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# Stratigraphic division of the Brazilian continental margin and its paleogeographic significance

By

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With 5 text figures

## ABSTRACT

The stratigraphy of the Brazilian Continental margin has been known by surface mapping and by subsurface surveys. The sedimentary column of almost all the basins were divided into formal lithostratigraphic units (groups, formations, and members), of incontestable operational value but not adequate for regional studies aiming paleogeologic reconstructions. The use of an unique set of units pertaining to the sequence rank can be extended through the entire margin and results in natural division that is more informative in terms of tectosedimentary relationship and more adequate for paleogeologic reconstructions. From this point of view the sedimentary column of the Brazilian continental margin can be divided into four sedimentary sequences whose given names are evocative of the dominant basinal environments in which they were deposited:

Sequence of the Continent – (Donjoanian), mainly clastics deposited in fluvial-lacustrine and eolian environments in tectonically quiescence continental interior basins.

Sequence of the Lakes – (Bahian), clastics deposited in fluvial-deltaic-lacustrine environment in tectonically active rift-type of basins.

Sequence of the Gulf – (Alagoan), evaporites and associated clastic sediments deposited in marine-restricted and transitional environments in relative quiescence tectonic conditions.

Sequence of the Sea (Albian to Recent), marine clastics and carbonates of shelf and slope systems and carbonates of shallow platform systems, deposited in a progressively subsiding margin.

Lower Cretaceous and Upper Cretaceous-Lower Tertiary dominantly basaltic igneous rocks are intercalated in the stratigraphic sections of some basins. The sedimentary sequences are related to the evolutionary stages that form the geologic history of the Brazilian continental margin.

Particular situations in each one of these stages can be inferred from the distribution, facies characteristics, and thickness variations of the sequences.

## KURZFASSUNG

Die Kenntnisse der Stratigraphie des brasilianischen Kontinentalrandes beruhen auf Kartierungen und Bohrungen. Die Sediment-Abfolgen in fast allen Becken wurden zunächst lithostratigraphisch eingeteilt (Gruppen, Formationen und Schichtglieder); dies ist ein wichtiges lokales Arbeitshilfsmittel, jedoch nicht ausreichend für palökologische Rekonstruktionen.

Die Verwendung von einheitlichen Sequenzen, denen die einzelnen Abfolgen zugeordnet werden, gestattet eine Behandlung des ganzen Kontinental-Randes. So lassen sich besser die tecto-sedimentären Beziehungen aufzeigen und geo-

dynamische Rekonstruktionen durchführen. Unter diesem Gesichtspunkt wurde die kretazische Sedimentabfolge des brasilianischen Kontinentalrandes in 4 Sequenzen eingeteilt; namengebend war die Region mit der jeweils typischen Ausbildung.

1. Kontinentale Abfolge (Donjoanian); vorwiegend klastisch, abgelagert im fluviatilen-limnischen oder äolischen Milieu in kontinentalen Becken unter tektonischer Ruhe.
2. See-Abfolge (Bahian); klastische Ablagerungen in einem fluviatilen-deltaischen Bereich unter tektonischer „Rift“-Aktivität.
3. Abfolge eines Golfes (Alagoan); Evaporite und begleitende klastische Sedimente abgelagert unter eingeschränkt marinen Bedingungen bei relativer tektonischer Ruhe.
4. Marine Abfolge (Alb bis rezent); marine Klastika und Karbonate eines Schelf- und Slope-Systems sowie einer

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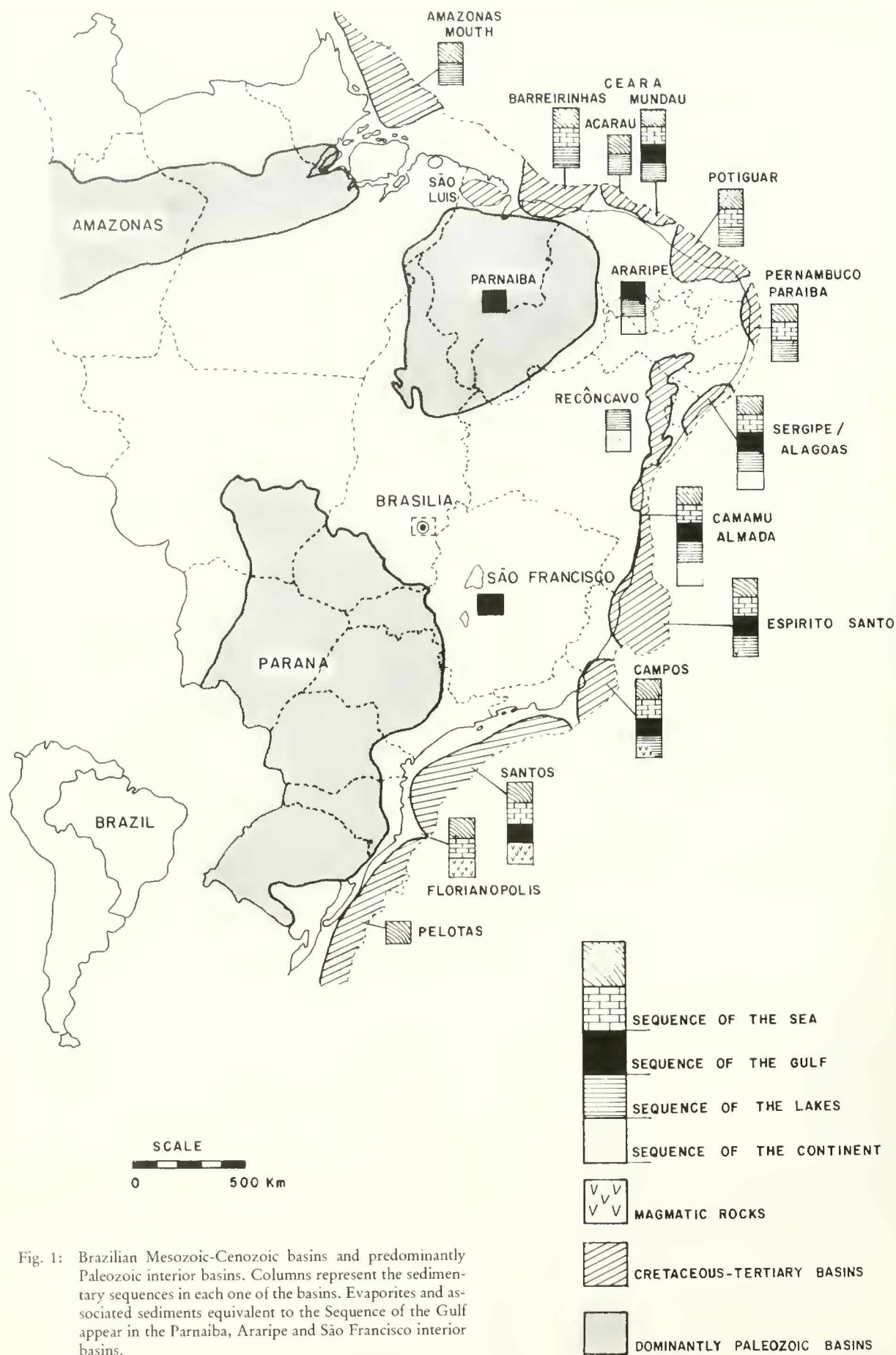


