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Roundness in Holocene Sands of the Paraiba do Sul Coastal Plain, Rio de Janeiro, Brazil[1]

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ABSTRACT

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Sea level changes during the late Quaternary played an important role in the construction of the extensive Paraiba do Sul River mouth coastal plain in the State of Rio de Janeiro, Brazil. Large volumes of sand have been transferred from the adjacent inner shelf to the coastal plain, as a consequence of a continuous and gradual sea level drop during the past 5,000 years. At the same time, longshore currents, dominantly trending south-to-north, were important in the shaping of the asymetric coastal plain on either sides of the Paraiba do Sul River mouth. Geological interpretation of the roundness of beach sands on both sides of the river mouth and in Holocene beach ridges from northern and southern terraces allows an evaluation of the roles played by sea level, river discharge fluctuations and longshore currents in the construction of the coastal plain.

ADDITIONAL INDEX WORDS: *Beach ridge, beach sands, coastal plain, degree of roundness, longshore current, sandy beach, sea level.*

INTRODUCTION

The Paraiba do Sul River is about 1,000 km long and forms a drainage basin of 45,000 km^2, flowing through the states of São Paulo, Minas Gerais and Rio de Janeiro. Until recently, the drainage basin was covered by a dense forest which inhibited the erosion of coarse sediments. However, deforestation initiated by settlers modified this picture, so that the volume of coarse sediments presently carried by the Paraiba do Sul River is quite different from that transported before deforestation.

A well developed, lobe-shaped Quaternary sedimentary coastal plain measuring 120 x 60 km with an area of about 3,000 km^2, occurs around the mouth of the Paraiba do Sul River. According to MARTIN *et al.* (1984), this coastal plain is formed by sandy marine terraces of Pleistocene (less than 120,000 B.P.) and Holocene (less than 5,100 B.P.) ages, and lagoonal and fluvial sediments (Figure 1).

The central part of the Brazilian coastline to which the Paraiba do Sul River mouth belongs was subjected to a continuous submergence until about 5,100 B.P. followed by emergence (MARTIN *et al.*, 1980, 1983; SUGUIO *et al.*, 1983). It thus differs from many other parts of the world where the highest sea level during the last 7,000 years has never gone beyond the present (Figure 2). This portion of the Brazilian littoral is characterized by a high energy oceanographic regime and longshore currents play an important role in the transportation of coarse sediments. During the submergence, which lasted until 5,100 B.P., the formation of barrier islands isolated an extensive lagoon where the Paraiba do Sul River built an intralagoonal delta. The emergence that followed was characterized by a tendency for a

