

LATE CRETACEOUS AND CENOZOIC HISTORY OF NORTHEASTERN BRAZIL

J.M. MABESOONE^{1,3}), JOSE LINS ROLIM¹) & CLAUDIO DE CASTRO²)

ABSTRACT

Mabesoone, J.M., J.L. Rolim & C. de Castro (1977). Late Cretaceous and Cenozoic history of northeastern Brazil, *Geol. Mijnbouw*, 56 p. 129-139.

The Late Cretaceous-Cenozoic history of northeastern Brazil is characterized by relief development, correlative sediments and paleosol profiles.

Between Albian and Miocene the so-called Sulamericana Surface developed on a slowly epigenetic doming area, with the formation of kaolinic and arenaceous soils. During the Miocene the uplift became stronger with consequent deposition of the correlative Serra do Martins Formation and basaltic volcanism. During the more quiet Pliocene a lateritic soil developed on these sediments (Cuité Soil).

The early Quaternary glaciations again caused rupture of the equilibrium, resulting in the removal of most of the sedimentary cover of the region, depositing the detritus along the coast. Erosion halted on the reappearing Jurassic planation surface elaborated in crystalline basement rocks (Sertaneja and Tabuleiros Surface). During the interglacial periods soil formation took place on the correlative deposits (Guarapes Formation, Riacho Morno Soil).

The last two glaciations which apparently were of stronger intensity, caused the formation of pediments with bornhardts, and river and coastal terraces (polyphase Paraguaçu Cycle). Correlative deposits were laid down in grabens caused by tectonic reactivation (Macaiba Formation). The covering Potengi Soil was formed during the last interglacials. Recent deposition of white sands suggests a new rupture of climatic equilibrium.

Paleontological evidence of this history is scarce.

RESUMO

Mabesoone, J.M., J.L. Rolim & C. de Castro (1977). Late Cretaceous and Cenozoic history of northeastern Brazil. *Geol. Mijnbouw*, 56, p. 000-000.

A história geológica do Nordeste brasileiro durante o Cretáceo Superior e Cenozóico é caracterizada pelos desenvolvimento do relevo, sedimentos correlativos e perfís de paleossolos.

Entre o Albiano e o Mioceno elaborou-se a Superfície Sulamericana sobre uma área em lento abaullamento epigenético, formando solos caulínicos e arenosos. Durante o Mioceno esse soerguimento aumentou com a conseguinte deposição da Formação Serra do Martins e um vulcanismo basáltico. Durante o Plioceno, fase mais tranquila, formou-se um solo laterítico nesses sedimentos (Intemperismo Cuité).

As primeiras glaciações quaternárias provocaram novamente uma ruptura do equilíbrio, resultando na remoção da maior parte da cobertura sedimentar da região, com a deposição do detrito na zona costeira. A erosão estagnou sobre a superfície de aplainamento jurássico elaborado nas rochas cristalinas do embasamento, quando a mesma reapareceu (Superfície Sertaneja e dos Tabuleiros). Durante os períodos interglaciais houve formação de solo sobre os depósitos correlativos (Formação Guarapes, Intemperismo Riacho Morno).

As duas últimas glaciações de maior intensidade causaram a formação de pedimentos com inselbergs, além de terraços fluviais e costeiros (Ciclo polifásico Paraguaçu). Os sedimentos correlativos depositaram-se em grabens causados por uma reativação tectônica (Formação Macaiba). O sobrejacente Intemperismo Potengi formou-se durante os últimos períodos interglaciais. Uma deposição recente de areias brancas sugere uma nova ruptura do equilíbrio climático.

As evidências paleontológicas dessa história são escassas.

¹) Dept. Geologia, Centro Tecnologia, Univ. Fed. Pernambuco (Cidade Universitária, 50.000 Recife (PE), Brasil)

²) Dept. Engenharia de Minas, Centro Tecnologia, Univ. Fed. Pernambuco

³) Research Fellow Conselho Nacional Desenvolvimento Científico e Tecnológico (CNPq), Rio de Janeiro.

INTRODUCTION

Northeastern Brazil offers a broad spectrum of crystalline and sedimentary rocks, showing almost the complete geological sequence (in age) as present in the country. The major part of the Precambrian and Early Cambrian rocks has been metamorphosed. The last orogenic event to which the region and the country as a whole were subjected, was the so-called Brazilian (= Baikalian) Orogeny, during the Early Cambrian, which showed its maximum intensity of metamorphism in the eastern part of the area studied. Later orogenic periods exercised only side effects, chiefly epirogenetic uplift and subsidence as well as faulting movements.

Almeida (1969) gave an outline of the Phanerozoic history into three main stages, called Transition, Stabilization and Reactivation. During the Transition Stage, the folded and partly metamorphosed sequences became mountain chains along which foreland molassic deposits accumulated; this stage lasted from Middle Cambrian to Early Silurian. During the next Stabilization Stage the Brazilian Shield became more stable with the development of four large synclises with anticlises in between. Remnants of the synclises are actually present as the sedimentary basins of Amazonia, Piauí-Maranhão (N.E. Brazil), Paraná (S.E. Brazil) and Chaco (only partly in Brazil). The stage has been subdivided in a thalassocratic (Late Silurian – Early Carboniferous) and a geocratic (Late Carboniferous – Late Jurassic) phase. Sedimentation was strong at first reducing almost to zero in the Middle Triassic. From that time to Late Jurassic an extensive planation surface developed, called the Gondwana Surface by King (1956).

