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The Central South Atlantic: The origin of its waters, its evolution and effects beyond

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Abstract: The primitive sea that occupied the Central South Atlantic (CSA), part of the intra-Gondwana rift during the Early Cretaceous, allowed precipitation of an extensive and thick layer of evaporites, the Ibura Salt, followed by the deposition of a prominent Albian carbonate package. Although the shallow platform facies do not contain classical benthic Tethys markers, the pelagic open sea carbonates are essentially dominated by planktonic elements coming from the Tethys Realm. This condition led some researchers to think that Tethys waters also contributed to salt formation, an idea that clashes with the geotectonic model of northward separation of Africa and South America and ingression of predominantly Austral marine waters. Now, new controversy arises as to the age of this salt layer when trying to position bio-events and lithological and chemostratigraphic markers from these rocks with respect to established data for the Global Boundary Stratotype Section and Point for the Aptian/Albian boundary (GSSP-Alb). Biochronostratigraphic information on planktonic foraminifera points to an Aptian age as opposed to the earliest Albian traditionally accepted for the carbonate section that overlies the giant salt layer. On the other hand, stratigraphic and geochronological data suggest an age of 113 Ma for the base of the salt, very near to the 113.2 ± 0.1 Ma arbitrated for the GSSP-Alb. In this study, we adopt the base of the evaporite bed as the Aptian/Albian boundary in the CSA, Equatorial South Atlantic (ESA), and northeastern Brazilian interior basins (BNE) as well. Based on these criteria, a broad review and the integration of available information have led to new interpretations regarding the earliest phase of these segments of the South Atlantic and adjacent areas. Initially, during the Aptian-Albian transition, an ephemeral interior sea within Brazil, drawing its waters from the north, would have contributed to salt deposition in the intra-Gondwana rift (evaporitic stage of the CSA). Afterward, but still within the earliest Albian, the evaporitic system evolved into a carbonate gulf when the northern barrier, the Exception Zone (EZ), disappeared. The lagoonal circulation pattern that then formed in the CSA created a hypersaline and warm outflow plume that swept across the marine bottom of the ESA

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and part of the Tethys Sea. Paleoceanographic events registered at Site 545, Mazagan Plateau, support this new hypothesis and illustrate the potential complexity of correlation of organic-rich deposits in which local influences have been greater than global ones. This long, narrow, and continuous carbonate gulf disappeared at the end of the Albian with the arrival of southern waters from the Meridional South Atlantic (MSA), and the South Atlantic became consolidated as a proto-ocean.

Keywords:

- earliest Albian;
- South Atlantic evolution;
- water source;
- hypersaline plume;
- origins of the "OEA1b";
- paleogeographic impacts

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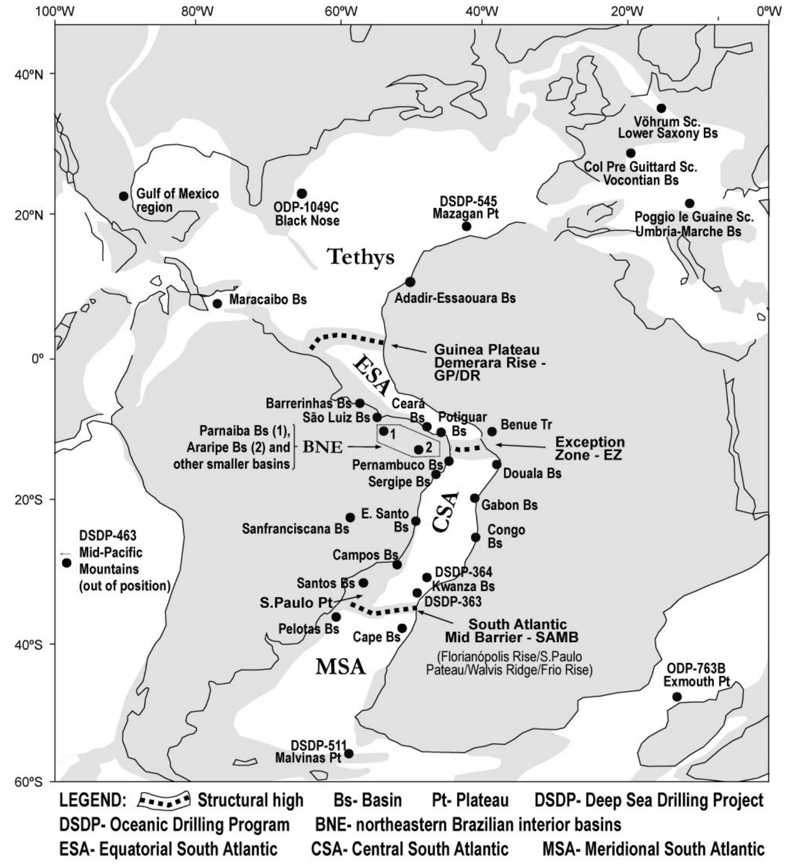
Résumé : *L'Atlantique Sud Central : Origine de ses eaux*, *son évolution et ses répercussions.-* Au Crétacé inférieur, la mer primitive qui occupait l'Atlantique Sud Central (ASC) était une composante du rift intra-gondwanien. Cette mer a permis le dépôt d'une couche salifère étendue et épaisse - le Sel d'Ibura (événement d'Ibura) - suivi ultérieurement (à l'Albien) celui d'une puissante sériecarbonatée. Alors que ces faciès carbonatés néritiques ne recèlent aucun des marqueurs benthiques classiques de la Téthys, les faciès pélagiques de mer ouverte sont dominés par des éléments planctoniques du domaine téthysien. Cette observation a conduit certains chercheurs à penser que les eaux issues de la Téthys auraient également pu contribuer à la formation des évaporites, un concept en contradiction avec le modèle géotectonique de séparation de l'Afrique et de l'Amérique du Sud à partir du sud, en direction du nord, avec pénétration d'eaux marines à prédominance australe. Une controverse surgit aujourd'hui concernant l'âge de la couche salifère, en tentant de recaler les événements biologiques et les marqueurs lithologiques et chimiostratigraphiques reconnus au sein de cette série carbonatée avec les données disponibles sur la Coupe et le Point Stratotypique Mondial de la limite Aptien/Albien (PSM-Albien). Les études biochronostratigraphiques fondées sur les foraminifères planctoniques indiquent un âge aptien pour la série carbonatée qui recouvre les dépôts salifères alors qu'un âge albien basal était traditionnellement accepté. Par ailleurs, les données stratigraphiques et géochronologiques suggèrent un âge de 113 Ma pour la base du Sel d'Ibura, très proche de celui arbitré pour le PSM-Albien (113,2 ± 0,1 Ma). Cette étude adopte la base de la couche salifère comme limite Aptien/Albien pour l'Atlantique Sud Central (ASC), l'Atlantique Sud Équatorial (ASE), ainsi que pour certains bassins intérieurs du nord-est du Brésil (BNE). Sur cette base, un réexamen approfondi et l'intégration de toutes les informations disponibles ont conduit à de nouvelles interprétations concernant la phase la plus ancienne de ces segments de l'Atlantique Sud et des zones adjacentes. Initialement, au cours de la transition Aptien-Albien, existait au Brésil une mer intérieure éphémère qui, tirant ses eaux du nord, aurait contribué au dépôt de sels dans le rift intragondwanien (phase évaporitique de l'ASC). Par la suite, toujours au cours de l'Albien basal, le système évaporitique a évolué vers un système carbonaté, une fois la barrière nord, *i.e.*, la zone d'exception (ZE), disparue. Le modèle de circulation confiné qui s'est alors établi dans l'ASC a créé un panache hypersalin et chaud qui, sortant de l'ASC, a balayé le fond marin de l'ASE et d'une partie de la Téthys. Les événements paléoocéanographiques enregistrés sur le site 545, plateau de Mazagan, soutiennent cette nouvelle hypothèse et illustrent la complexité potentielle de la corrélation des dépôts riches en matière organique dans lesquels les influences locales ont prévalu sur les influences globales. Ce fossé long, étroit et continu à sédimentation carbonatée a disparu à la fin de l'Albien avec l'arrivée d'eaux méridionales issues de l'Atlantique Sud Méridional (MSA), consolidant ainsi l'Atlantique Sud en un proto-océan.

Mots-clefs :

- Albien inférieur ;
- évolution de l'Atlantique Sud ;
- source d'alimentation en eau ;
- panache hypersalin ;
- origines de l' "OEA1b" ;
- impacts paléogéographiques

1. Introduction

The history of the implantation of the South Atlantic is the subject of questions that motivate different, if not contradictory, interpretations: did the process of creating oceanic crust occur before or after the deposition of the giant Ibura salt deposit? When did this occur? Where did such a volume of water come from to form these evaporites with distinct and in some places anomalous compositions? How did the transition from the evaporitic to the carbonate system take place? What water circulation model was dominant in the two scenarios? How long did the barriers persist that delimited the areas of occurrence of these evaporites and carbonates? Once these barriers disappeared, what influence did the new body of water linking the South Atlantic to the Tethys Sea have on global paleogeography? And, are any black shales related to the Oceanic Anoxic Event 1b (OAE 1b) preserved in the



◀ **Figure 1:** Location of the basins and sections considered in this study. Paleogeography represents that at 113 Ma ago (modified from AZEVEDO *et al.*, 2023).

South Atlantic basins? These and other questions have long intrigued researchers, yet in spite of much accumulated knowledge, uncertainties still provide room for new hypotheses and other controversies.

The principal objective of this paper is to think about the evolution of the South Atlantic, its relationship and influence elsewhere. To deal with this subject, many of the above questions have been addressed and the most consecrated interpretations have been summarized. Crucial to this discussion was information from wells drilled for oil exploration in Brazilian marginal basins of Central South Atlantic (CSA), Equatorial South Atlantic (ESA), and northeastern Brazilian interior basins (BNE). Other data came from different areas of the world, especially from African and Tethys basins. A section at Site 545 of the Deep Sea Drilling Project (DSDP) was reanalyzed in greater detail and used to exemplify paleoceanographic processes associated with the evolution of the Central South Atlantic that extended into Tethys (Fig. 1).

Taking into account all interpretations based on previous information, we found it was necessary to define and harmonize the data into a single chronostratigraphic solution. We chose to adopt the proposal by ANTUNES *et al.* (2018), with further arguments by AZEVEDO *et al.* (2023), that indicate an earliest Albian age for all processes involving the thick evaporite layer, the Ibura Salt or Ibura Event. This solution is distinct from the late Aptian age traditionally admitted for the salt formation (*e.g.*, ASMUS & PONTE, 1973; ASMUS & FERRARI, 1978; OJEDA, 1981; UESUGUI, 1987; BOEUF, 1988; REGALI, 1989a, 1989b; SALARD-CHEBOLDAEFF & BOLTENHAGEN, 1992; DIAS, 1998), as well as from those suggesting of a much older Aptian age (*e.g.*, TEDESCHI *et al.*, 2017; LIMA F.H.O. *et al.*, 2018; VIVIERS *et al.*, 2018; SANJINÉS *et al.*, 2022). Although the controversy regarding the age of the salt layer has yet to be resolved, data are presented here to justify the axiomatic solution of adopting the base of these evaporites as the Aptian/Albian boundary for the region under discussion.

Different models for the marine paleocirculation system that gave rise to the water masses responsible for the deposition of these evaporites and carbonates have been examined. New hypotheses are presented, recording not only the models' strengths but also their limitations. We also offer interpretations for the processes that led to overcoming the barriers that limited evaporitic and carbonate deposition in the CSA.

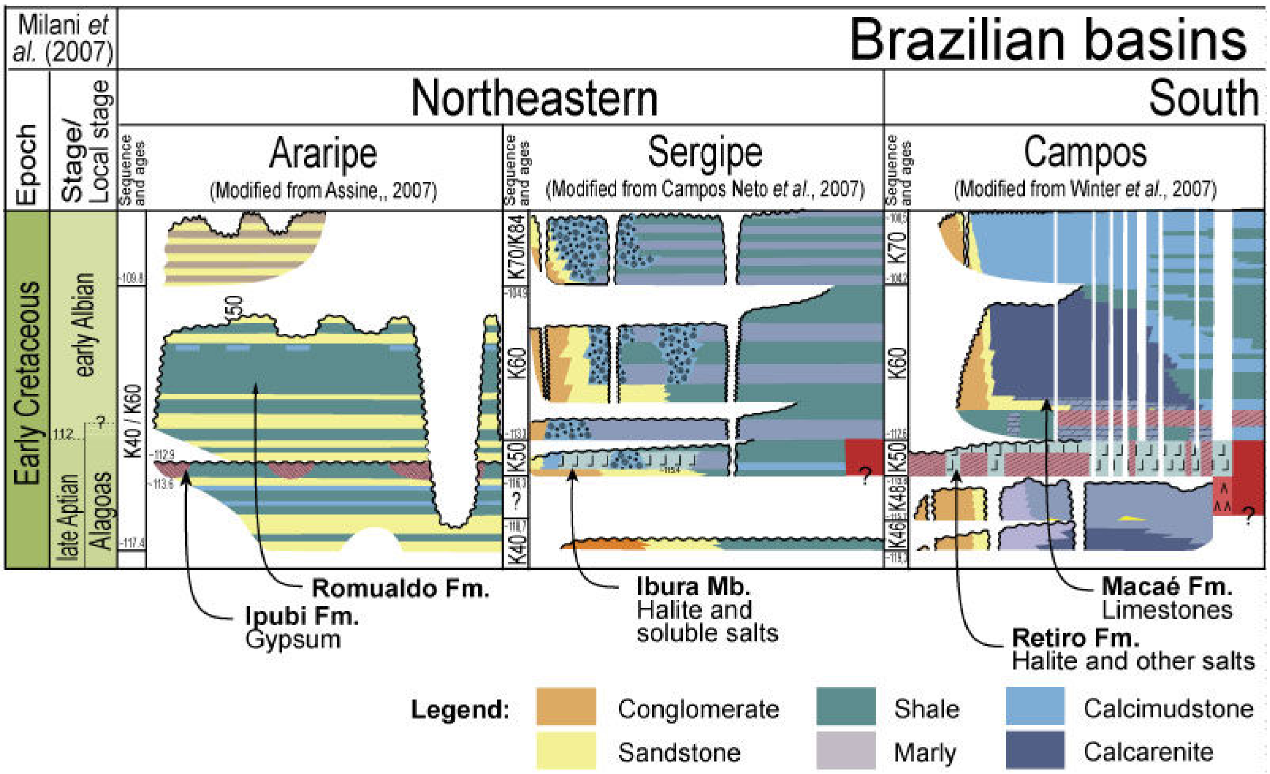


Figure 2: Stratigraphic chart for the Araripe (in the BNE), Sergipe, Campos, Santos, Kwanza (all in the CSA), and Pelotas (Meridional South Atlantic - MSA) basins for the late Aptian-Early Albian (AZEVEDO *et al.*, 2023). Stratigraphic adjustments for the Brazilian basins have taken into consideration geochronologic interpretations and the position of sequence boundaries described by MILANI *et al.* (2007), in accordance with the geological time scale of GRADSTEIN *et al.* (2004) - the left column -, and the alternative proposal of ANTUNES *et al.* (2018) that the base of the Ibura evaporite marks the Aptian/Albian boundary.

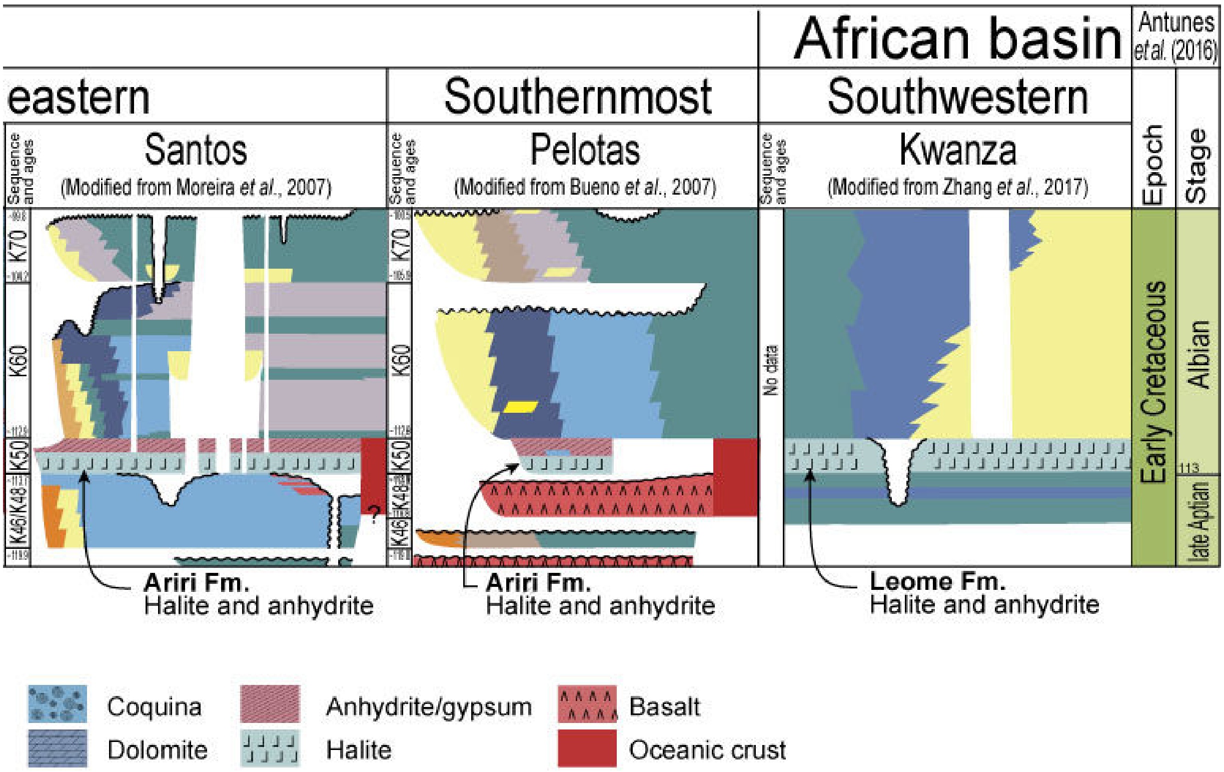
Although we recognize that much of the available evidence is still sparse, widely scattered, and commonly controversial, we believe that the new clues offered here will stimulate future research from the central perspective of impact of changes that occurred in the South Atlantic regarding global paleogeography and paleoceanography.

2. Geological context and the age of the Ibura Event

The CSA and ESA have geological histories directly related to fragmentation axes of Gondwana that developed during the Early Cretaceous, with orientations NNE-SSW to N-S, and ENE-WSW to E-W, respectively. The CSA basins are distributed between a barrier in the south, made up by the Florianópolis Rise, São Paulo Plateau, Walvis Ridge, and Frio Rise, here termed SAMB (the South Atlantic Middle Barrier), and one in the north, the Exception Zone (EZ), as designated by BARBOSA *et al.* (2008). The latter represents a strip of an exposed land bridge that extended along the Patos-Pernambuco/Ngaoundéré-Sanaga lineament to the Touros High. The ESA continued northwest from this continental high to the Guinea Plateau/Demerara Rise (Fig. 1).

During continental fragmentation, sediments were deposited during well-recognized rift, sag, and drift phases, mainly in the CSA (MILANI *et al.*, 2007). A local Early Cretaceous chronostratigraphy has been created in Brazil for the dominantly lacustrine deposits that accumulated in the rift phase, with distinct stages defined mainly by ostracod and palynomorph bio-events evident in the Sergipe-Alagoas, Recôncavo, and Tucano basins (*e.g.*, SCHALLER, 1969; VIANA *et al.*, 1971; DIAS-BRITO *et al.*, 1987; MOURA, 1988; ARAI *et al.*, 1989; REGALI & VIANA, 1989; POROPAT & COLIN, 2012; ANTUNES *et al.*, 2018). Studies dealing with non-marine Lower Cretaceous sections of African basins do not use local stages, choosing rather to position ostracods and palynomorphs zones of endemic species within international stages (*e.g.*, DOYLE, 1977; BATE, 1999; GROSDIDIER *et al.*, 1996; POROPAT & COLIN, 2012).

In the BNE, ESA, and CSA four salt layers are recognized with different dimensions and compositions. So far, there are no reliable indications of the presence of the three more



ancient salts at equivalent levels in African basins; only a Barremian-Aptian salt layer is recorded from Kwanza Basin (CHABOUREAU *et al.*, 2013). The oldest of these Brazilian evaporites occurrence is the Matarandiba bed, present in the Recôncavo Basin and associated with a Permian intracratonic section (DA SILVA *et al.*, 2007; GUIMARÃES *et al.*, 2018), thus clearly deposited prior to Gondwana fragmentation. The Sergipe-Alagoas Basin is the only one that hosts three other evaporitic events related to the rift and sag phases (MARTINS, 2016; SOUZA-LIMA *et al.*, 2021). The Horizonte and Paripueira salt layers, the two oldest, formed during the rift phase, are limited in area and thickness, and consist exclusively of halite enveloped by lacustrine clastic sediments. The youngest layer, the Ibura Member, the most widespread and diversified salt layer, was the one deposited during the transitional phase in the South Atlantic evolution.

The Horizonte salt layer is late Jiquiá in age (~ early Aptian, according to REGALI & VIANA, 1989), *Aequitriadites spinosus* Zone or P-220 code (MARTINS, 2016), and the Paripueira occurs in the middle part of the Alagoas Stage (Aptian, according REGALI & VIANA, 1989), in *Inaperturopollenites crisopolensis*/*I. turbatus* palynozones or P-230 and P-260 codes (UESUGUI, 1987). Paradoxically, a geochemical study by FLORENCIO (1996, 2001) and FLORENCIO and RIBEIRO (1998) on the Paripueira layer showed high bromine contents in samples of halite, more in keeping with a marine deposition than within an overly salty continental lake. However, a study of a thick halite section in non-marine deposits of Salar de Uyuni, central altiplano in Bolivia, showed how bromine profiles are affected by complex depositional processes, making it difficult to define a marine or non-marine origin for an evaporite based exclusively upon Br content (RISACHER & FRITZ, 2000). Recent works, however, have been reaffirming the idea of a continental origin for the Paripueira salt (MARTINS, 2016; SOUZA-LIMA *et al.*, 2021).

Two other hypotheses about possible marine invasions before the Alagoas Stage deserve comment. The first refers to the presence of benthic foraminifera in black shales associated with ostracod Zone *Petrobrasia marfinensis*, code NRT 007.2, that belonging to the Buracica local Stage (~Barremian in age). Affinities with marine environments of some of these fossils created expectations about the connection of the Recôncavo Basin with some arms of the sea. This interpretation was ruled out by SANTOS (1999), who called attention to both the coexistence of these foraminifers with non-marine ostracods, and the geochemical characteristics of those sediments.

A second hypothesis regarding possible marine invasions prior to the Alagoas Stage was proposed by GAMBOA *et al.* (2021) in a study supported by integrated gravity, magnetic, and seismic data, as well as knowledge of the depositional history of the Santos Basin. They observed seismic patterns indicating the presence of an older evaporite layer in the São Paulo Plateau, which was deposited in a restricted and shallow environment to the north of an aborted oceanic crust axis. This structural feature later shifted eastward, forming the definitive oceanic floor of the CSA. GAMBOA *et al.* (2021) suggest that this older axis would have served as the pathway for the initial Austral marine incursions into the Santos Basin. With the contribution of hydrothermal processes, these waters would have led to the formation of the first salt ponds in the peripheral and shallow depressions of the Santos Basin, predating the deposition of the Ibura Evaporite.

Part of the controversy about the age of giant Ibura salt deposits in the CSA, ESA, and BNE basins is related to scarce published data on these distinct evaporite beds. The picture is complex mainly due to lack of accuracy in the chrono-correlation between the local Brazilian and the international stages of the Lower Cretaceous. Conceptual changes promoted in the last three decades involving the Aptian and Albian and several pitfalls of bio-chronostratigraphic interpretations have broadened this controversy. For example, the concept of diachroneity concerning the giant evaporitic layer, as proposed by DAVISON (2007) and accompanied by KARNER and GAMBOA (2007), KUKLA *et al.* (2018), SAUNDERS *et al.* (2018), and CUI *et al.* (2023), adopted CARON's (1978) interpretation of an Aptian age for the sediments overlaying the salt at DSDP Site 364 (Kwanza Basin), a solution that conflicts with results ased on other fossil groups (BOLLI, 1978a; AZEVEDO *et al.*, 2023). DAVISON (2007) also indicated a value of 114.5 Ma for the youngest salt layer of the Sergipe-Alagoas Basin (Ibura Member), based on associations of planktonic foraminifera and ammonites described by KOUTSOUKOS *et al.* (1993). As a result, the salt in the Sergipe-Alagoas Basin would be older than the salt in the Santos Basin, estimated to be around 113 Ma.

The Ibura layer, the youngest salt unit in the Sergipe-Alagoas Basin, has been traditionally considered as coeval with other evaporite layers present in CSA, ESA, and BNE basins (*e.g.*, OJEDA, 1981; ASMUS & CAMPOS, 1983; REGALI, 1989a; ARAI, 2009; BASTOS *et al.*, 2022; AZEVEDO *et al.*, 2023). It belongs to the sag tectonic phase and was tentatively associated with the end of Aptian (MILANI *et al.*, 2007 - adjusted to the GTS 2004 - GRADSTEIN *et al.*, 2004). Because lithostratigraphic designations for this salt layer vary from basin to basin (Fig. 2), DIAS (1998, 2005) created the term "Ibura Event" to englobe the processes responsible for the almost "instantaneous" deposition of these evaporites.

