

# THE EVOLUTION OF THE CONTINENTAL AND COASTAL ENVIRONMENTS DURING THE LAST CLIMATIC CYCLE IN BRAZIL (120 KY. B.P. TO PRESENT)

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## ABSTRACT

Studies done in Brazil, under the CNPq (Brazil) and ORSTOM (France) agreement, allowed us to envisage the general trend of climatic changes that occurred during the last 60,000 years.

At first, examination of successive accumulation and erosion phases, recorded within Central Brazilian valley deposits, provided evidence of important changes in slope vegetation cover and in the hydraulic regime of water courses, and hence characteristics of precipitation and climate regimes. Studies of Tamanduá river valley deposits in the town of São Simão (State of São Paulo) showed that between 32 and 21 ky. B.P. the climate was humid, whereas between 17 and 11 ky. B.P. it was dry with very scarce and strong rains. From 10 ky to 8.5 ky. B.P. the climate was humid too. Finally, after 7.5 ky. B.P. the deposits revealed the existence of several dry episodes within a globally humid climate.

Palynological and sedimentological analyses of lacustrine deposits sampled by vibrocorers in the Eastern Amazon (Carajás, State of Pará) and in Central Brazil (Salitre, State of Minas Gerais) permitted us to outline the evolutionary history of the vegetation cover within these regions during the last 60,000 years for Carajás and 30,000 years for Salitre and thus to have a preliminary idea about their past climates. Then, it was possible to show that at Carajás regression of the evergreen rainforest occurred four times, at about 60, 40, between 23-11 and 7-4 ky. B.P. Moreover, apparently the last rainforest regression episode was quite different from the previous three episodes. At Salitre, the most characteristic is the indication of the existence of *Araucaria* forest between 12 and 8.5 ky. B.P. This *Araucaria* forest location is clearly much further north than at present, which suggests that during that time the climate was wetter and colder.

Finally, studies developed along the central Brazilian coast allowed us to show evidence of wind-/driven change in littoral dynamics during the last 5 ky. A detailed examination of Doce river (State of

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Espírito Santo) mouth beach-ridge geometry has shown inversions in littoral drift direction as a consequence of change in wave and then in wind regimes, reflecting characteristics of atmospheric circulation during the last 5 ky.

## RESUMO

Estudos feitos no Brasil, segundo um acordo entre o CNPq (Brasil) e ORSTOM (França), permitiram-nos vislumbrar a tendência geral de mudanças climáticas que ocorreram durante os últimos 60.000 anos.

Primeiramente, o estudo de sucessivas fases de erosão e sedimentação, registradas nos depósitos de vale do Brasil Central, forneceram evidências de importantes mudanças na cobertura vegetal de vertentes e no regime hidráulico de cursos fluviais e então chegando-se às características dos regimes pluviométricos e climáticos. Estudos de depósitos do vale do rio Tamanduá na cidade de São Simão (SP) mostraram que entre 32 e 21 ka. A.P. o clima foi úmido, enquanto entre 17 e 11 ka. A.P. ele foi seco com chuvas esparsas e fortes. De 10 ka. a 8,5 ka. A.P. o clima foi também úmido. Finalmente, após 7,5 ka. A.P. os depósitos revelaram a existência de vários episódios secos através do clima globalmente úmido.

Análises palinológicas e sedimentológicas de depósitos lacustres amostrados por vibrotestemunhador na Amazônia Oriental (Carajás, PA) e no Brasil Central (Salitre, MG) permitiram delinear a história evolutiva da cobertura vegetal nessas regiões, durante os últimos 60.000 anos para Carajás e 30.000 anos para Salitre, e então ter uma idéia preliminar sobre seus paleoclimas. Então foi possível mostrar que em Carajás por quatro vezes, há cerca de 60, 40, entre 23-11 e 7-4 Ka. A.P., ocorreu a regressão da floresta pluvial perene. Além disso, aparentemente o último episódio de regressão da floresta pluvial foi bem diferente dos três episódios anteriores. Em Salitre, mais característica é a indicação da existência de floresta de *Araucaria* entre 12 e 8,5 Ka. A.P. A localização desta floresta de *Araucaria* está claramente mais ao norte que atualmente, sugerindo que durante aquela época o clima era mais úmido e mais frio.

Finalmente, estudos desenvolvidos na costa do Brasil Central mostraram evidências de mudanças na dinâmica costeira comandadas pelo vento durante os últimos 5 Ka. Um estudo detalhado da geometria das cristas praias de desembocadura do rio Doce (ES) mostrou inversões no sentido da deriva litorânea como consequência de mudanças nos regimes da onda e do vento, permitindo conhecer as características da circulação atmosférica durante os últimos 5 Ka.