The following Reactivation Stage, which started at the end of the Jurassic and continued until the present day, was caused by the separation of the South-American and African continents. During the beginning of this stage ancient tectonic lines became reactivated and new faults developed. This unstable period lasted from about Purbeckian until Albian, accompanied by strong sedimentation in local basins, intra-continental as well as coastal. A quieter period started in the Albian, which is the subject of the present study. During this period a marked relief developed and many correlative sediments were deposited. Beurlen (1970) in his book on the geology of Brazil, pointed to certain occurrences which were confirmed and put in more detail by recent data.

Figure 1 shows the geographical data of the area as well as actual climates and geological provinces. Attention is especially drawn to the semi-arid climate of the interior.

RELIEF AND SEDIMENTS

Northeastern Brazil shows a large number of landscape forms which can, however, be grouped a rather small number of denudation and sedimentation cycles, as King (1956) already pointed out. These cycles follow one another through geologic time, with each one developing from the

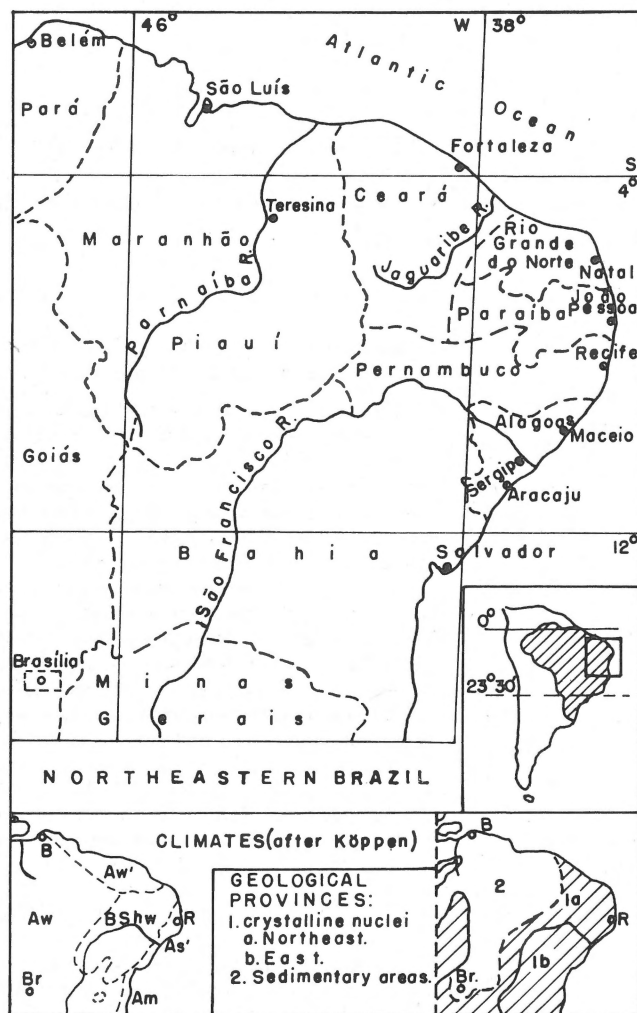


Fig. 1
Locality map of northeastern Brazil, with climates and geological provinces.

coast towards the interior, every younger cycle dissecting a former one and being dissected by a later one.

The landscape of the area studied is characterized by a number of plains or almost flat surfaces separated by escarpments, and with remnants of former landscapes on these. Two surfaces are immediately recognized, the upper one of which is more dissected. Two different geological provinces exist: the crystalline nuclei of Eastern and Northeastern Brazil covered with small patches of sediment, and the sedimentary basin of Piauí and Maranhão States (fig. 1). In both provinces the extent of the principal surface can easily be determined.

The sedimentary basin of Piauí-Maranhão is bordered in the E by a high cuesta, called Serra de Ibiapaba or Serra Grande. Westward, towards the centre of the basin, the principal forms are tablelands upon planated areas in a lower level and dissected by wide river valleys. Elevations are moderate, up to some 800 m.

age	cycle	phase	relief types	correlative deposits	observations and other phenomena
Holocene	polyphase	Lower Terrace	fluvial and littoral terraces, 2-3 m	white sands	possible new rupture of equilibrium, accumulation of sediment
Würm (Upper Wisconsinian)		Middle Terrace	fluvial and littoral terraces, 7-8 m; pediments		
Riss (Lower Wisconsinian or Iowan?)		Upper Terrace	fluvial terraces, 15-16 m; pediments, inselbergs		
Middle Pleistocene	Sertaneja and Tabuleiros Surface				Riacho Morno Soil
Early Pleistocene			regional pediplane, 40-500 m; resurrected older surface	Guararapes, Moura and Capim Grosso Formations	
Late Pliocene	Sulamericana				Cuité Soil (lateritic)
Early Pliocene		Borborema level	dissected peneplane, 200-900 m	Serra do Martins, Serra da Tabatinga and Jaicós Formations; basalts in Rio Grande do Norte and Paraíba	large epirogenetic uplift with doming of Sulamericana Surface; accumulation forming Borborema level
Miocene		Cariris Velhos level	formation of extensive peneplane		development of erosion surface; at the end intrusions and extrusions of basalts
Late Oligocene to Albian	Surface				local filling up of depressions (Eocene) kaolinic soil
Albian				Nova Iorque beds and Campos Novos Formation	area in epirogenetic uplift, with contemporaneous development of erosion surface (Cariris Velhos level)
Aptian to Late Jurassic	Gondwana Surface		reactivation, only local relief formation, no planation levels	various lithological units	strong tectonic reactivation, development and destruction of relief, no planation, accumulation of thick sedimentary beds
Late Jurassic					
Middle-Early Jurassic			represented by erosional unconformity		great regional tectonic stability, formation of red tropical soils

Table I. Late Cretaceous – Cenozoic history of northeastern Brazil

The crystalline nuclei possess a more differentiated relief within which evidently planated areas stand out at at least two levels, dissected by river valleys in which two more levels of reduced extent can be found. Upon these more or less plane areas isolated mountains, small ranges and tablelands composed of crystalline or sedimentary rocks occur. Elevations vary from one place to another, however, never exceeding 1.200 m. Chiefly in Paraíba and Rio Grande do Norte States, Miocene basaltic intrusions and extrusions occur as dykes and volcanic plugs.