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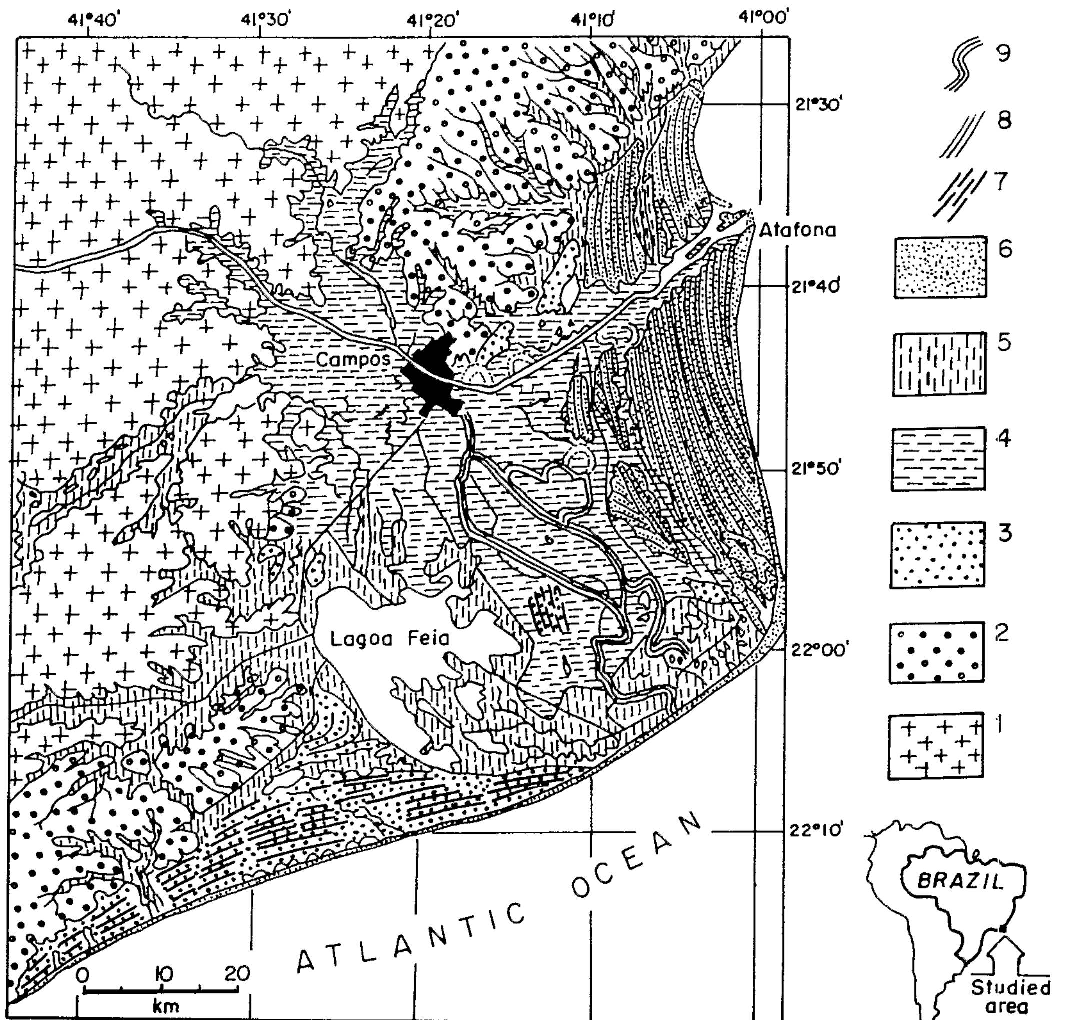

1=Precambrian crystalline basement; 2=Pliocene continental deposits (Barreiras Formation); 3=Pleistocene marine terrace; 4=Holocene fluvial deposits (paleodelta); 5=Holocene lagoonal deposits; 6=Holocene marine terrace; 7=Alignments of Pleistocene beach ridges, 8=Alignments of Holocene beach ridges, 9=Paleochannels of the Paraíba do Sul river.

Figure 1. Geological map of the Paraiba do Sul River mouth coastal plain.

desiccation of the lagoon and an accretion of beach ridges against the outer margin of barrier islands.

PROVENANCE OF THE COARSE SANDS IN THE PARAIBA DO SUL RIVER MOUTH

The two possible source areas of coarse sand for this coastal plain are the Paraiba do Sul River and the adjacent inner continental shelf.

The equilibrium profile of a sandy coast is a function of its dynamics and of the grain sizes of the available sediments. The coastal dynamics, controlled mostly by tidal ranges and wave heights, promotes continuous construction and destruction of this equilibrium profile. Nevertheless, over a long time interval, an average equilibrium profile will be established. Equilibrium will be destroyed when the sea level rises or falls, after which an attempt to