Biostratigraphic studies show that the Ibura Event is inserted in the palynozone *Sergipea variverrucata* or P-270 code, in the basins of northeastern Brazil and is also associated with the Last Stratigraphic Occurrence (LO) of "*Cytheridea*" sp. gr. 201-218 or RT-011 code (*e.g.*, UESUGUI, 1987; REGALI & VIANA, 1989; RANGEL *et al.*, 1994; VIEIRA *et al.*, 1994; FEIJÓ, 1994a). Counterpart rocks in Africa occur within the palynomorph Zone C-IX and ostracod Zone AS12 (DOYLE *et al.*, 1977; BATE, 1999; GROSDIDIER *et al.*, 1996; POROPAT & COLIN, 2012; ELDRETT *et al.*, 2023).

From a tectonic point of view, the salt accumulations in the CSA and ESA, in general, are interpreted as occurring upon continental crust subjected to different intensities and/or timing of stretching (*e.g.*, KOWSMANN *et al.*, 1982; MASCLE *et al.*, 1988; CHANG *et al.*, 1992; DEMERCIAN, 1996; TORSVIK *et al.*, 2009; MOULIN *et al.*, 2010, 2012; SCOTCHMAN *et al.*, 2010; HEINE *et al.*, 2013; MATOS *et al.*, 2021a, 2021b). For JACKSON *et al.* (2000), however, the salt accumulation occurred after initial formation of oceanic crust.

The Ibura Event result in accumulation of up to 2,000 m of evaporites and associated over an area of approximately 1.500 km by 500 km (c. 750,000 km^2), between the SAMB and the EZ (Fig. 1). Deposits are mainly halite and anhydrite, with other soluble salts present only in the southernmost and northernmost of CSA (SZATMARI *et al.*, 2021). Duration of deposition has been estimated as 530 ka (RODRIGUEZ *et al.*, 2018), 573 ka (FREITAS, 2006), and up to ~ 600 ka to 1 Ma (*e.g.*, DIAS, 1998, 2005; FRANÇA *et al.*, 2007; MOREIRA *et al.*, 2007; WINTER *et al.*, 2007). However, the absolute age for the onset of evaporite deposition is still controversial (*e.g.*, DAVISON, 2007; SZATMARI & MILANI, 2016; KUKLA *et al.*, 2018; SZATMARI *et al.*, 2021; AZEVEDO *et al.*, 2023).

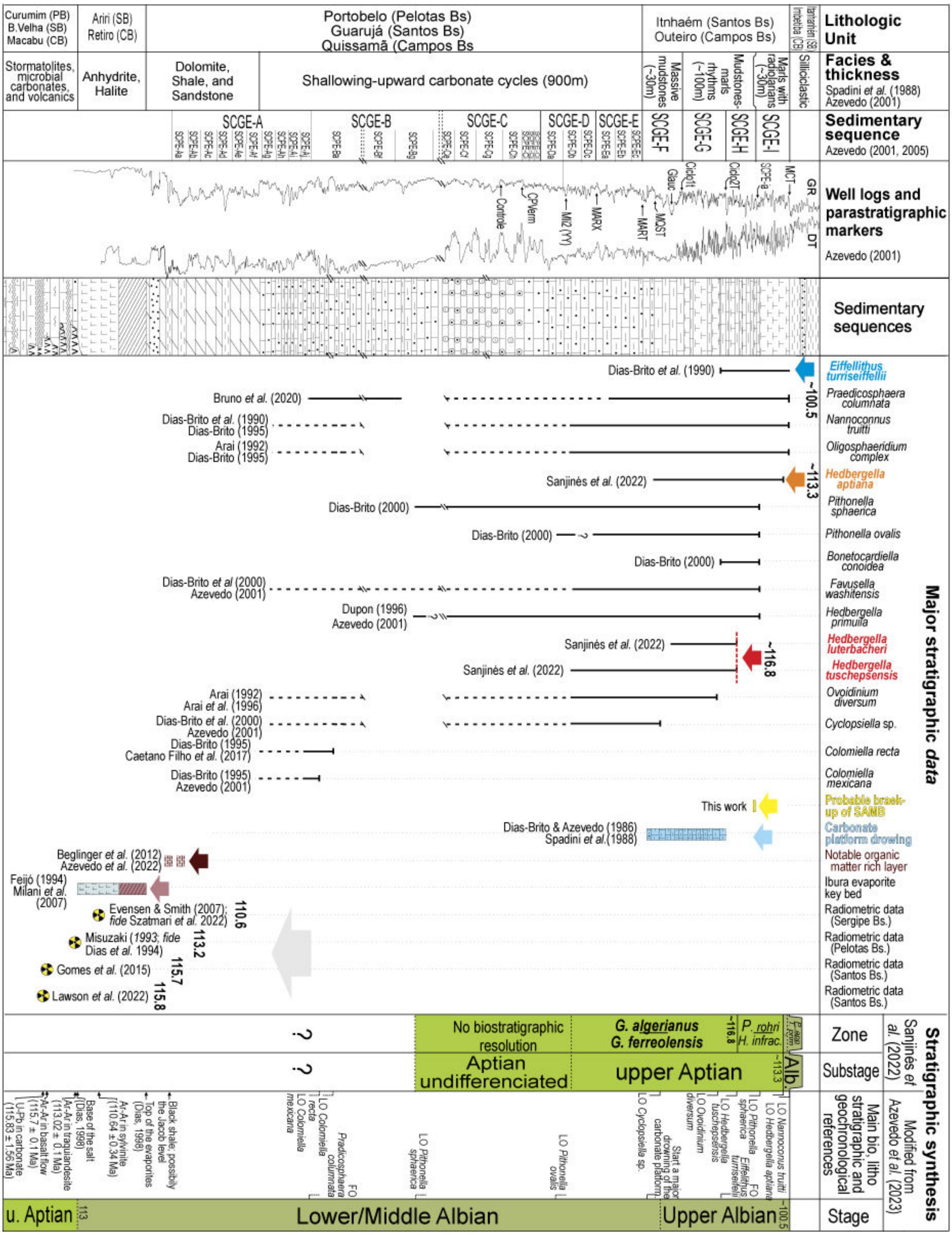


Figure 3: Schematic stacking of sedimentary succession and other geological parameters with respect to the Pelotas, Santos, Campos and Kwanza basins. Relevant stratigraphic data justify the differences between the solution proposed by Sanjinés *et al.* (2022) and that offered here. Lithological and geophysical profiles are from the type-section of the post-salt carbonate in well 1-RJS-135, Campos Basin (Rangel *et al.*, 1994). The parastratigraphic data are from Azevedo (2001) and the ages are from CGTS2020 and Azevedo *et al.* (2023).

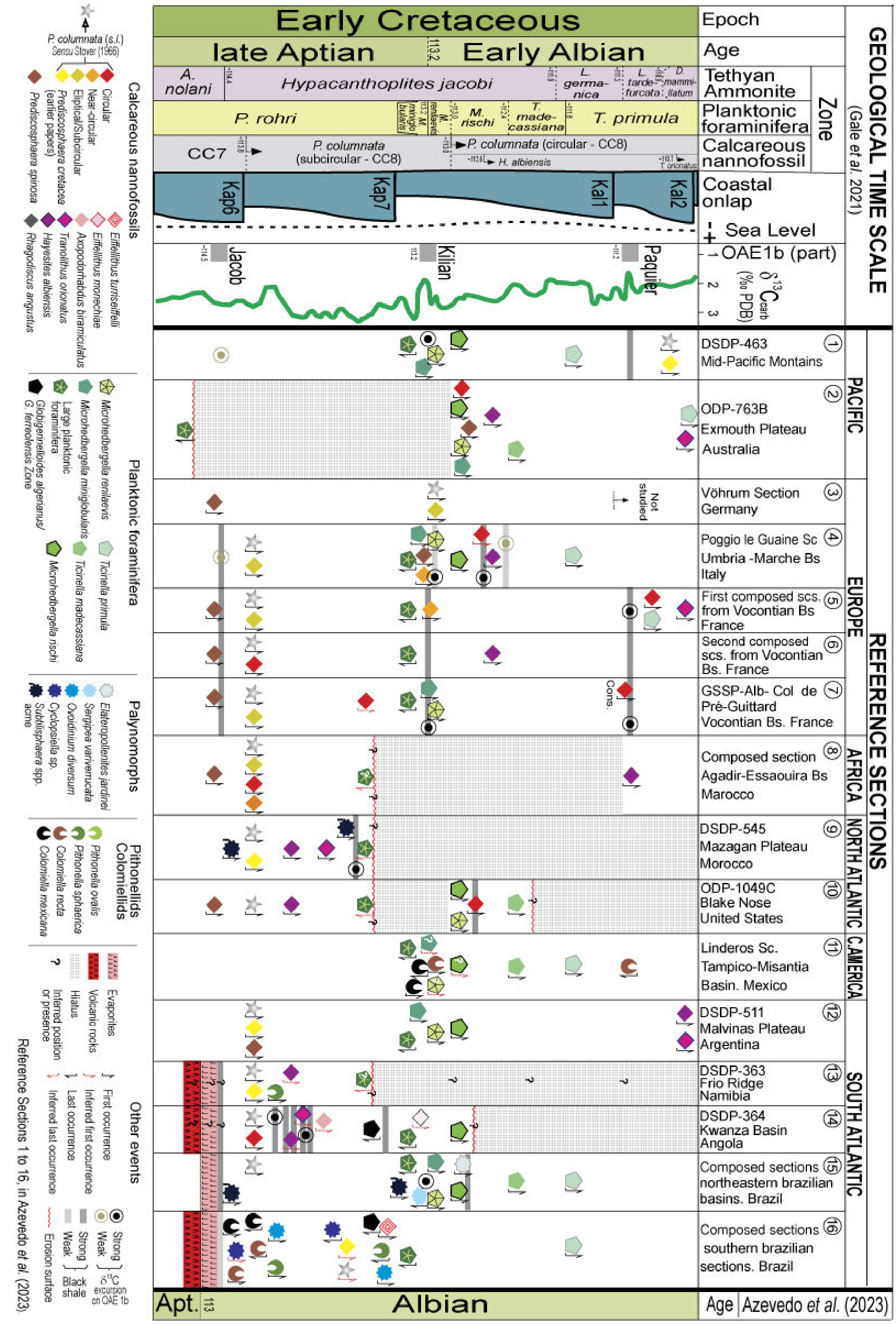
Current information on radiometric dating of the salt and rocks that allow age inferences based on stratigraphic relationships with the Ibura Salt are consolidated in AZEVEDO *et al.* (2023; Fig. 3). The most important result is an Ar/Ar age of 113.2 ± 0.1 Ma for a trachyandesite in well 1-SCS-1, on the Florianópolis High, extreme south of the CSA (MISUZAKI, 1993, *fide* DIAS *et al.*, 1994), that is nearly identical to the age defining the GSSP-Alb (KENNEDY *et al.*, 2017). According to DIAS (1998) the salt and the overlying carbonate onlap the SAMB volcanics, an observation that allowed AZEVEDO *et al.* (2023) to advocate the adoption of an age of 113 Ma for initiation of the Ibura Event. Radiometric results reported by EVENSEN and SMITH (2007) *fide* SZATMARI *et al.* (2021), GOMES *et al.* (2015), and LAWSON *et al.* (2022) give complementary support for the suggested age for the base of the salt.

The 113.1 ± 0.3 Ma age originally registered for the GSSP-Alb was based on the 238U/206Pb method, applied to measure in zircon from volcanic ash at Vöhrum, Germany (SELBY *et al.*, 2009; KENNEDY *et al.*, 2017). However, the GTS2020 revised the age to 113.2 ± 0.3 Ma (GALE *et al.*, 2021), employing spline-curve estimations adjusted for MILANKOVITCH-based stage duration (AGTERBERG *et al.*, 2021). Distant about 1000 km from Col de Pré-Guittard, the Vöhrum section does not contain planktonic foraminifera, so that support for the chrono-correlation between the two outcrops came from ammonite associations and the first stratigraphic occurrence (FO) of *Prediscosphaera columnata* (subcircular category) a few centimeters above the ash layer (MUTTERLOSE *et al.*, 2003). Several volcanic ash beds have been identified in the Subalpine Basin, SE France (BEAUDOIN *et al.*, 2012). Among them, the CÉZANNE bentonite bed exhibits the closest stratigraphic correlation with the Vöhrum tuff and is found just below the JACOB Event, the oldest OAE1b. Interestingly, the black shales associated with the JACOB level in the CSA, ESA, and BNE overlie the Ibura salt and were deposited prior to the formation of the extensive Albian carbonate system (AZEVEDO *et al.*, 2023).

Questions about the age of the salt entered a new chapter recently with the discovery of planktonic foraminifera taken as Aptian in marine carbonates overlying the Ibura salt (TEDESCHI *et al.*, 2017; VIVIERS *et al.*, 2018; LIMA F.H.O. *et al.*, 2018; SANJINÉS *et al.*, 2022). These carbonates formed in the open sea and register the beginning of the drift phase in the CSA and ESA basins, as well as in a few interior basins of the BNE (MILANI *et al.*, 2007). Prior to the 2010's, these rocks were considered Albian in age in both sets of stratigraphic charts of Brazilian basins published by Petrobrás (FEIJÓ, 1994b; MILANI *et al.*, 2007).

AZEVEDO *et al.* (2023) brought to light the conflict between this assemblage of planktonic foraminifera and certain regionally and globally relevant biostratigraphic, lithostratigraphic, and chemostratigraphic data (Figs. 3-4). The complexity of establishing a single global standard for the *datum* in the GSSP-Alb and in the GTS2020 (GALE *et al.*, 2021) is evident in the notable differences between the sedimentary sections of the North Atlantic and South Atlantic (Fig. 4, columns 9-10, 13-16), as compared to those of other regions (Fig. 4, columns 1-8, 12). The only exception is at Site 511, at the southern end of the South Atlantic, which is not part of the CSA. The incompatibilities that stand out most are within the successions of marker species of planktonic foraminifera and calcareous nannofossils. Moreover, black shales associated with OAE1b show a lack of synchronous deposition, with only the oldest event, the JACOB Level, possibly representing a global event. All of the above data support the alternative chronostratigraphic interpretation that the base of the Ibura evaporites should be considered as the *datum* marking the beginning of the Albian in basins of the CSA, ESA, and the BNE, as proposed by ANTUNES *et al.* (2018) and reaffirmed by AZEVEDO *et al.* (2023).

▶ **Figure 4:** Biostratigraphic, chemostratigraphic and lithological data for latest Aptian to Early Albian events, as indicated by AZEVEDO *et al.* (2023). The columns to the left are from GTS2020 (GALE *et al.*, 2021); the ones at the center are the sixteen sections analyzed and at the right is an idealized hypothetical section for the CSA, ESA, and BNE, encompassing the chronostratigraphic and geochronological limits suggested by AZEVEDO *et al.* (2023 - bibliographic references for each column can be found in this paper). The highlighted $\delta^{13}C$ excursions are limited to three OAE1b levels; they are tentatively differentiated based on strong (2‰) and weak (between 1 and 2‰) oscillations.


GEOLOGICAL TIME SCALE
(Gale et al. 2021)
Epoch
Early Cretaceous
Age
late Aptian
Early Albian
Zone
Tethyan Ammonite
A. nolani
Hypacanthoplites jacobi
L. germanica
L. tardefurcata
D. mammillatum
Planktonic foraminifera
P. rohri
M. rischi
T. madecassiana
T. primula
Calcareous nannofossil
CC7
P. columnata (subcircular - CC8)
P. columnata (circular - CC8)
H. albiensis
Coastal onlap
Kap6
Kap7
Kal1
Kal2
Sea Level
OAE1b (part)
Jacob
Kilian
Paquier
REFERENCE SECTIONS
PACIFIC
DSDP-463 Mid-Pacific Montains
ODP-763B Exmouth Plateau Australia
EUROPE
Vöhrum Section Germany
Not studied
Poggio le Guaine Sc Umbria -Marche Bs Italy
First composed scs. from Vocontian Bs France
Second composed scs. from Vocontian Bs. France
GSSP-Alb- Col de Pré-Guittard Vocontian Bs. France
AFRICA
Composed section Agadir-Essaouira Bs Marocco
NORTH ATLANTIC
DSDP-545 Mazagan Plateau Morocco
ODP-1049C Blake Nose United States
C.AMERICA
Linderos Sc. Tampico-Misantia Basin. Mexico
SOUTH ATLANTIC
DSDP-511 Malvinas Plateau Argentina
DSDP-363 Frio Ridge Namibia
DSDP-364 Kwanza Basin Angola
Composed sections northeastern brazilian basins. Brazil
Composed sections southern brazilian sections. Brazil
Apt.
Albian
Age
Azevedo et al. (2023)
Calcareous nannofossils
Circular
Near-circular
Elliptical/Subcircular
Prediscosphaera cretacea (earlier papers)
Prediscosphaera spinosa
P. columnata (s.l.) Sensu Stover (1966)
Eiffellithus turriseiffelii
Eiffellithus monechiae
Axopodorhabdus biramiculatus
Tranolithus orionatus
Hayesites albiensis
Rhagodiscus angustus
Planktonic foraminifera
Microhedbergella renilaevis
Microhedbergella miniglobularis
Large planktonic foraminifera
Globigerinelloides algerianus/ G. ferreolensis Zone
Ticinella primula
Ticinella madecassiana
Microhedbergella rischi
Palynomorphs
Elaterosporites jardinei
Sergipea variverrucata
Ovoidinium diversum
Cyclopsiella sp.
Subtilisphaera spp. acme
Pithonellids Colomiellids
Pithonella ovalis
Pithonella sphaerica
Colomiella recta
Colomiella mexicana
Evaporites
Volcanic rocks
Hiatus
Inferred position or presence
Other events
First occurrence
Inferred first occurrence
Last occurrence
Inferred last occurrence
Erosion surface
Strong
Weak
δ13C excursion on OAE 1b
Black shale
Reference Sections 1 to 16, in Azevedo et al. (2023).

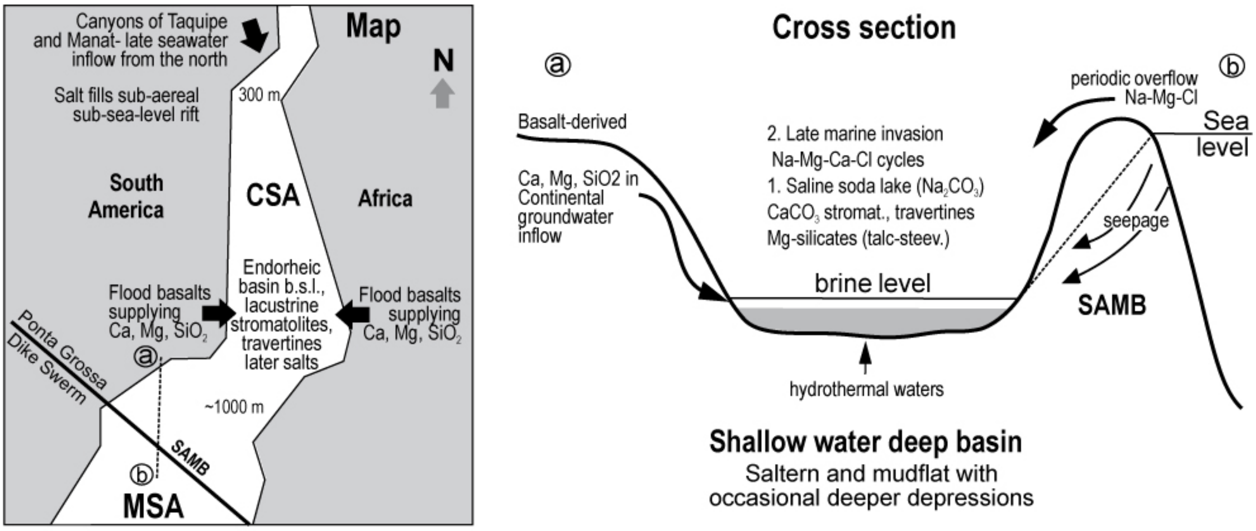


Figure 5: Mixed model for evaporite formation in a shallow-water setting within a deep basin ~1000m (adapted from SZATMARI & MILANI, 2016, based on OCHSENIUS' bar model, 1877 and later by HSÜ *et al.*, 1973). The SAMB limited the entry of marine waters from the MSA; different sources of continental, hydrothermal and marine waters (arrows) also contributed to salt formation in the CSA.

3. Formation of the Ibura evaporites and the Albian carbonates

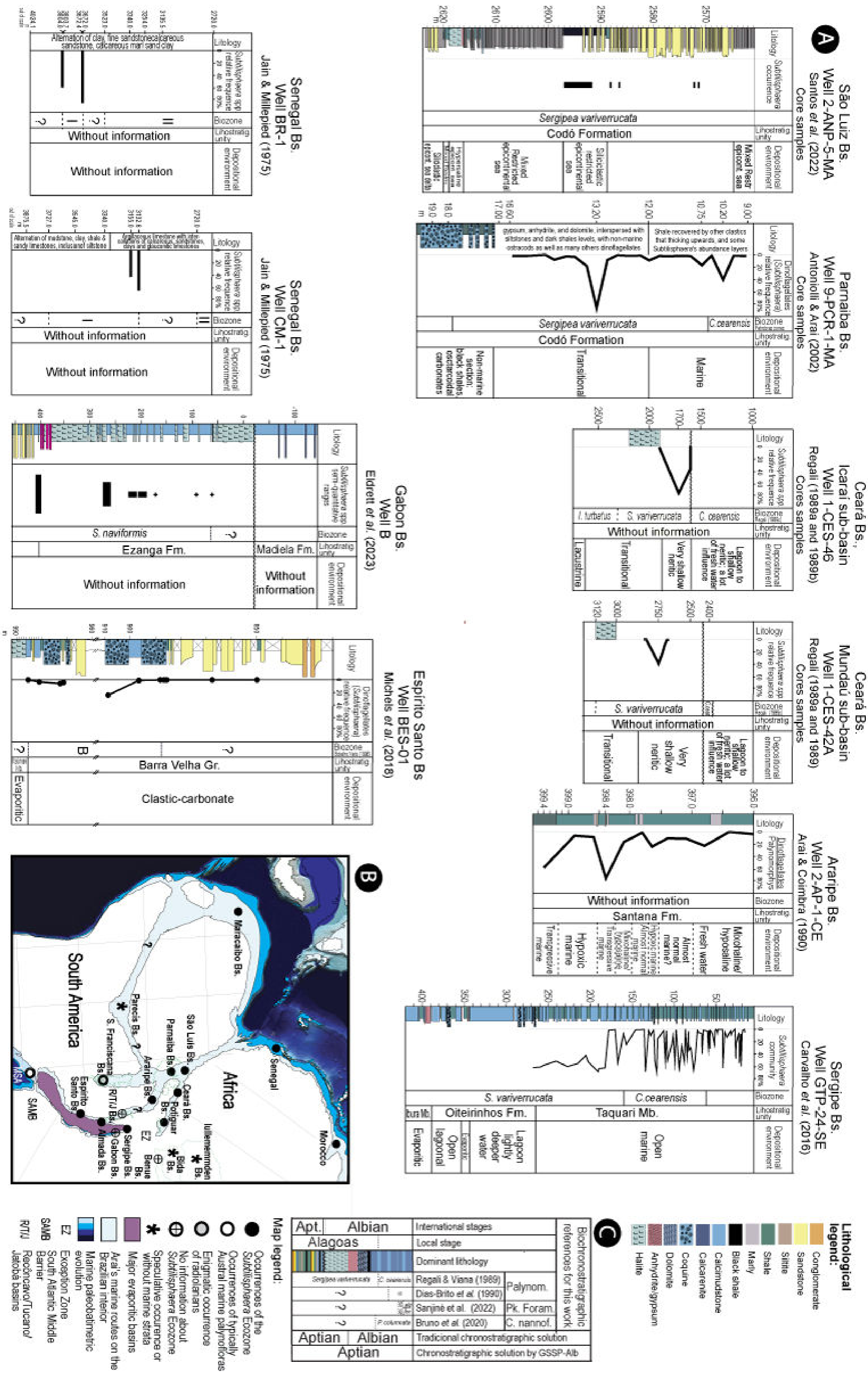
Different hypotheses have been proposed for the origin and possible routes of marine waters responsible for the deposition of the Ibura Salt and the overlying rocks, the post-salt carbonates. The problems with each model are discussed below to reach the most compatible water circulation proposal for the CSA and neighboring basins.

3.1. Hypotheses regarding the water mass responsible for the Ibura evaporites

RODRIGUEZ *et al.* (2018) presented a broad review of the Early Cretaceous salt deposits of the South Atlantic related to the Ibura Event, citing many studies and the controversies regarding the time of deposition, the accommodation models, genesis, and water sources that fed salt deposition. In turn, SZATMARI *et al.* (2021) presented a significant set of information on the regional and stratigraphic distribution of the different evaporites associated with the Ibura Event in support of genetic interpretations, their age and the paleogeographic scenarios that allowed their formation. Interestingly, the salt deposits in the northernmost (Sergipe, Gabon, and Congo) and southernmost (Santos) of the CSA basins register abundant soluble salts (Mg-K-Ca-salts-carnallite: bischoffite, and tachyhydrite) indicative of a broad evaporite paragenesis that has not been found so far in the other CSA basins.