The major part of the morphological features bear local names given by various authors. Recently, M a b e s o o n e & C a s t r o (1975) proposed the use of the following designations for the whole area: Sulamericana Surface for the upper level and Sertaneja or Tabuleiros Surface for the lower planation level. In the same paper the authors summarizing and simplifying the numerous names proposed before, established the following sequence of relief development (see Table I):

- (1) Gondwana Surface, represented by a regional erosional unconformity at the base of the Early Cretaceous sedimentary units;
- (2) Sulamericana Surface, possibly in two phases, present as the higher and much dissected erosional surface, at elevations between 200 and 900 m from the coast to the interior;
- (3) Sertaneja and Tabuleiros Surface, the extensive planation surface of the region, rising from the coast at 40 m (Tabuleiros) to over 500 m in the interior (Sertaneja);
- (4) Polyphase Paraguaçu Cycle, with two or three pediment and terrace levels of reduced extent, cut into the former surface, chiefly occurring in the river valleys and along the coast.

The correlative sediments of this relief development have been united in the Barreiras Group (M a b e s o o n e, C a m p o s e S i l v a & B e u r l e n, 1972), subdivided into a number of formations, mentioned below, with the following origin and depositional environments deduced from sedimentological analyses:

- (a) Nova Iorque beds and Campos Novos Formation, deposited in depressions of the Sulamericana Surface, of lacustrine origin, not included in the Barreiras Group;
- (b) Serra do Martins, Serra da Tabatinga, Jaicós Formations and Marituba Member of Piaçabuçu Formation, correlated to the depositional phase of the Sulamericana Surface, chiefly of fluvial origin;
- (c) Guararapes, Moura and Capim Grosso Formations, correlated to the Sertaneja and Tabuleiros Surfaces, of mixed origin: alluvial fans from dry climates, sand- and mudflows, and semi-arid fluvial deposits (intermittent rivers);
- (d) Macaiba Formation, local accumulations in grabens, by fluvial transport, prior to the Upper Terrace period of the Paraguaçu Cycle;
- (e) river and coastal terraces, representing the various phases of the Paraguaçu Cycle;
- (f) white sand series, probably actually in formation.

These sedimentary units are separated by erosional unconformities. On the surfaces of these interruptions soil

profiles developed, studied by F a l c ã o & M a b e s o o n e (1975), and subdivided as follows:

- (I) kaolinic soil, at the base of the Serra do Martins Formation and equivalent units, a senile tropical soil;
- (II) Cuité Soil, on top of the above mentioned formations, represented by a mature tropical lateritic soil with ironstone crust;
- (III) Riacho Morno Soil, on top of the Guararapes Formation and equivalent units, developed as an almost mature lateritic soil;
- (IV) Potengi Soil, covering the Macaiba Formation and river terraces, a rather young tropical red-yellow podsol.

The denudation planes of northeastern Brazil can be interpreted as peneplanes and pediplanes according to the definitions of B a u l i g (1956). Concluded from sedimentological analyses the correlative deposits of the Sulamericana Surface are of fluvial origin, the surface at that time being a peneplane. The correlative deposits of the Sertaneja and Tabuleiros Surface show sedimentation in semi-arid environments, indicating that the surface is essentially a pediplane.

FOSSILS

The fossil content of the Cenozoic sediments of northeastern Brazil is rather scarce, with the exception of the fauna of giant mammals typical of the continent.

In the Nova Iorque beds, A g u i a r (1971) mentions the existence of Eocene plants and fishes. In the Campos Novos Formation silicified molds of gastropods (*Ampularia* sp.)

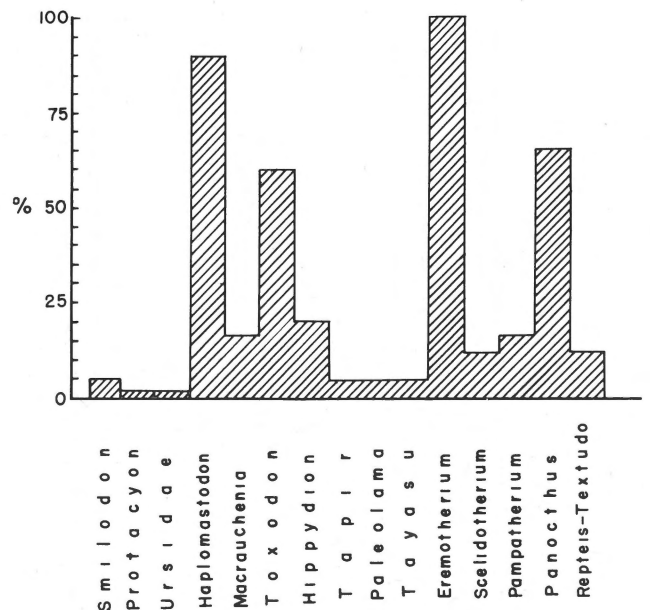


Fig. 2
Frequency diagram of Late Pleistocene faunal groups.

occur which are not determinative of a certain age. In the other lithostratigraphic units the almost entire absence of fossils is conspicuous since the kind of sediment is apt to preserve them. Only some silicified wood fragments have been described from the Guararapes Formation in Sergipe State, and some pollen from the same unit in Rio Grande do Norte State.