Fig. 1: Brazilian Mesozoic-Cenozoic basins and predominantly Paleozoic interior basins. Columns represent the sedimentary sequences in each one of the basins. Evaporites and associated sediments equivalent to the Sequence of the Gulf appear in the Parnaíba, Araripe and São Francisco interior basins.



flachen Karbonat-Plattform, unter fortschreitender Absenkung.

In manchen Becken sind in der Unterkreide und in der Oberkreide bis zum tieferen Tertiär basaltische Gesteine eingeschaltet. Die Sedimentfolgen stehen in Beziehung zu den

jeweiligen Entwicklungsstufen während der Ausbildung des Brasilianischen Kontinental-Randes.

Sonderentwicklungen während dieser Stadien können aus der Faziesverteilung und den Mächtigkeits-Schwankungen abgelesen werden.

## 1. INTRODUCTION

Stratigraphic data of the Brazilian marginal basins (Fig. 1) were derived from surface mapping and principally from sub-surface surveys. These data were obtained in a succession of phases closely related to the different stages of oil exploration carried out by Petrobras, the Brazilian oil company. In an initial stage, before and during the 1950's, most of the stratigraphic information was obtained by direct observation and description of outcrops in basins, such as Reconcavo, Potiguar, Sergipe/Alagoas, Pernambuco/Paraíba and Almada (Fig. 1) that lie partially in the emerged continent and are not entirely covered by Cenozoic sediments. Later on, in the 1960's and 1970's, a large number of wells – at present totalling about 500 –, drilled in the onshore and/or offshore portions of all the marginal basins, improved substantially the stratigraphic knowledge.

By combining the punctual stratigraphic data obtained by drilling holes, with multichannel reflection seismic profiles – distributed in a 300 000 km network – it is possible to delineate the spatial distribution of the main stratigraphic features. In addition, seismo-stratigraphic analyses permit to infer that the tectono-sedimentary processes along the Brazilian continental margin occurred in a systematic manner. As a consequence they can be arranged in a succession of evolutionary stages that are common to all the basins.

Although formal lithostratigraphic units (groups, formations and members), of incontestable operational value, had been proposed for practically each of the Brazilian marginal basins (PAMPLONA, 1969; SCHALLER, 1969; ASMUS and others, 1971; SCHALLER and others, 1971; VIANA and others, 1971; SAMPAIO & NORTHFLEET, 1973), these units proved inadequate for regional studies, mainly those dealing with paleogeological reconstructions. A division into large rank stratigraphic units, with clear genetic indications, that could be identified along all the margin and could be effective for interoceanic correlations would be obviously more adequate.

Along all the Brazilian margin, thick sedimentary prism occurs continuously; only locally, in the site of interbasinal highs, appear important sedimentary gaps and thinings. This sedimentary prism can be divided into discrete intervals of large units, discriminated from each other by faciological indications which, in turn, disclose the environment in which they were deposited. Such a division has been shown helpful for more accurate tectono-sedimentary analyses and for more comprehensive regional paleogeographic and paleogeological reconstructions.

## 2. STRATIGRAPHIC DIVISION OF THE BRAZILIAN MARGINAL BASINS

The history of the stratigraphic division of the Brazilian marginal basins in major units or sequences, in the concept of SILBERLING & ROBERTS, cited by GARY and others, 1973, ("a geographically discrete succession of major rocks units that were deposited under related environmental conditions"), began in 1970 with a paper by ASMUS & PONTE, published in 1973. These authors defined three non-formal units on the basis of their relative stratigraphic position and in accordance with the inferred dominant environments in which they were deposited: 1) Pre-Aptian continental sequence; 2) Aptian middle evaporitic sequence; and 3) Upper Cretaceous-Recent upper marine sequence.

ASMUS (1975) and PONTE & ASMUS (1976; 1978) associated the results of their own studies on the Brazilian marginal basins with general speculations of DICKINSON (1974) and FALVEY (1974) for Atlantic type of basins. As a result, those authors related the stratigraphic units of the division considered at

that time (1 – Jurassic fluvial-lacustrine basal sequence; 2 – Pre-Aptian fluvial deltaic lacustrine lower sequence; 3 – Aptian evaporitic and transitional middle sequence; and 4 – Upper Cretaceous to Recent shallow platform and open marine upper sequence) to regional tectonic features. Thus, the sedimentary infilling of the basins could be linked to the succession of tectonic environments that mark the evolutionary processes of the Brazilian continental margin: pre-rift, proto-oceanic, and oceanic.

In a subsequent step, ASMUS (1979) gave to the sequences names that are evocative of the main basinal environments in which these units were deposited: Sequence of the Continent, Sequence of the Lakes, Sequence of the Gulf, and Sequence of the Sea (Fig. 2).

The present paper intends to propose in a formal way, a lithostratigraphic division for the entire Brazilian continental margin.