The unusual massive deposition of tachyhydrite and MgSO4-depleted evaporites in the CSA basins motivated JACKSON *et al.* (2000) to argue that its precipitation did not come from normal seawater, suggesting rather that they were produced via hydrothermal alteration of a host rock, likely spilitized basalt. DEBURE *et al.* (2019), in turn, defended a serpentinization flux as a source of Ca, in view of the suggestion that the Aptian climate of the South Atlantic rift was not sufficiently arid for tachyhydrite precipitation (CHABOUREAU *et al.*, 2012). Nevertheless, the secular variation in Ca and SO4 in seawater over geologic time indicate the Cretaceous as a period of "calcite sea", in which KCl evaporite formation may have been associated with increased hydrothermal flux along the mid-oceanic ridge (SPENCER & HARDIE, 1990; HARDIE, 1996; LOWENSTEIN *et al.*, 2001; DEMICCO *et al.*, 2005; WARREN, 2010). This last author argued that the large volume of seawater necessary for the accumulation of huge volumes of halite or calcium sulfate in a sedimentary basin occurs frequently within hydrographically isolated and arid depressions below sea level that are fed by marine seepage.

▶ **Figure 6:** Sections with the *Subtilisphaera* ecozone or abundant occurrences of this genus (A) that support the paleogeographic map (B; modified from ARAI, 2009). Sections have different vertical scales and notations for *Subtilisphaera* abundance. The chrono-equivalence between the biozones and the local and international stages (C) are based on AZEVEDO *et al.* (2023).


São Luiz Bs.
Well 2-ANP-5-MA
Santos et al. (2022)
Core samples
Parnaíba Bs.
Well 9-PCR-1-MA
Antonioli & Arai (2002)
Core samples
Ceará Bs., Icaraí sub-basin
Well 1-CES-46
Regali (1989a and 1989b)
Cores samples
Ceará Bs. Mundaú sub-basin
Well 1-CES-42A
Regali (1989a and 1989)
Cores samples
Araripe Bs.
Well 2-AP-1-CE
Arai & Coimbra (1990)
Sergipe Bs.
Well GTP-24-SE
Carvalho et al. (2016)
Senegal Bs.
Well BR-1
Jain & Millepied (1975)
Senegal Bs.
Well CM-1
Jain & Millepied (1975)
Gabon Bs.
Well B
Eldrett et al. (2023)
Espírito Santo Bs
Well BES-01
Michels et al. (2018)
Sergipea variverrucata
Codó Formation
Without information
Santana Fm.
Oiteirinhos Fm.
Taquari Mb.
Ezanga Fm.
Madiela Fm.
Barra Velha Gr.
Clastic-carbonate
Evaporitic
Open marine
South America
Africa
Lithological legend:
Conglomerate
Sandstone
Siltite
Shale
Marly
Black shale
Calcimudstone
Calcarenite
Coquine
Dolomite
Anhydrite/gypsum
Halite
Biochronostratigraphic references for this work
International stages
Local stage
Dominant lithology
Regali & Viana (1989)
Dias-Brito et al. (1990)
Sanjinés et al. (2022)
Bruno et al. (2020)
Palynom.
Pk. Foram.
C. nannof.
Tradicional chronostratigraphic solution
Chronostratigraphic solution by GSSP-Alb
Apt.
Albian
Alagoas
Aptian
Map legend:
Occurrences of the Subtilisphaera Ecozone
Occurrences of typically Austral marine palynofloras
Enigmatic occurrence of radiolarians
No information about Subtilisphaera Ecozone
Speculative occurrence or without marine strata
Major evaporitic basins
Araí's marine routes on the Brazilian interior
Marine paleobatimetric evolution
EZ Exception Zone
SAMB South Atlantic Middle Barrier
RTJ Recôncavo/Tucano/ Jatobá basins

Based on these approaches SZATMARI *et al.* (2021) reaffirmed the barrier model developed by OCHSENIUS (1877, *fide* HSÜ *et al.*, 1973) that had been defended a few years earlier by SZATMARI and MILANI (2016). To them, the formation of the salt in the CSA occurred in a shallow-water setting within a deep subaerial basin that received water of varied nature and sources: infiltration through the SAMB via fractures and faults; continental runoff leaching basaltic terrains and siliciclastic Proterozoic rocks; hydrothermal flows ascending through rift faults; and inflow of marine waters from the north, which would have passed through the Taquipe and Manati canyons (Fig. 5). In line with SZATMARI and MILANI (2016), but focused on the Santos Basin, FARIAS *et al.* (2019) suggested that the Pre-Salt carbonates are a product of the same system that led to the precipitation of the halite-carnallite-tachyhydrite salts associated with the Ibura Event.

As commented ahead, the irrefutable Tethys nature of the carbonates overlying the CSA saliferous layer is an obstacle to the idea of a great primary contribution of Austral waters in the formation of these Ibura Evaporites. However, such is not the case for the rocks found in the MSA (*e.g.*, Pelotas Basin, well 1-RSS-2; DSDP, Site 511) as verified by DIAS-BRITO (1995). This author viewed the SAMB as an efficient barrier to the entry of southern waters and argued that the Tethys marine contribution reached the CSA via ESA and crossed the Exception Zone (EZ) in one or more transgressive pulses, thereby feeding the extensive evaporitic basin in the intra-Gondwana rift. The main limitation of this hypothesis is that salt paragenesis points to an extremely restricted environment at the time of deposition (SZATMARI *et al.*, 2021), a scenario less compatible with the dilution that would be expected for waters entering from Tethys through a Sergipe-Gabon gateway. Therefore, the presence of a via some place in the central region of the CSA (between Recôncavo and Campos and its counterpart in Africa) should be considered for feeding the water for Ibura Salt formation.

Ever since the 1960s, traces of the Albian-Aptian marine transition have been known in the northeastern Brazil onshore basins. Some maritime routes were postulated to explain how the water reached, for example, the Araripe Basin. Two of them suggesting that it came from the ESA, one through the São Luiz and Parnaíba basins (*e.g.*, BRAUN, 1966; BEURLEN & MABESOONE, 1969, *fide* MABESOONE & TINOCO, 1973; BEURLEN, 1971a, 1971b; ARAI *et al.*, 1994; CARVALHO *et al.*, 2012) and the other through the Potiguar Basin (*e.g.*, LIMA M.R., 1978; PETRI, 1987; VIANA, 1998, *fide* ARAI, 2014). Some authors defended a connection between the Araripe and Sergipe-Alagoas basins (SILVA-SANTOS, 1991; ASSINE, 1994) and others proposed that the Araripe Basin received marine contributions via all three of these basins (*e.g.*, LIMA FILHO *et al.*, 1996; MABESOONE *et al.*, 1999; VALENÇA *et al.*, 2003). A later suggestion was that the waters came from the south through the Tucano and Recôncavo basins (*e.g.*, ASSINE, 2007; ASSINE *et al.*, 2014, 2016; CUSTÓDIO *et al.*, 2017).

Conjectures that this mid-Cretaceous seaway extended significantly into a more central area of Brazil gained attention after radiolarians were found in chert levels interbedded with shales/siltstones containing dinoflagellates and other planktonic marine fossils in the southern Sanfranciscana Basin (KATTAH, 1991). ARAI (1999, 2000, 2016a) reinforced KATTAH's idea based on geomorphological, stratigraphical, sedimentological, paleontological, and geochemical criteria. For him, vestiges of an interior sea in many mid-Cretaceous Brazilian plateaus (or "chapadas") comprise evidence of marine ingressions over vast areas of Brazilian territory. Later, ARAI (2009, 2014) extended this epicontinental sea, connecting it to the intra-Gondwana rift through the Almada Basin, based mainly on *Subtilisphaera* blooms detected in clayey levels that usually occur overlying Ibura evaporitic deposits (ARAI *et al.*, 1994, 2000; ARAI, 2009, 2014). Figure 6.A shows the abundant occurrences of this dinoflagellate genus restricted to the *Sergipea variverrucata* Zone or another coeval zone; Figure 6.B displays the Brazilian interior seaway map formulated by ARAI (2009) based on the distribution of these fossils. More recent indications (*e.g.*, MICHELS *et al.*, 2018; SANTOS *et al.*, 2022; ELDRETT *et al.*, 2023) further confirm the chronostratigraphic relevance of this ecozone, despite the wide range of the genus *Subtilisphaera* (Late Jurassic to Tertiary). The occurrence of this dinoflagellate genus in the Almada Basin was not plotted because there it is related to older strata, the palynologic Zone *Transitopollis crisopolensis* (=*Inapturopollenites crisopolensis*), code P-230 (LANA & PEDRÃO, 2000).

CARVALHO *et al.* (2016) defended the idea that a wide interior sea covered a large part of Brazil connected to the CSA and even a small portion of Africa (Niger and Cameroon) during the span time of the *Sergipea variverrucata* Zone. They attributed the origin of this marine domain to one of the most extensive sea level rises of the entire Phanerozoic, an argument previously used by ARAI (1999). It is unlikely that eustasy alone can explain the formation of the interior sea, particularly because the end of the Aptian (sense GSSP-Alb) was marked by erosional events associated with a significant decrease in sea level (*e.g.*, HUBER & LECKIE, 2011; HAQ, 2014; GALE *et al.*, 2021). At that time, distensive phases created space for the formation of a group of sedimentary basins in the northern region of Brazil (SOARES JÚNIOR *et al.*, 2011), including the Bragança-Viseu, São Luís, Ilha Nova, Barreirinhas, and Pará-Maranhão basins, that contain marine carbonates and sporadic layers of evaporites (*e.g.*, HASHIMOTO *et al.*, 1987; SOARES *et al.*, 2007; ZALÁN, 2007).

A further proposal, that the waters came from the north, reaching the CSA through the African interior via the Benue (UMEJI, 2013), is based on the presence marine carbonates and lagoonal shales dated as Aptian-Albian in the central portion of the Benue Trough. However, similar deposits are not found in the northern portion of the Benue Trough, nor have they been recognized in any basin of the West and Central Africa Rift System, which formed concurrently with the fragmentation of Gondwana (GUIRAUD *et al.*, 2005; HEINE *et al.*, 2013; ABUBAKAR *et al.*, 2014; SULEIMAIN, 2016). Rather, it is more reasonable to attribute these carbonates and lagoonal shales to marine incursions from the west (AKANDE *et al.*, 2012; KELECHI, 2017), especially given that the Benue Basin had its origin in the fragmentation of the equatorial segment of Gondwana (MATOS, 1992).

3.2. The "ARAI Sea" as the supplier of the waters that formed the Ibura evaporites

Though the deposition of the Ibura evaporites is associated with the sag phase, in which thermal subsidence predominated, many studies have shown that tectonic processes continued from the Cretaceous to the Neogene, producing in gaps in the sedimentary record of the Brazilian interior basins (*e.g.*, MAGNAVITA *et al.*, 1994; KARNER *et al.*, 2003; JAPSEN *et al.*, 2012; CHABOUREAU *et al.*, 2013; KLÖCKING *et al.*, 2020). Moreover, much biochronostratigraphic and paleoecological data are lacking, so it is difficult to make well-founded interpretations about the supply and volume of the water required for the formation of the giant evaporitic deposits preserved in the CSA, ESA, and BNE. Such gaps in knowledge invite elaboration of new hypotheses on this subject, for example, that which we present here that integrates, with reservation, part of the models defended by ARAI (2009, 2014) and SZATMARI and MILANI (2016).

As an unusual group of soluble salts occur only at both ends of the giant Ibura evaporitic province (SZATMARI *et al.*, 2021) and since there is no evidence of marine water inflow from Africa, it is assumed here that waters coming from the west/northwest possibly diluted the brine in the central region of the CSA. Therefore, the narrow, shallow, and ephemeral epicontinental sea initially imagined by ARAI (2009, 2014) gains greater dimension in the present study (Fig. 7.A). It is designated here as 'the ARAI Sea', in honor of Mitsuru ARAI for his prolific contributions to Brazilian geology. The outline of this sea is defined by the distribution of mid-Cretaceous "chapadas" (*i.e.*, plateaus) bearing marine fossils (ARAI, 1999, 2000, 2016a) and occurrences of Brazilian evaporites (CHUMAKOV *et al.*, 1995; Fig. 7.A). As the *Subtilisphaera* spp. Ecozone occurs just above the salt layer, it is the best proxy to track a possible seawater route that fed the formation of the Ibura evaporites.

There are some issues with this model. For ASSINE *et al.* (2016), the marine incursion inferred by ARAI (2009, 2014) is incompatible with paleocurrent patterns of the BNE. There are also doubts regarding the marine nature of the facies enclosing the evaporites in some basins of Northeastern Brazil (*e.g.*, PAZ & ROSSETTI, 2001; BAHNIUK *et al.*, 2014; DIAS-BRITO *et al.*, 2015). In addition, there is uncertainty regarding both the marine influence upon the Sanfranciscana Basin and the possible connections of this epicontinental sea with the intra-Gondwana rift.

To ASSINE *et al.* (2016), the idea of a seawater advancing into the continental interior is in complete contradiction to the paleocurrent directions of contemporaneous river flow in the Araripe and Tucano basins. They also offer lithofaciological arguments that "suggest a paleogeographic scenario in which the Parnaíba and Potiguar basins were set apart of each other and of the system formed by the Araripe, Tucano and Jatobá basins, configuring three distinct drainage basins in the northeast Brazil". The problem is that there are other paleontological and geological data that indicate more affinities than incompatibilities between BNE basins. As ARAI (2016b) commented, if "the aforementioned drainage divides actually existed, it would clearly constitute a biogeographic barrier inhibiting the development of similar biota in these basins". A good example that this paleogeographic isolation did not occur is the record of turtle species in common in the Codó and Romualdo formations within Parnaíba and Araripe Basin, respectively (BATISTA *et al.*, 2023).

Organic-rich calcimudstone beds above and below the salt (DIAS-BRITO *et al.*, 2015) show environmental and chronological similarities in different ESA and BNE basins. These and other authors, such as BAHNIUK *et al.* (2014), associate both records, or only the older strata, with lagoonal deposits. It is currently widely agreed that the evaporites of the ESA and BNE basins are marine in origin, but there is no consensus yet regarding the salts of the Codó Formation, Parnaíba Basin (*e.g.*, RODRIGUES, 1995; PAZ & ROSSETTI, 2001; ANTONIOLI & ARAI, 2002; ROSSETTI *et al.*, 2004; BAHNIUK *et al.*, 2014; BASTOS *et al.*, 2014; DIAS-BRITO *et al.*, 2015). However, marine evidence can be found in these rocks at levels just below the salt (BASTOS *et al.*, 2022). Over the evaporites occur organic-rich layers containing biomarkers associated with marine organisms of the photic zone tolerant of anoxic conditions (HEIMHOFER *et al.*, 2008; SOUSA JÚNIOR *et al.*, 2013), and *Subtilisphaera* spp. Ecozone, helping to track the route of marine incursion in the interior of Brazil (ARAI, 2009, 2014).

Another debatable point concerns the marine fossils in the southern Sanfranciscana Basin. For PESSAGNO and DIAS-BRITO (1996), the radiolarians recovered there have characteristics of an Austral association of Pacific origin and point to a Barremian/Aptian age for the chert. However, palynological data obtained for one of two sets of shale samples collected by KATTAH (1991) revealed a much younger age, inferred from the presence of poorly preserved dinoflagellates, including one belonging to the genus *Oligosphaeridium*, and the *incertae sedis Cyclopsiella*

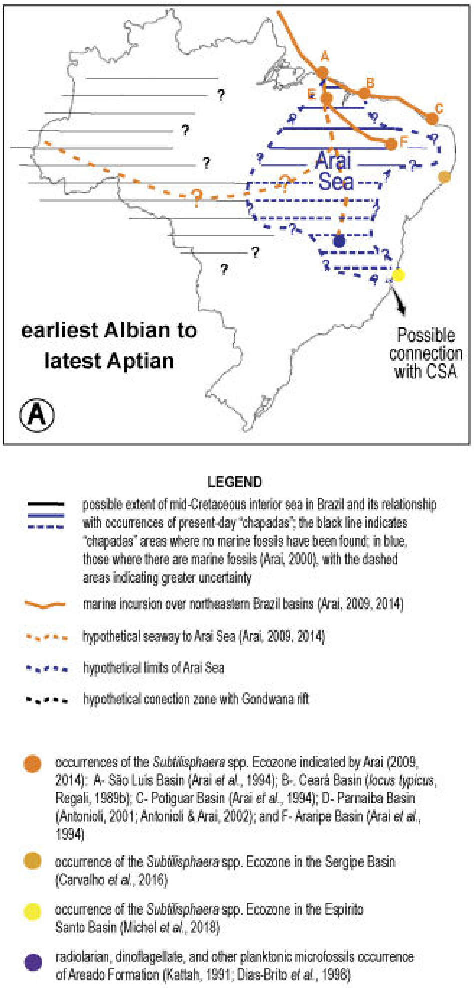
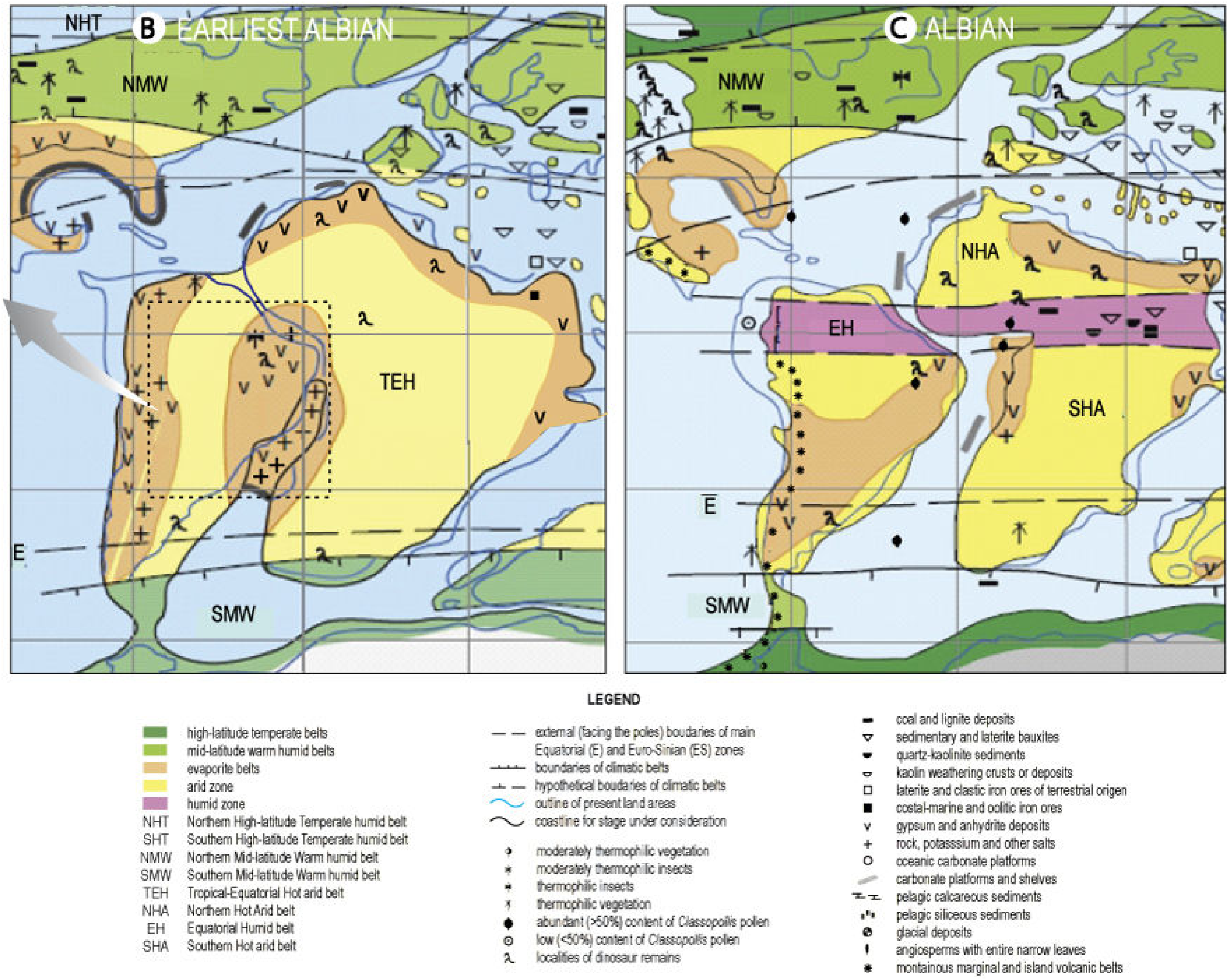


Figure 7: Sections with the *Subtilisphaera* ecozone or abundant occurrences of this genus (A) that support the paleogeographic map (B; modified from ARAI, 2009). Sections have different vertical scales and notations for *Subtilisphaera* abundance. The chrono-equivalence between the biozones and the local and international stages (C) are based on AZEVEDO *et al.* (2023).

(A.T. HASHIMOTO, in Annex III, Palynological Analysis, KATTAH, 1991). The Last Occurrence (LO) of *Cyclopsiella* is the reference marker for the Lower-Middle Albian packet in southeastern Brazilian basins (DIAS-BRITO *et al.*, 1990), which favors the idea that this interior route may have supplied water for the formation of the enormous evaporitic layer of the CSA. Nevertheless, the *Tucanopollis crisopolensis* Zone (= *Transitoripollis crisopolensis*), of Barremian age, was indicated in the second set of samples (M. ARAI, in Annex III, Palynological Analysis, KATTAH, 1991). Despite chronostratigraphic imprecision and conflicts regarding the origin of waters that transported the radiolarians and other microfossils to the Sanfranciscana Basin, KATTAH's



discovery is important because it allows conjecture as to that this area was possibly part of the ARAI Sea in central Brazil.

Assuming an endorheic basin model for salt deposition in the CSA (SZATMARI & MILANI, 2016; FARIAS *et al.*, 2019), it is reasonable to expect that canyons would have formed in the more elevated borders of the intra-Gondwana rift where waters from rivers or the ARAI Sea entered such basins, similarly to what occurred throughout the Mediterranean during the Messinian salinity crisis (HSÜ *et al.*, 1973; ESTRADA *et al.*, 2011). The adoption of *Subtilisphaera* spp. acme as a proxy for recognizing probable connections between the ARAI Sea and the CSA leads us to deduce that the most probable final outlet was located in the coastal area of the Espírito Santo Basin, where OLIVEIRA *et al.* (1993, *fide* ARAI *et al.*, 1994) and MICHELS *et al.* (2018) recognized blooms of this dinoflagellate in rocks just slightly above the Ibura salt. Moreover, among CSA basins, it is the Espírito Santo Basin that exhibits the westernmost occurrences of both evaporites and post-salt carbonates in onshore areas. In addition, imposing paleocanyons sculpted in this basin during the Late Cretaceous (ANTUNES, 1984, 1990) and the Paleogene (ESTRELLA *et al.*, 1984) suggest uplift of continental crust that would have adversely affected preservation of the sedimentary record left by this marine route through the interior of Brazil.

Figure 8.A presents data from two sedimentary sections at opposite ends of the proto-South Atlantic, the Parnaíba Basin in the ESA and the Santos Basin in the CSA (BASTOS *et al.*, 2022), and shows a paleogeographic reconstruction at the time of Ibura salt deposition, with waters mainly coming from Tethys, by a route involving the ARAI Sea and the Espírito Santo Basin (Fig. 8.B).