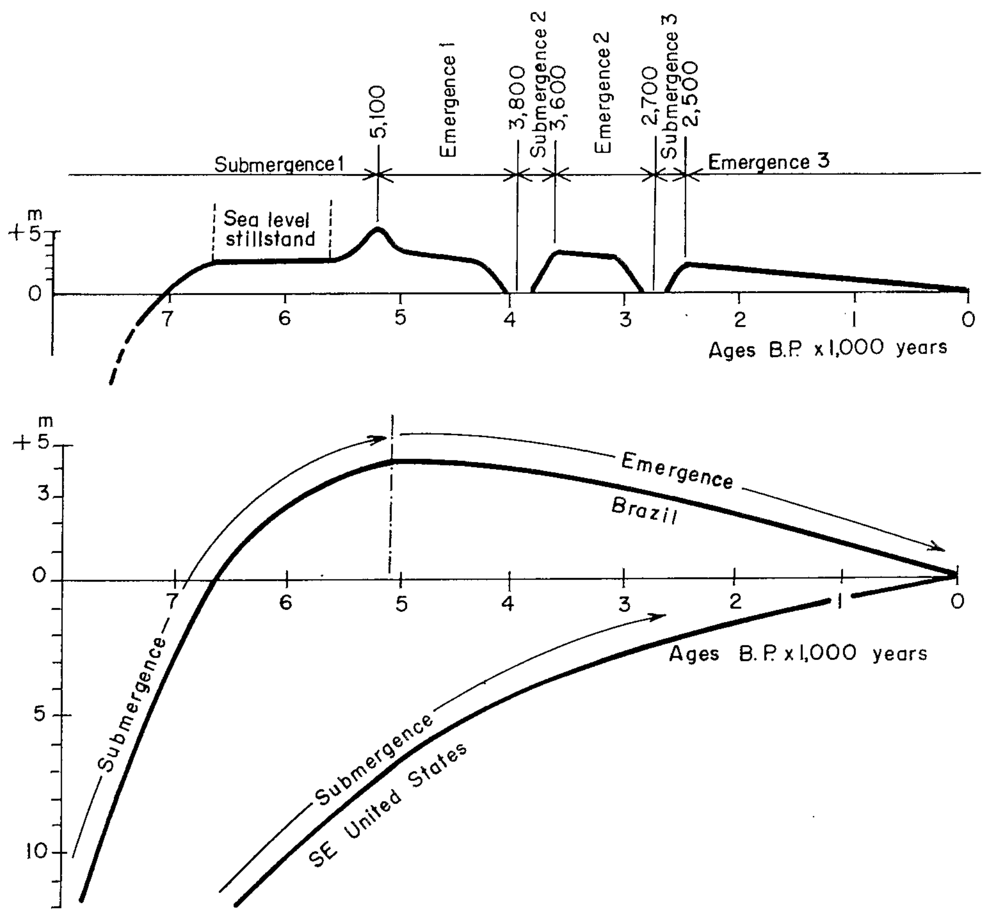

Figure 2. An example of a relative sea level fluctuation curve during the last 7,000 years north of Salvador, Bahia, Brazil(Top). Schematic average curves of relative sea level fluctuations along the central Brazilian and south-eastern United States coasts during the last 7,000 years (Bottom).

recover the equilibrium profile will be triggered. When sea level rises, the equilibrium profile will be restored by transfer of sands from backshore and adjacent land areas to the foreshore (BRUUN, 1962). An inverse mechanism will act when sea level falls so that the foreshore, which now is at a higher level, will be eroded; the eroded sands will be transferred to the backshore. Therefore, only relative sea level falls are capable of furnishing large volumes of sand for beach construction. Gentle foreshore slopes favor extensive reworking with consequent greater sediment transport to the backshore. This mechanism will be efficient only when the inner continental shelf is very sandy.

THE ROLE PLAYED BY LONGSHORE CURRENTS

The transportation of sediments along a sandy beach is mostly promoted by longshore currents generated by waves. In fact, near the beach, the water depth becomes insufficient for propagation of the waves and they break, with great liberation of energy. This energy is partially used to suspend the finer sediments and partially to originate longshore currents. This phenomenon will occur only when the waves reach the shoreline obliquely.

Although the longshore currents have a low velocity, their transport effectiveness is high, with the result that large volumes of sediments can be transported in suspension. Moreover, a combination of wave action and longshore currents originates transportation of sands along zig-zag paths. Clearly, the direction of transportation will depend on the angle of incidence of the waves that reach the shoreline.

When the relative sea level drops, sands transferred from the offshore to the backshore will be partially removed along the shoreline by longshore currents. This transportation will continue until sands are retained by traps or other obstacles. This mechanism could explain some large discrepancies in the sedimentation pattern of areas located within a region subjected to a regular relative sea level drop. Sand terraces will be poorly developed, or absent, within transit zones but become notable where traps or obstacles have allowed sand accumulation. Sinuous coastlines and islands and shoals that form sheltered areas (traps) as well as rocky headlands and river mouths that block longshore transportation (obstacles) are some examples of morphological features which promote accumulation of sediments.

BLOCKING OF LONGSHORE TRANSPORTATION BY A RIVER FLOW

During floods, a river will block longshore transportation of sediments with a resultant accumulation of sands on one side of the river mouth and erosion on the other (KOMAR, 1973, 1976). Nevertheless, in most cases equilibrium will be re-established by the deposition of coarse sediments carried by the river (Figure 3B).

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 (Figure 3C).

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 (Figure 3D). The coastal plain on either side of the river mouth will thus be asymetric with the updrift portion of alternating sandy ridges and clayed-sandy wetlands. Displacements controlled by the river mouth will be recorded as unconformities in the alignment of sandy ridges (Figure 3D).