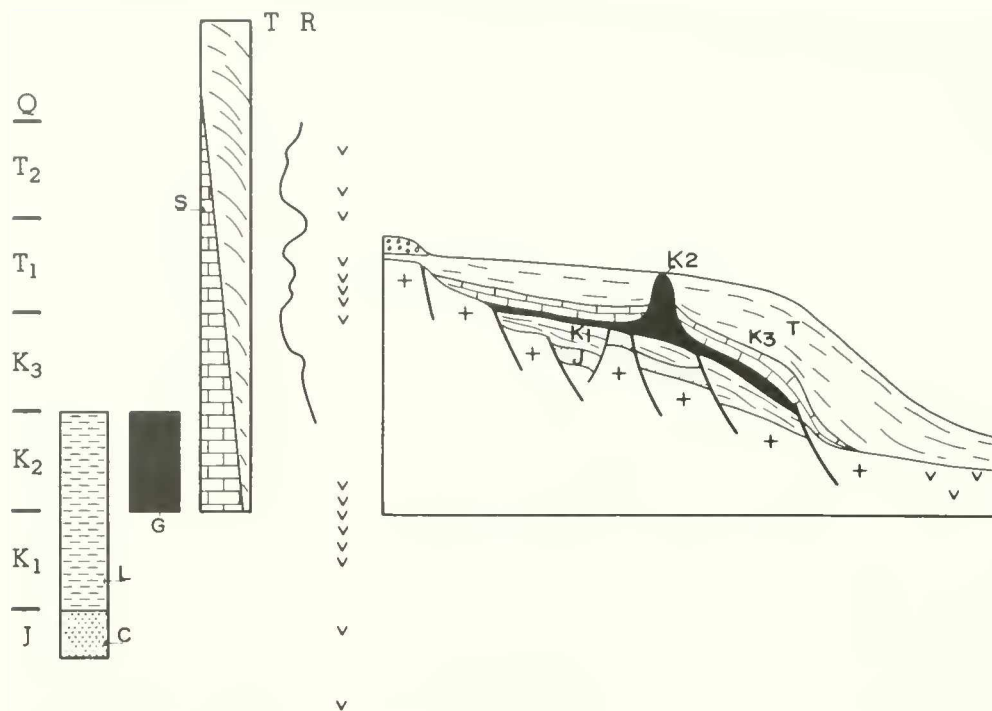


Fig. 2: Stratigraphy of the Brazilian marginal basins. Columns represent the sedimentary sequences (C = Continent; L = Lakes; G = Gulf; and S = Sea) and their position in the stratigraphic column (J = Donjoanian; K1 = Bahian; K2 = Alagoan; K3 = Albion to Maastrichtian; T = Tertiary; Q = Quaternary) the curve to the right of the column represents the main periods of transgression (T) and regression (R) that occurred during the deposition of the Sequence of the Sea. v represents intercalated magmatic rocks. The section to the right shows the distribution of different sequences in an ideal profile of the continental margin.

### 3. DESCRIPTION OF THE SEQUENCES

#### 3.1 SEQUENCE OF THE CONTINENT

This sequence consists of reddish lutites with intercalations of arkosic sandstones in its upper part, and fine to coarse grained sandstones in its upper part. The thickness of the sequence varies from 200 m to 500 m and its lithological characteristics present a striking lateral persistence over large areas. It is well exposed and studied in detail in the Reconcavo Basin which is therefore considered the type-area for this unit. In the Reconcavo Basin the entire sequence corresponds to the Brotas Group that includes the Aliança Formation (lower argillaceous section) and the Sergi Formation (upper sandy section). The Sequence of the Continent is also represented in the Sergipe/Alagoas Basin through the Bananeiras (= Aliança) and Serraria (= Sergi) formations. The Almada Basin is the southernmost area in which this sequence has been recorded. It appears there in an incomplete form since the lower argillaceous section is lacking. The northernmost occurrence of the sequence is not well known. GHIGNONE & NORTHFLEET (1977) suggest that it extends northward as far as the present Potiguar Basin. This suggestion is supported by remnants of a wider distribution preserved in small tectonic interior basins in the northeastern part of Brazil (v. g., Araripe Basin). In the east-west direction it extends as far as 400 km inland.

The Sequence of the Continent correlates with the homotaxial units M'Vone (= Aliança = Bananeiras) and N'Dombe (= Sergi = Serraria), in Western Africa. The distribution of

these units in the West African marginal basins is similar to the distribution of their correlative units along the Brazilian margin. In fact, in the Gabon Basin this sequence appears in its complete form. But, to the south, in the Congo-Cabinda Basin, in the same way as in the Brazilian Almada Basin, only the upper sandy section is present. From the Congo-Cabinda Basin to the south, analogously to the Espírito Santo Basin to Pelotas Basin, in Brazil, there are no records of this sequence (ASMUS, 1975; PONTE & ASMUS, 1978).

On the basis of the facies changes and geographic distribution it is possible to infer that the depositional basin of this sequence was surrounded by extensive topographic highs. These highs supplied terrigenous material that fed the depositional systems of the peripheral basins. MUNNE (1972) pointed out that the reddish argillaceous and the sandstones resulted from a conjugated system of interior lakes and braided streams. The time span in which this sequence was deposited can be assigned as tectonically quiescent.

The Sequence of the Continent has been paleontologically typified in its lower part by minute lacustrine ostracodes of the *Bisulcocypris pricei* biozone. In addition to this species the *B. pricei* biozone contains *B. uninodosa* and some forms of *Metacypris*, *Condonia* and *Darwinula*. The upper section is characterized by the local occurrence of silicified wood referred to as *Dadoxylon benderi*. These fossils cannot be correlated with the standard international time stratigraphic column.