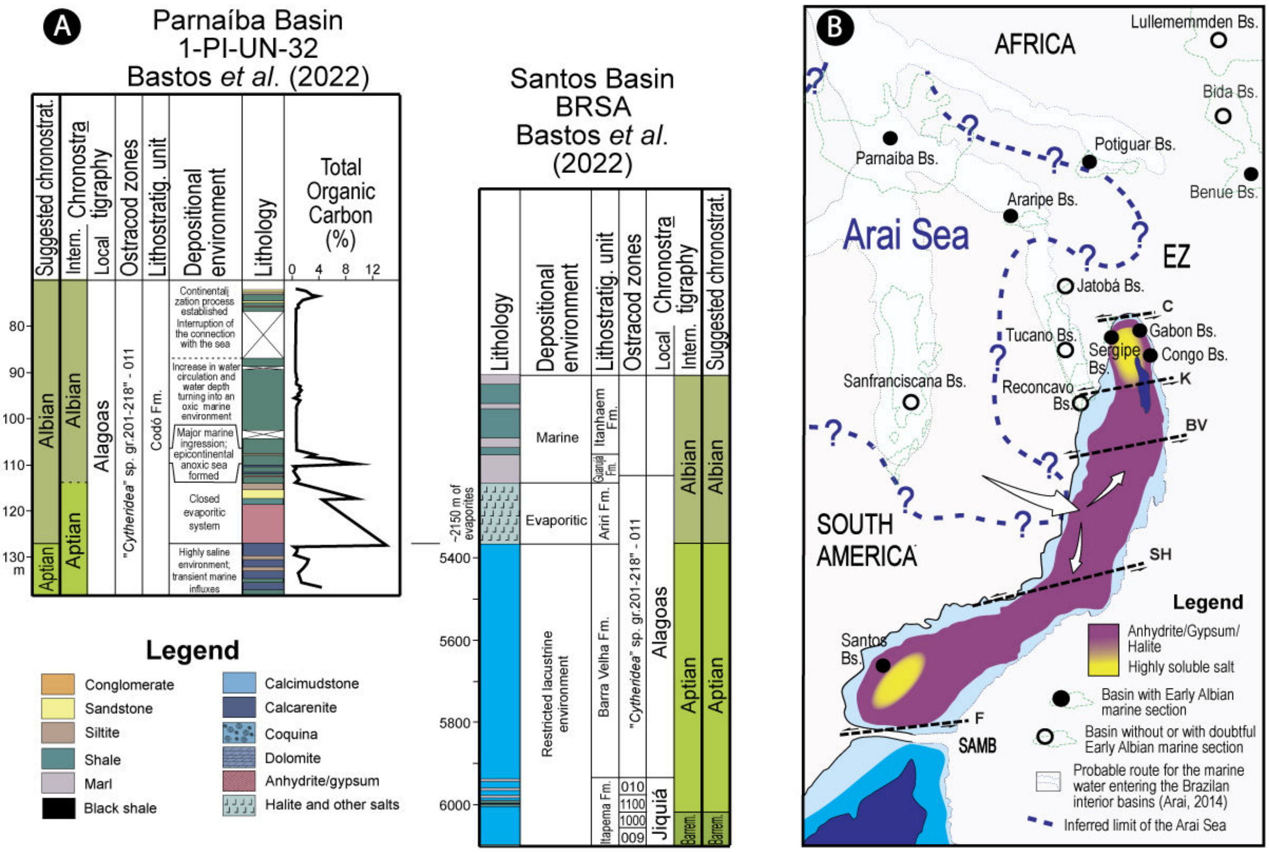


Figure 8: Chrono-correlated sections between as far away as the Parnaíba and Santos basins confirm the synchronous character of the Ibura evaporites (modified from Bastos *et al.*, 2022). Black shales around the salt deposition reflect the rapid, intense environmental changes, that concluded with a continentalization process affecting the BNE basins and the imposition of a carbonate system in the ESA and CSA. The map on the right, based on Szatmari *et al.* (2021), shows the general trend of the evaporite distribution, with the soluble salts limited to the extremities of the CSA. The fracture zones defined by Matos *et al.* (2021a, 2021b) are indicated by: C- Charcot; K- Kribi; BV- Bode Verde; SH- St Helen; and F- Florianópolis. Chronostratigraphic indications are based on Azevedo *et al.* (2023).

As commented above, this solution reconciles the restriction of extreme conditions for the formation of soluble salts to the north and south ends of the CSA (Szatmari *et al.*, 2021), which leads to the exclusion of Sergipe Basin from the area covered by this epicontinental sea. As neither marine sediments associated with the evaporitic phase nor *Subtilisphaera* spp. have ever been found in the Jatobá, Tucano, and Recôncavo basins, this area has not been considered a possible water supply route for salt formation in the CSA.

Bastos *et al.* (2022) showed that in both the Santos and Parnaíba basins most sedimentary records, including the evaporite layers, are inserted within the ostracod Zone "*Cytheridea*" sp. gr. 201-218 (or 11 code), belonging to the local Alagoas Stage (Fig. 8.A). In the stratigraphic chart of the Campos Basin, Rangel *et al.* (1994) also associate the evaporite layer with this biozone and with the same age, without indicating an equivalent palynological unit. The biostratigraphic synthesis for the Santos Basin does not include any information for the section beneath the post-salt carbonates (Pereira & Feijó, 1994). In turn, the Codó Formation (Parnaíba Basin) is also included in the ostracod biozone "*Cytheridea*" sp. gr. 201-218 (~*Harbinia* spp. 201-218 *sensu* Do Carmo *et al.*, 2008), and the *Sergipea variverrucata* palynozone (Antonioli & Arai, 2002; Machado, 2022), which is limited to the northeastern Brazil basins.

To Bastos *et al.* (2022), sediments of the Codó Formation initially accumulated in a hypersaline lacustrine environment; it was converted into a closed evaporite complex due to episodic Atlantic marine influxes into the basin. Still according to them, this evaporitic phase was followed by an important marine ingression with the installation of an expressive regional epicontinental sea linking several basins in northeastern Brazil; the uppermost sediments of the Codó Formation reflect a progressive continentalization of the system. *Subtilisphera* blooms were associated with the epicontinental sea phase (Neves *et al.*, 2007). Figure 8.A also shows expressive post-evaporitic marine deposits in the Codó section made up of organic-rich mudstones that record the OAE1b global perturbation signal (BASTOS *et al.*, 2022). In this case, emphasis is placed on its chronocorrelation with the JACOB event, as interpreted by AZEVEDO *et al.* (2023).

However, the presence of microforaminiferal linings immediately underlying the Ipubi gypsiferous strata, in the Araripe Basin (ARAI, 2012; GOLDBERG *et al.*, 2019), previously considered lacustrine, opens the perspective that broad areas of the BNE may have been covered by marine waters prior to the Ibura Event.

Assuming the paleoclimatic context indicated by CHUMAKOV *et al.* (1995), we see the shallow ARAI Sea as an ephemeral entity that occupied a broad, warm and arid area. It was influenced by tectonic movements related to continental fragmentation to the east and dried up relatively quickly, thus ending water flow into the CSA.

It remains, now to answer another crucial question: how did the evaporite system pass to the stage of a long and narrow carbonate gulf with a lagoonal circulation pattern?

3.3. Marine conditions during post-salt carbonate deposition

The geodynamic model of progressive south-to-north rupture of Gondwana has long sustained the dominant idea that the giant Ibura salt deposits was originated by waters coming predominantly from the south (*e.g.*, ASMUS & PONTE, 1973; PREMOLI-SILVA & BOERSMA, 1977; KUMAR *et al.*, 1977; NATLAND, 1978; JACKSON *et al.*, 2000; DAVISON, 2007; DAVISON *et al.*, 2012; HEINE *et al.*, 2013). By the same token, the predominantly carbonate deposits overlying the evaporite succession would have originated from temperate waters likewise coming from the south (*e.g.*, GORDON, 1973; KAUFFMAN, 1973; SCHEIBNEROVÁ, 1978; PHILIP, 1982; RAT, 1987; SOHL, 1987). This scenario is well expressed by prevailing paleogeographic reconstructions for the Aptian-Albian time interval (*e.g.*, SCOTESE, 2014).

It was the presence of Tethys ammonite species at DSDP sites 363 and 364 (Walvis Ridge and Kwanza Basin, respectively) that led WIEDMANN and NEUGEBAUER (1978) to defend the idea of a broad invasion of northern water into the CSA in mid Albian times, when the common history of these two water masses would have begun. However, these authors considered the possibility that the South and North Atlantic were connected even earlier, in late Aptian times. MOULLADE and GUÉRIN (1982) also indicated contact of the northern South Atlantic (CSA plus ESA) with northern waters since the Middle Albian, based on the high number of Tethys foraminifera species of that time found in South Atlantic sediments.

As commented early, the Aptian-Albian marine deposits and a limited influence of northern waters in BNE basins have been known for more than a half a century. It fell to DIAS-BRITO (1982) suggested that this marine incursion extended throughout the CSA since Albian times. Comparing microfaciological and micropaleontological information from fine Albian carbonates of the Campos and Angola basins, he wrote: "It is worth highlighting the occurrence of carbonate strata rich in calcispherulids. Not restricted to the Late Albian sediments of the Campos Basin, but distributed in this time interval throughout the Atlantic-Brazilian margin and Angola Basin (BOLLI, 1978b), such levels must represent an important event in the paleoceanographic context of the South Atlantic (North Atlantic or Mediterranean Tethys contact with the South Atlantic ?)." Three years later, DIAS-BRITO (1985a, 1985b) concluded that connections between South and North Atlantic waters had already been established since Early-Middle Albian times. Micropaleontological data from Sergipe-Alagoas and Ceará basins led DIAS-BRITO (1987) to consider "the possibility that the break up [...] would have occurred immediately after the evaporitic phase". Along the same line, DIAS-BRITO (1992) and KOUTSOUKOS (1992) make it clear that in late Aptian to Early Albian times there was direct communication between surface waters of the South Atlantic and Tethys. KOUTSOUKOS (1992) also showed that "about 80-90% of microfaunistic elements was present in low-latitude central North Atlantic-western Tethys regions", and that "all the microfaunistic elements from Sergipe that have been reported form high-latitude southern regions are also known to occur in the central North Atlantic-western Tethyan/Transitional realm."

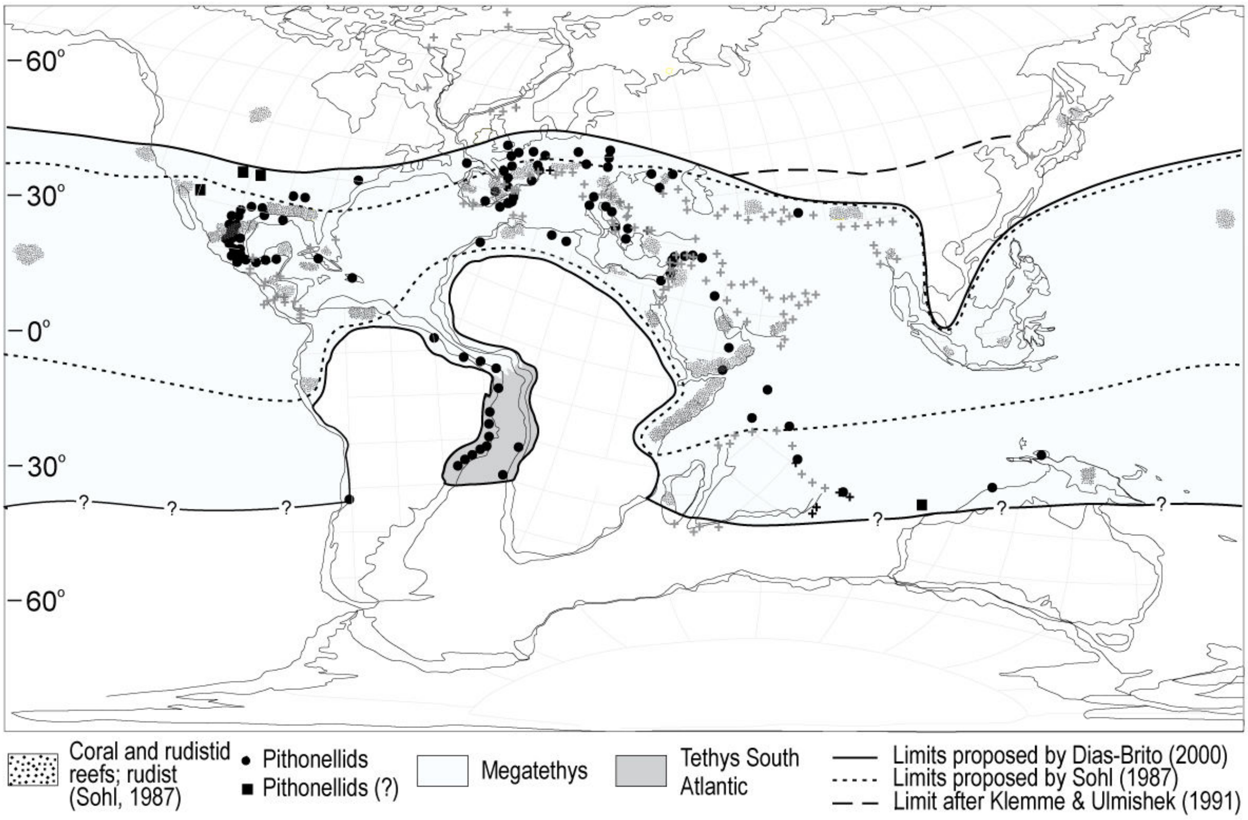


Figure 9: The Mid-Cretaceous Megatethys, a planetary realm of warm waters occupying a latitudinal band between 40° N and 40° S during a global warming phase, as conceived by DIAS-BRITO (1992, 1995, 2000). The limits of the Megatethys are based on the global distribution of pithonellids, which because of their thermophilic nature serve as excellent tracers of Tethys waters. This map represents, to a large extent, the Late Albian scenario. Figure from DIAS-BRITO in TUCKER and DIAS-BRITO (2017).

Microfaciological data concerning post-salt pelagic carbonates from the entire Brazilian margin and some information from literature on West African basins (*e.g.*, CHEVALIER & FISCHER, 1982; DSDP Leg 40, several authors) combined with an exhaustive global biogeographical survey on a select group of Tethys calcareous planktonic elements found in Cretaceous limestones and marls, led DIAS-BRITO (1992, 1994, 1995, 2000) to elaborate an oceanographic evolutionary model for the Albian northern-equatorial South Atlantic, *i.e.*, from SAMB to the north (a continuum formed by CSA plus ESA). He visualized this segment - a long, narrow and predominantly carbonate gulf - as an arm of the Megatethys (TUCKER & DIAS-BRITO, 2017; Fig. 9).

The pelagic carbonates of this Tethys extension into the South Atlantic are dominated by a planktonic content (Fig. 3), *i.e.*, calpionellids (*Colomiella Mexicana*, *C. recta*), pithonellids (*Pithonella sphaerica*, *P. ovalis*, *P. perlonga*, *P. trejoi*, *Bonetocardiella conoidea*), colomispherids, cadosinids, stomiospherids, nannoconids, several species of planktonic foraminifera, and crinoids (roveacrinids and saccocomids, including *Poecilocrinus*, *Lombardia*, *Microcalamoides diversus*, and *Eothrix alpina*). This association is present in pelagic carbonates from eastern Mexico, the Gulf of Mexico and the Western Carpathians and used as a marker of latest Aptian-earliest Albian time (TREJO, 1975; BORZA, 1984; MCNULTY, 1985; REHÁKOVA & MICHALÍK, 1993; NÚÑEZ-USECHE *et al.*, 2016; MONIER-CASTILLO *et al.*, 2018; GUTIERREZ-PUENTE *et al.*, 2021). Nektonic ammonites are also present, best recorded in the onshore Benguela and Sergipe basins (*e.g.*, TAVARES, 2007; BENGTSON *et al.*, 2018), but sporadic occurrences have also been recognized on well cores, like DSDP-363 and DSDP-364 (BOLLI *et al.*, 1978a, 1978b) and others drilled by oil companies (unpublished reports).

Paradoxically, however, the shallow-water limestones are virtually devoid of some key Tethys fossils, such as orbitolinids (GRANIER & DIAS-BRITO, 2015), discyclinids and alveolinids. Ostreid boundstones and thrombolite mounds preserved *in situ*, with doubtful ages, were recorded in the Sergipe Basin (Riachuelo Formation, Lower-Middle Albian?) and in the Albian? of Namibe Basin (GRANIER

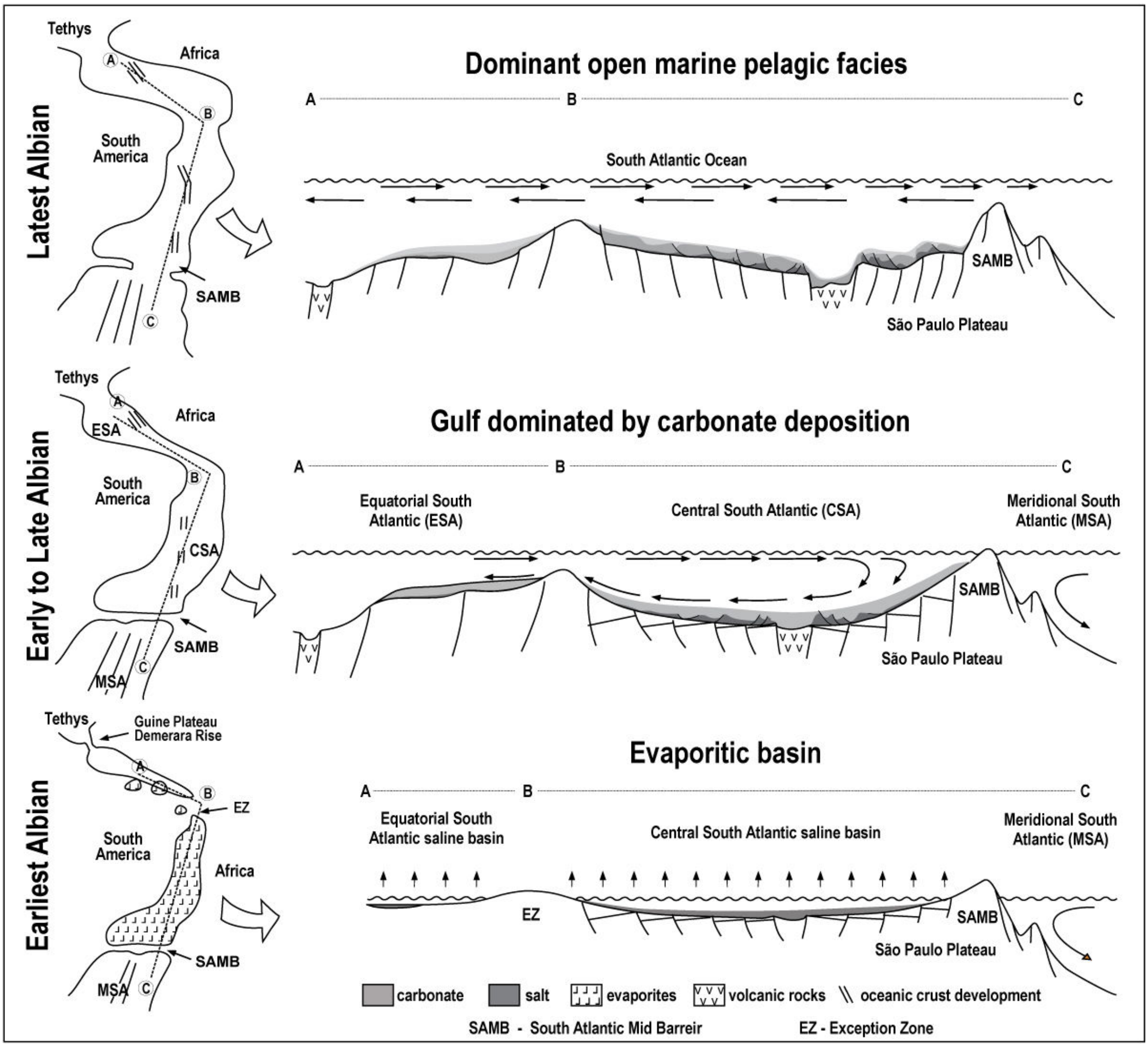


Figure 10: Evolution of dominant circulation patterns of the South Atlantic - Tethys during the Albian (modified from AZEVEDO, 2001).

& DIAS-BRITO, 2015; SCHRÖDER *et al.*, 2015; TUCKER & DIAS-BRITO, 2017; ANDRADE *et al.*, 2019). Shallow water environments, especially those located in Brazilian basins further south in the gulf, were inhabited by cyanobacteria which produced oncoidal packstones and grainstones that are commonly associated with oolitic carbonate deposits (SPADINI *et al.*, 1988; CARVALHO, 1989, 1996). Also present a poor and little-diversified microbiota (*e.g.*, benthic foraminifera, including *Coscinoconus*, *Lenticulina* and other nodosarids, miliolids, and a few metazoans, such as echinoderms, mollusks, and ostracods; *e.g.*, AZEVEDO *et al.*, 1987).

DIAS-BRITO (1995, 2000) designated this arm of Tethys in the South Atlantic as the Paratethys Province, a paleogeographic model in clear opposition to the dominant classical view that roots the primitive CSA in Austral waters coming from the MSA. He assumes that episodic pulses led southern waters to cross SAMB, a barrier that was only definitively overcome at the end of the Albian.

Based on the concepts formulated by DIAS-BRITO, AZEVEDO (2001, 2004) defended a lagoonal circulation pattern for the long, narrow South Atlantic carbonate gulf, similar to that in the modern Red Sea (Fig. 10). According to AZEVEDO's model, warm superficial waters from the north carrying Tethys faunal elements would have entered the gulf and progressed southward until they reached the SAMB. Once there, these now much denser waters returned north as hypersaline and almost always oxygenated bottom currents.

Throughout the Early-Middle Albian, the carbonate system was characterized by numerous cycles (on the scale of meters to hundreds of meters) piled up in different orders, organized in basic, shallowing-upward units (AZEVEDO, 2005). The relatively stable creation of space for third-order cyclothem formation through thermal subsidence was occasionally interrupted by halokinetic or tectonic instabilities (CASTRO & FUGITA, 2004; TAGLIARI *et al.*, 2013).

This situation changed greatly in the Late Albian when the carbonate ramp underwent a remarkable phase of prolific planktonic production, which evolved to form a chalk-marl rhythmite, followed by complete drowning of the carbonate system, as indicated by marls and shales of the uppermost part of the section (*e.g.*, DIAS-BRITO, 1982; SPADINI, 1982; DIAS-BRITO & AZEVEDO, 1986; VIVIERS, 1986; AZEVEDO *et al.*, 1987; SPADINI *et al.*, 1987, 1988). A geochemical study of an Albian section in the Campos Basin records substantial change in the values of major, minor and trace elements at the uppermost Albian (AZEVEDO & LOBO, 2013) that point to a marked tectonic event with rearrangement of source areas that furnished the first turbiditic sandstones to the basin. Due to its expression and stratigraphic position, it is reasonable to speculate that this serves as a proxy for the moment of rupture of the SAMB (Fig. 3) and the birth of the South Atlantic by the unification of the MSA, CSA, and ESA (*e.g.*, DIAS-BRITO 1995, 2000; AZEVEDO, 2001; Fig. 10).

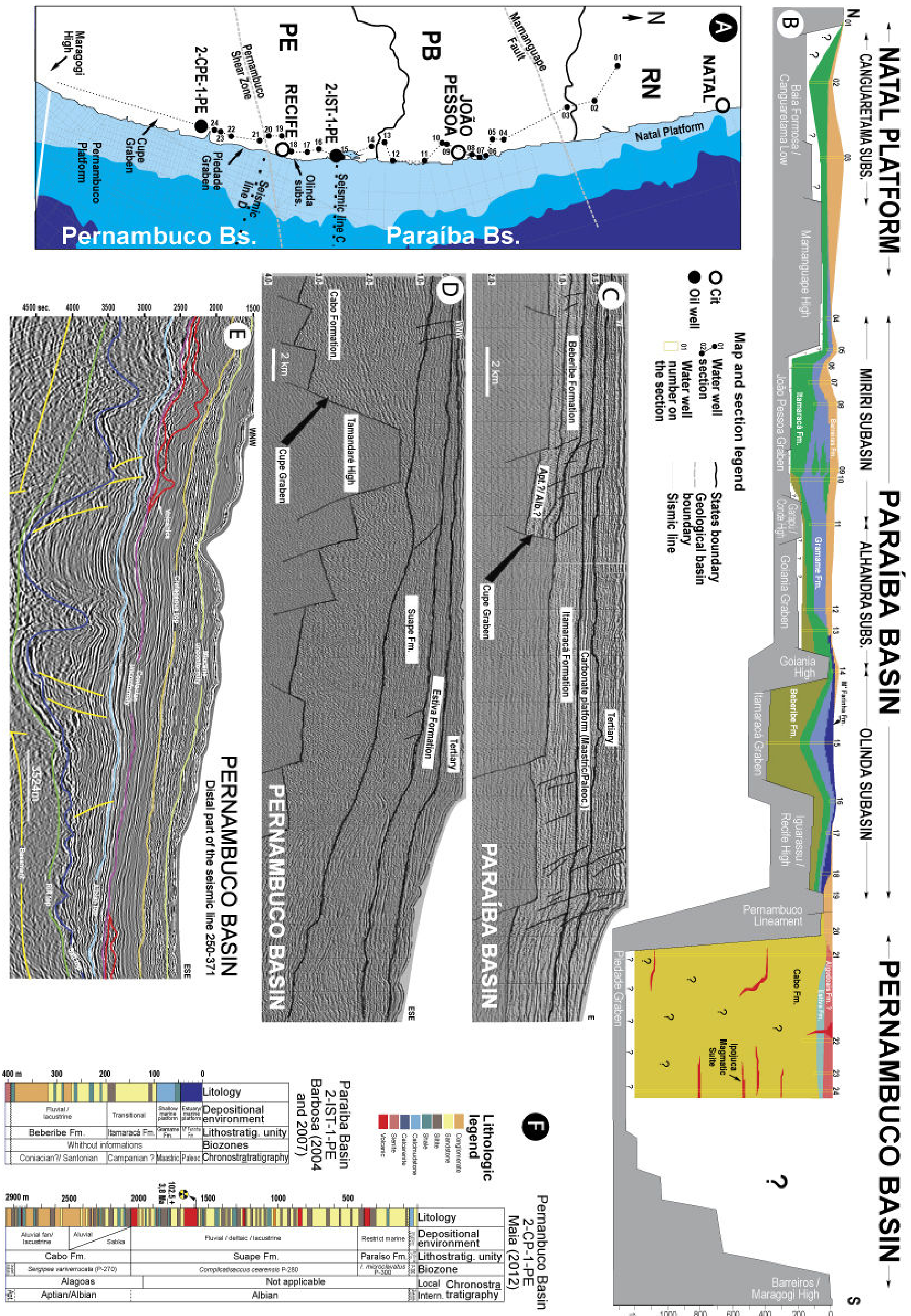
3.4. Breaching of the Exception Zone and the formation of the South Atlantic Gulf

The ephemeral ARAI Sea lasted long enough to be an important water source for salt formation in the CSA. The geological scenario changed when the two rift segments, housing the ESA and CSA, became definitively linked with the rupture of the Exception Zone - EZ (BARBOSA *et al.*, 2008), the last connection between South America and Africa at the northern end of the CSA. The first results were quick deposition of siliciclastics, including back shale, and *Subtilisphaera* blooms, followed by the implantation of the widespread Atlantic Albian carbonate system, involving the ESA and CSA basins, with some minor lithofaciological differences. According to the chronostratigraphic interpretation of ANTUNES *et al.* (2018) and AZEVEDO *et al.* (2023), an earliest Albian age is suggested for the collapse of the EZ that resulted in the formation of the South Atlantic Gulf.