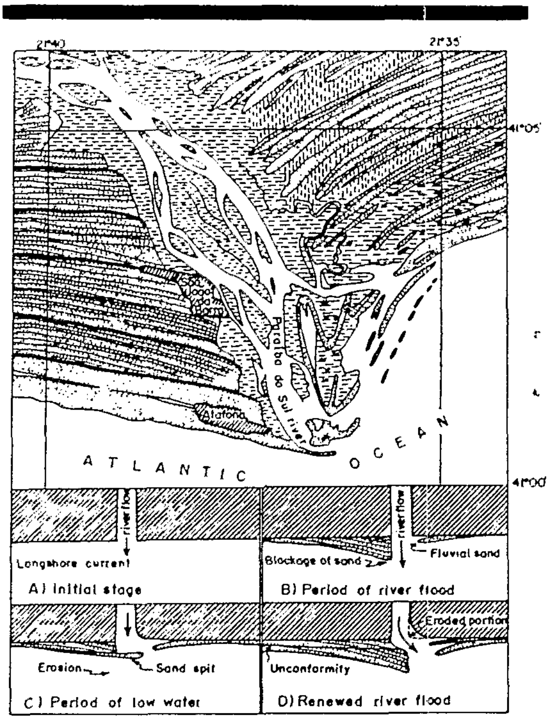

Figure 3. Paraiba do Sul River mouth and the mechanism of blocking of sands supplied by longshore currents.

The deposition pattern and the characteristics of the sands on both sides of the river mouth may be different when 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.

COASTAL DYNAMICS AND PARAIBA DO SUL RIVER MOUTH

Direction of Longshore Drift

Waves from two different directions are observed at the mouth of Paraiba do Sul River. A south-southeast 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 wave regime comes from the northeast and is associated with trade winds. The waves from the south-southeast are much stronger than those from the northeast and dominate in the longshore drift of sediments. When northeast waves are superimposed on the long-wave length south-southeast waves, only the latter are active in the longshore drift of sediments.

The south to north longshore transportation of sediments is demonstrated by the geometry of the Holocene beach ridges (DOMINGUEZ *et al.*, 1983) and by the fact that accumulation occurs to the south (updrift) of the Barra do Furado groin; erosion is accelerated to the north (downdrift).

Morphological Characteristics of the River Mouth

The Paraiba do Sul River mouth is characterized by the following features (Figure 3): (a) Strong asymmetry between the northern and southern parts of the river mouth. The southern part is formed by a series of beach ridges, while the northern part is characterized by an alternation of sandy ridges and swampy lowlands. (b) The presence of a well-developed sand spit. The construction of this spit was followed by intensive coastal erosion that destroyed many houses at Atafona. The coastline of Atafona was displaced in a landward direction about 100 m between 1956 and 1976. In February 1976, during a flood of the Paraiba do Sul River, the sand spit was almost completely destroyed. In February 1981, a 300 m-long new sand spit was formed. (c) Stepwise unconformities of beach ridge alignments which can be related to the periods following the sand spit formation.

DEGREE OF ROUNDNESS OF SANDS

Sands of Present Beaches Around River Mouth

If the proposed model is correct, the degree of roundness of sands, on both sides of Paraiba do Sul River mouth should be different (SUGUIO *et al.*, 1984). This hypothesis has been tested, using twenty-one sand samples collected between Macaé (southern limit of the coastal plain) and Guaxindiba (northern limit of the coastal plain), and three samples from the Paraiba do Sul River. The degree of roundness of quartz particles was studies in several fractions; following CAILLEUX and TRICARD (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 (Figure 4) show that there are two distinctive types of sands. The sands from Macaé to Grussai 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 (Paraiba do Sul River 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 Paraiba do Sul River. At Atafona, near the river mouth, the sands (samples 70 and 71) exhibit intermediate characteristics probably because sampling was conducted at a time when northeast waves were dominant.

A similar pattern emerges when three 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 and sub-angular, respectively (Figure 5). These differences in degree of roundness suggest that the river sands are deposited almost entirely to the north of the river mouth.

SANDS OF HOLOCENE TERRACES ON BOTH SIDES OF THE RIVER MOUTH

Histograms of degree of roundness for twelve samples from the north and south sides of the Paraiba do Sul River mouth are shown in Figures 6 and 7.