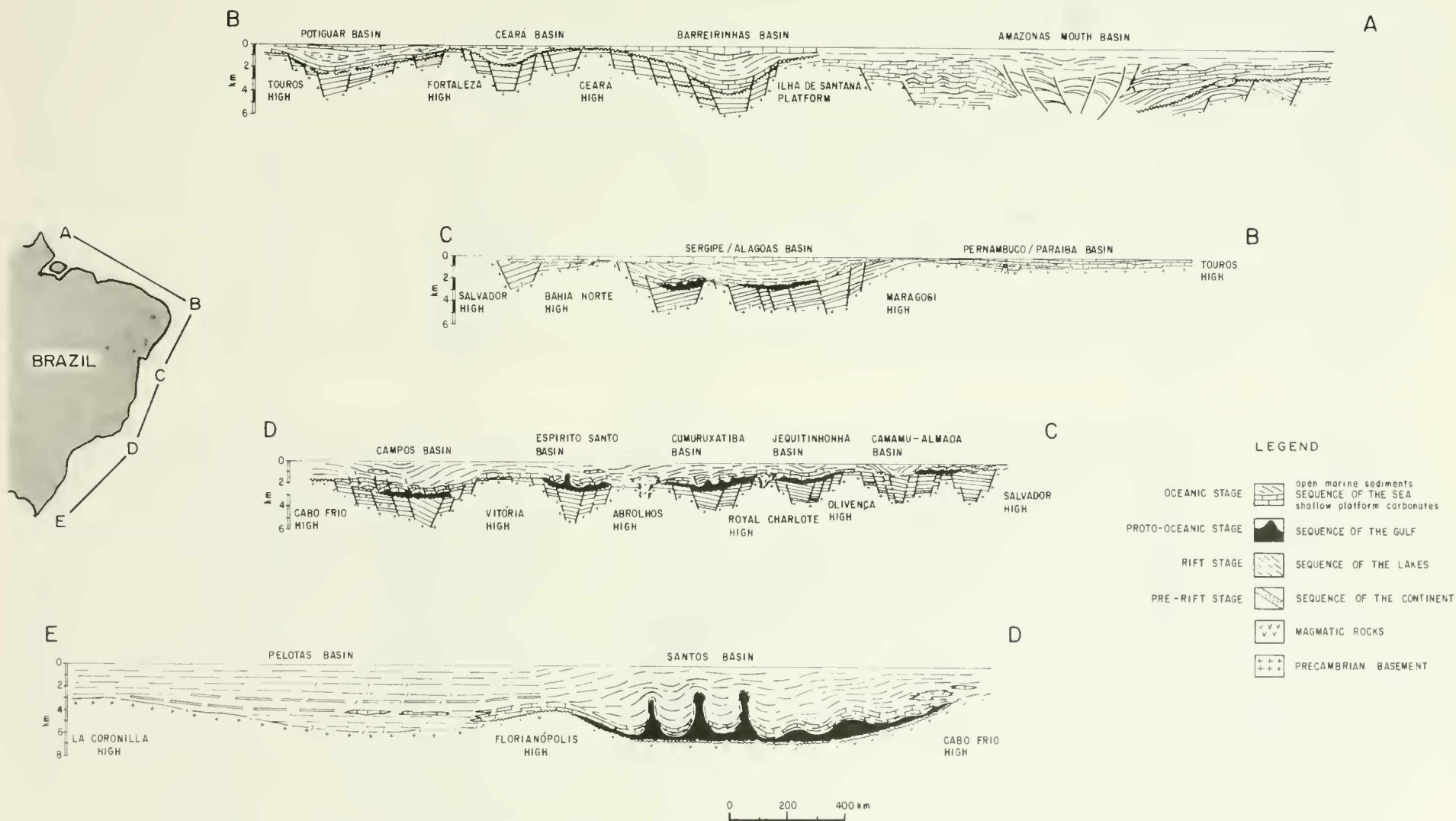


Fig. 3: Longitudinal sections of the various segments of the Brazilian continental margins showing the sedimentary basins, intervening highs, and the distribution of the different sedimentary sequences.

### 3.2 SEQUENCE OF THE LAKES

The main lithology of this sequence includes an alternation of sandstones and shales with local interpositions of thick syntectonic conglomeratic wedges; secondarily, there are disseminated thin limestone beds. The thickness of this sequence varies widely from a few hundred meters to about 6000 m.

This sequence is present along almost all the Brazilian margin (Fig. 3); it has not been observed only in the Pelotas Basin. The areas of the marginal basins in which it occurs are much better delineated than the underlying Sequence of the Continent. This is because the sediments that form the Sequence of the Lakes are circumscribed in tectonic basins bounded by normal faults. It has been deduced that this sequence was deposited syntectonically in rift type of basins submitted to intense tectonic reactivations. This resulted in a wide range of facies variations. Abandoned arms of these rift type basins are still present in Marajó/Amazonas Mouth, São Luiz/Barreirinhas and Reconcavo basins. In the Reconcavo Basin, the area in which the Sequence of the lakes occur represents the type-area for the sequence and the sedimentological model for its deposition. GAMA (Jr.) (1970) suggested a fluvial-deltaic lacustrine model for this sequence in the Reconcavo Basin. Based upon the analyses of surface and subsurface data he identified the various facies that characterize such a depositional environment. This same depositional model has been extended to the Sequence of the Lakes in most of the Brazilian marginal basins. Actually, only the Santos Basin deviates from the suggested model. There the rift type of basin differs from the rifts observed in the other segments of the Brazilian margin, otherwise, sediments that are typical of the Sequence of the Lakes do not occur in the Santos Basin. In the corresponding stratigraphic position of this sequence appears a thin section (about 300 m) of weathered basalts locally overlain by reddish argillaceous sediments containing basalt pebbles. This section is indicative of a predominantly sub-aerial deposition.

Fossils found in this sequence are mainly non-marine ostracodes and pollen; secondarily appear mollusks, fishes and reptiles. A rich fauna of non-marine ostracodes includes as the most important species, according to VIANA and others (1971): *Theriosynoecum varietuberatum* GREKOFF/KRÖMMELBEIN; *Cypridea (Morinoides) candeensis* KRÖMMELBEIN; *Pracypridea brasiliensis* KRÖMMELBEIN; *Cypridea dromedarius* KRÖMMELBEIN; *Cypridea salvadorensis* KRÖMMELBEIN; *Petrobrasias marfinensis* KRÖMMELBEIN; *Coriacina coriacea* KRÖMMELBEIN; *Cypridea (Sebastianites?) sostensis sostensis* KRÖMMELBEIN; *Cypridea (Sebastianites) fida fida* KRÖMMELBEIN.