Any interpretation to the age of the EZ rupture process necessarily comes up against the precariousness of available data on the mid-Cretaceous for the Pernambuco and especially the Paraiba basins and their African counterparts. Figure 11.A shows the difference in the density of seismic data for the two Brazilian continental margin basins and the limitation of information from wells restricted to the onshore portion, where coarse-grained siliciclastic facies dominate, with reduced fossil preservations and, consequently, limited biochronostratigraphic indicators. The section constructed from data from water wells (Fig. 11.B) and the seismic lines (Fig. 11.C-E) show the differences in the tectonic-depositional regime of the two basins (*e.g.*, LIMA FILHO, 1998; BARBOSA, 2004, 2007; LIMA FILHO *et al.*, 2005; BARBOSA & LIMA FILHO, 2005, 2006; BARBOSA *et al.*, 2007; LIMA FILHO & BARBOSA, 2010; MAIA, 2012). The offshore data also reveal their differentiated sedimentary evolution, with the presence of halokinetic features in the Pernambuco Basin, making it the northernmost limit of salt deposition on the Brazilian continental margin (LIMA FILHO, 2013; MATOS *et al.*, 2021b; Fig. 11.C-D).

The tectonic evolution model presented by LIMA FILHO *et al.* (2005, 2006) proposes that, as observed in other CSA basins, NE/SW aligned grabens and horsts developed progressively in the Pernambuco Basin (Fig. 12.A). Initially, the EZ prevented extension of this process to the Paraiba Basin because it accommodated strain originating from tectonic deformation associated with the propagation of rifts in the CSA, ESA, interior of the Brazilian northeast, and Benue Trough, Africa (POPOFF, 1988; MATOS, 1992), and resulting in the creation or reactivation of several

▶ **Figure 11:** Geological and geographical data from the Pernambuco and Paraiba basins, extreme northwestern CSA (A). Stratigraphic section based on water well data (BARBOSA & LIMA FILHO, 2005; in B). Two dip seismic lines showing structural differences in the basement of the basins (C and D, modified from BARBOSA & LIMA FILHO, 2005), and, in E, a detail of an offshore dip seismic line, with the presence of halokinetic features in the Pernambuco Basin (modified from LIMA FILHO, 2013). The precarious nature of age information for the sedimentary deposits was confirmed in the two oil wells drilled in these basins (F).


NATAL PLATFORM
PARAÍBA BASIN
PERNAMBUCO BASIN
CANGUARETAMA SUBS.
MIRIRI SUBASIN
ALHANDRA SUBS.
OLINDA SUBASIN
Natal Platform
Paraíba Bs.
Pernambuco Bs.
NATAL
RN
PB
PE
JOÃO PESSOA
RECIFE
2-IST-1-PE
2-CPE-1-PE
Mamanguape Fault
Pernambuco Shear Zone
Maragogi High
Cupe Graben
Piedade Graben
Pernambuco Platform
Olinda subs.
Map and section legend
Cit
Oil well
Water well
States boundary
Geological basin boundary
Sismic line
Beberibe Formation
Itamaracá Formation
Carbonate platform (Maastric/Paleoc.)
Tertiary
Cupe Graben
Cabo Formation
Tamandaré High
Suape Fm.
Estiva Formation
PARAÍBA BASIN
PERNAMBUCO BASIN
Distal part of the seismic line 250-371
Lithologic legend
Paraíba Basin
2-IST-1-PE
Barbosa (2004 and 2007)
Pernambuco Basin
2-CP-1-PE
Maia (2012)
Litology
Depositional environment
Lithostratig. unity
Biozones
Chronostratigraphy
Beberibe Fm.
Itamaracá Fm.
Cabo Fm.
Suape Fm.
Paraíso Fm.
Aptian/Albian
Albian
Alagoas
Not applicable

basins on the continent (Fig. 12.B). The high stretching rates and low heat flow of the rifting process between the Maragogi and Touros highs, within the EZ (MATOS, 1999), led LIMA FILHO *et al.* (2006) to allege an almost instantaneous separation of Brazil from Africa over about 5 Ma. Nevertheless, for these authors, the entire process extended from the Aptian to late Turonian/Santonian, with the creation of the Paraíba Basin and the Natal Platform on the Brazilian side and the Niger Basin and South Cameroon basins on the African side.

The lack of proven records of mid-Cretaceous and Cenomanian rocks allows different evolutionary interpretations for the Paraíba Basin. LIMA FILHO *et al.* (2005, 2006) considered the stratigraphy of well 2-CPE-1-PE, drilled by Petrobrás in the Pernambuco Basin (Fig. 11.F), as evidence of a limited extension of the Aptian-Albian strata from the Cupe Graben into the Paraíba Basin. Well 2-IST-01-PE (Fig. 11.F), drilled in this basin, cuts about 300m of sandstones associated with the Beberibe and Itamaracá formations, that directly overlie the basement (FEIJÓ, 1994c; BARBOSA, 2004; BARBOSA *et al.*, 2007). Although a Coniacian?-Santonian age is attributed to the oldest known lithostratigraphic unit, the Beberibe Formation, BARBOSA (2007) has called attention to the uncertainty regarding this information. Studies of water wells and outcrops in the Natal Platform permit tentative correlation with deposits of the Jandaira Formation in the Potiguar Basin, with the oldest strata suggesting a Turonian age (LANA & ROESNER, 1999a, 1999b).

Seismic lines reaching the offshore portion of the Paraiba Basin (*e.g.*, BARBOSA & LIMA FILHO, 2005; BARBOSA, 2007; MAIA, 2012; LIMA FILHO, 2013) do not allow precise basinward tracking of the Lower Cretaceous. The steep face of the slope in the region represents an obstacle to tracking reflectors from the shelf to the continental rise without calibration by direct data, such as biochronostratigraphic markers, which is only possible in drill core samples. The lack of these data and the subtle lithologic distinctions among the siliciclastic units in outcrops or sampled by onshore drilling also compromise broader chrono-correlations based on radiometric dating of volcanic rocks of the Cabo Magmatic Province in the Pernambuco Basin.

The time of separation of the two continents has been much debated, and different ages have been suggested for the rupture: latest Aptian (DIAS-BRITO, 1987); late Aptian-Middle Albian (MOULLADE *et al.*, 1998; PLETSCH *et al.*, 2001); late Albian (MASCLE *et al.*, 1996a, 1996b; SAINT-MARC & N'DA, 1997; GUIRAUD *et al.*, 1987, 2005); late Albian/early Cenomanian (MASCLE *et al.*, 1988; POPOFF, 1988) based on biostratigraphic inferences and the tectonic evolution of the South Atlantic and Africa, with much data from the Côte d'Ivoire-Ghana marginal ridge.

Some recent papers offer new micropaleontological and geochemical data and tectonic interpretations on Gondwana breakup, supported by the GSSP-Alb criteria. In a study involving eight fossil groups (ammonites, calcareous nannofossils, echinoids, planktonic and benthonic foraminifera, ostracods, palynomorphs, and radiolarians) from 107 sites in the Sergipe-Alagoas Basin, LUFT-SOUZA (2022) confirmed the strong affinity with the Tethys Realm of an Aptian-Albian marine biota, as well as indications of provincialism/endemism as expected for the restricted South-Atlantic Sea. Their paleogeographic maps suggest an Aptian-Early Albian marine connection between the CSA and the ESA.

In turn, by integrating geochemical and micropaleontological data from DSDP sites 363 (Walvis Ridge) and 364 (Kwanza Basin), DUMMANN *et al.* (2023) constrained the onset of shallow (<500 m) and intermediate (<~1000 m) water mass exchange across the Equatorial Atlantic Gateway (EAG, equivalent to the EZ) to 113 Ma and 107 Ma, respectively. Furthermore, for them, deep water mass exchange (>2000 m) was in place by at least about 100 Ma. The construction of age models was based on calcareous nannofossil successions recognized at site 364 (BRUNO *et al.*, 2020), and site 363 (DUMMANN *et al.*, 2023, Supplemental Material). The oldest reliable age, 112.95 Ma, is indicated by the first stratigraphic occurrence of the calcareous nannofossil *Prediscophaera columnata*, at the 1032.37m horizon at Site 364, in which Nd isotope values increase, a fact that DUMMANN and collaborators used to establish the age of 113 Ma for the connection between the CSA and ESA. However, as demonstrated by AZEVEDO *et al.* (2023), the

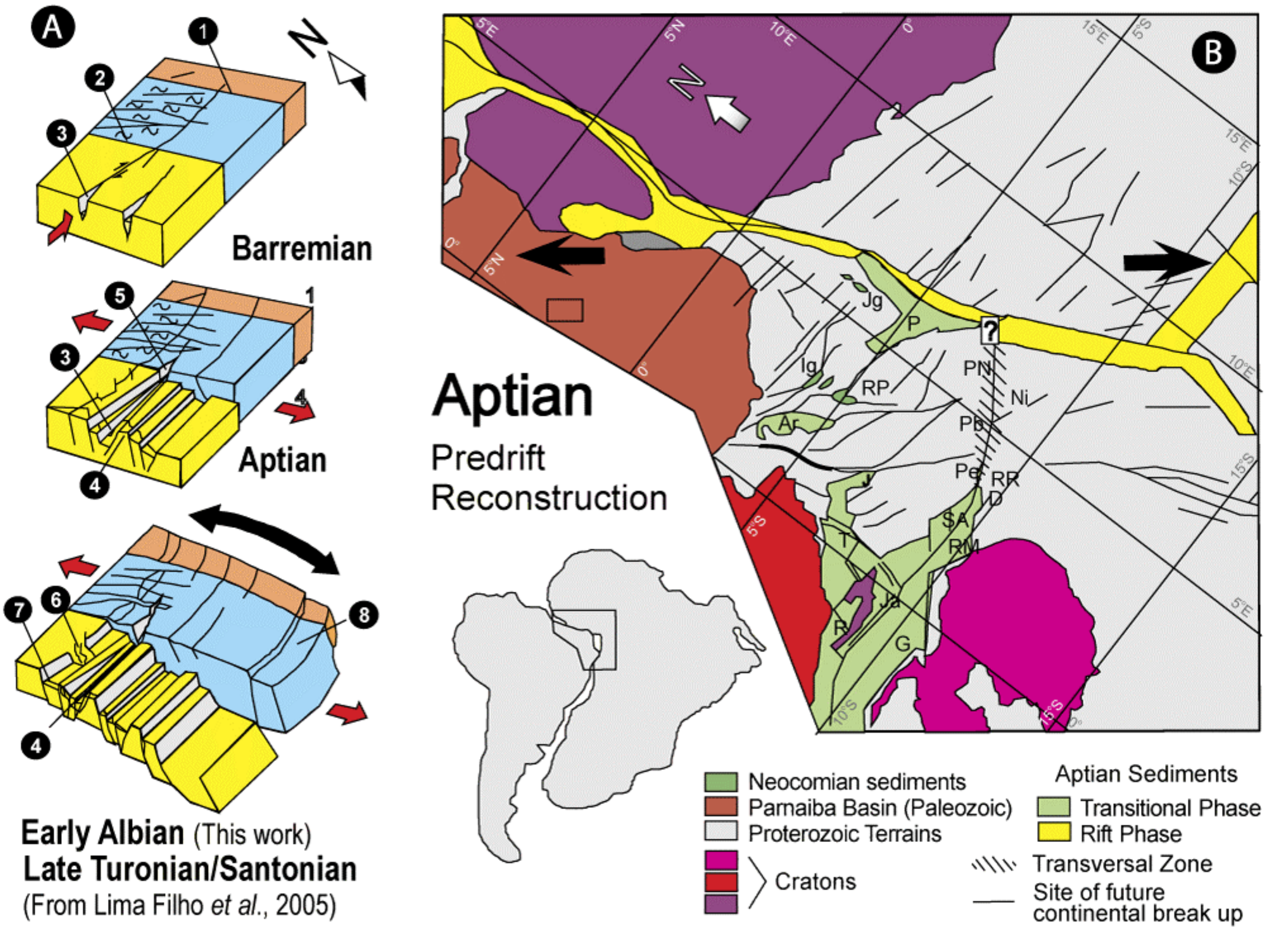


Figure 12: In A, schematic model of tectonic evolution of the Exception Zone: 1: Patos Shear Zone; 2- Pernambuco Shear Zone; 3- Cupe Rift; 4: Tamandaré High; 5: Olinda Basin; 6 Cabo de Santo Agostinho Granite; 7- Piedade Graben; and 8- Paraíba Basin. In B, tectonic setting during the breakup of South America and Africa. Large arrows indicate the main direction of extension. Represented basins are: Pe- Pernambuco; SA- Sergipe/Alagoas; J- Jatobá; T- Tucano; R-Recôncavo; Ar- Araripe; Jg- Jacaúna Graben; Ja- Jacuípe; Ig- Iguatu, Malhada, Malhada Vermelha, Lima Campos and Icó; P- Potiguar/Ceará; RP- Rio do Peixe; RR- Rio del Rey; D- Douala; RM- Rio Muni; G- Gabon basins. The basins formed after the collapse of the EZ: Pb- Paraíba; NP- Natal Platform; and Ni- Nigeria (modified from MATOS, 1992).

values attributed to the bio-events from this fossil do not match the succession of data for planktonic foraminifera described in the GSSP-Alb. At Site 364 KOCHHANN *et al.* (2013) recognized *Paraticinella eubejaouensis* Zone (= *P. rohri* Zone), a proxy of the Aptian/Albian limit, around 200 m above where DUMMANN *et al.* (2023) indicated the "opening of the Equatorial Atlantic Gateway (EAG)". Hence, the only compatible choice for this geochronological interpretation is with the use of the base of the Ibura Event as a reference for the beginning of the Albian.

Focusing mainly on the tectonic evolution of the South America and Africa continents, MATOS *et al.* (2021a, 2021b) and MATOS (2021) offered a robust interpretation of Gondwana fragmentation based on analyses of both the equatorial (here treated as ESA) and southern (CSA) arms, and the rupture process of the Orthogonal Zone - OZ (MATOS *et al.*, 2019; = to the EZ). They identified six structural segments limited by major fracture zones, some shown in Figure 8.B B. They indicated that rifting was triggered at the Pernambuco and Paraíba basins and their counterpart in Africa during the early Aptian and Albian, and a full spreading center was developed at the end of the Albian. This last inference is based on the age-progressive magmatism observed within the Borborema Large Igneous Province (LIP) from 135 to 104 Ma (MATOS *et al.*, 2021a), interpreted "as a possible hotspot track of the St. Helena plume on continental crust. During late Albian time, the possible arrival of the St. Helena plume head at an already stretched intraplate continental margin would explain the widespread along-axis magmatism and seaward-dipping reflectors between the Jacuípe and Paraíba basins, as recorded by a 750-

km-long array of deep-water magmatic bodies (CAIXETA *et al.*, 2015)."

Recent and different approaches thus offer indications of older ages for the breaching or definitive rupture of the EZ (BARBOSA *et al.*, 2008), or OZ (MATOS *et al.*, 2021a), or the EAG (DUMMANN *et al.*, 2023), that allowed the implementation of the South Atlantic Gulf. But they do not end the controversies regarding the age of this event. This will only be possible when deep sea well samples can clarify the age of the sedimentary succession of the Paraíba Basin. Until then, new interpretations can be made, like the one presented here that considers this latter basin as the strait of a long hypersaline longitudinal gulf.

CAPELLA *et al.* (2019) found that erosional and/or non-depositional processes associated with outflow of Mediterranean water into the North Atlantic depend upon differences in water mass density and the dimensions of the strait between the two bodies of water. In cases such as the Mediterranean and the Red Sea, both with lagoonal circulation patterns, the outflow velocity and erosional and/or non-depositional processes around the exit area will be higher the greater the contrast in water density between the two seas and narrowed the strait connecting the water bodies. A similar situation may explain the stratigraphic gaps that make it difficult to attribute ages to EZ fragmentation or to the sedimentary rocks preserved in the Paraíba Basin and on the Natal Platform.

Our interpretation is that the EZ rupture occurred in the earliest Albian, thereby ending evaporitic sedimentation and establishing the South Atlantic Gulf. The FO of *Prediscosphaera columnata* right after salt deposition at Site 364 (BRUNO *et al.*, 2020; Fig. 4, column 14) validates this age for the opening of this barrier. This phenomenon created conditions for the occupation of the CSA by a fossil assemblage of Tethys affinity and a higher faunal and floral diversity, as observed in the post-salt carbonates of the Sergipe-Alagoas Basin (DIAS-BRITO, 1994; TERRA & LEMOS, 1999). This resulted from the quality of the surficial water mass in terms of nutrients (probably eutrophic) as it entered the gulf and became progressively oligotrophic towards the other end of the gulf, similar to what currently happens in the Red Sea (SCHOLLE, 1996).

4. The South Atlantic Gulf and its effects on the Tethys

According to HAY *et al.* (2006), Mesozoic was a time of generally declining salinity associated with the deep sea salt extractions for the young ocean basins which developed of the North Atlantic and Gulf of Mexico (Middle to Late Jurassic) and South Atlantic (Early Cretaceous). In the mid-Cretaceous the opposite occurred, and much of this salt was dissolved and returned to the oceans (HAY, 1988), notably just after the opening to the north of the South Atlantic, thereby raising average salinity in the sea to as high as 41.6%. Major dense water masses then defined a halothermal circulation pattern, in which the saltier bottom waters acted as the most important element in global marine circulation.

Current circulation models for restricted water bodies, with a negative hydrologic balance (evaporation > runoff), give a good idea of what happens when their higher densities waters flow to the open sea (*e.g.*, AIKI *et al.*, 2006; MATT & JOHNS, 2007; JIA *et al.*, 2007; ROGERSON *et al.*, 2012; CAPELLA *et al.* 2019). Outcomes depend on a number of geographic variables, such as climate and the physiography of both the surrounding continents and the bottom of the receiving water body. Nevertheless, lagoonal circulation inevitably generates hypersaline water plumes where it enters the open sea. For example, the water mass entering the Aden Gulf from the Red Sea exerts an influence over a distance on the order of 200 km (AIKI *et al.*, 2006). Similarly, the plume that leaves the Mediterranean advances across much of the North Atlantic (ROGERSON *et al.*, 2012).

Therefore, it is reasonable to imagine that a similar plume, originating in the South Atlantic Gulf, advanced as a bottom current across much of the adjacent Tethys Sea (central North Atlantic/Caribbean zone) at the beginning of the Albian when the EZ opened up. By the same token, similar plumes may have existed at the same or different times in the Tethys and the Gulf of Mexico, where evaporitic deposits are somewhat frequently overlain by biofacies indicative of a restricted sea with a negative hydrologic balance (DIAS-BRITO, 1994; HAY *et al.*, 2006; GALLOWAY, 2008). Despite the fa-

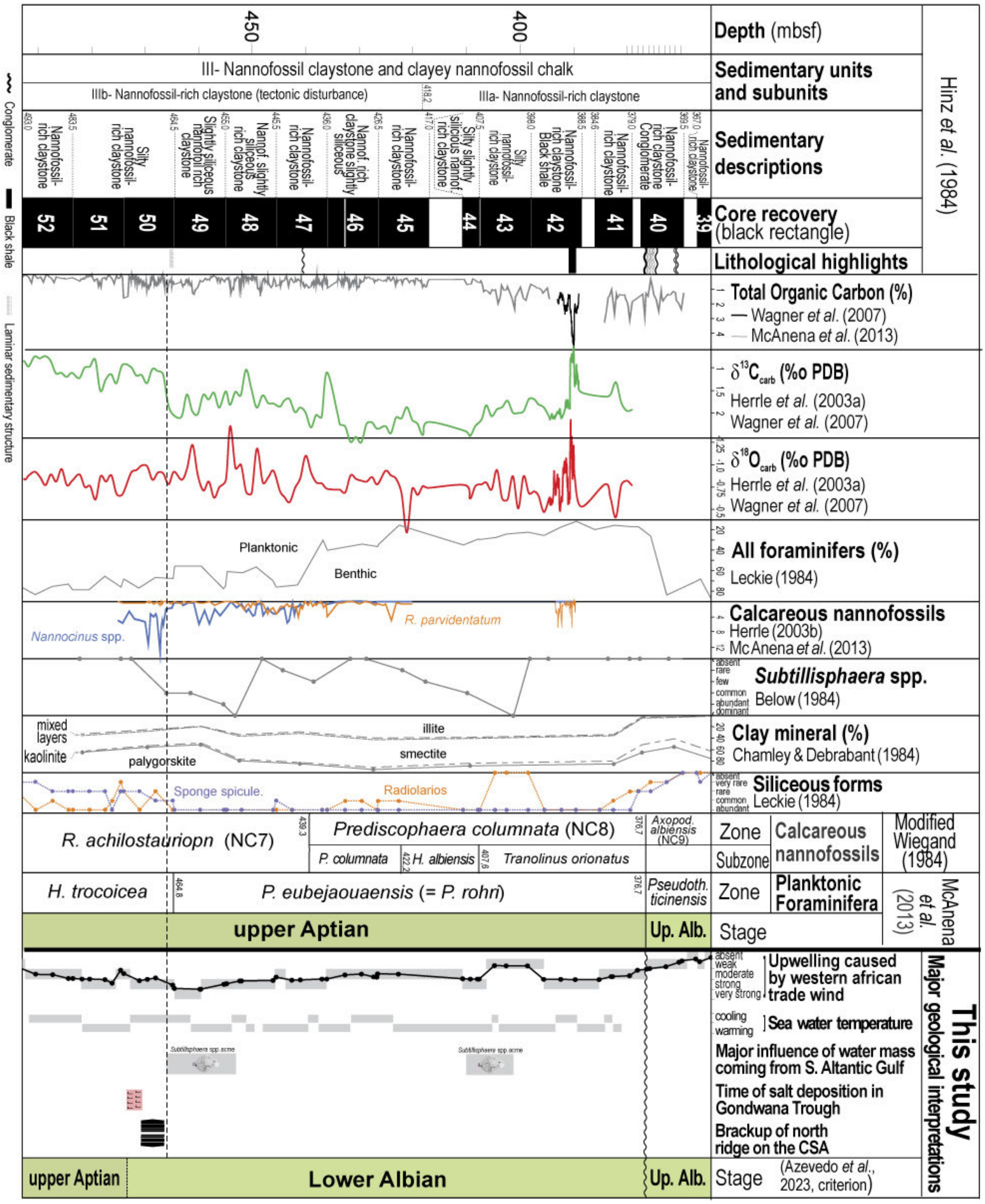


Figure 13: Summary of geological data for Site 545, DSDP, Mazagan Plateau. On the right are the interpretations of the main processes recorded in the section in the Shipboard Scientific Results. Legend for "Lithological highlights" is as follows: wavy lines = conglomerate; thick black line = black shale; dotted lines= laminar sedimentary structure. Trend in "Sea water temperature" is based on d^{18}Ocarb curve; the "Upwelling caused by western African trade wind" was constructed by weighting the variable abundances of radiolarians and sponge spicules, and palygorskite percentage. The dotted line highlights the EZ rupture that induced many changes in the geological processes on Site 545.

vorable paleogeographic scenario, few studies point to thermohaline circulation and anomalous phenomena resulting from it as a relevant factor in mid-Cretaceous sedimentation (*e.g.*, BRÉHÉRET *et al.*, 1986; ERBACHER *et al.*, 2001; TRABUCHO ALEXANDRE *et al.*, 2010; HUBER *et al.*, 2011).

At the end of evaporite precipitation, the South Atlantic Gulf was favorable for deposition of organic-rich rocks in around the CSA, ESA, tentatively associated by AZEVEDO *et al.* (2023) with the JACOB Level, the oldest OAE1b layer (Figs. 3-4). At the same time, an anomalous bloom of *Subtilisphaera* spp. occurred in many of these basins (ARAI, 2009, 2014; BASTOS *et al.*, 2022). This ecozone is also registered in apparently coeval sections of the Maracaibo Basin (Venezuela) and on the continental margin of Senegal and Morocco, which suggests great influence of water flowing from the South Atlantic Gulf into the Tethys Sea at the beginning of the Albian.

A review of the data from the DSDP Site 545 on the Mazagan Plateau on the Morocco continental margin illustrates the relationship between *Subtilisphaera* spp. blooms, geochemical signals and ephemeral oceanographic processes (Fig. 13). Approximately 140 m of an apparently continuous sedimentary succession were recovered from the drill core (HINZ *et al.*, 1984). Two *Subtilisphaera* spp. blooms were recognized by BELOW (1984) within an Aptian-Albian section, as determined by the planktonic foraminifera *Hedbergella trochoidea*, *Paraticinella rohri*, and *Pseudothalmanninella ticinensis* zones (LECKIE, 1984; HUBER & LECKIE, 2011; MCANENA *et al.*, 2013). This section has been subject to many different, even contradictory, geologic interpretations (*e.g.*, LECKIE *et al.*, 2002; HERRLE, 2002; HERRLE *et al.*, 2004; WAGNER *et al.*, 2007, 2008; HOFMANN *et al.*, 2008; TRABUCHO ALEXANDRE *et al.*, 2011).