## INTRODUCTION

The survival of mankind on this planet depends on environmental preservation which, at least until the beginning of the industrial revolution, was affected almost only by natural causes. However, nowadays, man has acquired an enormous capacity for construction as well as for destruction, being capable even to interfere in the course of the natural environmental evolution. Our recognition and our posture in the face of this fact is one of the most important challenges for contemporaneous human society.

To forecast the evolution of environmental conditions, as a preparatory step, it is necessary to know in detail the involved mechanisms. This knowledge can be obtained through the study of the present and past ecosystems, because the understanding of the modern environments is difficult if evolutionary history is disregarded and, reciprocally, the past records can be adequately interpreted only when firmly based on the knowledge of the present environments. Finally, this knowledge allows forecasts of possible future environ-

ronmental changes.

For reconstruction of the evolution of the continental and coastal environments during the last climatic cycles in Brazil (120 ky. B.P. to present) a research program is being carried-out through an agreement between CNPq (Brazil) and ORSTOM (France), coming out of two preceding projects, namely, "Intertropical paleoclimates" and "Relative sea-level changes along the Brazilian coast during the Quaternary and their role in littoral sedimentation".

The major objective of this program is the reconstruction of changes in paleoclimates at several sites in Brazilian territory and their consequences in paleogeographic evolution. This is an integrated study embracing diversified methods and techniques, such as, sedimentological, palynological, mineralogical, isotopic (stable and radioactive), and organic matter analyses. Hopefully, the obtained data will allow us to draw up a conceptual model for a better understanding of the global meteorological regime and, as a consequence, of past and present climates, thus helping to forecast future environmental changes.

This project has a possibility to produce interesting results, such as:

a) **Forecasting of future climates** - The integration of these studies should improve our knowledge of the most important mechanisms controlling climatic phenomena, which is essential to forecast future climates. This objective became a fundamental and even a vital problem, mostly in countries whose economies may be strongly disturbed by the advent of a pluriannual climate anomaly. This could be the case in Brazil if, eventually, "El Niño" - like conditions once again occur with a duration of several tens to some hundreds of years, which seems to be recorded within the beach-ridges of the Doce river coastal plain (State of Espírito Santo), as

shown by Martin et al. (1991, 1993a).

b) **Natural environmental management** - The paleoclimatic studies suggest that some landscapes are or have a possibility of becoming in disequilibrium with the present climate, and natural environmental management projects must be conducted more carefully in these areas. Many soils of intertropical regions have originated under climates different from the present one and, as a consequence, they are more sensitive to anthropic interference such as deforestation which, roughly, simulates a situation of climate aridification. Groundwater resources of some presently arid areas have accumulated during some wetter periods of the last millennia and, thus, they are not today a completely renewable resource. Moreover, research mentioned here directed toward the surface formations could provide helpful information for prospection and rational exploitation of placer deposits, peat deposits, etc.

c) **Application in archeological and prehistorical studies** - The evolution and dispersion of prehistoric man have been largely controlled by paleoenvironmental changes. In fact, the penetration of man into the American continent occurred when its landscapes were very different from today. Therefore, by disclosing the mechanism of these environmental changes, we are obtaining one of the keys essential for archeological and prehistorical studies.

d) **Formation of new scientists** - Paleoclimatological research is necessarily multidisciplinary and only the perfect integration of the obtained data allows us to reach the global conception of the problem. This type of research propitiates a mobilization of numerous human contingents and encourages national and international cooperation activities, favoring technical-scientific formation of new scientists.

## RECORDS OF PALEOCLIMATIC FLUCTUATIONS FOUND IN FLUVIAL TERRACES FROM SOUTHEASTERN AND CENTRAL-WESTERN REGIONS

### GENERALITIES

By the 60's, several papers had shown discrepancies between geomorphological features, as well as, faunistic and floristic distribution, and the presently existing climate in several areas of the Brazilian territory (Ab'Saber, 1957; Tricart, 1958, 1977; Bigarella & Ab'Saber, 1964; Hafer, 1969; Vanzolini, 1986).

Continental deposits from river valleys or from adjacent slopes may register paleoclimatic fluctuations indicating possible changes in the run-off pattern, that is, in the hydrological cycle; or indirect change in vegetation cover which will influence the nature of the continental sedimentation. On the other hand, the radiocarbon dating of these deposits has allowed us to establish the ages of the paleoclimatic fluctuations.