Fossils, present in the Sequence of the Lakes are not adequate to establish precise correlations with the standard time stratigraphic column. Local stages (Rio da Serra, Aratu, Buracica and Juquia) were defined on the basis of biostratigraphic zoning of the above mentioned ostracode fauna and pollen (SCHALLER, 1969; VIANA and others, 1971; VIANA, 1980).

Several authors, referred to by PONTE & ASMUS (1978), indicated possible correlations between the Brazilian Sequence of the Lakes, mainly in Reconcavo and Sergipe/Alagoas basins, and the Coccobeach Series, in the Gabon and Congo basins (West African continental margin), on the basis of the fossil content and stratigraphic relationship.

### 3.3 SEQUENCE OF THE GULF

The dominant lithologies in the Sequence of the Gulf are evaporites, mainly anhydrite and halite. Locally, as in the Santos and Sergipe/Alagoas basins, potash and magnesium soluble salts are present. In an associate form appear carbonates, euxinic shales, sandstones and conglomerates.

In the eastern Brazilian continental margin this sequence is distributed in a triangular shape whose base, extends for 600 km and coincides with the southern limit of the São Paulo Plateau (Santos Basin). From there toward the north, the evaporitic triangular area narrows progressively until the Sergipe/Alagoas Basin where the evaporitic interval terminates (LEYDEN & NUNES, 1972; LEYDEN and others, 1976). The southern limit of the evaporites lies immediately to the north of a topographic-structural feature (Florianopolis Lineament) (Fig. 3). This feature has been interpreted as the barrier responsible for the restriction in the evaporitic basin (LEYDEN & NUNES, 1972; ASMUS, 1975; LEYDEN and others, 1976; KUMAR, 1979). The northern limit of the salt distribution lies to the south of a crustal block, uplifted during and after the evaporites deposition, which corresponds to the present Pernambuco/Paraíba Basin (ASMUS & CARVALHO, 1978).

Diapirism and other halokinetic structures, having modified the original salt beds, hinder possible estimates of the evaporites actual thickness (Fig. 3 and 4).

Various criteria, stratigraphic (FERNANDES, 1966), paleontological (VIANA, 1980), geochemical and mineralogical (WARDLAW & NICHOLS, 1972), and paleogeological (PONTE, 1971; LEYDEN & NUNES, 1972; LEYDEN and others, 1976) have permitted to correlate the Sequence of the Gulf of the eastern Brazilian margin with the evaporitic interval that occurs in the West African continental margin.

In addition to the large evaporite occurrence in the eastern Brazilian margin, time equivalent evaporites are present offshore in the northern margin (Ceará Basin) and onshore in the Paraíba and Araripe basins (Fig. 1). Evaporites in the northern Brazilian margin are cut by normal faults that delineate rift type of basins. These rift basins characterize one of the initial stages of the Brazilian margin evolution. In the eastern area the Sequence of the Gulf is not particularly affected by tectonism and the rift forming faults were active before the evaporitic deposition.

The Sequence of the Gulf overlies older sequences or Precambrian basement rocks with a unconformity type of contact.

The type area for this sequence is the area in which occur this interval in the Sergipe/Alagoas Basin. In this basin the Sequence of the Gulf has been studied in great detail because of its importance in terms of hydrocarbons, evaporites and sulphur deposits.

The first illustrated Brazilian fossil was a fish specimen *Rhacolepis* collected in the Araripe Basin in sedimentary beds included in what is now called Sequence of the Gulf. In fact fishes are one of the best known fossils in this sequence. They are represented by 18 species that have been found in Araripe, Paraíba and Reconcavo/Tucano basins. Other common fossils present in the scanty paleontological assemblage of this unit are non-marine ostracods and palynomorphs.