Upwelling events recorded in rocks at Site 545 were noted by HINZ *et al.* (1984) and LECKIE (1984), based mainly on the increase in the number of siliceous carapaces (radiolarians and sponge spicules) and, secondarily, on the substantial change in the foraminifera fauna. The site lay within the easterly trade wind belt, whose influence on sedimentation in the area can be inferred from the high frequency of the clay-mineral palygorskite (CHAMLEY & DEBRABANT, 1984), thought to have come from the erosion of evaporitic deposits located in the Northern Hot and Arid (NHA) climate belt in West Africa by CHUMAKOV *et al.* (1995, Fig. 9C; PLETSCH *et al.*, 1996; TRABUCHO ALEXANDRE *et al.*, 2011).

Data from LECKIE (1984) demonstrate that the increase in the number of radiolarians coincides with the beginning of a progressive, non-linear reduction in the planktonic/benthic foraminifera ratio. Sponge spicules become abundant a little later (upper portion of core 50, base of core 49), a moment marked by other important bio-events, such as the *Subtilisphaera* spp. bloom, a significant drop in the abundance of *Nannoconus* spp., and FO of the *Paraticinella eubejaouaensis* = *P. rohri* Zone (Fig. 13). A few tens of meters above this level occurs the FO of *Prediscosphaera columnata s.l.*, almost coeval with the disappearance of the genus *Nannoconus* (core 47).

From a stratigraphic point of view, the bio-event succession described for Site 545 is similar to that of Site 364 (Fig. 4, columns 9 and 14, respectively), with the FO of *Hayesites albiensis* and *Tranolithus orionatus* below the LO of *Paraticinella rohri*. It is also important to highlight that at Site 545 the oldest *Subtilisphaera* spp. bloom precedes the FO of *Prediscophaera columnata s.l.*, confirming the stratigraphic relationship suggested for the CSA, ESA and BNE basins.

Other geological parameters evident in the upper portion of core 50 (Fig. 13) demonstrate the importance of the environmental changes during the deposition of these sediments. There is a decrease in bioturbation in the strata that mark the base of the anomalous *Subtilisphaera* spp. bloom, and this silty claystone exhibits much thinner lamination than usual. Furthermore, there is a noticeable increase on the order of 1‰ in the $\delta^{13}C_{carb}$ curve without a concomitant change in TOC values (WAGNER *et al.*, 2007; MCANENA *et al.*, 2013). The strata encompassing the period in which these events occurred also shows an increase in the percentage of palygorskite, which is indicative of increased eolian contribution to sedimentation in the area.

Oscillations in wind intensity influences upwelling. To evaluate the evolution of this phenomenon on the Mazagan Plateau, the abundances of radiolarians, sponge spicules, and palygorskite were weighted to obtain a curve representative of this phenomenon over time (Fig. 13 ; see Supplementary data). The result shows that the process was not linear: it began at the Aptian/Albian limit, lasted part of the Albian, and lost intensity until it all but ceased in the Late Albian. Significantly, the peak of this process was broadly coeval with the important transformations identified above in the upper portion of core 50.

The first *Subtilisphaera* spp. ecozone appeared at a moment of strong upwelling but soon ceased, whereas the second *Subtilisphaera* spp. bloom occurred during a less important upwelling event (Fig. 13). No correlation was found between these dinoflagellate abundances and water mass cooling/ warming cycles, as inferred from the $\delta^{18}O_{carb}$ curve. Thus, if there is no unique relationship between *Subtilisphaera* spp. blooms and eolian influences, then some other physical variable among the paleoenvironmental conditions of the Mazagan Plateau must be sought to explain the two acmes of these dinoflagellates.

As previously mentioned, the answer may well lie in the strength of the hypersaline plume emerging from the South Atlantic Gulf, as strongly suggested by the dynamic that has governed the outflow of water from the Mediterranean since the Messinian (CAPELLA *et al.*, 2019). Hence, the first pulse, resulting from the opening of the South Atlantic, involved a water mass of elevated salinity and rapid displacement into the Tethys. Together with the intensified eolian influence at the beginning of the Albian, the force of this displacement caused the ascension of more highly saline waters into the Mazagan Plateau region, creating ideal conditions for the anomalous *Subtilisphaera* spp. acme.

The second pulse of resurgence, that promoted a new *Subtilisphaera* bloom, may have been associated with increased dissolution of salt because of an important tectonic (TAGLIARI *et al.*, 2013) and/or halokinetic event in the CSA during the Early Albian (*e.g.*, raft tectonics, DUVAL *et al.*, 1992; CASTRO & FUGITA, 2004). Such processes would have led to the exhumation and dissolution of expressive volumes of evaporites, increasing the salinity and velocity of the plume that flowed out of the South Atlantic Gulf.

The installation of this relatively warm, hypersaline plume is also interpreted as responsible for increased in primary productivity and carbon fractionation, elevating $\delta^{13}C_{carb}$ values throughout the entire Early Albian (Fig. 13). The low TOC percentage suggests, moreover, that this new circulation dynamic occurred, initially, within an unrestricted basin lacking environmental factors favorable for promoting preservation of organic matter on the seafloor.

The second *Subtilisphera* spp. acme coincides with an elevation in the amount of TOC that began in core 44 of Site 545 (Fig. 13), whereas the $\delta^{13}C_{carb}$ values progressively decrease and $\delta^{18}O_{carb}$ values oscillate without any clear tendency. These data suggest that this anomalous bloom took place under environmental conditions different from those of the first bloom. Rapid climatic oscillations and increased runoff would explain the decrease in $\delta^{13}C_{carb}$ values and the increase in TOC values, possibly influenced by the establishment of the Equatorial Humid belt (EH) a little to the south during the Albian (CHUMAKOV *et al.*, 1995; Fig. 7C).

Lastly, it is important to discuss the origin of the decimetric layer of black shales in core 42, Site 545. This lithological unit shows a decrease on the order of 1 ‰ in $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values (Fig. 13). The abrupt excursion in the behavior of the latter geochemical parameter was coeval with an increase in TOC, thereby permitting a precise definition of the base of the organic-rich layer. In turn, $\delta^{18}O_{carb}$ clearly increases by 0.5%o, then initiates a decreasing tendency amidst intense, high-frequency oscillations, until it reaches its lowest values for the black shale. For HOFMANN *et al.* (2008), these rocks are the product of momentary atmospheric heating that attenuated the NE trade wind system and resulted in decreased intensity of upwelling. Thus, the increased rainfall implicit in the warming of the surface of the oceans would have led to an increased supply of continental organic matter and nutrients to the basin. Supporting this hypothesis is the inference by WAGNER *et al.* (2008) of ingression of organic matter of continental origin (as determined from average values of C_{27}, C_{29}, C_{31} n-alkanes) that would have preceded an increase in organic matter of marine origin (based on C_{27} steranes) contemporary with the sudden decrease in $\delta^{13}C_{carb}$ mentioned above and the initiation of deposition of the organic-rich bed.

Processes that transfer a large volume of organic matter from the water column to bottom sediments should leave much more positive $\delta^{13}C_{carb}$ values, instead of negative ones, when measured in carbonates present in black shales (JENKYNS, 2010), and more negative values in coeval organic matter ($\delta^{13}C_{org}$). Nevertheless, it is not uncommon to observe negative excursions in the $\delta^{13}C_{carb}$ curves associated with Oceanic Anoxic Events (OAEs), as seen in the PAQUIER and KILIAN levels (*e.g.*, OGG *et al.*, 2016; GALE *et al.*, 2021; Fig. 4) and at site 545 (Fig. 13). Explanations for these low values in black shales revolve around an increase in light CO_2 in the marine reservoir originating from volcanogenic processes, dissociation of gas hydrates and/or remobilization of coal deposits. However, as a rule, the efficiency of such processes in affecting isotope values has yet to be demonstrated (JENKINS, 2010).

It is important to note that the negative KILIAN and PAQUIER $\delta^{13}C_{carb}$ excursions are related to regressive coastal onlap, during sea level fall (HAQ, 2014; OGG *et al.*, 2016; GALE *et al.*, 2021; Fig. 4). On the other hand, the JACOB Level occurred at the end of a transgressive phase, time of eustatic maximum and registered positive values in the "global" $\delta^{13}C_{carb}$ curve. If it is already difficult to offer a genetic explanation for these different behaviors for OAE 1b events, it is even more so in a world possibly lacking polar ice caps that could have influenced eustatic shifts in sea level.

Various authors (*e.g.*, HAY & LESLIE, 1990; WENDLER J.E. & WENDLER I., 2016; WENDLER J.E. *et al.*, 2016; SAMES *et al.*, 2020) have associated third- and fourth-order sea level fluctuations with aquifer oscillations observed during greenhouse periods lacking polar ice caps. As part of the aquifer-eustatic model, they suggest that sea level drops during periods of great humidity and rises when the climate becomes more arid. According to SAMES *et al.* (2020), $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ curves in a marine environment tend to record positive values during eustatic drops (warm Greenhouse - humid state), when TOC preservation also increases. The opposite pattern tends to be seen during warm Greenhouse - arid states. Thus, this model also fails to explain many notable decreases of $\delta^{13}C_{carb}$ values in black shales deposited during eustatic drops.

An alternative empirical interpretation based on conditions surrounding the KILIAN and PAQUIER events may provide more consistency in explaining the negative excursions and may be applied to results obtained at Site 545. Organic-rich sediments originating from intense productivity and elevated depositional rates, as described by PEDERSEN and CALVERT (1990), should be strongly affected by early diagenetic processes during aquifer-eustatic drops. At these times there would have been retention of greater volumes of water in continental aquifers and greater evaporation of seawater because of higher temperatures and an intensified hydrologic cycle (WENDLER J.E. *et al.*, 2016). Under such conditions, sulfate-reduction processes would have been favored, liberating CO_2 rich in ^{12}C and ^{16}O that would have lowered primary $\delta^{13}C_{carb}$ and $\delta^{18}C_{carb}$ signals significantly. This hypothesis is supported by the lack of significant oscillations in the carbon isotope curve for the JACOB event, which occurred during a high-stand transgressive phase.

This interpretation, therefore, shows that anomalous and ephemeral local environmental conditions can explain Carbon and Oxygen isotope results measured in carbonates from black shales. It thus reduces the expectation of identifying anoxic events and organic-rich layers in organic carbon of global scope, whose effective indication must be supported by careful chronostratigraphic measurement.

5. The South Atlantic and Tethys paleogeography at the beginning of the Albian

To DUMMANN *et al.* (2023), the Cretaceous opening of the Equatorial Atlantic gateway is considered to have been a driver of major changes in global oceanography, carbon cycling, and climate. To explore the effects of this episode, stratigraphic details and the analogy with the Red Sea or the Mediterranean Sea allow us to conclude that the plume that flowed from the South Atlantic Gulf must have influenced bottom circulation and sedimentary features elsewhere. As previously mentioned, anomalous *Subtilisphaera* spp. blooms and black shales are observed on the continental margin of Senegal in northern Africa (JAIN & MILLEPIED, 1975; WU *et al.*, 2019) and in the Maracaibo Basin in northern South America (COLMENARES, 1994; DOT *et al.*, 2015), both of which were bathed by the Tethys Sea and under the influence of the same easterly trade wind belt and Aptian-Albian resurgence as the area discussed above (TRABUCHO ALEXANDRE *et al.*, 2011).

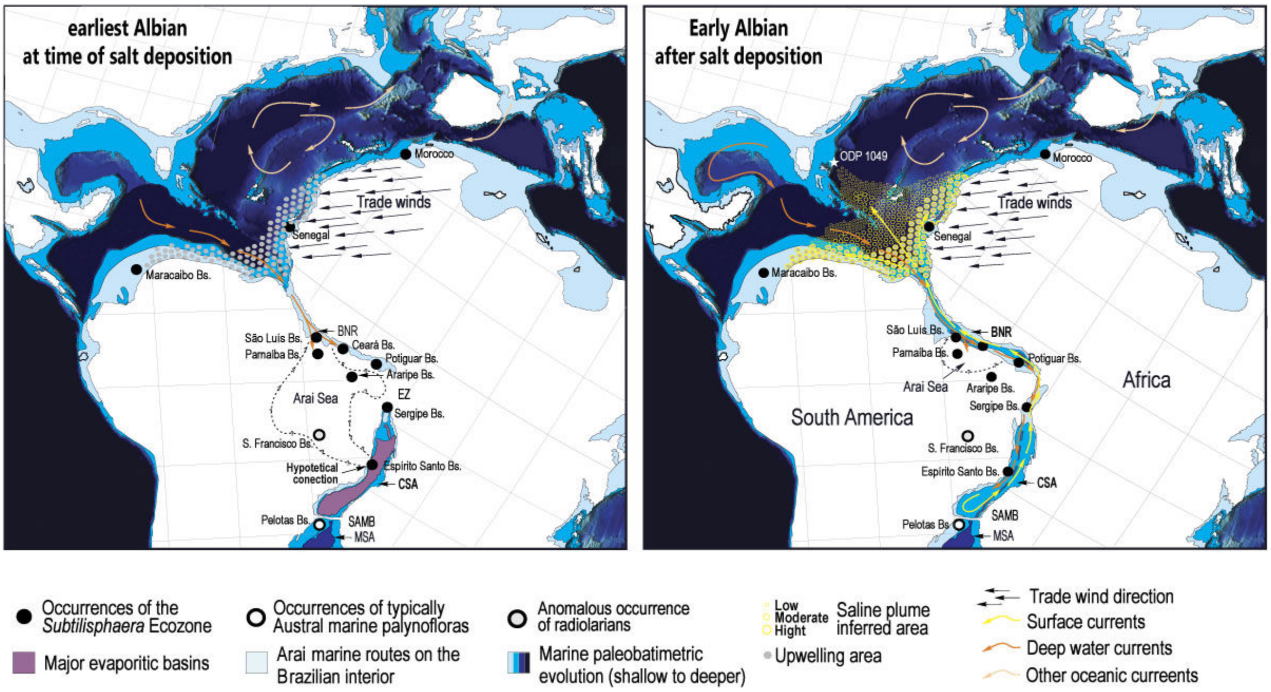


Figure 14: Early Albian paleogeographic evolution at times of salt deposition (left) and when lagoonal circulation began in the Tethys South Atlantic, creating a relatively warm, high saline plume that flowed out into the North Atlantic (right). Maps modified from ARAI (2014).

Figure 14, which integrates data from DIAS-BRITO (1994), CHUMAKOV *et al.* (1995), ARAI (2009, 2014) and TRABUCHO ALEXANDRE (2011), graphically shows the profound paleogeographic transformation that took place in the Early Albian, from salt deposition in the CSA to installation of the South Atlantic Gulf, when a new, definitive, more open connection with Tethys Sea was established. Given a barrier limiting the connection between the Tethys and the Pacific, the clockwise circulation imposed by the Coriolis force in the Northern Hemisphere would have extended the effect of the bottom currents to the coasts of North America, Central America, and the Caribbean. This circulation pattern is similar to that modeled by POULSEN *et al.* (2003) taking into consideration the opening of the gateway between the North and South Atlantic Oceans. Despite certain chronological imprecision in their study, covering dates from Early Albian to Turonian, their model predicts vigorous circulation between the two oceans, substantial changes in sea water temperature and salinity, and the transfer of atmospheric convection over the North Atlantic to northwestern Africa, enhancing the westward wind stresses over parts of the northern North Atlantic Ocean.

The influence of hypersaline waters was used by ERBACHER *et al.* (2001) and HUBER *et al.* (2011) to justify the exceptional preservation of foraminifera carapaces having elevated oxygen isotope values recovered from Oceanic Drilling Program (ODP) Site 1049, drilled at Blake Nose, North American continental margin. Although HUBER *et al.* (2011) did not explicitly state that upwelling was the cause of these isotopic signals, they did suggest that the South Atlantic and the Caribbean may have been the sources of deep warm saline water masses that circulated from the latest Aptian into the Early Albian. The establishment of the South Atlantic Gulf has led to the increased occurrence of this phenomenon, which has the JACOB Level and the FO of *Prediscosphaera columnata s.l.* as potential chronostratigraphic data for many CSA basins. In the case of the ESA, BNE, and other basins along the northwestern African coast and northern South America, the acme of *Subtilisphaera* spp. may hold a similar chronostratigraphic value, although additional biostratigraphic support would be necessary.

One should also not rule out the possibility that the hypersaline plume leaving the South Atlantic Gulf may well have influenced other regions of Tethys, even if only ephemerally, promoting stratification of water masses in restricted basins or even renovating oxygen in bottom waters in others. Thus, it fully merits consideration as a possible variable for explaining the recurrence of anoxic events unrelated to traditionally cited global mechanisms, such as volcanism or eustasy (*e.g.*, LECKIE *et al.*, 2002; SABATINO *et al.*, 2018; MATSUMOTO *et al.*, 2020) - these, in fact, may have played a much less significant role.

6. Conclusions

Adopting the base of the Ibura evaporites as a stratigraphic criterion to define the Aptian/Albian limit in the CSA, ESA, and BNE basins, has allowed us to present a new interpretation regarding the formation of these salts and the overlying carbonates. We suggest that the ephemeral epicontinental ARAI Sea, covering a large portion of northeastern and central Brazil, became an important supplier of waters from the Tethys Sea to the intra-Gondwana rift. The waters would have reached the CSA through the Espírito Santo Basin favoring deposition of anhydrite and halite in the basins of the central portions of the rift and precipitation of an uncommon suite of soluble salts in more restricted areas of this elongated evaporitic system- the Sergipe, Gabon, and Congo basins, in the north, and the Santos Basin, in the south. Hydrothermal sources, infiltration through the SAMB via fractures and faults, and runoff from neighboring continents, within the dynamic context of the developing rift, ensured the volume of water and the chemical composition needed for precipitation of a gigantic volume of salts in a short time (530 to 1.000 ka).

The rupture of the EZ, the last link between Africa and South America at the northern end of the CSA, and the end of evaporite precipitation, still in the earliest Albian indicated by the FO of *Prediscophaera columnata* in Site 364, favored the explosion of life and the deposition of organic-rich rocks in the basins of the CSA, ESA, and BNE, an event associated with the JACOB Level, the oldest OAE1b. The anomalous bloom of *Subtilisphaera* spp. was the major expression of this phenomena. Soon thereafter, a carbonate gulf became established in the CSA with a lagoonal pattern of marine circulation that created warm, hypersaline waters that flowed out from it as a plume that began to influence the ESA, BNE and even Tethys Sea.

At times, the water mass flowing out from the South Atlantic Gulf ascended to the surface along the South American and African margins under the influence of the easterly trade wind belt. As conceptualized for the Mediterranean Sea, it is probable that the high exit velocity of the plume from this gulf was a second factor that induced recurrent resurgence and allowed anomalous *Substilisphaera* spp. blooms, as recorded at Site 545, Mazagan Plateau, and was accompanied as well as by other regional transformations in biota, sedimentation, and geochemical variables. Not only did the first pulse of brine flow out of the CSA after the EZ collapsed, but episodic tectonic and/or halokinetic events exposed and induced salt dissolution to form denser deep water in the CSA, which led to an increase in the velocity of hypersaline plumes, further favoring upwellings elsewhere during the Albian.

It is thought that this wedge of salty bottom water reached the Black Nose Plateau of North America, which would explain the positive $\delta^{18}O_{carb}$ values and the excellent preservation of the foraminifera recovered from Site 1049C drilled by ODP. The great extent of this plume's influence raises the possibility that this phenomenon may also have contributed to the recurrent anoxic events in other structurally isolated basins of Tethys Sea.

To explain the origin of a thin black shale level associated with a negative $\delta^{13}C_{carb}$ excursion at Site 545 required an alternative interpretation, one related to intense early diagenetic processes resulting from resurgence-related sulfate-reduction in periods of aquifer-eustatic drops. This example calls attention to the real possibility that local phenomena may have exerted greater influence on the deposition of anoxic strata than global phenomena.

The hypothesis presented here opens up new perspectives for future studies based on the premise that the South Atlantic Gulf played an important role in global marine circulation from the Albian onward.

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Bibliographic references

ABUBAKAR M.B., MAIGARI A.S., BABANGIDA S.Y.D., ABDULLAH W.H., AHMED I.H., JOHN S.J., BAPPAH U.A. & ABDULKARIM H.A. (2014).- A re-focus on the tectono-stratigraphic evolution of the Upper Benue Trough, northeastern Nigeria: Implications on petroleum exploration.- *NAPE Bulletin*, Lagos, vol. 26, no. 1, p. 27-33.

AGTERBERG F.P., DA SILVA A-C. & GRADSTEIN F.M. (2021).- Geomathematical and statistical procedures. *In*: GRADSTEIN F.M., OGG J.G., SCHMITZ M.D. & OGG G.M. (eds.), Geologic time scale.- Elsevier, p. 1023-1086.

AIKI H., TAKAHASHI K. & YAMAGATA T. (2006).- The Red Sea outflow regulated by the Indian monsoon.- *Continental Shelf Research*, vol. 26, no. 12-13, p. 1448-1468.

AKANDE S.O., EGENHOFF S.O., OBAJE N.G., OJO O.J., ADEKEYE O.A. & ERDTMANN B.D. (2012).- Hydrocarbon potential of Cretaceous sediments in the Lower and Middle Benue Trough, Nigeria: Insights from new source rock facies evaluation.- *Journal of African Earth Sciences*, vol. 64, p. 34-47.

ANDRADE E.J., FRANCO NETO E., MOREIRA JUNIOR C.A., VARJÃO A.G., SILVA SANTOS A.F., SANTANA N.M., SANTO LIMA H.F., ANDRADE J.O., CARNEIRO A.L. & SOUZA J.C. (2019).- Considerações sobre a preservação e o resgate dos trombolitos do Membro Maruim, Formação Riachuelo, Bacia de Sergipe-Alagoas. *In*: Anais do 28º Simpósio de Geologia do Nordeste, Aracaju.- Sociedade Brasileira de Geologia, São Paulo, SGNE-03 140/537, 1 p. (abstract).

ANTONIOLI L. (2001, unpublished).- Estudo palinocronoestratigráfico da Formação Codó – Cretáceo Inferior do Nordeste Brasileiro.- PhD Thesis, Universidade Federal do Rio deJaneiro, 265 p.

ANTONIOLI L. & ARAI M. (2002).- O registro da Ecozona *Subtilisphaera* na Formação Codó (Cretáceo Inferior da Bacia do Parnaíba, Nordeste do Brasil): Seu significado paleogeográfico.- Boletim do 6º Simpósio sobre o Cretáceo do Brasil/ 2º Simpósio sobre el Cretácico de America del Sur, UNESP, Rio Claro, p. 1-6.

ANTUNES R.L. (1984).- Geohistória do paleocanyon de Fazenda Cedro, Bacia do Espírito Santo – Brasil, segundo dados biocronoestratigráficos. *In*: Anais do 33º Congresso Brasileiro de Geologia, Rio de Janeiro.- Sociedade Brasileira de Geologia, São Paulo, vol. 1, p. 670-684.

ANTUNES R.L. (1990).- Eventos erosivos na seção terciária do paleocânion de Regência (Bacia do Espírito Santo, Brasil): Um enfoque com base na bioestratigrafia dos nanofósseis calcários. *In*: Anais do 36º Congresso Brasileiro de Geologia, Natal.- Sociedade Brasileira de Geologia, São Paulo, vol. 1, p. 455-469.

ANTUNES R.L., AZEVEDO R.L.M. & LOBO J.T. (2018).- Reflexões sobre a Série Recôncavo, Brasil.- *Anuário do Instituto de Geociências - UFRJ*, Rio de Janeiro, vol. 41, p. 276-296. DOI: https://doi.org/10.11137/2018_2_276_296

ARAI M. (1992).- Dinoflagellates from the middle cretaceous in the offshore campos basin, southeastern Brazil. *In*: Resumos expandidos do 2º Simpósio sobre as bacias cretácicas brasileiras.- UNESP, Rio Claro, p. 27-29.

ARAI M. (1999).- A transgressão marinha mesocretácea: Sua implicação no paradigma da reconstituição paleogeográfica do Cretáceo no Brasil. *In*: Boletim do 5º Simpósio sobre o Cretáceo do Brasil/1º Simpósio sobre el Cretácico de América del Sur.- UNESP, Rio Claro, p. 577-582.

ARAI M. (2000).- Chapadas: Relict of mid-Cretaceous interior seas in Brazil.- *Revista Brasileira de Geociências*, São Paulo, vol. 30, no. 3, p. 436-438. URL: https://ppegeo.igc.usp.br/index.php/rbg/article/view/10668

ARAI M. (2009).- Paleogeografia do Atlântico Sul no Aptiano: Um novo modelo a partir de dados micropaleontológicos recentes.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 17, no. 2, p. 331-351.

ARAI M. (2012).- Evidência micropaleontológica da ingressão marinha Aptiana (pré-evaporítica) na Bacia do Araripe, Nordeste do Brasil. *In*: Anais do 46º Congresso Brasileiro de Geologia, Santos.- Sociedade Brasileira de Geologia, São Paulo (CD-ROM).