Radiocarbon ages obtained by Bigarella (1971) in fluvial deposits of the Pirabeiraba river (State of Santa Catarina) and by Meis & Monteiro (1979) indicated the occurrence of fluvial terraces, whose basal portion was dated as about 10.5 ky. B.P. in both cases. Silva de Moura & Meis (1986) discovered the presence of paleosoils, with a similar age, in slope deposits of the Bananal river (State of São Paulo). Finally, more recent fluvial terraces from the State of Santa Catarina have been dated, also by Bigarella (1971), as 1.5 and 2.8 ky. B.P. Therefore, many of these fluvial terraces of southeastern and southern Brazil were built during the Holocene and, frequently, they are related to paleoclimatic fluctuations of the postglacial transition, when the upper Pleistocene dry climate changed to the Holocene more humid cli-

mate (Ab'Saber, 1980).

### Alluvial deposits

The field work carried-out under the scope of this program comprised partially the states of São Paulo, Minas Gerais and Goiás (Fig. 1). The Precambrian crystalline basement rocks of these areas exhibit a very flat-topped plateau shape or a hilly mountainous surface (Serra do Mar, Serra da Mantiqueira, Serra do Espinhaço, etc.), and is covered by a thick weathering mantle. The vegetation types include savanna-like formations (*cerrados*), semi-deciduous forests and tropical *mata Atlântica* rainforests.

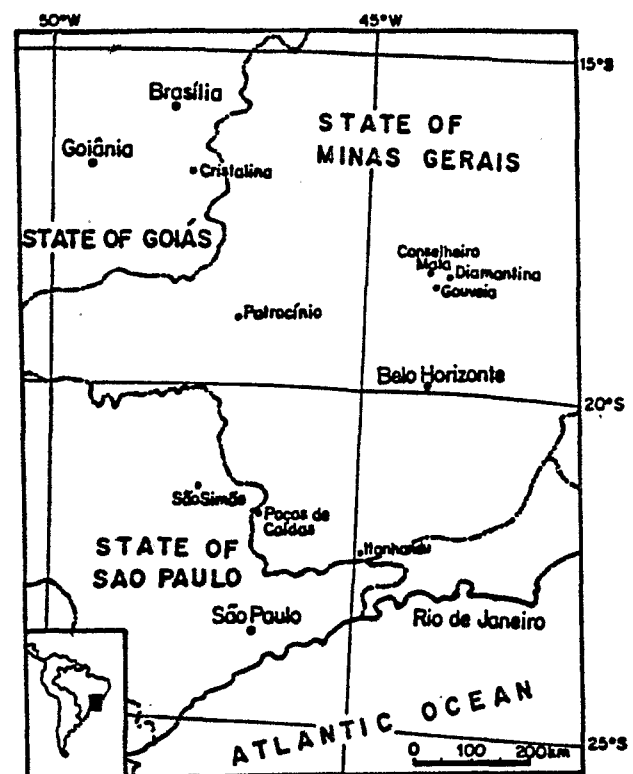


Figure 1 - Parts of the states of Minas Gerais, Goiás and São Paulo, with the most important locations where fluvial terraces have been studied.

A reconnaissance survey of upper Quaternary alluvial continental deposits in Central-Western Brazil, supported by radiocarbon datings, revealed the presence of at least two phases of sedimentation, prob-

ably influenced by paleoclimatic fluctuations. They are very well represented by the Tamanduá river alluvial deposits (São Simão, State of São Paulo), situated about 700 m a.s.l. (above sea level). At the base of the profile clayey deposits, locally enriched in organic matter, have been dated as  $16,920 \pm 340$  years B.P. (Bondy 17) and  $10,430 \pm 330$  years B.P. (Bondy 44). At the top of the profile, lying upon an erosional surface, there are peaty deposits which were dated as  $5,180 \pm 250$  years B.P. (Bondy 18) and  $5,650 \pm 250$  years B.P. (Bondy 14).

These two phases, representing probable fluctuations in the hydrological cycle, found in São Simão, seem to be present at other sites. In the Poços de Caldas area (State of Minas Gerais), situated about 1,130 m a.s.l. the most ancient phase is represented by a paleosoil with an age of  $14,860 \pm 350$  years B.P. (Bondy 45), resting directly above a stoneline and covered by colluvial deposits.

In Cristalina (State of Goiás), situated about 1,200 m a.s.l., more northward, there are some terraces formed from the bottom to the top, by gravel, sand and organic-rich silt, that has been dated as  $13,750 \pm 300$  years B.P. (Bondy 74). Lower levels in Cristalina and organic deposits at the base of a terrace representing several fluvial episodes in Gouveia (State of Minas Gerais) situated about 1,100 m a.s.l., have been dated respectively, at  $20,870 \pm 360$  (Bondy 73) and  $31,950 \pm 450$  (Bondy 72) years B.P.

The erosional episode before 6 ky. B.P. seems to represent an important event in Central Brazil, as observed in São Simão (State of São Paulo). Tree trunks above a basal gravel of a lower terrace have been dated as  $5,770 \pm 290$  years B.P. (Bondy 8) in the Lageado creek (Goiânia, State of Goiás) and as  $4,890 \pm 240$  years B.P. (Bondy 7) in Poços de Caldas.