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 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: (A) sands dominated by sub-angular and sub-rounded grains (as found in the present beach) and (B) 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 Paraiba do Sul River (Type A), alternating with sands derived from the adjacent inner continental shelf (Type B), and that the supply of either sand type depends on changes in energy of the Paraiba do Sul River. During high energy periods, the river load consists mainly of sands that accumulate in front of the river mouth. They are then 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

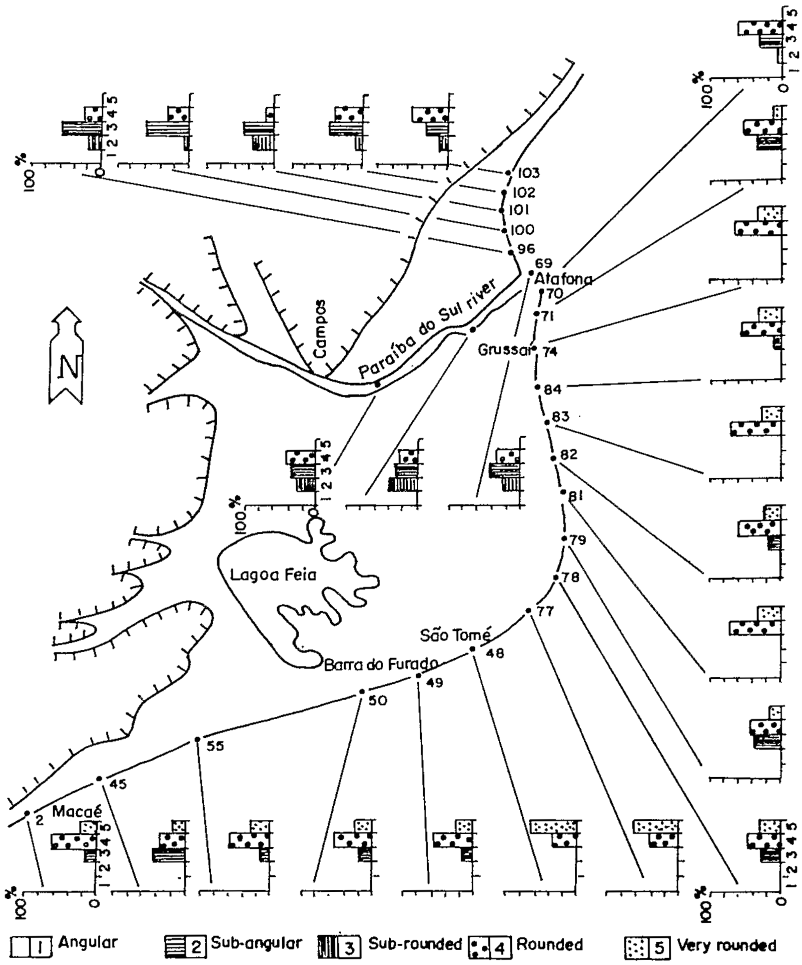

Figure 4. Degrees of roundness of sands (5 classes) sampled along the beaches and river bed of the Paraiba do Sul River mouth coastal plain.

northern part of the coastal plain come mostly from the adjacent inner continental shelf.

CONCLUSIONS

The degree of roundness of sands on the modern beaches astride the Paraiba do Sul River mouth shows significant differences. Sands from the south of the river mouth are dominated by rounded and very rounded grains, whereas those to the north are dominated by sub-angular and sub-rounded grains. The latter are similar to sands collected from the Paraiba do Sul River, and it is concluded that the modern river deposits sands to the north of its mouth where these are redistributed farther northwards by longshore drift.

In the coastal plain of the Paraiba do Sul River, the relative sea level has fallen approximately 4 to 5 m during the last 5,000 years causing a large influx of sand from the adjacent inner continental shelf. These sands were reworked by northward moving longshore currents into sandy terraces on both sides of the river mouth. A study of the degree of rounding of sands from these terraces indicates that in the south they are almost always rounded to very rounded and are comparable to the sands in the modern beaches. This situation seems to have persisted for the last 5,000 years. In contrast, the sands from the terraces to the north are a mixture of two populations: sub-rounded to sub-angular,

