by Kenitiro Suguio

Recent progress in Quaternary geology of Brazil

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Until very recently, papers dealing with Quaternary geology were very scarce in the Brazilian geoscientific literature. In spite of its multidisciplinary nature, the only existing publications on this subject were related to geotechnical and/or geomorphical characteristics. In the last 30 years, this picture changed due to several international programs such as the IGCP projects and agreements between ORSTOM (France) and CNPq (Brazil). They have started with studies of relative sea-level changes along northeastern, central, and southeastern coasts, conducted together with 700 radiocarbon dates. These researches have been followed by paleoclimatic studies, mostly done by palynological and stable carbon isotopes analyses, mainly in Amazon, central-western and southern areas. Finally, several neotectonic studies are in progress, especially in Amazon and southeastern regions. Those studies resulted in a better knowledge about the Quaternary evolutionary history of Brazil, mostly during the Late Pleistocene and Holocene. More of those studies have to be developed in order to adequately subsidize the sustainable development of this country.

Introduction

Quaternary geology deals with the ultimate chapter of Earth's history, covering the last 1.81 Ma (Van Couvering, 1997). The majority of the geologic processes existing during this short time interval are still active nowadays and will continue during the next million years. Therefore, the study of those processes is fundamental for environmental geology, which is commonly considered as synonymous with applied geology (Keller, 1988).

Moreover, building materials like sands and gravels are provided by Quaternary unconsolidated deposits; and because of their voluminous consumption, they can be considered the most important mineral resource for modern civilization (Lüttig, 1979).

Quaternary sediments are also important due to the following additional reasons:

a) About 70% of the human population live on coastal plains and floodplains, originated respectively by marine and fluvial processes.
b) The great majority of civil engineering works (building, bridge, highway, harbor, etc.) are located on Quaternary unconsolidated sediments. Consequently, a better knowledge of those sediments is essential for a suitable evaluation of soil mechanics data.
c) Farming and forestry activities are essentially developed over Quaternary sediments and soils. Therefore, Quaternary geology becomes very important for pedological researches.
d) Frequently Quaternary deposits constitute important aquifers, providing abundant groundwater for industrial and domestic uses.

Although the observations presented above are well known, Quaternary geology remained practically ignored by a great majority of Brazilian geologists during a long time. Meanwhile in the Northern Hemisphere, Quaternary geological studies began with Penck and Brückner (1909), dealing with Alpine glacial landscapes. In Brazil, these researches were intensified only about 30 years ago, notwithstanding the pioneer geomorphological works done mostly by A.N. Ab'Saber and J.J. Bigarella.

Intensification of Quaternary geological studies coincided with the creation in 1971 of the "Quaternary Technical-Scientifical Commission" within the SBG (Brazilian Geological Society). Four special symposia on the Brazilian Quaternary studies have been organized by this commission, which was replaced in 1984 by the ABEQUA (Brazilian Association of Quaternary Studies). As a society affiliated to SBG, ABEQUA is holding its 7th Congress in October 1999 at Porto Seguro (State of Bahia).

In accordance with the inter- and multidisciplinary peculiarities of the Quaternary geology, some of the most important themes developed in recent years in Brazil are as follows:

a) Quaternary relative sea-level changes,
b) Quaternary climatic fluctuations,
c) Neotectonics and Quaternary tectonics.

Quaternary relative sea-level changes

Although Darwin (1841) first recognized the beachrocks present along the State of Pernambuco coast as evidence of Holocene sea-level change, these studies were very scarce until the seventies (Tessler and Mahiques, 1996).

The first studies using radiocarbon ages were done by Laborel and his colleagues (Van Andel and Laborel, 1964; Delibrias and Laborel, 1971). The REMAC (Global Reconnaissance of the Brazilian Continental Margin), a joint project involving many universities and governmental agencies, probably brought about the most significant progress in this subject (Kowsmann et al., 1977; Corrêa, 1987).

Since 1974, many studies have been done on the central and southern Brazilian coastal plains, which improved the relative sea-level change history in these regions, mostly for the last 7,000 years (Suguio et al., 1985; Villwock et al., 1986; Villwock and Tomazelli, 1995; Martin et al., 1996).