A similar type of change in sedimentation, characterized by depositional and erosional periods, has been recorded in the Bonito area (State of Mato Grosso do Sul), situated about 130 m a.s.l. The fact that these several sites are located at different altitudes and possess different vegetation covers suggests that these changes are not a result of local mechanisms.

### Possible paleohydrological and paleoclimatological significance of the studied sites

The sedimentological characteristics and the obtained radiocarbon ages permit several hypotheses to be formalized as to the possible paleoenvironmental changes in the studied areas:

a) From 32 to 21 ky. B.P. organic-rich deposits formed the basal portions of São Simão, Gouveia, and Cristalina fluvial terraces. This type of deposit would suggest a low competence of surface runoff (fine grain size) and superficial water table (accumulation of organic matter), indicating a wetter paleoclimate. In fact, a wetter paleoclimate has been suggested for intertropical latitudes of South America (Van der Hammen, 1974) and Africa (Servant, 1986), during the period 30-20 ky B.P.

b) The fluvial deposits of São Simão, dated between 17 and 10 ky. B.P., indicate a reasonably strong fluvial discharge and slope erosion, which favored the filling of the fluvial valley by sediments. The presence of peaty layers could be related to probably ephemeral superficial water levels. At the same time, at the altitude of Poços de Caldas the development of a paleosoil was occurring. This phase, dated as 15 ky. B.P., would represent a time of slope stability, between a strong surface runoff period (drier ?), registered by a stoneline, followed by a gravitational (colluvium) deposit. The organic clays of Cristalina,

dated at 14 ky. B.P., overlying the fluvial sands and underlying the silty colluvia from the slopes could be correlated with the alluvial deposits of São Simão. This time interval, from 17 to 10 ky. B.P., seems to be characterized by slope erosion probably related to a scarce vegetation cover and to the occurrence of heavy rainfalls.

c) Several materials originated from highlands have been dated between 10 and 8.5 ky. B.P. in many alluvial plains. This accumulation phase of the river valleys probably could be correlated to the last intensive colluviation phase recognized in the region of the Doce and Jequitinhonha rivers (Servant et al., 1989a,b; Turcq et al. 1991).

Before 7 ky. B.P., sedimentation was frequently interrupted by the following erosional episodes: 6-7 ky. B.P. (Gouveia, Lageado creek, Conselheiro Mata), 4-5 ky. B.P. (Gouveia, Poços de Caldas and Itanhandu), 2.5-3 ky. B.P. (Gouveia) and 0 - 0.3 ky B.P. (Gouveia and Timóteo). The most recent erosional event promoted the inlaying of the present fluvial channels. These events suggest the occurrence of several short duration fluctuations within a globally humid paleoclimate.

## RECORDS OF PALEOCLIMATIC FLUCTUATIONS FOUND IN LACUSTRINE DEPOSITS

Frequently, sedimentological and geomorphological studies of fluvial terraces supply us very quickly with results. However, normally it is not possible to go back very far in time using these records. On the other hand, as a consequence of peculiarities of each drainage basin, the events will not be necessarily recorded within all sites. Similarly, some deposits could have been destroyed by a later erosional event. To try to obtain the most continuous records, drill cores have been

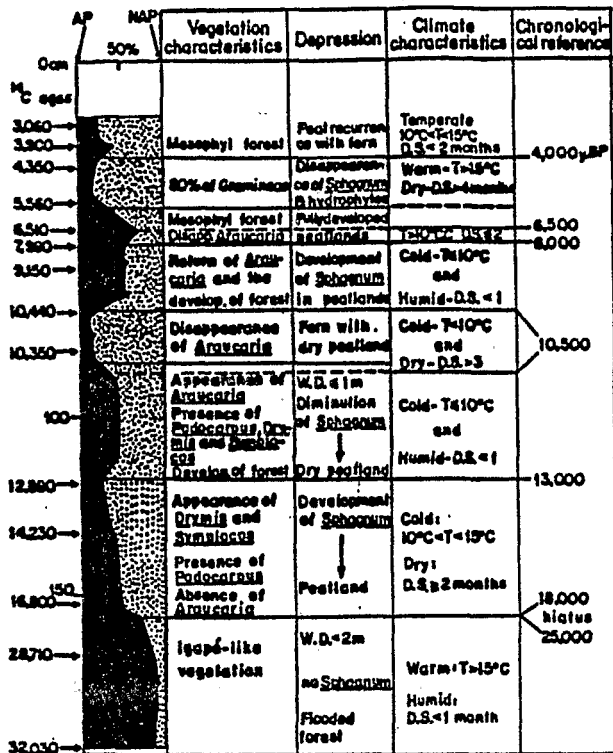
taken from swamps and lakes situated within depressions free from the influence of fluvial dynamics that could disturb lacustrine and/or swampy sequences.