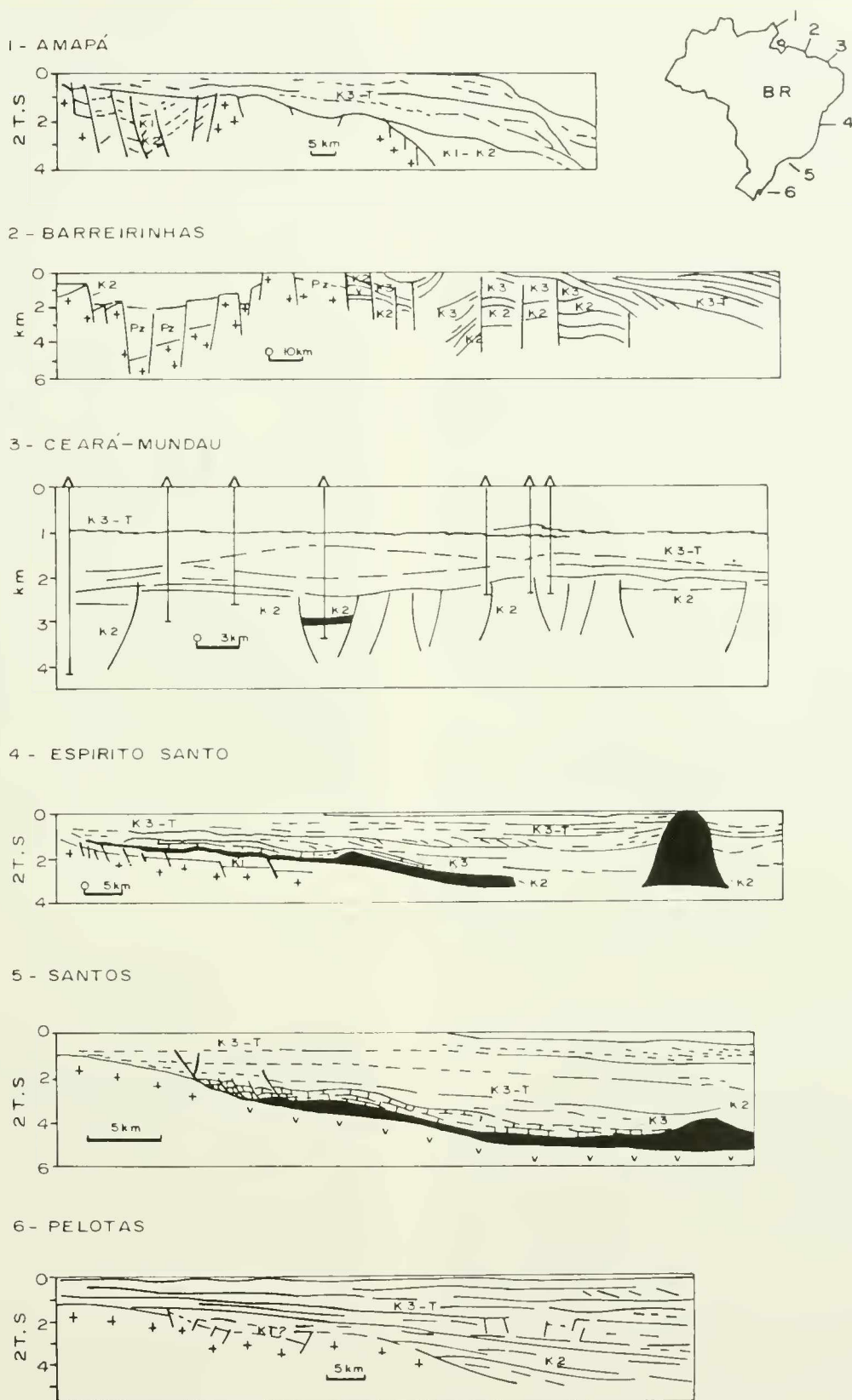


Fig. 4: Geological and seismological cross sections. Faults are pre-Alagoan (Bahian, K1) in the eastern segment of the margin (exemplified by section 4, Espírito Santo), and syn- and post-Alagoan (K2 and K3) in the northern segment (exemplified by sections 2-Barreirinhas and 3-Ceará Mundau).

### 3.4 SEQUENCE OF THE SEA

The Sequence of the Sea includes two sections or subsequences: the lower one, carbonatic, and the upper one, dominantly clastic (Fig. 2).

The carbonatic subsequence consists of calcarenites and calcilutites. Oolitic and pisolitic textures are common in this section. Laterally, in a landward direction the carbonates grade to sandstones which in some places can be coarse grained; in an oceanward direction the carbonates grade to pelitic sediments. The nature and distribution of these facies permit to infer the depositional model as a shallow platform/slope carbonate system with some clastic terrigenous contribution by delta fan systems.

This subsequence is found along all the Brazilian continental margin except in the Pelotas Basin (Fig. 1, 3 and 4), where the terrigenous sediments dominate the whole marine section, and in the Reconcavo Basin.

The clastic marine subsequence consists of shales and sandstones. They were deposited contemporaneously from coastal areas to deep waters, through a complex depositional system which resulted in coastal, shelf, slope and rise facies. Secondly this subsequence contains platform and shelf edge carbonate facies intercalated in or lain on the marine clastic section. In some basins, such as Amazonas Mouth, Ceara and Espirito Santo (Fig. 3), these carbonates can attain considerable thicknesses.

The upper terrigenous subsequence occurs continuously all along the Brazilian margin (Fig. 1 and 3), including the Reconcavo Basin where there is a narrow and thin local occurrence of marine shale.

PORTO & DAUZACKER (1978) and PONTE and others (1978) recognized in the Sequence of the Sea a lower interval dominantly transgressive and an upper interval dominantly regressive. The transgressive phase corresponds to the late Cenomanian to Early Coniacian transgression, as pointed out by ASMUS & PONTE (1973) in the Sergipe/Alagoas Basin, and by REYMENT and others (1975) in northern and western regions of Africa. ESTRELLA-BRAGA and DELLA FAVERA (1978) identified based upon seismo-stratigraphic interpretations in all the Brazilian marginal basins, sedimentological subunits within the Sequence of the Sea. These subunits are discriminated from each other by geological discontinuities delineated by continuous reflectors. According to these authors, the most important discontinuities in the Brazilian margin coincide with the main cycles of sea level changes defined by VAIL and others (1977).

The period of deposition of this sequence was marked by tectonic quiescence and it is less affected by deep seated structural processes than the other underlain sequences. The only exhibited structures are those of geostatic type, caused mainly by gravitational sliding and growth faults.

Contrarily to the underlying sequences, the Sequence of the Sea has a rich fossiliferous record of planctonic foraminifera. Moreover, in the emerged areas of Sergipe/Alagoas, Recife/João Pessoa and Potiguar basins, occur ammonoid faunas, studied by several authors, mainly BEURLEN, K. (1967), BEURLEN, G. (1967; 1968), REYMENT & TAIT (1972), and BENGTSON (1977). These faunas have allowed good correlations with the international timestratigraphic column.

## 4. STRATIGRAPHIC POSITION OF THE SEDIMENTARY SEQUENCES

As cited in the previous section, the lack of marine forms in the fossil assemblage of rocks that comprise most parts of the sedimentary sequences (sequences of the Continent, Lakes, and Gulf) do not permit precise stratigraphic correlations of this part of the Brazilian continental margin with the international time stratigraphic column. Consequently, this non-marine section, by far the most intensively studied due to its economic importance for oil exploration, has been referred to by local stratigraphic names (Dom Joao, Rio da Serra, Aratu, Buracica, Jiquia, and Alagoas), defined by Petrobras geologists (SCHALLER, 1969; VIANA and others, 1971). Recently, BRITO & CAMPOS (1982) analysed critically this division and proposed the stages Donjoanian, Bahian and Alagoan. The equivalence of the sedimentary sequences and the stratigraphic division of BRITO & CAMPOS is, as follows: Sequence of the Continent – Donjoanian; Sequence of the Lakes – Bahian and Alagoan; Sequence of the Gulf – Alagoan.

Concerning the marine sedimentary rocks of the Sequence of the Sea, which extend from the Upper Aptian onwards, it is possible to establish good correspondence with the standard column.

### 4.1 DONJOANIAN STAGE

The Aliança and Sergi formations that correspond to the Sequence of the Continent are sometimes ascribed to the Purbeckian Stage only because of its continental character. In the Petrobras classification, the time span, in which these formations were deposited, have been called Brotas "Stage" or Dom João "Stage". BRITO & CAMPOS (1982) proposed the formal name Donjoanian for the rocks deposited during this time interval. This stage is represented by the sediments of Aliança and Sergi formations in the Reconcavo Basin and by homochronous sediments in other Brazilian basins.