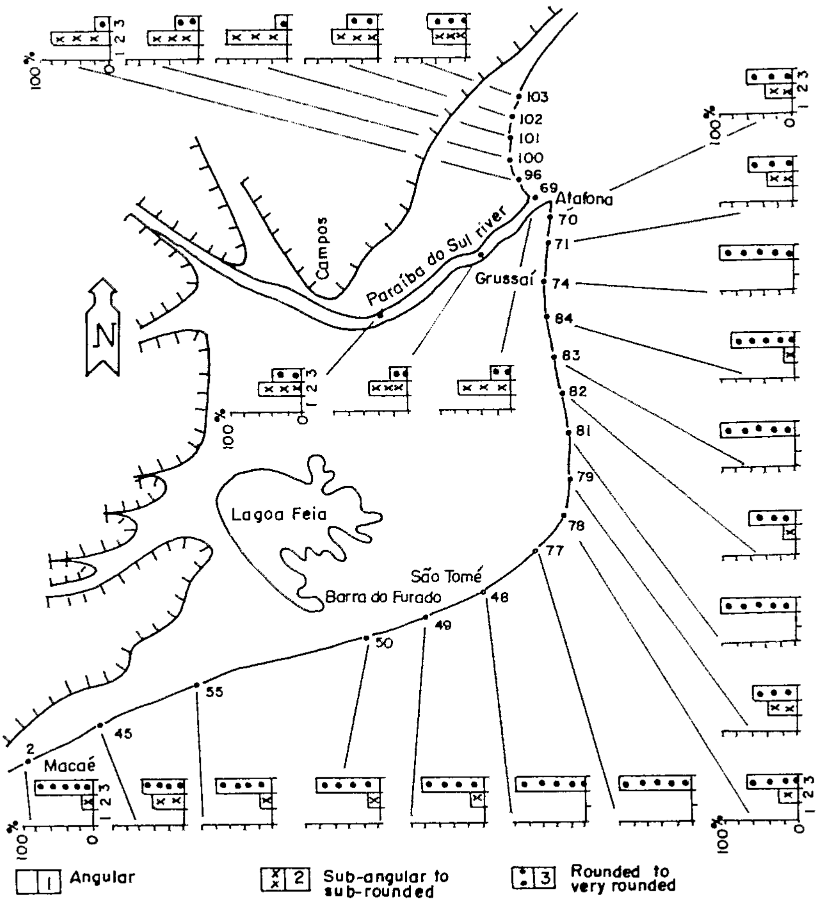

Figure 5. Degrees of roundness of sands (3 classes) sampled along the beaches and river bed of the Paraiba do Sul River mouth coastal plain.

comparable to the modern northern beaches and derived from the river; and rounded to very rounded, as found on southern terraces. Fluvial sands were supplied mainly during high-energy phases related to rainy periods whereas sands dominantly of marine origin were supplied when river discharge was low, *i.e.* during low energy phases related to dry periods.

It is possible that a more detailed study of roundness of sand grains from the north of the river mouth involving the sampling and dating of every beach ridge, will allow us to establish a precise chronology of climatic fluctuations in the area during the Late Quaternary.

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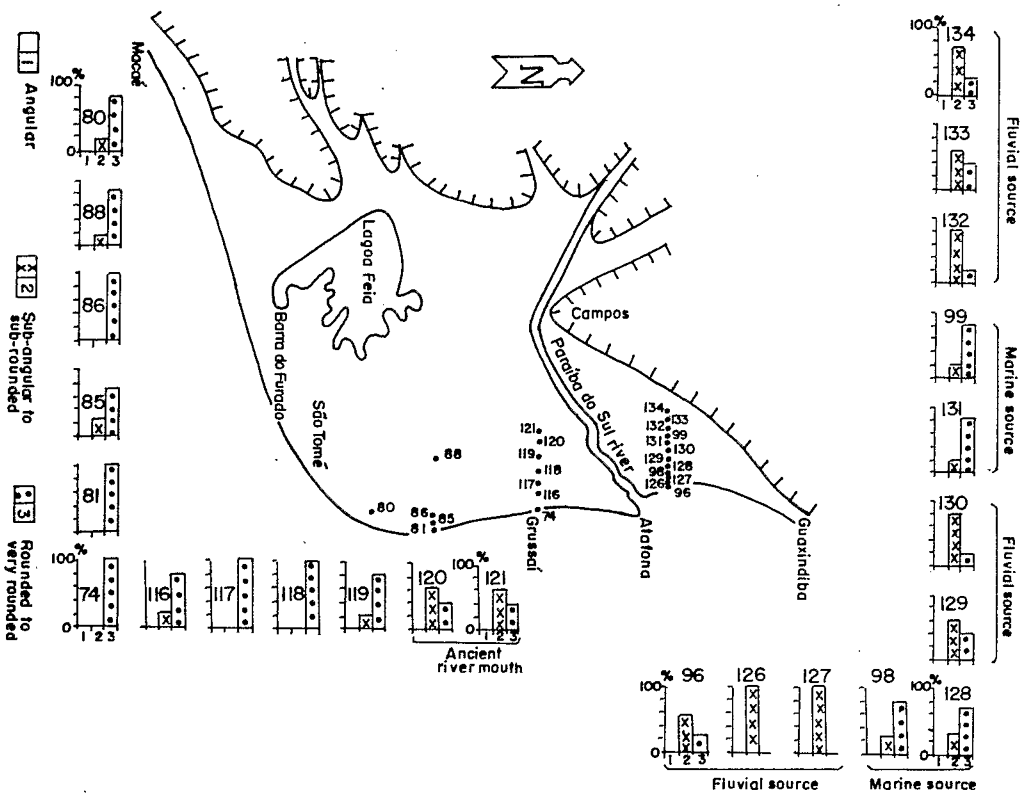