The rather abundant fauna of mammals is found in water-holes, associated with rudaceous deposits with an arkosic matrix. This fauna is attributed to the Late Pleistocene. The frequency index of the faunal groups (fig. 2) found in paleoterraces, thus belonging to one of the phases of the Paraguaçu Cycle, indicates the population density of the various dominant species in the region. This fauna abruptly disappeared from the region due to reasons to be explained below.

Associated with this mammalian fauna, various species of fresh-water gastropods have been found, which were described by Muniz & Ramirez (1971), together with unrecognizable impressions of leaves and twigs. The age of these fossils is Quaternary, but cannot be further specified.

SEQUENCE OF EVENTS

Pre-Albian

The regional unconformity at the base of the Early Cretaceous sequences developed between Middle Triassic and Late Jurassic (taking about 70 million years) with thick red tropical soils (Gondwana Surface). When the Reactivation started these soils were removed and deposited in sedimentary basins, often grabens, as a red clayey lithostratigraphic unit constituting the base of the sequence. After the complete removal of these clayey soils the bedrock produced more sandy deposits whose sedimentation lasted until about Aptian times. The structural rearrangement and the significant sedimentation, with sequences up to some thousands of metres, did not permit the formation of extensive planation surfaces as suggested by Tricart & Cardoso da Silva (1968). Interpretation of lithology and fossils from this period has been effectuated by Petrobrás and the results have been published in various papers; in these sequences exploitable oil and salt accumulations are rather frequent.

Albian – Oligocene

At the end of the Albian, sedimentation in the interior of the area studied had almost finished. The last sedimentary unit is a sandstone sequence of fluvial origin which must have covered most of the area (Ghignone, 1972). From Middle Cretaceous times on, the faulting movements became less intense except along the coast, whereas in the interior a phase of epirogenetic uplift started. This uplift was very slow permitting the development of a soil profile without rupture of the equilibrium, resulting in an almost non-depositional period. Only in local depressions some lacustrine sedimenta-

tion took place, now preserved as the Nova Iorque beds and the Campos Novos Formation. Meanwhile in the coastal sedimentary basins a marly limestone to shale sequence developed (Mura & Barbosa, 1972).

Thus, between Albian and Oligocene almost no coarse to medium clastic material reached the sea, this being retained on the continent. Such a period points to a certain tectonic stability and/or exuberant vegetation under favourable climatic conditions. Under such circumstances a thick soil profile could develop, remainders of which have still been preserved at some places, where covered with younger sediments. This is the so-called kaolinic soil. Since kaolinite is the most abundant clay mineral, occurring together with simple oxides, the climate during their formation must have been fairly humid and warm. The Sulamericana Surface then was a peneplane with an undulating relief caused by down-wearing.

Oligocene – Pliocene

At the end of the Oligocene and the beginning of the Miocene, the epirogenetic uplift became stronger. As a consequence the equilibrium was disturbed and an erosional phase could start. The residual complex of the soils was transported chiefly by fluvial action, and deposited in the river valleys, along the coast and in the coastal basins (Serra do Martins Formation and equivalents; fig. 3A). These latter basins show an essentially sandy deposition during the Early Miocene. At the same period basaltic magma appeared at the surface; Miocene basaltic lava flows are known from Paraíba and Rio Grande do Norte States. Even volcanic plugs appear preserved in the present landscape. Towards the end of the Miocene and during the Pliocene, a tectonically quiet period dominated again. On top of the correlative deposits of the Sulamericana Surface a new soil profile developed, still partly preserved as the lateritic Cuité Soil, characterized by its ironstone crusts.

Pliocene – Holocene

The end of the Pliocene is marked by the beginning of the glaciations. From that time on, climatic oscillations determined soil formation, sediment deposition and relief development. Generally, the effects of the high-latitude glaciations are not very evident in tropical areas, northeastern Brazil being no exception. Besides, only the last two glaciations were very intensive, the earlier four produced minor effects. This means that, at least until the Middle Pleistocene, no marked climatic oscillations could be detected in the area studied. However, successive phases of soil formation and sediment deposition existed as is proved by the accumulation of the Guararapes Formation and its equivalents (figs. 3B, 4). The detritus was derived from the residual complex of the Cuité Soil and from the ancient sediments that became exposed after the removal of this soil.

The removal of such a great quantity of detritus caused the development of the Sertaneja erosion Surface, the most important surface of the interior of northeastern Brazil. This