### Records of paleoclimatic changes from Campestre lake (Salitre, State of Minas Gerais)

This lake is situated within a depression with a diameter of about 2 km, and an altitude of 1,050 m a.s.l., near Patrocínio (State of Minas Gerais). This depression was formed in association with a carbonatite intrusion.

Lake sediments were sampled using a vibrocorer with a diameter of about 3" at a distance of more-or-less 100 m from the margin. The perforation reached bedrock at 6 m, and crossed in the upper part down to 3 m, a blackish to brownish organo-mineral sediment rich in plant fibres, followed by a brownish concretionary clayey layer poorer in organic carbon. Radiocarbon ages were obtained from some levels of the upper part. These ages indicated a continuous sedimentation from about 17 ky. B.P. (164 cm depth) until 3 ky. B.P. (18 cm depth). Below this level, there is a hiatus until an age of nearly 29 ky B.P. found at 170 cm depth. Even if specific geochemical markers for paleoenvironmental changes in the area are being studied, with some preliminary results (Soubies et al., 1991a), more significant data have been found by Ledru (1991, 1993) and Ledru et al. (1991), using palynological analyses of the well-dated upper portion of the core (Fig. 2).

Around 30 ky. B.P., it seems that the paleoclimate was warm and humid, supporting an "igapó-type" permanently flooded forest in the depression. From 17 to 13 ky. B.P. a cold and less humid paleoclimate favored the regression of the forest and the *Sphagnum* peats. Between 13 and 8 ky. B.P., the paleoclimate was probably characterized by high humidity



T=mean temperature during the winter in °C.  
D.S.=duration of the dry season in months.  
W.D.=water depth within the depression in meters.  
AP= arboreal plants; NAP= non-arboreal plants.

Figure 2 - Paleoclimatic interpretation of the palynological data of Ledru (1991), from 30 - 3 ky. B.P. in lacustrine sediments cored within Lagoa Campestre, Patrocínio (State of Minas Gerais). Modified from Ledru (1993).

rates and winter temperatures lower than present ones. These conditions promoted the development of *Araucaria* forest in the area. About 10.5 ky. B.P. a short dry period has been recorded by the disappearance of arboreal plant pollen, mostly of *Araucaria*, and by an increase of Gramineae pollen. After 8 ky. B.P. the *Araucaria* forest was replaced by a semi-deciduous forest, which corresponds to a higher temperature. A new dry period, characterized by a strong diminution of arboreal plant pollen, was recorded between 6.5 and 4 ky. B.P. After 4 ky. B.P., the expansion of the semi-deciduous forest characterizes a return of wetter conditions.

**Records of paleoclimatic changes from**

**Serra dos Carajás (State of Pará)**

The southern Serra dos Carajás, situated at 6°20' southern latitude and 50°25' western longitude, is a narrow 700-800 m - high plateau developed upon a "banded iron formation", and surrounded by the Amazonian rainforest. The plateau surface, covered by more-or-less dense scrub savannas, exhibits numerous small lakes. These lakes are situated within partially interconnected and semi-closed depressions, whose form looks like dolines. They are relatively shallow and show several stages of silting by fine to very fine sediments very rich in organic matter. This region forms a NW-SE elongated "drier corridor", whose annual precipitation of 1,500 to 2,000 mm is low for a rainforest, representing a region more sensitive to climatic variations. Moreover, as these lakes are free of erosional processes and are receiving incessant "pollen rains", they present the ideal records of changes in past climate and vegetation in the area. The lacustrine deposits from the Serra dos Carajás have supplied paleoclimatic records corresponding to the longest time interval among the regions studied until now in this project (Absy et al., 1989, 1991; Soubiès et al., 1989, 1991b; Sifeddine et al., 1991a, 1994a, b).

Drill core CSS-2, obtained by a vibrocorer from a southern Serra dos Carajás lake, was submitted to the following laboratory analyses: radiocarbon dating, water content, density, inorganic geochemistry (total Fe and P), organic geochemistry (organic C and total N), quantitative infrared spectrometry (quartz, kaolinite, amorphous silica and siderite dosages), organic matter petrography (reflectance, fluorescence and palynofacies), and palynological analyses.