ARAI M. (2014).- Aptian/Albian (Early Cretaceous) paleogeography of the South Atlantic: A paleontological perspective.- *Brazilian Journal of Geology*, São Paulo, vol. 44, no. 2, p. 339-350. DOI: https://doi.org/10.5327/Z2317-4889201400020012

ARAI M. (2016a).- Quão continentais são os arenitos ditos fluviais? *In*: Anais do 48º Congresso Brasileiro de Geologia, Porto Alegre.- Sociedade Brasileira de Geologia, São Paulo, p. 2416 (abstract).

ARAI M. (2016b).- Reply to the comments of ASSINE *et al.* (Comments on paper by M. ARAI "Aptian/Albian (Early Cretaceous) paleogeography of the South Atlantic: A paleontological perspective").- *Brazilian Journal of Geology*, vol. 46, no. 1, p. 9-13. DOI: https://doi.org/10.1590/2317-4889201620150046B

ARAI M., BOTELHO NETO J., LANA C.C. & PEDRÃO E. (2000).- Cretaceous dinoflagellate provincialism in Brazilian marginal basins.- *Cretaceous Research*, vol. 21, p. 351-366.

ARAI M. & COIMBRA J.C. (1990).- Análise paleoecológica do registro das primeiras ingressões marinhas na Formação Santana (Cretáceo Inferior da Chapada do Araripe). *In*: Atas do I Simpósio sobre a Bacia do Araripe e Bacias Interiores do Nordeste, Crato.- DNPM, Brasília, p. 225-239.

ARAI M., HASHIMOTO A.T. & UESUGUI N. (1989).- Significado cronoestratigráfico da associação microflorística do Cretáceo Inferior no Brasil.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 3, no. 1-2, p. 87-103.

Arai M., Lana C.C. & Pedrão E. (1994).- Ecozona Subtilisphaera: Registro Eocretáceo de um importante episódio ecológico do oceano Atlântico primitivo.- *Acta Geologica Leopoldensia*, São Leopoldo, vol. 32, no. 2, p. 521-538.

Arai M., Shimabukuro S. & Viviers M.C. (1996).- Caracterização do Vraconiano (Albiano superior, Cretáceo Inferior) no Brasil: Uma contribuição paleomicroplanctônica. *In:* Anais do 4º Simpósio sobre o Cretáceo do Brasil, Águas de São Pedro.- UNESP, Rio Claro, p. 39-45.

Asmus H.E. & Campos D.A. (1983).- Stratigraphic division of the Brazilian continental margin and its paleogeographic significance.- *Zitteliana*, München, vol. 10, p. 265-276.

Asmus H.E. & Ferrari A.L. (1978).- Hipótese sobre a causa do tectonismo Cenozóico na região sudeste do Brasil. *In*: Aspectos estruturais da margem continental Leste e Sudeste do Brasil.- Petrobrás/CENPES (Série Projeto REMAC 4), Rio de Janeiro.

Asmus H.E. & Ponte F.C. (1973).- The Brazilian marginal basins. *In*: Nairn A.E.M. &. Stehli F.G. (eds.), The South Atlantic.- Springer, Science + Business Media, New York, p. 87-133.

Assine M.L. (1994).- Paleocorrentes e paleogeografia na Bacia do Araripe, Nordeste do Brasil.- *Revista Brasileira de Geociências*, São Paulo, vol. 24, no. 4, p. 223-232.

Assine M.L. (2007).- Bacia do Araripe.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 371-389.

Assine M.L., Perinotto J.A.J., Custódio M.A., Neumann V.H., Varejão F.G. & Mescolotti P.C. (2014).- Sequências deposicionais do Andar Alagoas da Bacia do Araripe, Nordeste do Brasil.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 22, no. 1, p. 3-28,

Assine M.L., Quaglio F., Warren L.V. & Simões M.G. (2016).- Comments on paper by M. Arai "Aptian/Albian (Early Cretaceous) paleogeography of the South Atlantic: A paleontological perspective".- *Brazilian Journal of Geology*, São Paulo, vol. 46, no. 1, p. 3-7.

Azevedo R.L.M. (2001, unpublished).- O Albiano no Atlântico Sul: Estratigrafia, paleoceanografia e relações globais.- PhD Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, 401 p.

Azevedo R.L.M. (2004).- Paleoceanografia e a evolução do Atlântico Sul no Albiano.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 12, no. 2, p. 231-249.

Azevedo R.L.M. (2005).- Os ciclos sedimentares e seus significados na formação das sequências deposicionais carbonáticas da Bacia de Campos.- *Revista Brasileira de Geociências*, São Paulo, vol. 35, p. 127-138.

Azevedo R.L.M., Antunes R.L. & Bruno M.D.R. (2023).- Issues in the identification of the Aptian/Albian boundary in South Atlantic basins and beyond.- *Carnets Geol.*, Madrid, vol. 23, no. 1, p. 1-42. DOI: 10.2110/carnets.2023.2301

Azevedo R.L.M., Gomide J. & Viviers M.C. (1987).- Geo-história da Bacia de Campos, Brasil: Do Albiano ao Maastrichtiano.- *Revista Brasileira de Geociências*, São Paulo, vol. 17, no. 2, p. 139-146.

Azevedo R.L.M. & Lobo J.T. (2013).- Geoquímica inorgânica em apoio à estratigrafia e interpretações paleoambientais: Albiano da Bacia de Campos.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 21, no. 2, p. 397-416.

Bahniuk A.M., Anjos S.M.C., França A.B., Matsuda N., Eiler J., Mckenzie J.A. & Vasconcelos C. (2014).- Development of microbial carbonates in the Lower Cretaceous Codó Formation (north-east Brazil): Implications for interpretation of microbialite facies associations and palaeoenvironmental conditions.- *Sedimentology*, vol. 62, no. 1, p. 155-181.

Barbosa J.A. (2004, unpublished).- Evolução da Bacia da Paraíba durante o Maastrichtiano-Paleoceno: Formações Gramame e Maria Farinha, NE do Brasil.- MSc Thesis, Universidade Federal de Pernambuco, Recife, 230 p. URL: https://repositorio.ufpe.br/bitstream/123456789/6564/1/arquivo6853_1.pdf

Barbosa J.A. (2007, unpublished).- A deposição carbonática da faixa costeira Recife-Natal: Aspectos estratigráficos, geoquímicos e paleontológicos).- PhD Thesis, Universidade Federal de Pernambuco, Recife, 264 p. URL: https://repositorio.ufpe.br/handle/123456789/6380

Barbosa J.A. & Lima Filho M. (2005).- Os domínios da Bacia da Paraíba. *In*: 3º Congresso Brasileiro de P&D em Petróleo e Gás.- Instituto Brasileiro de Petróleo e Gás - IBP, Salvador. URL: http://portalabpg.org.br/PDPetro/3/trabalhos/IBP0333_05.pdf

Barbosa J.A. & Lima Filho M. (2006).- Aspectos estruturais e estratigráficos da faixa costeira Recife-Natal: Observações em dados de poços.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 14, no. 1, p. 287-306.

Barbosa J.A., Lima Filho M., Neumann V.H., Neto J.C.J. & Araújo J.A.A. (2008).- Potencial exploratório das bacias da Paraíba e da plataforma de Natal, NE do Brasil. *In*: Rio Oil & Gas Expo and Conference 2008.- Instituto Brasileiro de Petróleo, Gás e Biocombustíveis - IBP, Rio de Janeiro, 8 p.

Barbosa J.A., Neumann V.H., Lima Filho M., Souza E.M. & Moraes M.A. (2007).- Estratigrafia da faixa costeira Recife-Natal (Bacia da Paraíba e Plataforma de Natal), NE Brasil.- *Estudos Geológicos*, Pernambuco, vol. 17, no. 2, p. 3-30.

Bastos L.P.H., Jagniecki E.A., Santos W.H., Cavalcante D.C, Menezes C.J., Alferes C.L.F., Silva D.B.N., Bergamaschi S., Rodrigues R. & Pereira E. (2022).- Organic geochemical evidence for the transition of Aptian-Albian hypersaline environments into marine restricted seas: The South Atlantic oceanic northern gateway and its implications for the pre-salt deposits.- *Marine and Petroleum Geology*, vol. 140, article 105632, 16 p.

Bastos L.P.H., Pereira E., Cavalcante D.C. & Rodrigues R. (2014).- Estratigrafia química aplicada à Formação Codó nos furos de sondagem UN-24-PI e UN-37-PI (Aptiano/Albiano da Bacia do Parnaíba).- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 22, no. 2, p. 289-312.

Bate R.H. (1999).- Non-marine ostracod assemblages of the Pre-Salt rift basins of West Africa and their role in sequence stratigraphy.- *Geological Society*, *Special Publications*, London, vol. 153, no. 1, p. 283-292.

Batista D.L., Carvalho I. de S. & Fuente M.S. de la (2023).- *Araripemys barretoi*: Paleoecological analysis of a pelomedusoid Chelonia from the Lower Cretaceous of Araripe and Parnaíba basins, Brazil.- *Cretaceous Research*, vol. 148, article 105503, 9 p.

Beaudoin B., Friès G. & Bulot L. (2012).- Van Gogh, Cézanne et autres impressionnistes : Bentonites aptiennes/albiennes du SE de la France ... et plus loin. *In*: Conférence : Les événements de l'Aptien-Albien.- Réunions thématiques du Groupe Français du Crétacé, École des Mines, Paris.

Beglinger S.E., Doust H. & Cloetingh S. (2012).- Relating petroleum system and play development to basin evolution: Brazilian South Atlantic Margin.- *Petroleum Geoscience*, vol. 18, p. 315-336.

Below R. (1984).- Aptian to Cenomanian Dinoflagellate Cysts from the Mazagan Plateau, Northwest Africa (Sites 545 and 547, Deep Sea Drilling Project Leg 79). *In*: Hinz K. & Winterer E.L. (eds.), Leg 79 of the cruises of the Drilling Vessel Glomar Challenger. Las Palmas, Grand Canary Island, to Brest, France. April-May 1981.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. LXXIX, p. 621-649. URL: http://deepseadrilling.org/79/volume/dsdp79_23.pdf

Bengtson P., Zucon M.H. & Sobral A. da C.S. (2018).- Cretaceous ammonite zonation of the Sergipe Basin, northeastern Brazil.- *Cretaceous Research*, vol. 88, p. 111-122.

Beurlen K. (1971a).- As condições ecológicas e faciológicas da Formação Santana na Chapada do Araripe (Nordeste do Brasil).- *Anais Academia Brasileira de Ciências*, Rio de Janeiro, vol. 43 (Suplemento), p. 411-415.

Beurlen K. (1971b).- Bacia sedimentares no bloco brasileiro.- *Estudos Sedimentológicos*, Rio de Janeiro, vol. 1, no. 2, p. 7-31.

Beurlen K. & Mabessone J.M. (1969).- Bacias cretácicas intracratônicas do Nordeste do Brasil.- *Notícias Geomorfológicas*, Campinas, vol. 9, no. 18, p. 19-34

Boeuf A.G. (1988).- Rabi-Kounga field, Southern Gabon. *In*: Annual meeting of the AAPG, Houston - TX.- OSTI Identifier: 6921225.

Bolli H.M. (1978a).- Synthesis of the Leg 40 biostratigraphy and paleontology. *In*: Bolli H.M., Ryan W.B.F., McKnight B.K., Kagami H., Melguen M., Siesser W.G., Natland J.H., Longoria J.F., Proto Decima F., Foresman J.B. & Hottman W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 1063-1067. URL: http://deepseadrilling.org/40/volume/dsdp40_31.pdf

Bolli H.M. (1978b).- Cretaceous and Paleocene Calcisphaerulidae from DSDP Leg 40, Southeastern Atlantic. *In*: Bolli H.M., Ryan W.B.F., McKnight B.K., Kagami H., Melguen M., Siesser W.G., Natland J.H., Longoria J.F., Proto Decima F., Foresman J.B. & Hottman W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 819-837. URL: http://deepseadrilling.org/40/volume/dsdp40_21.pdf

Bolli H.M., Ryan W.B.F., Foresman J.B., Hottman W.E., Kagami H., Longoria J.F., McKnight B.K., Melguen M., Natland J., Proto-Decima F. & Siesser W.G. (1978a).- Walvis Ridge-Sites 362 and 363. *In*: Bolli H.M., Ryan W.B.F., McKnight B.K., Kagami H., Melguen M., Siesser W.G., Natland J.H., Longoria J.F., Proto Decima F., Foresman J.B. & Hottman W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 183-356. URL: http://deepseadrilling.org/40/volume/dsdp40_03.pdf

Bolli H.M., Ryan W.B.F., Foresman J.B., Hottman W.E., Kagami H., Longoria J.F., McKnight B.K., Melguen M., Natland J., Proto Decima F. & Siesser W.G. (1978b).- Angola continental margin-Sites 364 and 365. *In*: Bolli H.M., Ryan W.B.F., McKnight B.K., Kagami H., Melguen M., Siesser W.G., Natland J.H., Longoria J.F., Proto Decima F., Foresman J.B. & Hottman W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 357-455. URL: http://deepseadrilling.org/40/volume/dsdp40_04.pdf

Borza K. (1984).- The Upper Jurassic-Lower Cretaceous parabiostratigraphic scale on the basis of Tintinninae, Cadosinae, Stomiosphaeridae, Calcisphaerulidae and other microfossils from the West Carpathians.- *Geologica Carpathica*, Bratislava, vol. 35, p. 539-550.

Braun O.P.G. (1966).- Estratigrafia dos sedimentos da parte interior da Região Nordeste do Brasil (Bacias de Tucano-Jatobá, Mirandiba e Araripe).- *Boletim DNPM/DGM*, Rio de Janeiro, vol. 236, 81 p.

Bréhéret J.G., Caron M. & Delamette M. (1986).- Niveaux riches en matière organique dans l'Albien Vocontien ; quelques caractères du paléoenvironnement ; essai d'interprétation génétique.- *Documents du Bureau de Recherches Géologiques et Minières*, Orléans, vol. 110, p. 141-191.

Bruno M.D.R., Fauth G., Watkins D.K. & Savian J.F. (2020).- Albian-Cenomanian calcareous nannofossils from DSDP Site 364 (Kwanza Basin, Angola): Biostratigraphic and paleoceanographic implications for the South Atlantic.- *Cretaceous Research*, vol. 109, article 104377, 12 p.

Bueno G.V., Zacharias A.A, Oreiro S.G., Cupertino J.A., Falkenhein F.U.H. & Martins Neto M.M. (2007).- Bacia de Pelotas.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 551-559.

Caetano-Filho S., Dias-Brito D., Rodrigues R. & Azevedo R.L.M. (2017).- Carbonate microfacies and chemostratigraphy of a late Aptian-early Albian marine distal section from the primitive South Atlantic (SE Brazilian continental margin): Record of global ocean-climate changes?- *Cretaceous Research*, vol. 74, p. 23-44.

Caixeta J.M., Lima Machado D. Jr, Ferreira T.S. & Romeiro T.M.A. (2015).- O desenvolvimento da margem rifteada vulcânica albiana no Nordeste brasileiro e seu perfil para a geração de petróleo.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 23, no. 1-2, 18 p.

Campos Neto O.P.A., Lima W.S. & Cruz F.E.G. (2007).- Bacia de Sergipe-Alagoas.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 405-415.

Capella W., Flecker R., Hernández-Molina F.J., Simon D., Meijer P.Th., Rogerson M., Sierro F.S. & Krijgsman W. (2019).- Mediterranean isolation preconditioning the Earth System for late Miocene climate cooling.- *Scientific Reports*, vol. 9, article 3795, 8 p. DOI: https://doi.org/10.1038/s41598-019-40208-2

Caron M. (1978).- Cretaceous Planktonic Foraminifers from DSDP Leg 40, Southeastern Atlantic Ocean. *In*: Bolli H.M., Ryan W.B.F., McKnight B.K., Kagami H., Melguen M., Siesser W.G., Natland J.H., Longoria J.F., Proto Decima F., Foresman J.B. & Hottman W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 651-678. URL: http://deepseadrilling.org/40/volume/dsdp40_14.pdf

Carvalho I.S., Freitas F.I. & Neumann V. (2012).- Chapada do Araripe. *In*: Hasui Y., Carneiro C.D.R., Almeida F.M.A. & Bartorelli A. (ed.), Geologia do Brasil.- BECA, São Paulo, p. 510-513.

Carvalho M.A., Bengtson P. & Lana C.C. (2016).- Late Aptian (Cretaceous) paleoceanography of the South Atlantic Ocean inferred from dinocyst communities of the Sergipe Basin, Brazil.- *Paleoceanography*, vol. 31, no. 1, p. 2-26.

Carvalho M.D. (1989, unpublished).- Microfácies, modelo deposicional e evolução da Plataforma Carbonática do Eo/Mesoalbiano da Bacia de Santos.- MSc Thesis, Universidade Federal do Rio de Janeiro, 110 p.

Carvalho M.D. (1996).- Modelos de rampa carbonática e de margem de plataforma do Cretáceo da Bacia de Santos: Fácies, paleoambientes e sequências deposicionais. *In*: Anais do 39º Congresso Brasileiro Geologia, Salvador.- Sociedade Brasileira de Geologia, São Paulo, p. 239-242.

Castro M.R. & Fugita A.M. (2004).- Tectônica de jangada (Raft tectonics) na área norte da Bacia de Campos. *In*: Anais da Rio Oil & Gas Expo and Conference 2004.- IBP, Rio de Janeiro, 155-04, 7 p. URL: https://www.osti.gov/etdeweb/servlets/purl/21008402

Chaboureau A.C., Donnadieu Y., Sepulchre P., Robin C., Guillocheau F. & Rohais S. (2012).- The Aptian evaporites of the South Atlantic: A climatic paradox?- *Climate of the Past*, vol. 8, p. 1047-1058.

Chaboureau A.C., Guillocheau F., Robin C., Rohais S., Moulin M. & Aslanian D. (2013).- Palaeogeographic evolution of the central segment of the South Atlantic during Early Cretaceous times: Paleotopographic and geodynamic implications.- *Tectonophysics*, vol. 604, p. 191-223.

Chamley H. & Debrabant P. (1984).- Mineralogical and Geochemical Investigations of Sediments on the Mazagan Plateau, Northwestern African Margin (Leg 79, Deep Sea Drilling Project). *In*: Hinz K. & Winterer E.L. (eds.), Leg 79 of the cruises of the Drilling Vessel Glomar Challenger. Las Palmas, Grand Canary Island, to Brest, France. April-May 1981.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. LXXIX, p. 497-508. URL: http://deepseadrilling.org/79/volume/dsdp79_16.pdf

Chang H.K., Kowsmann R.O., Ferreira Figueiredo A.M. & Bender A.A. (1992).- Tectonics and stratigraphy of the East Brazil Rift system: An overview.- *Tectonophysics*, vol. 213, p. 97-138.

Chevalier J. & Fischer M. (1982).- Présence de *Colomiella* Bonet (Calpionellidae) dans le Crétacé inférieur (Madiéla) du Gabon.- *Cahiers de Micropaléontologie*, Paris, vol. 2, p. 29-34.

Chumakov N.M., Zharkov M.A., Herman A.B., Doludenko M.P., Kalandadze N.N., Lebedev E.L., Ponomarenko A.G. & Rautian A.S. (1995).- Climatic belts of the Mid-Cretaceous Time.- *Stratigraphy and Geological Correlation*, vol. 3, no. 3, p. 241-260.

Colmenares O.A. (1994, unpublished).- Lower Cretaceous palynostratigraphy, organic sedimentology and evolution of the Maracaibo basin, western Venezuela.- PhD Thesis, University of Toronto, 382 p.

Cui X.Q., Wignall B., Freeman K.H. & Summons R.E. (2023).- Early Cretaceous marine incursions into South Atlantic rift basins originated from the south.- *Communications Earth & Environment*, vol. 4, no. 6, 11 p. DOI: https://doi.org/10.1038/s43247-022-00668-3

Custódio M.A., Quaglio F., Warren L.V., Simões M.G., Fürsich F.T., Perinotto J.A.J. & Assine M.L. (2017).- The transgressive-regressive cycle of the Romualdo Formation (Araripe Basin): Sedimentary archive of the Early Cretaceous marine ingression in the interior of Northeast Brazil.- *Sedimentary Geology*, vol. 359, p. 1-15.

Da Silva O.B., Caixeta J.M., Milhomem P.S. & Kosin M.D. (2007).- Bacia do Recôncavo.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 423-431.

Davison I. (2007).- Geology and tectonics of the South Atlantic Brazilian salt basins. *In*: Reis A.C., Butler R.W.H. & Graham R.H. (eds.), Deformation of the continental crust: The legacy of Mike Coward.- *Geological Society*, *Special Publications*, London, vol. 272, p. 345-359.

Davison I., Anderson L. & Nuttall P. (2012).- Salt deposition, loading and gravity drainage in the Campos and Santos salt basins. *In*: Alsop G.I., Archer S.G., Hartley A..J., Grant N.T. & Hodgkinson R. (eds.), Salt tectonics, sediments and prospectivity.- *Geological Society*, *Special Publications*, London, vol. 363, p. 159-174.

Debure M., Lassin A., Marty N.C., Claret F., Virgone A., Calassou S. & Gaucher E.C. (2019).- Thermodynamic evidence of giant salt deposit formation by serpentinization: An alternative mechanism to solar evaporation.- *Scientific Reports*, vol. 9, article 11720, 11 p. DOI: https://doi.org/10.1038/s41598-019-48138-9

Demercian L.S. (1996, unpublished).- A halocinese na evolução da Bacia de Santos do Aptiano ao Cretáceo Superior.- MSc Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, 201 p.

Demicco R.V, Lowenstein T.K., Hardie L.A. & Spencer R.J. (2005).- Model of seawater composition for the Phanerozoic.- *Geology*, Boulder - CO, vol. 33, no. 11, p. 877-880.

Dias J.L. (1998, unpublished).- Análise sedimentológica e estratigráfica do Andar Aptiano em parte da margem leste do Brasil e no Platô das Malvinas - Considerações sobre as primeiras incursões marinhas e ingressões marinhas do oceano Atlântico Sul Meridional.- PhD Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, 145 p.

Dias J.L. (2005).- Tectônica, estratigrafia e sedimentação no Andar Aptiano da margem leste brasileira.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 13, no. 1, p. 7-25.

Dias J.L., Sad A.R.R., Fontana R.L. & Feijó F.J. (1994).- Bacia de Pelotas.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 235-245. URL: https://www.sgb.gov.br/publique/media/recursos_minerais/livro_geo_tec_rm/capIII-n.pdf

Dias-Brito D. (1982).- Evolução paleoecológica da Bacia de Campos durante a deposição dos calcilutitos, margas and folhelhos da Formação Macaé (Albiano and Cenomaniano?).- *Boletim Técnico da Petrobrás*, Rio de Janeiro, vol. 25, no. 2, p. 84-97.

Dias-Brito D. (1985a).- Calcisphaerulidae do Albiano da Bacia de Campos. Rio de Janeiro, Brasil: Investigações taxonômicas, biocronoestratigráficas e paleoambientais. *In*: Coletânea de Trabalhos Paleontológicos.- *Geologia* 27, *Paleontologia*, *Estratigrafia* 2, Brasília, p. 295-305.

Dias-Brito D. (1985b).- Calcisphaerulidae e microfósseis associados da Formação Ponta do Mel - Bacia Potiguar, Brasil: Considerações paleoecológicas e biocronoestratigráficas. *In*: Coletânea de Trabalhos Paleontológicos. Departamento Nacional da Produção Mineral, Brasília.- *Geologia* 27, *Paleontologia*, *Estratigrafia* 2, p. 307-314.

Dias-Brito D. (1987).- A Bacia de Campos no mesocretáceo: Uma contribuição à paleoceanografia do Atlântico Sul primitivo.- *Revista Brasileira de Geociências*, São Paulo, vol. 7, no. 2, p. 162-167.

Dias-Brito D. (1992).- Ocorrência de calcisferas pelágicas em depósitos carbonáicos do Atlântico Sul: Impacto na configuração paleoceanográfica do Tétis cretácico. *In*: Resumos expandidos do 2° Simpósio sobre as Bacias Cretácicas Brasileiras.- UNESP, Rio Claro, p. 30-34.

Dias-Brito D. (1994).- Comparação dos carbonatos pelágicos do Cretáceo médio da Margem Atlântica Brasileira com os do Golfo do México: Novas evidências do Tétis Sul-Atlantiano. *In*: Boletim do 3° Simpósio sobre o Cretáceo do Brasil.- UNESP, Rio Claro, p. 11-18.

Dias-Brito D. (1995, unpublished).- Calcisferas and microfácies em rochas carbonáticas pelágicas mesocretáceas.- PhD Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, 688 p.

Dias-Brito D. (2000).- Global stratigraphy, palaeobiogeography and palaeoecology of Albian-Maastrichtian pithonellid calcispheres: Impact on Tethys configuration.- *Cretaceous Research*, vol. 21, p. 315-349.

Dias-Brito D., Arai M., Shimabukuro S. & Azevedo R.L.M. (1990).- Estratigrafia do plâncton Albiano da Bacia de Campos: Um reconhecimento a partir do poço 3-BO-3-RJS. *In*: Boletim de Resumos do 1° Simpósio sobre as Bacias Cretáceas Brasileiras.- UNESP, Rio Claro, p. 41-42.