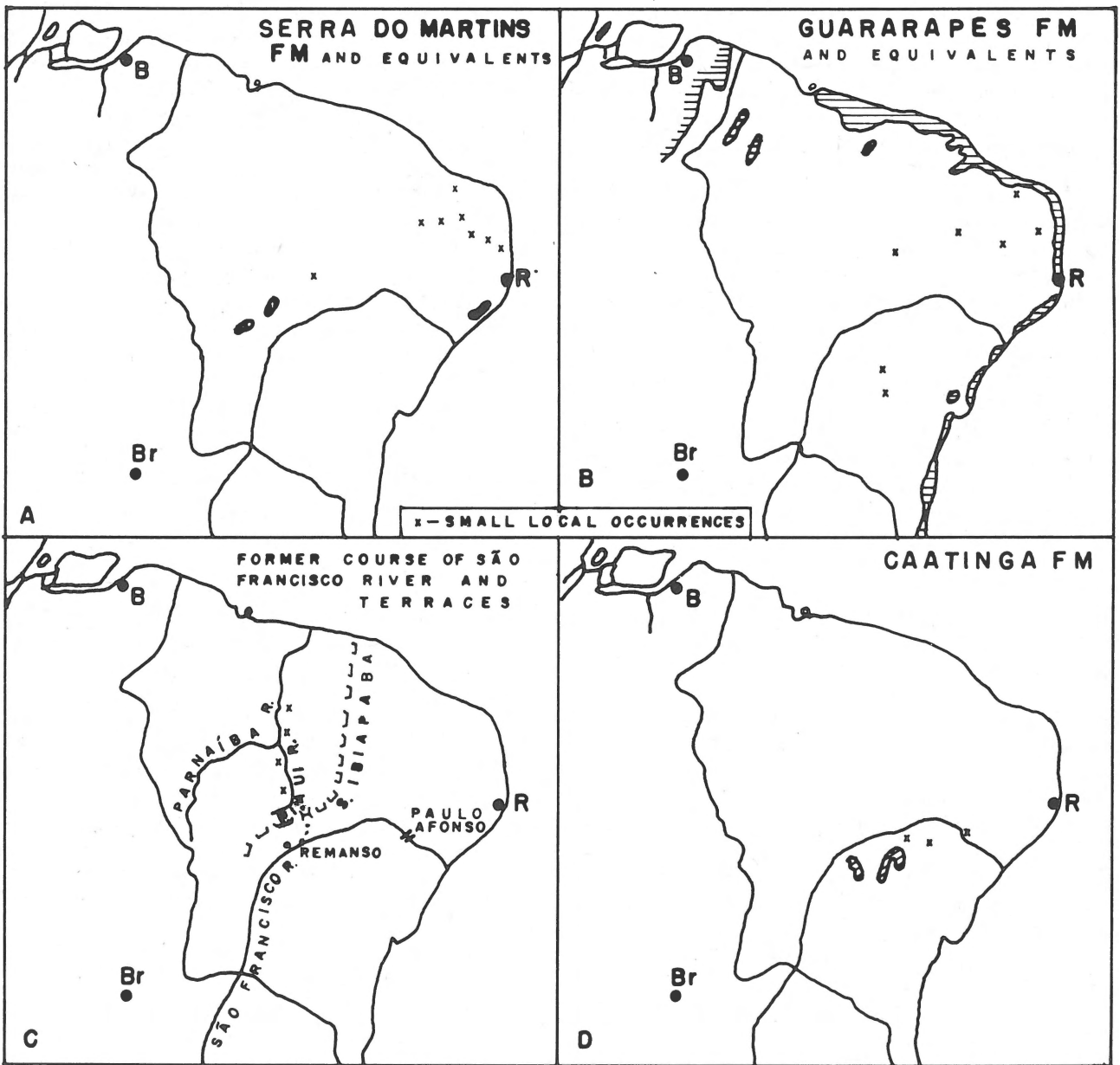


Fig. 3
Occurrences of correlative deposits and former São Francisco river course.

surface developed chiefly on crystalline basement rocks, whereas the detrital equivalent occurs along the coast as the Tabuleiros Surface. However, the short period (about 2 million years) available for the formation of such an extensive erosion surface suggests the following facts:

(1) the material eroded was chiefly sedimentary, the Middle Cretaceous sandstones and the Sulamericana Surface correlatives;

(2) the removal halted on the crystalline basement rocks which presented already a more or less flat surface.

That is why the Sertaneja Surface is supposed to be only the exhumed Gondwana Surface, reappearing after the

removal of an extensive sediment cover and the dissection of the former Sulamericana Surface (fig. 5). The exhumed surface has later been slightly modified by back-wearing processes under semi-arid to arid climatic conditions. On top of the Guararapes Formation and the other rocks outcropping at that time, another soil profile developed (fig. 4). This Riacho Morno Soil is a not completely mature red tropical soil with initial ironrust formation; its development must have been interrupted during periods of sediment removal, so that more profiles, one superimposed on the other, with or without transported sediment between them, may exist. A few localities indeed show this feature. This period with