These laboratory studies supplied numerous data which allowed us to reach the following conclusions (Fig. 3): (a) at

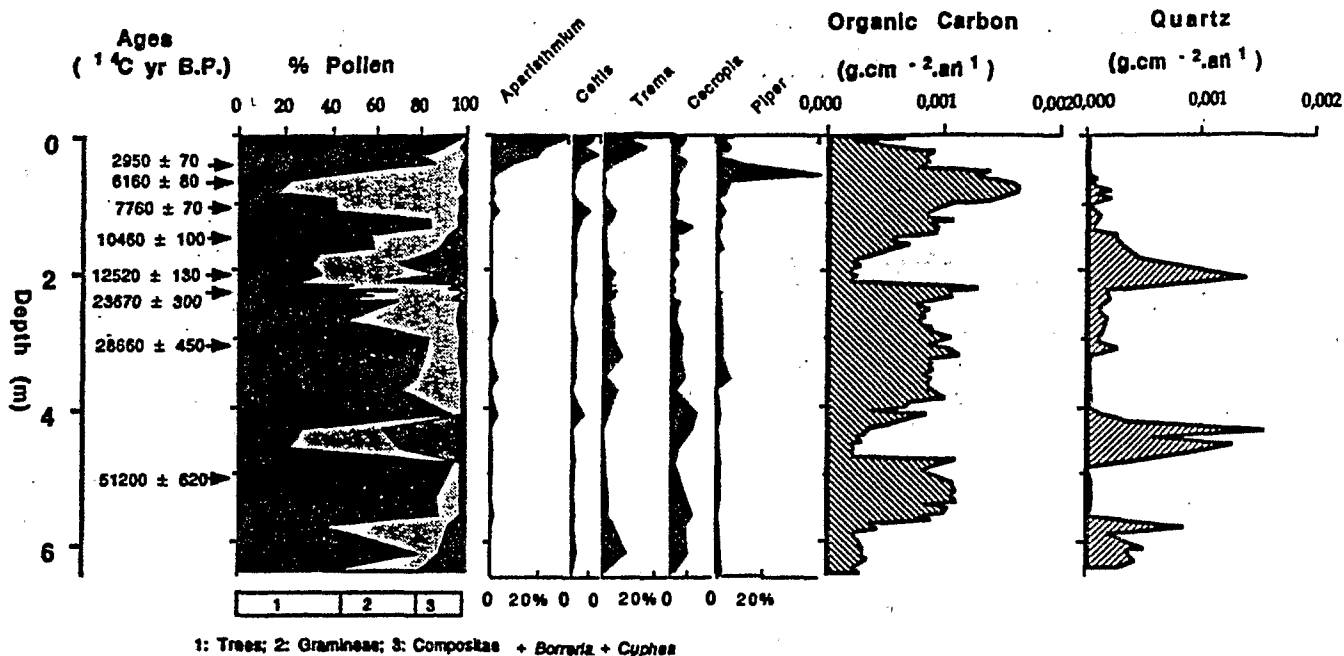


Figure 3 - Palynological data, flux of detrital quartz grains and organic carbon content were some of the most useful information for paleoclimatic interpretation of the last 60 ky. in the Serra dos Carajás area (State of Pará). Modified from Martin et al. (1993a).

least four rainforest regression episodes (around 60, 40, 23 to 13 and 7 to 4 ky. B.P.) occurred in the eastern Amazon area, when the climate was drier than today; (b) the last rainforest regression episode, from 7 to 4 ky. B.P., was quite different from the previous ones. This anomaly is suggested by the low frequency of savanna vegetation pollen grains. Contrarily to what had occurred during the previous dry episodes, forest recovery was characterized by a high percentage (more than 40%) of *Piper* (pioneer vegetation) pollen grains. This fact suggests that in spite of climatic conditions favorable for forest development, the pioneer vegetation stage was not surpassed. The absence of savanna pollen grains, the low levels of erosion revealed by low sedimentary fluxes, and the permanence of rainforest pioneers indicate somewhat wetter climates than during the Pleistocene dry episodes. The great abundance of charcoal microfragments in the sediment of this interval, corresponding to the highest carbon fluxes registered in the

core, suggests repeated fires. This evidence leads to the conclusion that the forest regression between 7 and 4 ky. B.P. was not due to permanent dryness but probably due to a series of dry periods alternating with slightly wetter periods.

#### POSSIBLE CHANGES IN THE WIND-DRIVEN COASTAL DYNAMICS DURING THE LAST 5 KY

On a low coast, the longshore transport direction depends on the swell orientation. If the coast is submitted to several swell patterns, the "efficient swells" are defined as those determining longshore transport, which are not necessarily the most common ones. Presently, the most frequent swells are related to NE, being generated by return trade winds. The second comes from the SE sector, being related to the penetration of polar air masses throughout the South American continent. The latter is particularly frequent



during the austral winter and autumn, and its influence reaches to about 12° southern latitude. It is important to emphasize that the southeastern waves are much stronger than the northeastern ones and play a dominant role along the shorelines where these two systems work alternately. Some days or even some hours of action of the southeastern waves may move a volume of sand still more important than the action of several months of weak northeastern waves. This fact is presently observed in the erosion of beaches provoked by "cold fronts".