Evidence of relative sea-levels below the present

The continental margin between Torres and Chuí (State of Rio Grande do Sul) is best studied and supplied with many ancient sea-levels situated between 20–26 m, 32–45 m, 60–70 m, 100–110 m, and 120–130 m (Corrêa and Toldo Júnior, 1996). They are represented by ancient shorelines, originated during relative sea-level still-stand episodes.

Based on the eustatic curve delineated by Corrêa (1990), the paleogeographic evolution of the continental shelf along the State of Rio Grande do Sul coast can be subdivided into three phases :

a) *First phase* — 17,500 to 16,000 years BP. About 17,500 years BP, when relative sea-level was at least 130 m below the present one, practically all the continental shelf was emerged and submitted to an intensive erosion. The relative sea-level rose very rapidly (about 2 cm/year), being stabilized about 16,000 years ago. The ancient shoreline of this phase is represented by fine sand on the inner shelf, intercalated by medium sand, probably supplied by the coastal drainage net.

b) *Second phase* — 16,000 to 11,000 years BP. The relative sea-level rise during this phase was diminished to about 0.6 cm/year. This transgressive episode is recorded on the middle and outer continental shelves. Based on microorganisms, the relative sea-level between 60–70 m indicated the beginning of the Holocene when a climatic amelioration was verified.

c) *Third phase* — 11,000 to 6500 years BP. During this episode the relative sea-level rise was speeded up to about 1.6 cm/year, with two still-stand episodes between 32–45 m and 20–25 m. Meanwhile a transgressive process was active and the shoreline was shifting westwardly. During this phase, fine sediments covered the transgressive sands situated on middle and outer continental shelves. The still-stand episodes are represented by biodetrital gravel and heavy mineral-rich layers, which are indicative of ancient shorelines.

Evidence of relative sea-levels above the present

They have been better studied between the States of Santa Catarina and Bahia, where about 700 radiocarbon ages were obtained by Suguio and his colleagues (Suguio et al., 1985; Martin et al., 1996). These results are also valid for the State of Rio Grande do Sul.

The evidence of these relative sea-levels, including the upper Pleistocene sea-levels, is represented by geological (wave-built and wave-cut terraces, as well as beachrocks), biological (vermetid incrustations, coral reef buildups, and *Callichirus* burrows) and prehistorical (shell-middens) records.

According to these studies, at least four phases of relative sea-levels higher than the present one have been recognized during the Quaternary:

a) *Relative sea-levels before 123,000 years BP*. They are represented by two ancient barrier island-lagoonal systems, situated at about 20–25 m (Barrier I) and 15 m (Barrier II). They have been tentatively dated as 400,000 years BP and 325,000 years BP and are attributed respectively to oxygen isotope stages 11 and 9.

Barrier I is represented only in the State of Rio Grande do Sul coastal plain; there are vestiges of Barrier-II terrace between states of Santa Catarina and southern São Paulo.

b) *Relative sea-levels of about 123,000 years BP*. This episode is recorded by wave-built terraces situated at about 8 ± 2 m, continuous from the states of Rio Grande do Sul to Paraíba.

Five Io/U ages were obtained from coral (*Siderastrea*) samples (Bernat et al., 1983) collected from the basal portion of the terrace in the State of Bahia. The average age of those sediments is 123,500 ± 5,700 years BP. This episode could be correlated with the Sangamon (North America) or Eemian (Scandinavia) transgression previously recognized by Bloom et al. (1974). It corresponds to Barrier III of the State of Rio Grande do Sul (Villwock et al., 1986), and is tentatively attributed to the oxygen isotope stage 5.

c) *Holocene relative sea-levels higher than the present.* The last 6500 years after the third phase of the transgressive episode (Corrêa, 1990), recognized on the State of Rio Grande do Sul continental shelf, was studied in detail. This episode is internationally known as Flandrian or Postglacial Transgression, but according to the difference in feature from the curves obtained for the majority of the Northern Hemisphere countries, it is called more adequately the Santos Transgression in Brazil.

Geological evolution of the Brazilian coastal plains

Based on Quaternary relative sea-level changes it was possible to establish a general evolutionary model, useful in the sector of the Brazilian coast between Macaé (northern State of Rio de Janeiro) and Recife (State of Pernambuco). This coastline stretches about 3,000 km, being characterized by the presence of Tertiary Barreiras Formation, situated between the rearguard Precambrian crystalline rock mountains and the Quaternary coastal plains (Martin et al., 1987). On the other hand, along the southern part of State of São Paulo and the states of Paraná and Santa Catarina coasts, this model is partially useful for local reasons (Martin, Suguio, and Flexor, 1987a).