The fossils of the *Bisulcocypris pricei* biozone and *Dadoxylon benderi* have been considered important for the definition of the Donjoanian Stage. However, it is relevant to consider that PINTO & SANGUINETTI (1958) described *B. pricei* and *B. uninodosa* from a locality (Tabuleiro Redondo, Icó, State of Pernambuco), that lies far away from the type-locality of the stage. The time equivalence between the type locality and the far fossiliferous site has not yet been confirmed.

Concerning the silicified trunks of *D. benderi*, MUSSA (1959) described this species based on a wood fragment supposedly collected in the locality of Malhada dos Bois, near



Propriá, State of Sergipe. However, this provenance is doubtful and must be treated with restrictions.

Summarizing, the fossil content of the Donjoanian stage as well as the biozones of its possible fossils need a better definition. Studies have also to be done regarding the real stratigraphic position of the unit, whether in Upper Jurassic or in Lower Cretaceous.

#### 4.2 BAHIAN STAGE

The stratigraphy of the Brazilian marginal basins has been particularly studied in the Reconcavo Basin. In this basin, the units that are now included in the Sequence of the Lakes have been ascribed to Neocomian or Wealden due to their continental characteristics.

Some geologists tend to consider a Reconcavo "Series" divided into local "stages" (Rio da Serra, Aratu, Buracica, and Jiquia). According to this classification the chronos Rio da Serra, Aratu, Buracica, and Jiquia, represent the time span in which the above mentioned sediments were deposited.

BRITO & CAMPOS (1982) reinstated the Bahian Stage, proposed originally in 1870 by HARTT, as follow: "...for the fresh-water beds at Bahia, I would propose the name Bahian group." At that time the term group had a chrono-stratigraphic meaning.

According to BRITO & CAMPOS (1982) all the sedimentary beds between the top of the Sergi Formation and the bottom of the Marizal Formation are included in the Bahian Stage. Thus, the entire Sequence of the Lakes that occurs in the eastern Brazilian margin, from Campos to Pernambuco/Paraíba Basin, are related to this stage.

#### 4.3 ALAGOAN STAGE

GARDNER (1849), after a field trip to the Araripe Basin, was the first to record rocks of the Cretaceous System in Brazil. Results of this trip were initially published in 1841 by GARDNER in collaboration with AGASSIZ who studied Gardner's fish collection.

The rocks described by GARDNER are now included in what is currently called Sequence of the Gulf. This Sequence comprises sediments in onshore and offshore basins. These sediments have been ascribed to Aptian, a position that cannot be confirmed due to the non-marine fossil content in the Sequence of the Gulf. Thus, several authors (v. g. VIANA and others, 1971; PONTE & ASMUS, 1978; VIANA, 1980) have applied the name Alagoas to designate the time span in which the above mentioned units were deposited.

BRITO & CAMPOS (1982) proposed the name Alagoan Stage for the rocks deposited in this time span. The area type, according to the same authors, corresponds to the area in which the Muribeca Formation, in the Sergipe/Alagoas Basin occurs.

The Alagoan Stage includes sedimentary intervals situated between the Bahian Stage on the bottom and the Upper Ap-

tian marine sediments in the top. It lies probably in the middle to upper part of the Lower Cretaceous. In the Brazilian margin in addition to the Sequence of the Gulf that occurs mainly in the eastern segment, also the clastic sediments typically of the Sequence of the Lakes, in Barreirinhas, Ceara and Potiguar basins (northern margin) are placed in the Alagoan Stage.

#### 4.4 APTIAN-ALBIAN TO TERTIARY

The sequence of the Sea is represented by sediments that have an age range from Aptian-Albian up to Tertiary. These sediments are marine and contain ammonoids, foraminifera and other important groups of fossils that permit to establish correlations with stages of the standard stratigraphic column. This is particularly true for the Cretaceous, whose fossils have been studied since the last century. All the stages of the Cretaceous System above the Aptian are well defined in the Brazilian marginal basins, mainly those of the northeastern region. Based largely upon ammonoids the marine Cretaceous of Brazil is subdivided in the following biozones:

Maastrichtian:	<i>Sphenodiscus</i> – <i>Pachydiscus</i> biozone
Campanian:	Foraminifera biozones
Santonian:	Foraminifera biozones
Coniacian:	<i>Prionocycloceras</i> – <i>Barroisiceras</i> biozone
Up. Turonian:	<i>Subprionocyclus</i> biozone
Md. Turonian:	<i>Benueites</i> – <i>Coilopoceras</i> – <i>Mammites</i> biozone
Lw. Turonian:	<i>Pseudoaspidoceras</i> – <i>Vascoceras</i> , <i>Inoceramus labiatus</i>
Cenomanian:	<i>Kanabicerias</i> , <i>Acanthoceras</i> , <i>Stoliczkaia</i> – <i>Graysonites</i> biozones
Up. Albian:	<i>Mortoniceras</i> – <i>Elobiceras</i> biozone
Md. Albian:	<i>Oxytropidoceras</i> biozone
Lw. Albian:	<i>Chelonicerias</i> biozone

#### 4.5 MAGMATIC ROCKS

Locally, interposed in the stratigraphic column, there are magmatic rocks in the form of both intrusions and lava flows, mainly basaltic and alkaline. They have an age range extending from Triassic up to Tertiary.