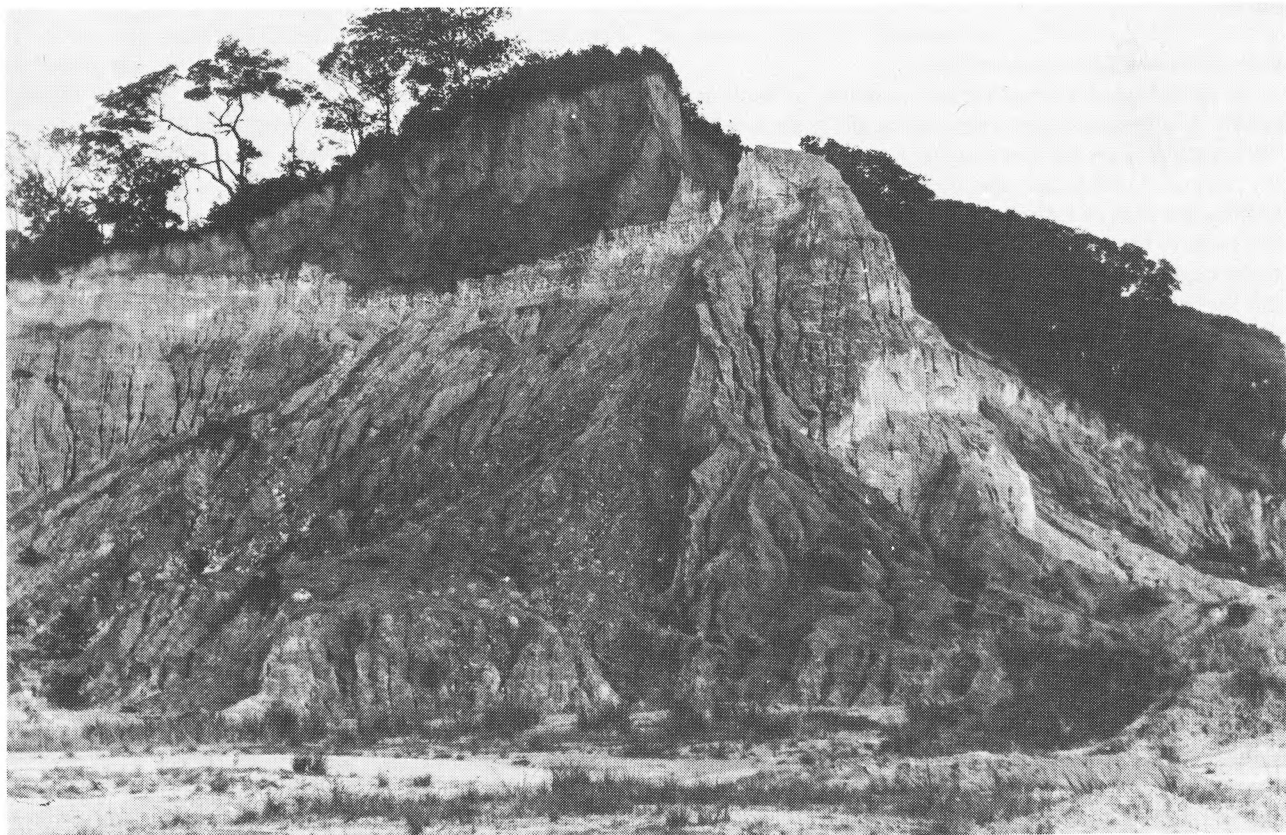


Fig. 4
Guararapes Formation (lower part); Riacho Morno Soil (white band) and Potengi Soil (top) – Road BR-101, Macaxeira, Recife.



Fig. 5
Sertaneja Surface, in the background Araripe plateau (remainder of Sulamericana Surface) – Araripina, Pernambuco.

slight climatic oscillations is supposed to have continued until about Mindel = Illinoian times.

At just about this latter period, a number of faults in the coastal area became reactivated, causing the grabens in which the principal rivers are now flowing. *Tricart & Cardoso da Silva* (1968) also mention the reactivation of the well-known fault of Salvador, although these authors suppose the event to have occurred somewhat later. Anyhow, in these faulttroughs part of the Riacho Morno Soil was deposited as the kaolinic Macaiba Formation. Its level came almost up to that of the Tabuleiros Surface.

Besides these faulting movements in the coastal area, some tectonic activity also occurred in the interior, chiefly a certain tilting towards W of the Piauí-Maranhão Basin, as has been suggested by *Beurlen* (1970 and *Projeto RADAM* (1973). This had its consequence on the river courses of the region. As can be observed on the map (fig. 1), the São Francisco river initially flows to the north and then bends abruptly towards the east, in the north of Bahia State, following in a more or less south-easterly direction towards the Atlantic Ocean. This last stretch runs through a valley which — although wide — is full of rapids and small cataracts and even contains the famous waterfalls of Paulo Afonso (with a height of about 100 m). The S-N course is evidently a mature valley with extensive alluvial deposits, whereas the lower course appears to be very young. Thus, formerly this São Francisco river must have run another way towards the ocean, a fact already suggested by *Moraes Rego* in 1936 and later by other authors (see summary in *Beurlen*, 1970, p. 358). This former course probably followed the wide valley of the actual Piauí river, towards the Parnaíba river (fig. 3C).

In this valley thick and large pebbly terraces occur, too extensive for a river of the present size. Besides, the upper course of this river is separated by a gap from the São

Francisco river system, N of Remanso (Bahia State). One of the present authors (*Rolim*) found in this gap a pebbly deposit similar to those of the actual S-N course of the São Francisco. Thus this latter river originally did run northward through the Piauí and Parnaíba river valleys towards the Atlantic Ocean, where a large delta exists at the mouth. The pebbly terraces of the Piauí river can thus be explained, also because immediately north of the mentioned gap, the valley is cut into the conglomeratic Serra Grande Formation of Late Silurian — Early Devonian age. When the São Francisco river course became interrupted, the waters were not immediately diverted into another direction so that a certain damming up occurred, forming a number of shallow lakes in the Remanso-Petrolina region and more to eastward. In these lakes a locally calcareous deposit could form, the fresh-water Caatinga Limestone, dated as Quaternary by its fossils (fig. 3D). This unit is calcareous where ancient limestones crop out nearby, and more clastic in other areas. Comparing the erosion and denudation levels of the area, one must suppose that the São Francisco became diverted at about the Mindel glaciation time.

The last two glacial periods (Riss = Early Wisconsinian or Iowan? and Würm = Late Wisconsinian) caused stronger effects even in tropical areas, chiefly by more vigorous climatic oscillations and changing sea levels. Thus, in the Sertaneja and Tabuleiros Surfaces river incision and filling took place, resulting in the polyphase Paraguaçu Cycle. Its Upper Terrace phase extended far into the interior, where extensive pediments developed although these did not constitute pediplanes. During this phase also the famous inselbergs (bornhardts) were formed (fig. 6). All this shows that the climate had become extremely dry, which occurred especially during the severe Riss glaciation. *Vander Hammen* (1972) in his study about the Amazon region, pointed to the fact that during the glacial periods the climate of the region