Figure 6. See top of page 351 for caption.

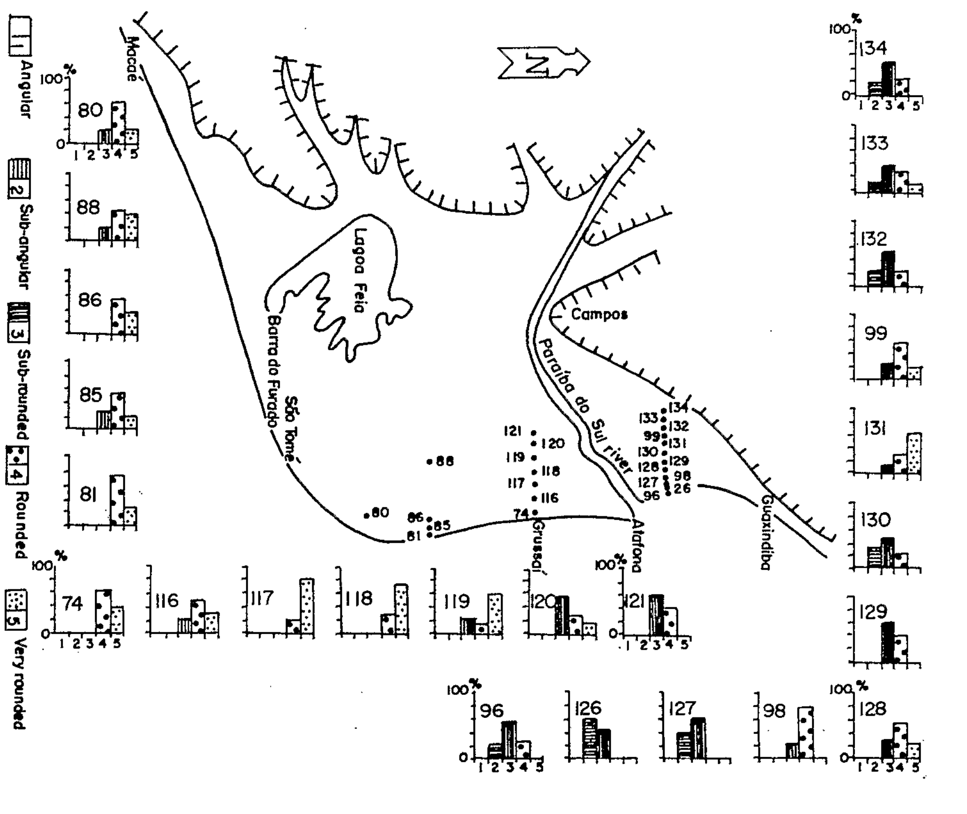

Figure 7. See top of page 351 for caption.

Figure 6. Degrees of roundness of sands (5 classes) from Holocene marine terraces of the Paraiba do Sul River mouth coastal plain.

Figure 7. Degrees of roundness of sands (3 classes) from Holocene marine terraces of the Paraiba do Sul River mouth coastal plain.

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