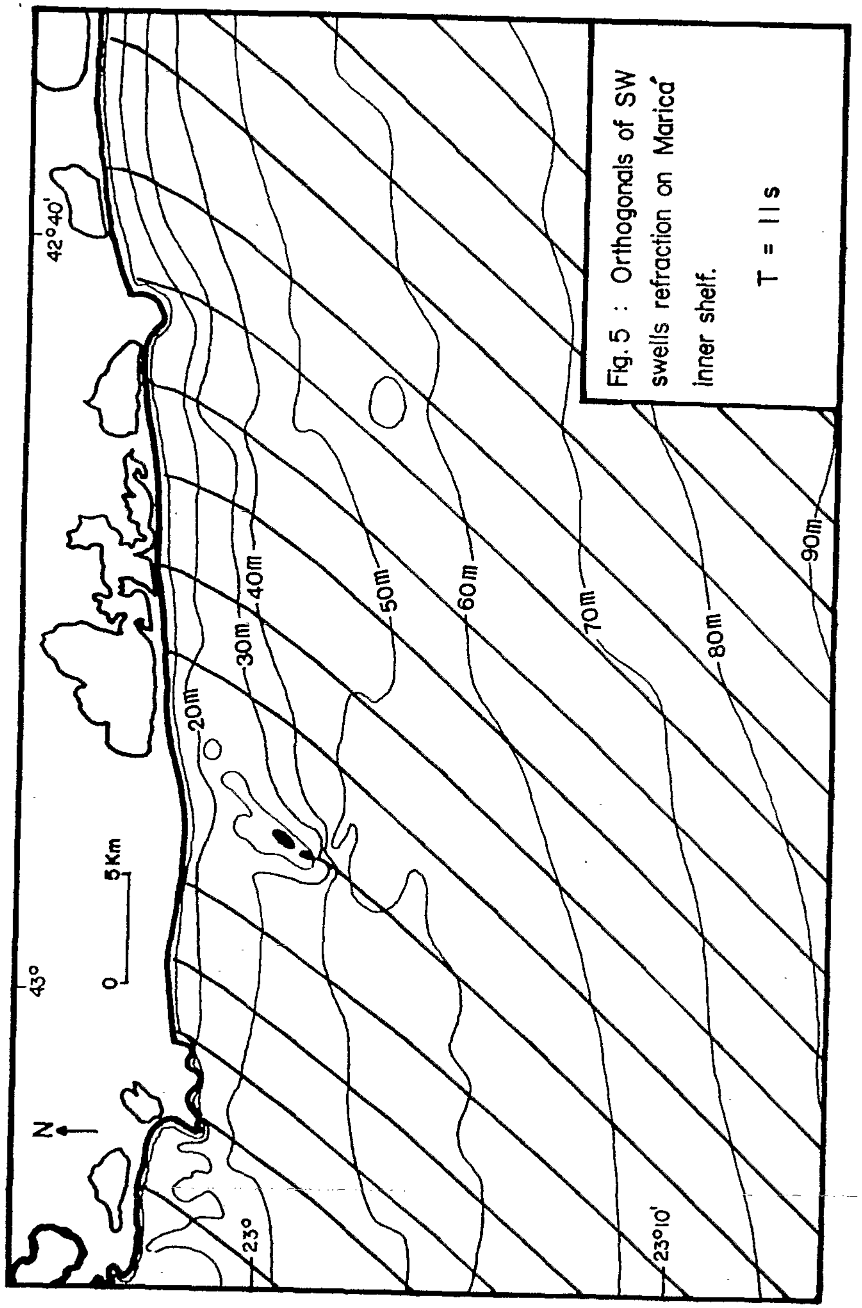

Fig. 5 : Orthogonals of SW swells refraction on Maricá inner shelf.

corresponding to the action of swells parallel to the shoreline (Zenkovitch, 1969). The position of the tombolo-like convexity, northward of the Maricá islands, also fits in with this southern influence. Construction of a swell orthogonal refraction diagram (Shore Protection Manual, 1973) allowed an interpretation of the observed granulometrical gradient. This diagram (Figure 5) was constructed for 11sec period swell, in agreement with the observated mean period (Muehe, 1979). The deep-sea swell orthogonals have a regular spacing and each one represents the same quantity of energy. The modifications of this spacing due to wave refraction on the continental shelf bottom indicated the consequent energy redistribution: the nearer the orthogonals are, the higher the swell energy is. In the case of Maricá region, orthogonals of the southwestern swells indicated a decreasing tendency of the swell energy at the coast from west to east. This decrease explains to a large extend the observed granulometrical gradient.

The facts exposed above enhance the close relationship between swell pattern and beach characteristics. The granulometrical study shows that the present beach, the third generation ridge and the second one have almost the same granulometrical characteristics. Both ridges also adopted the tombolo-like shape northward of the Maricá islands. This tends to prove that:

1. The beach ridges are mainly constructed by waves, the wind action would be limited to superficial reworking and would not, alone, explain beach ridge migration;

2. There are no variations in swell pattern since 5000 years BP in this region.

The remaining hypothesis, supporting that the variations of beach orientation is due to neotectonic movements, is, then, the most probable. The existence of recent tectonism in the central region of Brazil was proposed by Fulfaro and Poncano (1974).

CONCLUSIONS

Two events of beach ridge formation are recognized in the region of Maricá. The first one is pleistocenic (probably 120.000 years BP), and corresponds to a past high sea level. At this time the swells from southwest to southeast directions were weaker than the present ones.

The second event related to the last holocenic high sea level (5000 years BP), show a good relationship between past beach ridge generations and the present coastal hydrodynamics which, since at least 5000 years BP, should have remained almost constant.

We observed a variation of shoreline orientation and a consequent transgressive migration of the coast since 3500 years BP. Although wind transport or slight variations of coastal hydrodynamics should explain this dislocation, it seems more likely that neotectonical movements are substantially involved.

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