This pattern is disturbed during strong "El Niño" events, when the polar frontal systems are blocked by an enhanced subtropical jet (Kousky et al., 1984). During these episodes, the frontal systems remain for an extended time in southern and southeastern Brazil. Consequently, the swells from the southern sector do not reach the central part of the Brazilian coast. In such cases, the northern sector swells become the efficient one. In 1983, year of an important "El Niño" event, a longshore transport disturbance was observed by Ferreira et al. (1985) along a beach in Salvador area.

When fossil beach ridges exist, as along the central Brazilian coast, their geometry reflects the directions of longshore transport. Thus, one can determine from which sector the past efficient swells came, thereby allowing the past atmospheric circulation pattern to be characterized. The construction of a beach ridge plain is controlled by sea-level changes and longshore sand transport processes. Sea-level fluctuations during the last 7 ky. are well known for the central part of the Brazilian coast (Martin et al., 1987). Three main episodes of submergence (7-5.1, 3.9-3.6 and 2.7-2.5 ky.B.P.), alternated with three main episodes of emergence (5.1-3.9, 3.6-2.7 and after 2.5 ky.B.P.).

Under favorable conditions, episodes of submergence and emergence, as well as past directions of the longshore sand transport, may be identified by a detailed study of the beach-ridge geometry. A study in the Doce river coastal plain (State of Espírito Santo) allowed us to reconstruct changes in the direction of longshore currents from 5 ky. B.P. to today (Martin et al., 1991 and Martin & Suguio, 1992), as shown in Figure 4, which provides the following information:

a) before 5.1 ky. B.P., the absence of beach ridges, due to submergence episode, does not permit inference of any longshore transport direction;

b) between 5.1 and 3.9 ky. B.P. (emergence episode) the longshore sand transport, that normally is northward changed to southward, and this would imply that during seven separate episodes the southeastern efficient swells did not reach the study area;

c) between 3.9 and 3.6 ky. B.P., the sea-level was rising and thus it is impossible to determine the direction of longshore transport of sands due to the absence of beach-ridges;

d) between 3.6 and 2.8 ky. B.P., corresponding to another emergence episode, the longshore sand transport was continuously northward because the southeastern swells remained permanently efficient;

e) between 2.8 and 2.5 ky. B.P., this direction cannot be determined as a consequence of the relative sea-level rise; and

f) from 2.5 ky. B.P. to present, corresponding to an emergence episode, three times, that is, around 2.2, 1.3 ky. B.P. and an undefined most recent age, longshore transport reversed southward. This indicates that, during these three time intervals the southeastern efficient swells did not reach this region. These inversions can be explained only by changes in the direction of the effective waves and, hence, in the