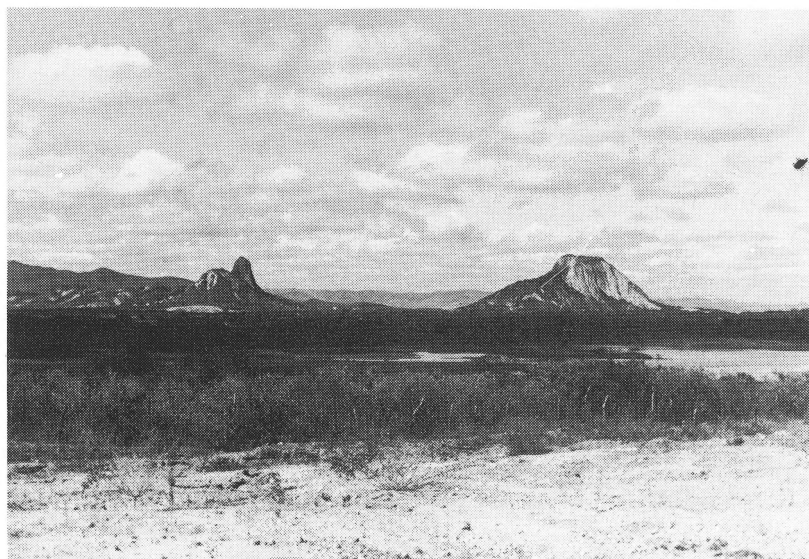


Fig. 6
Inselbergs on Upper Terrace level of Paraguaçu Cycle — Patos, Paraíba.

was drier and colder. This extreme dryness must have been the cause of the disappearance of the giant-mammal fauna of the area studied.

The less intense Würm glaciation did not have the same effect, its terraces and pediments being much smaller and having no bornhardts formed. Its deposits belong to the Middle Terrace phase of the Paraguaçu Cycle.

Finally the Lower Terrace phase is represented by river and coastal terraces at 2-3 m above mean level. The terraces are not pebbly and occur only near the river mouths, so that they could not be indicated on the map (fig. 7). The age of this terrace is Holocene, possibly related to a higher sea level stand, a few thousands of years ago.

On top of the Macaiba Formation and the upper and middle river terrace levels, there occurs another soil profile, the Potengi Soil, being a tropical red-yellow podsol in its younger stage. Where the former Riacho Morno Soil does not possess a cover of sediment, the Potengi Soil is developed directly upon it, thus presenting a complex soil profile (fig. 4).

The coast actually shows a transgression with the formation of estuaries and the development of mangrove swamps more landward in quiet places. More inland, there is also a cover of white sands present, the leaching product of sandy weathering complexes, partly removed to its actual position on slopes and at the bottoms of small river valleys. As this white sand series covers the Potengi Soil with a sharp transition, it is supposed to be the beginning of a new sedimentation phase.

CONCLUSIONS

From the interpretation of geological data and the sequence of events, a number of interesting conclusions about the Late Cretaceous – Cenozoic history of northeastern Brazil may be drawn. These conclusions refer to the paleoclimate, paleogeography and paleontology.

Paleogeography and paleoclimate

At the end of the Albian period the landscape of northeastern Brazil was almost entirely determined by the Albian fluvial sandstones which covered most of the area. This means that the greater part of the relief was moderately flat, possibly with some mountains composed of crystalline basement rocks occurring as elevations. On iron-poor, chiefly crystalline rocks a kaolinic soil developed whereas on the sandstones only regosols formed. Besides, the extensive sandstone plains could not support a dense vegetation which was restricted to the steppes. Meanwhile, the area passed through a phase of slow epirogenetic uplift with doming without the destruction of vegetation, and thus with uninterrupted soil formation. In this way the area passed through a biostatic phase in the sense of Erhart (1967) in which, under certain vegetation cover and consequent soil formation almost only soluble material could be transported to the ocean. Because most of the area had a steppe vegetation part

of the clay fraction could also be removed, resulting in a sedimentation of marly limestones and shales in the marine coastal basins. Some of this clay was also deposited in shallow lakes and ponds.

The epirogenetic uplift with doming became more intense towards the Oligocene-Miocene transition. At this time a period of erosion started with destruction of the vegetation, removal of the residual complexes of the soils, transportation of these through river valleys and deposition of the detritus at quiet places, maybe in the proper river valleys, along the coast and in the marine coastal basins (resistatic phase of Erhart). Eruptions of basaltic lavas occurred, locally covering the lacustrine deposits of the former phase. This event lasted until about the end of the Miocene. The landscape (Sulamerica Surface) showed a planated surface at that time. On its correlative sediments a tropical lateritic soil developed during the greater part of the Pliocene, attaining a mature stage and characterized by an ironstone crust. As the underlying deposits were chiefly sandy the vegetation remained that of a steppe.

From the end of the Pliocene the alternations of glacial and interglacial periods provoked oscillations of the climate which showed drier and cooler phases during the glaciations. Thus there was also a strong alternation of resistatic and biostatic phases. During the glacial periods a strong erosion and denudation took place removing the lateritic soils, the extensive sediment cover and part of the crystalline basement rocks. The detritus was deposited in the coastal area and in some river valleys and depressions of the interior as the Guararapes Formation and its equivalents, constituting the Tabuleiros Surface. During the interglacial periods a soil developed on these deposits. The Sulamerica Surface became strongly dissected, much of the ancient sediment was removed and the ancient Gondwana Surface on the crystalline basement (Sertaneja Surface) became exhumed. Because the intensity of these earlier glaciations is not supposed to have been great, almost no distinction could be made between these, with exception of Riacho Morno type soils intercalated within the Guararapes Formation, found at a few places. During this period the fauna, chiefly of giant mammals must have entered the area. At the end of the period some tectonic activity took place, with filling up of grabens and deflection of river courses.

Starting with the Riss glaciation the climatic oscillations became more evident, resulting in incision and accumulation of river valleys in the Sertaneja and Tabuleiros Surfaces. The climate of the area was very dry, especially during the Riss glaciation, resulting in extensive pediment and inselberg formation and the disappearance of the greater part of the mammal fauna from the area. The Würm glaciation, being less intense, caused minor effects of the same type, with the exception of inselbergs. The youngest terrace phase is due to minor climate oscillations a short time ago. On the sediments a young tropical podsol soil developed.