The complete evolutionary model with four barrier island lagoonal systems were recognized only in the State of Rio Grande do Sul coast (Villwock and Tomazelli, 1996).

Geological evolution of Quaternary coastal plains situated at the mouths of the most important rivers, which was preliminarily studied by Bacoccoli (1971), is presently well-known thanks to the innumerous papers published (Martin et al., 1993).

Quaternary climatic fluctuations

Starting in the fifties, several papers emphasizing strong discrepancies between the present faunistic, floristic and geomorphological distributions and the climates, have been published (Ab'Saber, 1957; Tricart, 1958; Haffer, 1969; Bigarella et al., 1975 and Vanzolini, 1992). Among several paleoclimatic indicators, frequently known as proxy records, palynological analyses, accompanied by radiocarbon ages, have been done in Brazil. Also charcoals present in soils, lacustrine and paludal deposits or in eolian dune sands have been frequently used as paleoclimatic indicators (Soubies et al., 1980; Barreto et al., 1996; Turcq et al., 1998). Commonly, there is doubt if the charcoals have a natural or an artificial origin (anthropogene), but in any case they represent a record of drier and warmer climates.

In a virtual absence of palynological or even of charcoal records, like in ferralitic soils of equatorial and tropical areas, $^{13}C/^{12}C$ ratios of soil organic matters can be used to obtain information of previous existing vegetation communities. According to Troughton et al. (1974) this parameter could indicate the presence of C_3 (arboreal) or C_4 (non-arboreal) plants, as well as their relative proportions in net biomass primary productivity of the past.

Some examples of Quaternary paleoclimatic studies

One of the best examples of paleoclimatic study, using mostly palynological data and radiocarbon ages, was done in Serra dos Carajás (State of Pará). Palynological data obtained from 50 samples collected from a 6.50 m-long lacustrine sediment core allowed the establishment of eight palynological zones. Absy et al. (1991) recognized, in this study of the Amazon area, the existence of:

a) *Rainforest retraction periods.* The obtained palynological spectra indicated that about 60,000, 40,000, and 23,000 to 11,000 years

BP, a rainforest retraction occurred, when the climate was drier than presently in the area.

b) *Rainforest expansion periods.* High frequencies of pollen of arboreal plants, especially between 9,500 and 8,000 years BP, are indicative of a wetter paleoclimate than the present in this area.

Other studies using mineral components (quartz, kaolinite, siderite, and amorphous silica), C/N and $^{13}C/^{12}C$ ratios, according to Sifeddine et al. (1994), ratified the previous palynological studies.

Many other palynological studies were performed in several sites in Brazil, mostly after 1980, including areas presently dominated by savanna vegetation (Central Brazil), by *Araucaria* forest (Southern Brazil), and by "caatinga" (Northeastern Brazil).

In spite of many paleoclimatic studies done throughout Brazil, using palynological, isotopical, and mineralogical analyses, the correlation of these data is not a simple task, mostly due to their diachronicities. However, it is encouraging that some Quaternary worldwide paleoclimatic changes, like *hypsithermal* age (about 9,000–2,500 years BP), neoglaciation (about 2,500–1,000 years BP), and the *little ice age* (1,450 to 1,890 AD), are apparently recognizable in the Brazilian paleoclimatic records.

Neotectonics and Quaternary tectonics

The pioneer works on neotectonics in Brazil appeared about 50 years ago (Sternberg, 1950; Freitas, 1951). However, only 20 years later Brazilian geologists got interested in this subject, mainly due to huge civil engineering works like hydroelectrical and thermonuclear projects, and harbor constructions. Probably the best known regions of Brazil regarding neotectonics are the Amazon area (Costa et al., 1996) and the Southeastern Brazil (Riccomini, 1989).

As demonstrated by Suguio and Martin (1996), there is no doubt that neotectonics played a very important role in geological evolution of Brazilian coastline. Unfortunately there are only a few places where tectonic movements have been dated (Martin et al., 1986).

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