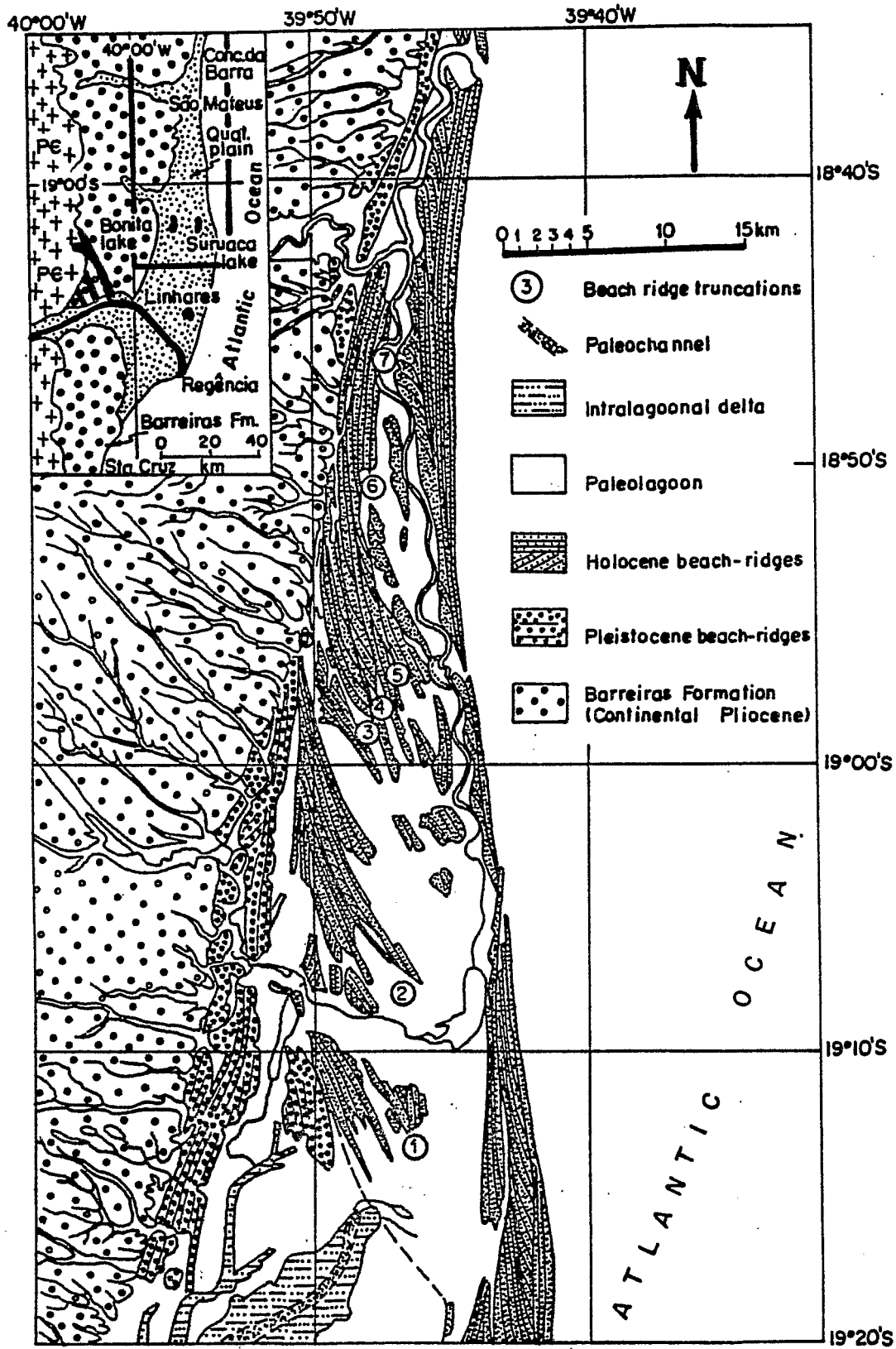


Figure 4 - Doce river coastal plain (State of Espírito Santo) showing the littoral drift inversion episodes recognized from changes in the geometry of alignments in beach-ridges on sandy plains. Modified from Martin & Suguio (1992)

paleowind regime.

The inversion in the direction of littoral sand transport, as a consequence of change in the orientation of the dominant waves, that has been recorded in the Doce river coastal plain could be explained by the occurrence of two successive systems of atmospheric circulation. When the dominant waves come from the south, the atmospheric circulation would be equivalent to the present situation, which is characterized by northward ascension of polar air masses and associated frontal systems during autumn and winter. When dominant waves come from the north, the atmospheric circulation is attributable to an "El Niño" - like circulation with a duration of some tens to hundreds of years, since the true "El Niño" events provoke similar disturbances in littoral transport but with a duration of several months. Therefore, the "El Niño" - like conditions recorded by the beach-ridge geometry are not true paleo-"El Niño" events (i.e., past occurrences of "El Niño" events similar to the present ones), but represent average paleoclimatic situations that generate the same kind of perturbations as strong as "El Niño" events observed during the last decade.

## FINAL CONSIDERATIONS

The paleoclimatic and vegetation cover evolutionary data from Brazil, when compared with that obtained in Africa (Giresse et al., 1991; Maley et al., 1991; Servant et al., 1993), permitted us to infer that:

a) before 8 ky. B.P. (end of the last glaciation and beginning of the present interglacial stage), the tropical forests and the lake levels evolved similarly;

b) after 8 ky. B.P. (present interglacial stage), the tropical forests and the lake levels evolved differently, in opposition on both sides of the Atlantic Ocean.

Apparently, since then changes in tropical ocean surface temperatures (particularly of the Pacific Ocean) played an important role in the recorded paleoclimatic changes.

So, after the existence of "El Niño" - like conditions with a duration of several tens to hundreds of years was made clear, Martin et al. (1993) developed a paleoclimatic scenario that predicted, for example, the occurrence of successive short duration dry periods in Amazon area before 4 ky. B.P. The data from southern Serra dos Carajás (State of Pará) is in agreement with this forecast. Similarly, the existence of a dry phase at Salitre (State of Minas Gerais) is also in accordance with the above mentioned scenario.

The existence of short duration events of this type has considerable significance for understanding the evolution of tropical paleoclimates. Due to their short duration they are not easily recorded within geological sequences and are not commonly taken into account in climatic models. This type of short duration event could be at least partially responsible for the seasonality enhancement observed within tropical areas, and particularly in South America (Markgraf, 1989).

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