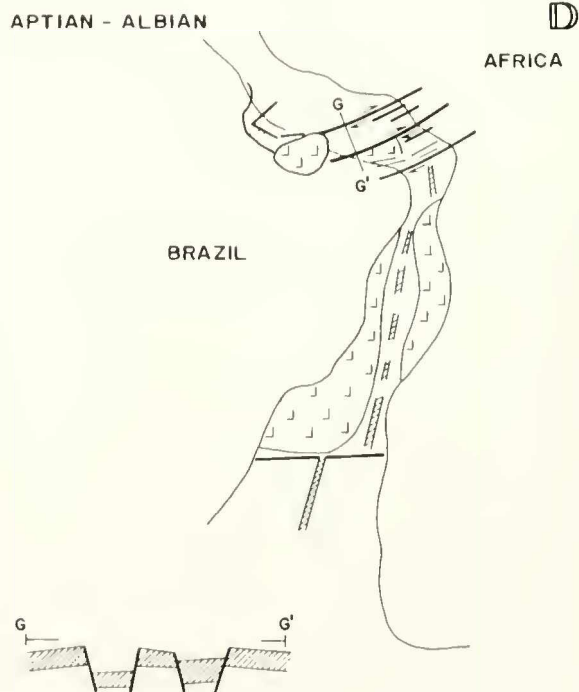
The greatest number of volcanic sites occur in the southeastern and southern areas. These are areas of the extensive and thick basaltic lava flows in the interior Paraná Basin (Fig. 1) (130–105 M y.B.P.) that are synchronous with an important volcanic activity in the southeastern margin (Santos and Campos basins). ASMUS & GUZZELLI (1981) interpreted that basaltic rocks beneath the evaporites in the Santos Basin and, in a lesser extent, in the Campos Basin are Lower Cretaceous lava flows upon Precambrian basement rocks rather than true oceanic basement rocks. (Fig. 4–5).

In the southeastern area occurs also a great number of volcanic sites, with an age between 90–40 M y.B.P. Most of these volcanic sites, both onshore and offshore are in the same latitudes in which lie crustal fractures (lineaments).



V V  
V SITES OF VOLCANIC ACTIVITY

C



INCIPIENT RIFTS OF CREVICE-TRANSCURRENT TYPE RESULTING  
FROM CRUSTAL EXTENSION IN THE SOUTHERN AREA

MID-ATLANTIC RIDGE



## DISCUSSIONS, INFERENCES AND CONCLUSIONS

The sequences included in the stratigraphic column of the Brazilian marginal basins conform the evolutionary stages of the theoretical model used to explain the build up of an Atlantic type of margin through rifting and drifting processes (Fig. 5).

The Sequence of the Continent is associated to the pre-rift stage, dominated by quiescent tectonic conditions. The Sequence of the Lakes is related to the rift-valley stage, defined by an intense tectonic activity and by the fragmentation of the continental crust. The Sequence of the Gulf resulted from the first important sea ingressions in restricted elongated gulfs that marked the proto-oceanic stage. The Sequence of the Sea is associated with drifting processes accompanied by margin subsidence and the consequent piling up of a thick sedimentary prism.

Analyses of the distribution, thickness variations and faciological changing of the sedimentary sequences allow the interpretation of particular events for each of the stages that comprise the general evolutionary model. Thus, observing the way the Sequence of the Continent is distributed, it is possible to infer uplifted and subsided areas during Jurassic. Faciological variation in the Sequence of the Lakes combined with the distribution of Early Cretaceous igneous rocks allow the identification of different types of rift-valley basins. The limits of the main evaporitic basin, and the effect of the principal tectonic episodes in the Sequence of the Gulf are useful to reconstruct the initial evolutionary stages of the South Atlantic. Thickness variations in the Sequence of the Sea indicate areas with different relative subsidence. Moreover, seismo-stratigraphic studies in this upper sequence allowed ESTRELA-BRAGA & DELLA FAVERA (1978) to determine the main transgressive and regressive cycles.

Based on these evidences and deductions it is possible to draw paleogeological reconstructions at the time of deposition of each one of these sequences: Donjoanian, Bahian, Alagoan, and Aptian-Albian (beginning of deposition of the Sequence of the Sea).

The pre-rift stage marks the deposition of the Sequence of the Continent (Fig. 5.A). During that time peripheral basins were formed adjacently to uplifted areas (section A-A'). The most proeminent of these positive areas were formed in the southeastern part of Brazil (section B-B') as a result of a sub-

crustal thermal anomaly (ASMUS, 1981). This area was the site of important volcanic activity whose main records date Early Cretaceous and Late Cretaceous to Early Tertiary.

The Bahian marks the formation of rift type of basins in two different times, referred to as I (Fig. 5.B.I) and II (Fig. 5.B.II). Based upon structural and stratigraphic characteristics it is possible to identify two main types of rift like structures: arch volcanic type (section C-C') and crevice type (section D-D').

The deposition of evaporitic rocks (Sequence of the Gulf) in an elongated gulf, in the eastern Brazilian margin, was the most important event during Alagoan times (Fig. 5.C.) Evaporitic rocks were also deposited in interior basins in the northeastern part of Brazil (Araripe, Ceará and Parnaíba basins). At that time only incipient faults had been developed in the northern segment of the margin (section E-E'). These faults, responsible for the build up of rift basins in the northern segment, are younger than the salt deposition.

Since it is thought that faulting in the northern segment was caused by the initial drifting of Brazil and Africa, it is possible to say, based entirely upon geological evidences, that the Alagoan evaporites, including those of the São Paulo Plateau (Santos Basin), were deposited on continental crust (section F-F').

Figure 5. D complements what was previously said with respect to the age of rifting and consequently the age of the Sequence of the Lakes in the northern segment of the margin. The faults in this segment cut the Alagoan salt and thus they have been active at a time when the eastern margin was characterized by tectonic quiescence.

The subsequent stages in the evolutionary history of the Brazilian continental margin (oceanic stage) was characterized by tectonic quiescence and by the deposition of the Sequence of the Sea.

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Fig. 5: Inferred paleogeographic and paleogeological configurations of the Brazilian continental margin in its initial stages of evolution.

Donjoanian – The Sequence of the Continent was deposited in basins peripheral to uplifted areas by fluvial-lacustrine and eolian processes.

Bahian – In most of the eastern margin the Sequence of the Lakes was deposited in fluvio-deltaic lacustrine conditions; in the rift of arch volcanic type (Santos Basin) it has been inferred that sedimentation occurred in dominantly subaerial conditions.

Alagoan – This time marks the deposition of the Sequence of the Gulf in the eastern margin and of the Sequence of the Lakes in the northern margin. Thus, faulting in the northern area is younger than faulting in the eastern margin.

Aptian – Albian – At this time, in most of the marginal basins began the deposition of the Sequence of the Sea. This sequence was deposited in a shallow carbonatic platform at first and in an open marine environment afterwards. Faulting continued till the Late Cretaceous (K3) in some sectors (Barreirinhas Basin) of the northern margin.



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