Actually, a new erosion phase started with the deposition of white sands.

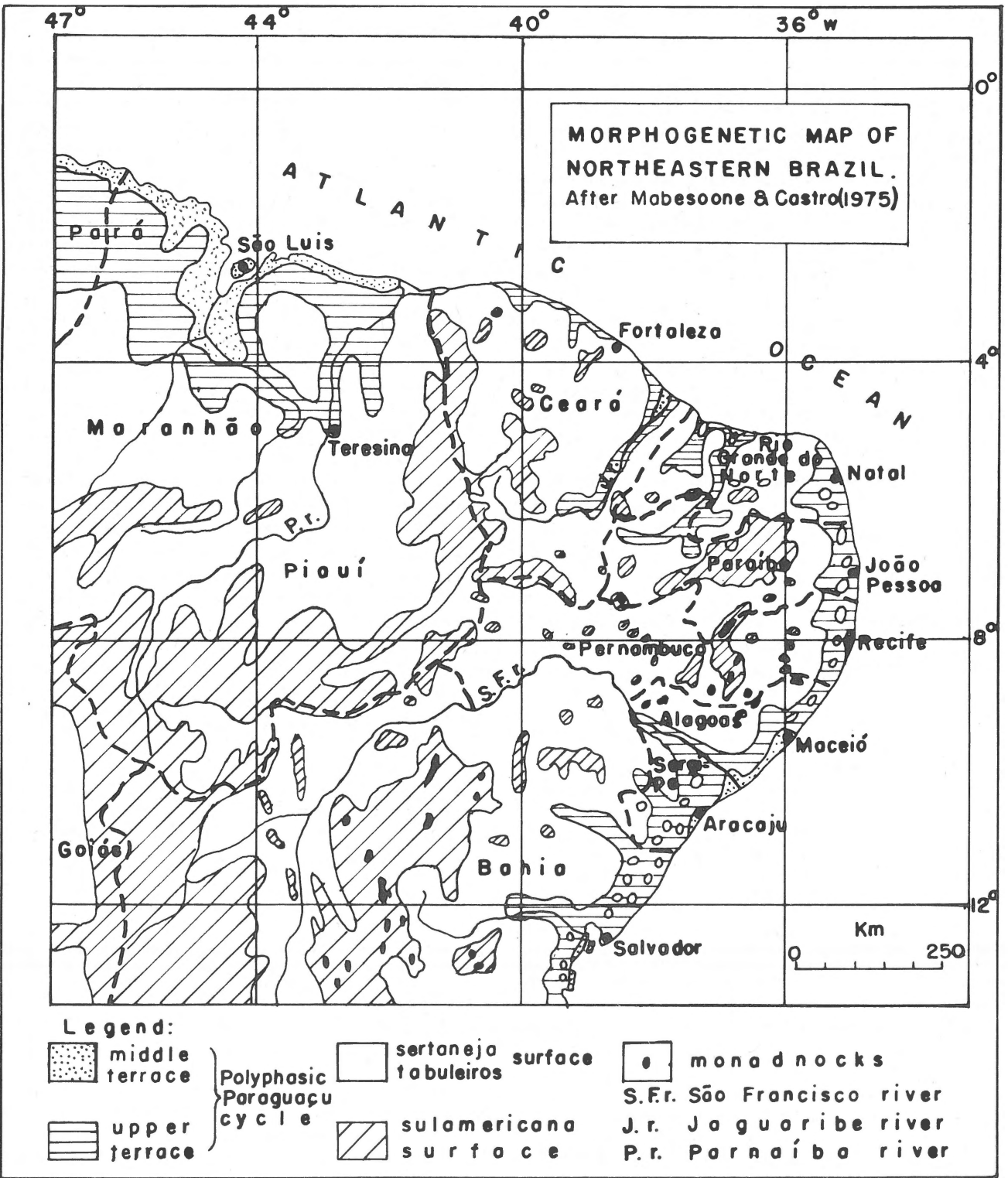


Fig. 7
Morphogenetic map of northeastern Brazil.

Paleontology

The fossil content of the Quaternary continental deposits of northeastern Brazil constitutes a factor supporting the interpretation of the regional paleogeography, paleoclimate and paleoecology (Rolim, 1974).

During the Tertiary and the Early Pleistocene the ecological conditions were still not favourable to the implantation of a fauna of great herbivores (Edentata and Proboscidea). The former landscape of cuestas and slopes in sedimentary rocks did not permit the formation of a permanent dense vegetation cover, able to maintain such a fauna. This is testified by the absence of these fossils in the Guararapes Formation and older deposits in spite of the good fossilization possibilities. Only near the end of the Guararapes period (Middle Pleistocene) the geomorphological conditions permitted the invasion of a more dense vegetation (savannah), creating a new habitat for the herbivores. This fauna was already present in more distant areas to the centre and south of the country, migrating northward only in the Pleistocene.

The strong back-wearing processes of the dry Riss glaciation left only small water-holes in the pediments and river terraces, where the fauna concentrated when water and vegetation became scarce. This extreme dryness caused thus the disappearance of the greater part of the fauna from the area, chiefly the giant forms the remains of which accumulated in the above mentioned water-holes. The lack of precipitation broke the equilibrium, with the disappearance of the short-lived savannah vegetation and the introduction of the semi-arid caatinga (shrub) vegetation in the area, which did not support the habitat of the giant-mammal fauna.

Final remarks

In Table I the chief events in northeastern Brazil during the period discussed here have been summarized. In figure 7 the principal relief elements actually present in the area have been presented, as a morphogenetic map.

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