Dias-Brito D. & Azevedo R.L.M. (1986).- As seqüências deposicionais marinhas da Bacia de Campos sob a ótica paleoecológica. *In*: Anais do 34° Congresso Brasileiro de Geologia, Goiânia.- Sociedade Brasileira de Geologia, São Paulo, p. 38-49.

DIAS-BRITO D., PESSAGNO E.A. Jr & CASTRO J.C. (1998).- Novas considerações cronoestratigráficas sobre o silexito a radiolários no sul da Bacia Sanfranciscana, Brasil, e a ocorrência de foraminíferos planctônicos nestes depósitos. *In*: Boletim do 5º Simpósio sobre o Cretáceo do Brasil.- UNESP, Rio Claro, p. 567-575.

DIAS-BRITO D., TIBANA P., ASSINE M.L. & ROSSETI D.F. (2015).- Laminitos lacustres organo-calcários neoaptianos ricos em ostracodes no Nordeste do Brasil: Bacias do Araripe, Potiguar e Parnaíba, Aptiano superior (Alagoas superior). *In*: DIAS-BRITO D. & TIBANA P. (eds.), Calcários do Cretáceo do Brasil: Um atlas.- 1º Ed. Rio Claro: UNESP-IGCE-UNESPetro, vol. 1, p. 49-120.

DIAS-BRITO D., UESUGUI N. & HASHIMOTO A.T. (1987).- Reflexão histórica em torno do Andar Alagoas, importante e problemática unidade cronoestratigráfica do Cretáceo inferior do Brasil.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 1, no. 1, p. 111-115.

DO CARMO D.A., COIMBRA J.C., WHATLEY R.C., ANTONIETTO L.S. & PAIVA CITON R.T. de (2008).- Taxonomy of limnic Ostracoda (Crustacea) from the Alagamar Formation, middle-upper Aptian, Potiguar Basin, northeastern Brazil.- *Journal of Paleontology*, Cambridge (UK), vol. 87, p. 91-104.

DOT J.A.M., BAAMONDE J.M., REYES D. & WHILCHY R. (2015).- The Cogollo Group and the oceanic anoxic events 1a and 1b, Maracaibo basin, Venezuela.- *Brazilian Journal of Geology*, São Paulo, vol. 45, Suppl. 1, p. 41-61.

DOYLE J.A., BIENS P., DOERENKAMP A. & JARDINÉ S. (1977).- Angiosperm pollen from the pre-Albian Lower Cretaceous of equatorial Africa.- *Bulletin des Centres de Recherches Exploration-Production elf-Aquitaine*, Pau, vol. 1, no. 2, p. 451-473.

DUMMANN W., HOFMANN P., HERRLE J.O., FRANK M. & WAGNER W. (2023).- The early opening of the Equatorial Atlantic gateway and the evolution of Cretaceous peak warming.- *Geology*, Boulder - CO, vol. 51, p. 476-480.

DUPONT G. (1996).- Principaux foraminifères planctoniques du Crétacé gabonais (Aptien à Campanien inférieur). *In*: JARDINÉ S., KLASZ I. de & DEBENAY J.- P. (eds.), Géologie de l'Afrique et de l'Atlantique Sud.- *Mémoire des Centres de Recherches Exploration-Production elf-Aquitaine*, Pau, vol. 16, p. 83-121.

DUVAL B., CRAMEZ C. & JACKSON M.P.A. (1992).- Raft tectonics in the Kwanza Basin, Angola.- *Marine and Petroleum Geology*, vol. 9, no. 4, p. 389-404.

ELDRETT J.S., BERGMAN S.C., HEINE C., EDWARDS P., JAKEMAN M., MILES N., HAMBACH B., BOHATY S.M. & WILDING M.R. (2023).- Integrated bio- and chemo-stratigraphy for Early Cretaceous strata offshore Gabon: Additional constraints on the timing of salt deposition and rifting of the South Atlantic.- *Marine and Petroleum Geology*, vol. 148, article 106037, 15 p.

ERBACHER J., HUBER B.T., NORRIS R.D. & MARKEY M. (2001).- Increased thermohaline stratification as a possible cause for an ocean anoxic event in the Cretaceous period.- *Nature*, vol. 409, p. 325-327.

ESTRADA F., ERCILLA G., GORINI C., ALONSO B., VÁZQUEZ J.T., GARCÍA-CASTELLANOS D., JUAN C., MALDONADO A., AMMAR A. & ELABBASSI M. (2011).- Impact of pulsed Atlantic water inflow into the Alboran Basin at the time of the Zanclean flooding.- *Geo-Marine Letters*, vol. 31, no. 5-6 p. 361-376.

ESTRELLA G.O., TSUBONE K., MELLO M.R., ROSSETTI E., GAGLIANONE P.C., CONCHA J., AZEVEDO R.L.M. & BRÜNING I.M.R.A. (1984).- The Espírito Santo Basin (Brazil) source rock characterization and petroleum habitat. *In*: DEMAISON G. & MURRIS R.J. (eds.), Petroleum geochemistry and basin evaluation.- *AAPG Memoir*, Tulsa - OK, vol. 35, p. 217-227.

EVENSEN N. & SMITH P. (2007).- $^{39}Ar/^{40}Ar$ geochronology of Sylvinite and Carnallite in Sergipe. University of Toronto, unpublished report.

FARIAS F., SZATMARI P., BAHNIUK A. & FRANÇA A.B. (2019).- Evaporitic carbonates in the pre-salt of Santos Basin - Genesis and tectonic implications.- *Marine and Petroleum Geology*, vol. 105, p. 251-272.

FEIJÓ F.J. (1994a).- Bacia de Sergipe e Alagoas.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 149-161.

FEIJÓ F.J. (1994b).- Introdução.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 5-8.

FEIJÓ F.J. (1994c).- Bacia de Pernambuco – Paraíba.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 149-161.

FLORENCIO C.P. (1996, unpublished).- Geologia dos evaporitos Paripueira na porção alagoana da Bacia de Sergipe/Alagoas.- MSc Thesis, Universidade de São Paulo, 94 p. DOI: https://doi.org/10.11606/D.44.1996.tde-08092015-095505

FLORENCIO C.P. (2001, unpublished).- Geologia dos evaporitos Paripueira na sub-bacia de Maceió, Alagoas, Região Nordeste do Brasil.- PhD Thesis, Universidade de São Paulo, 160 p. URL: https://doi.org/10.11606/T.44.2001.tde-27102015-142649

FLORENCIO C.P. & RIBEIRO FILHO E. (1998).- Geoquímica do bromo em halitas da sub-bacia evaporítica de Maceió.- *Revista de Geologia*, Fortaleza, vol. 11, p. 5-14. URL: http://www.repositorio.ufc.br/handle/riufc/14990

FRANÇA R.L., REY A.C. del, TAGLIARI C.V., BRANDÃO J.R. & FONTANELLI P. de R. (2007).- Bacia do Espírito Santo.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 501-509.

FREITAS R.T.J. de (2006, unpublished).- Ciclos deposicionais evaporíticos da Bacia de Santos: Uma análise cicloestratigráfica a partir de dados de 2 poços e de traços de sísmica.- MSc Thesis, Universidade Federal do Rio Grande do

Sul, Porto Alegre, 160 p. URL: https://lume.ufrgs.br/handle/10183/6213

Gale A.S., Mutterlose J. & Baternburg S. (2021).- The Cretaceous Period. *In*: Gradstein F.M., Ogg J.G., Schmitz M.D. & Ogg G.M. (eds.), Geologic time scale.- Elsevier, p. 1023-1086.

Galloway W.E. (2008).- Depositional evolution of the Gulf of Mexico sedimentary basin. *In*: Hsü K.J. (ed.), The sedimentary basins of the United States and Canada.- *Sedimentary Basins of the World*, vol. 5, p. 505-549.

Gamboa L.A.P., Ferraz A.E.P.P.D., Drehmer L.H. & Demercian L.S. (2021).- Seismic, magnetic, and gravity evidence of marine incursions in the Santos Basin during the Early Aptian. *In*: Mello M.R., Yilmaz P.O. & Katz B.J. (eds.), The supergiant Lower Cretaceous pre-salt petroleum systems of the Santos Basin, Brazil.- *AAPG Memoir*, Tulsa - OK, vol. 124, p. 257-272.

Goldberg K., Premaor E., Bardola T. & Souza P.A. (2019).- Aptian marine ingression in the Araripe Basin: Implications for paleogeographic reconstruction and evaporite accumulation.- *Marine and Petroleum Geology*, vol. 107, p. 214-221.

Gomes L.C., Lima F.M., Vieira I.S., Lobo J.T. *et al.* (2015, unpublished).- Magmatismo Jiquiá e Alagoas na Bacia de Santos.- Petrobrás, Relatório Interno, Rio de Janeiro.

Gordon W.A. (1973).- Marine life and ocean surface currents in the Cretaceous.- *Journal of Geology*, vol. 81, p. 269-284.

Gradstein F.M., Ogg J.G., Smith A.G., Bleeker W. & Lourens L.J. (2004).- A new Geologic Time Scale with special reference to Precambrian and Neogene.- *Episodes*, Bangalore, vol. 27, p. 83-100. DOI: https://doi.org/10.18814/epiiugs/2004/v27i2/002

Granier B. & Dias-Brito D. (2015).- End of a modern geological myth: There are no rudists in Brazil! Paleobiogeographic implications.- *Carnets Geol.*, Madrid, vol. 15, no. 11, p. 123-136. DOI:10.4267/2042/56880

Grosdidier E., Braccini E., Dupont G. & Moron J.-M. (1996).- Biozonation du Crétacé inférieur non marin des bassins du Gabon et du Congo. *In*: Géologie de l'Afrique et de l'Atlantique Sud.- Actes Colloques Angers 1994, p. 67-82.

Guimarães J.T., Grissolia E.M., Ferreira J.C.S., Souza J.L.M., Villar P.M., Santiago R. & Sobrinho V.S. (2018).- Relatório preliminar: Ilha de Matarandiba/Bahia.- CPRM - Serviço Geológico do Brasil, MME/SGM, Salvador, 23 p. URL: https://rigeo.cprm.gov.br/jspui/bitstream/doc/20607/1/relatorio_matarandiba_07_nov_18_final.pdf

Guiraud R., Bellion Y., Benkhelil J. & Moreau C. (1987).- Post-Hercynian tectonics in Northern and Western Africa. *In*: Bowden P. & Kinnaird J.A. (eds.), African geology reviews.- *Geological Journal*, vol. 22, p. 433-466.

Guiraud R., Bosworth W., Thierry J. & Delplanque A. (2005).- Phanerozoic geological evolution of Northern and Central Africa: An overview.- *Journal of African Earth Sciences*, vol. 43, p. 83-143.

Gutiérrez-Puente N.A., Barragán R. & Núñez-Useche F. (2021).- Paleoenvironmental changes and biotic response to AptianeAlbian episodes of accelerated global change: Evidence from the western margin of the proto-North Atlantic (central-eastern Mexico).- *Cretaceous Research*, vol. 126, article 104883, 27 p.

Haq B.U. (2014).- Cretaceous eustasy revisited.- *Global and Planetary Change*, vol. 113, p. 44-58.

Hardie L.A. (1996).- Secular variations in seawater chemistry: An explanation for the coupled secular variation in the mineralogy of marine limestones and potash evaporites over the past 600 m.y.- *Geology*, Boulder - CO, vol. 24, no. 3, p. 279-283.

Hashimoto A.T., Appi C.J., Soldan A.L. & Cerqueira J.R. (1987).- O Neo-Alagoas nas Bacias do Ceará, Araripe and Potiguar (Brasil): Caracterização estratigráfica e paleoambiental com base em estudos sedimentológicos, bioestratigráficos e geoquímicos.- *Revista Brasileira de Geociências*, São Paulo, vol. 17, no. 2, p. 118-122.

Hay W.W. (1988).- Paleoceanography: A review for the GSA centennial.- *Geological Society of America Bulletin*, Boulder - CO, vol. 100, no. 12, p. 1934-1956.

Hay W.W. & Leslie M.A. (1990).- Could possible changes in global groundwater reservoir cause eustatic sea level fluctuations? Sea Level Change. *In*: Studies in geophysics.- National Research Council, Washington - DC, p. 161-170.

Hay W.W., Migdisov A., Balukhovsky A.N., Wold C.N., Flögel S. & Söding E. (2006).- Evaporites and the salinity of the ocean during the Phanerozoic: Implications for climate, ocean circulation and life.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 240, no. 1-2, p. 3-46.

Heimhofer U., Hesselbo S.P., Pancost R.D., Martill D.M., Hochuli P.A. & Guzzo J.V.P. (2008).- Evidence for photic zone euxinia in the Early Albian Santana Formation (Araripe Basin, NE Brazil).- *Terra Nova*, vol. 20, no. 5, p. 347-354.

Heine C., Zoethout J. & Müller R.D. (2013).- Kinematics of the South Atlantic rift.- *Solid Earth*, vol. 4, p. 215-253. DOI: https://doi.org/10.5194/se-4-215-2013

Herrle J.O. (2002).- Paleoceanographic and paleoclimatic implications on Mid-Cretaceous black shale formation in the Vocontian Basin and the Atlantic: evidence from calcareous nannofossils and stable isotopes.- *Tübinger Mikropaläontologische Mitteilungen*, vol. 27, 144 p.

Herrle J.O., Kößler P., Friedrich O., Erlenkeuser H. & Hemleben C. (2004).- High-resolution carbon isotope records of the Aptian to Lower Albian from SE France and the Mazagan Plateau (DSDP Site 545): A stratigraphic tool for paleoceanographic and paleobiologic reconstruction.- *Earth and Planetary Science Letters*, vol. 218, no. 1-2, p. 149-161.

Hinz K., Winterer E.L., Baumgartner P.O., Bradshaw M.J., Channell J.E.T., Jaffrezo M., Jansa L.F., Leckie R.M., Moore J.N., Rullkötter J., Schaftenaar C., Steiger T.H., Vuchev V. & Wiegand G.E. (1984).- Site 545. Shipboard Scientific Part. *In*: Hinz K. & Winterer E.L. (eds.), Leg 79 of the cruises of the Drilling Vessel Glomar Challenger. Las Palmas, Grand Canary Island, to Brest, France. April-May 1981.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. LXXIX, p. 81-177. URL: http://deepseadrilling.org/79/volume/dsdp79_03.pdf

Hofmann P., Stüsser I., Wagner T., Schouten S & Sinninghe Damsté J.S. (2008).- Climate-ocean coupling off North-West Africa during the Lower Albian: The Oceanic Anoxic Event 1b.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 262, no. 3-4, p. 157-165.

Hsü K.J., Ryan W.B.F. & Cita M.B. (1973).- Late Miocene desiccation of the Mediterranean.- *Nature*, vol. 242, p. 240-244.

Huber B.T. & Leckie R.M. (2011).- Planktic foraminiferal species turnover across deep-sea Aptian/Albian boundary sections.- *Journal of Foraminiferal Research*, Lawrence - KS, vol. 41, p. 53-95.

Huber B.T., MacLeod K.G., Gröcke D.R. & Kucera M. (2011).- Paleotemperature and paleosalinity inferences and chemostratigraphy across the Aptian/Albian boundary in the subtropical North Atlantic.- *Paleoceanography*, vol. 26, no. 4, article PA4221, 20 p. DOI: https://doi.org/10.1029/2011PA002178

Jackson M.P.A., Cramez C. & Fonck J.-M. (2000).- Role of subaerial volcanic rocks and mantle plumes in creation of South Atlantic margins: Implications for salt tectonics and source rocks.- *Marine and Petroleum Geology*, vol. 17, no. 4, p. 477-498.

Jain K.P. & Millepied P. (1975).- Cretaceous microplankton from Senegal basin, W. Africa, Pt. II. Systematics and biostratigraphy.- *Geophytology*, Lucknow, vol. 5, no. 2, p. 126-171.

Japsen P., Bonow J.M., Green P.F., Cobbold P.R., Chiossi D., Lilletveit R., Magnavita L.P. & Pereira A. (2012).- Episodic burial and exhumation in NE Brazil after opening of the South Atlantic.- *GSA Bulletin*, Boulder - CO, vol. 124, no. 5-6, p. 800-816.

Jenkyns H.C. (2010).- Geochemistry of oceanic anoxic events.- *Geochemistry*, *Geophysics*, *Geosystems*, vol. 11, no. 3, article Q03004, 30 p.

Jia Y., Coward A.C., Cuevas B.A., Webb D.J. & Drijfhout S.S. (2007).- A model analysis of the behavior of the Mediterranean water in the North Atlantic.- *Journal of Physical Oceanography*, Washington - DC, vol. 37, no. 3, p. 764-786. DOI: https://doi.org/10.1175/JPO3020.1

Karner G.D., Driscoll N.W. & Barker D.H.N. (2003).- Syn-rift region subsidence across the West African continental margin; the role of lower plate ductile extension. *In*: Arthur T.J., MacGregor D.S. & Cameron N.R. (eds.), Petroleum geology of Africa: New themes and developing technologies.- *Geological Society*, *Special Publications*, London, vol. 207, p. 105-129.

Karner G.D. & Gambôa L.A.P. (2007).- Timing and origin of the South Atlantic pre-salt sag basins and their capping evaporites. *In*: Schreiber B.C., Lugli S.& Bąbel M. (eds.), Evaporites through space and time.- *Geological Society*, *Special Publications*, London, vol. 285, p. 15-35.

Kattah S. (1991, unpublished).- Análise faciológica e estratigráfica do Jurássico Superior, Cretáceo Inferior na porção meridional da Bacia Sanfranciscana, oeste do estado de Minas Gerais.- MSc Thesis, Universidade Federal de Ouro Preto, Minas Gerais, 227 p.

Kauffman E.G. (1973).- Cretaceous bivalvia. *In*: Hallam A. (ed.), Atlas of paleobiogeography.- Elsevier, p. 353-358.

Kelechi O. (2017).- The Southern Benue trough and Anambra Basin, Southeastern Nigeria: A stratigraphic review.- *Journal of Geography*, *Environment and Earth Science International*, Hooghly, vol. 12, no. 2, p. 1-16.

Kennedy J.W., Gale A.S., Huber B.T., Petrizzo M.R., Bown P.R. & Jenkyns H.C. (2017).- The Global Boundary Stratotype Section and Point (GSSP) for the base of the Albian Stage, of the Cretaceous, the Col de Pré-Guittard section, Arnayon, Drôme, France.- *Episodes*, Beijing, vol. 40, p. 177-188.

Klemme H.D. & Ulmishek G.F. (1991).- Effective petroleum source rocks of the world: Stratigraphic distribution and controlling depositional factors.- *AAPG Bulletin*, Tulsa - OK, vol. 75, no. 12, p. 1809-1851.

Klöcking M., Hoggard M.J., Rodríguez Tribaldos V., Richards F.D., Guimarães A.R., Maclennan J. & White N.J. (2020).- A tale of two domes: Neogene to recent volcanism and dynamic uplift of northeast Brazil and southwest Africa.- *Earth and Planetary Science Letters*, vol. 547, article 116464, 13 p.

Kochhann K.G.D., Koutsoukos E.A.M., Fauth G. & Sial A.N. (2013).- Aptian-Albian planktic foraminifera from DSDP Site 364 (offshore Angola): Biostratigraphy, paleoecology, and paleoceanographic significance.- *Journal of Foraminiferal Research*, Lawrence - KS, vol. 43, no. 4, p. 443-463.

Koutsoukos E.A. (1992).- Late Aptian to Maastrichtian foraminiferal biogeography and palaeoceanography of the Sergipe Basin, Brazil.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 92, no. 3-4, p. 295-324.

Koutsoukos E.A., Destro N., Azambuja Filho N.C. & Spadini A.R. (1993).- Upper Aptian Lower Coniacian carbonate sequences in the Sergipe Basin, northeastern Brazil. *In*: Simo J.A.T., Scott R.W. & Masse J.- P. (eds.), Cretaceous carbonate platforms.- *AAPG Memoir*, Tulsa - OK, vol. 56, p. 127-144.

Kowsmann R.O., Costa M.P.A., Almeida H.P., Guimarães P.P.D. & Boa-Hora M.P.P. (1982).- Geologia estrutural do Platô de São Paulo. *In*: Anais do 32° Congresso Brasileiro de Geologia, Salvador.- Sociedade Brasileira de Geologia, São Paulo, vol. 4, p. 1558-1569.

Kukla P.A., Strozyk F. & Mohriak W.U. (2018).- South Atlantic salt basins - Witnesses of complex passive margin evolution.- *Gondwana Research*, vol. 53, p. 41-57. URL: https://doi.org/10.1016/j.gr.2017.03.012.

Kumar N., Gambôa L.A.P., Schreiber B.C. & Mascle J. (1977).- Geologic history and origin of Sao Paulo Plateau (Southeastern Brazilian Margin), comparison with the Angolan margin, and the early evolution of the northern South Atlantic. *In*: Supko P.R., Perch-Nielsen K., Neprochnov Y.P., Zimmerman H.B., McCoy F., Kumar N., Thiede J., Bonatti E., Fodor R., Boersma A., Dinkelman M.G. & Carlson R.L. (eds.), Leg 39 of the cruises of the Drilling Vessel Glomar Challenger. Amsterdam, Netherlands to Cape Town, South Africa. October-December 1974.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XXXIX, p. 927-945. URL: http://deepseadrilling.org/39/volume/dsdp39_40.pdf

Lana C.C. & Pedrão E. (2000).- Um episódio de incursão marinha no Eoaptiano (Eoalagoas) da Bacia de Almada, BA, Brasil.- *Revista da Universidade de Guarulhos*, *Geociências* V (Número Especial), p. 89-92.

Lana C.C. & Roesner E.H. (1999a).- O Cretáceo Superior na região de Natal, RN: Novas interpretações com base na palinologia. *In*: Anais do 16º Congresso Brasileiro de Paleontologia, Crato.- Sociedade Brasileira de Paleontologia, p. 55-56.

Lana C.C. & Roesner E.H. (1999b).- Palinologia do Cretáceo Superior marinho subaflorante na região de Natal, RN.- *Anais da Academia Brasileira de Ciências*, Rio de Janeiro, vol. 71, no. 1, p. 149-150.

Lawson M., Sitgreaves J., Rasbury T., Wooton K., Esch W., Marcon V., Henares S., Konstantinou A., Kneller E., Gombosi D., Torres V., Silva A., Alevato R., Wren M., Becker S. & Eiler J. (2022).- New age and lake chemistry constraints on the Aptian pre-salt carbonates of the central South Atlantic.- *GSA Bulletin*, Boulder - CO, vol. 135, no. 3-4, p. 595-607.

Leckie R.M. (1984).- Mid-Cretaceous planktonic foraminiferal biostratigraphy off central Morocco. *In*: Hinz K. & Winterer E.L. (eds.), Leg 79 of the cruises of the Drilling Vessel Glomar Challenger. Las Palmas, Grand Canary Island, to Brest, France. April-May 1981.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. LXXIX, p. 579-620. URL: http://deepseadrilling.org/79/volume/dsdp79_22.pdf

Leckie R.M., Bralower T.J. & Cashman R. (2002).- Oceanic anoxic events and plankton evolution: Biotic response to tectonic forcing during the mid-Cretaceous.- *Paleoceanography*, vol. 17, no. 3, p. 1-29. DOI: https://doi.org/10.1029/2001PA000623

Lima F.H.O., Sanjinés A.E.S., Maizatto J.R., Ferreira E.P., Ng C., Costa D.S., Anjos-Zerfass G.S., Alves C.F., Strohschoen O. Jr, Viviers M.C., Lana C.C., Arai M., Beurlen G., Shimabukuro S. & Galm P.C. (2018).- Aptian marine post-salt rocks in Santos, Campos and Espírito Santo basins, Brazil: A biochronostratigraphical approach. *In*: Anais do 49º Congresso Brasileiro de Geologia, Rio de Janeiro.- Sociedade Brasileira de Geologia, São Paulo, p. 2023 (abstract). URL: http://cbg2018anais.siteoficial.ws/resumos/4924.pdf

Lima Filho M.F. (1998, unpublished).- Análise Estrutural e Estratigráfica da Bacia Pernambuco.- PhD Thesis, Universidade de São Paulo, 139 p. DOI: https://doi.org/10.11606/T.44.1998.tde-03092013-090232

Lima Filho M.F. (2013).- Bacia Pernambuco & Paraíba. *In*: Brasil, 11º Rodada Licitações de Petróleo e Gás, Rio de Janeiro.- Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, 51 p. URL: https://www.gov.br/anp/pt-br/rodadas-anp/rodadas-concluidas/concessao-de-blocos-exploratorios/11a-rodada-licitacoes-blocos/arquivos/seminarios/bacia_pepbrodada11.pdf

Lima Filho M.F. & Barbosa J.A. (2010).- The peculiar tectono-stratigraphic evolution of the eastern margin of Northeast Brazil, and its African Counterpart. *In*: II Central & North Atlantic Conjugate Margins Conference: Re-discovering the Atlantic. New winds to an old sea.- Universidade de Lisboa, vol. VIII, p. 304-308.

Lima Filho M.F., Barbosa J.A., Neumann V.H.M.L. & Souza E.M. (2005).- Evolução estrutural comparativa da Bacia de Pernambuco e da Bacia da Paraíba. *In*: Boletim de Resumos Expandidos do 5º Simpósio Nacional de Estudos Tectônicos, Curitiba.- Sociedade Brasileira de Geologia, São Paulo, p. 45-47.

Lima Filho M.F., Barbosa J.A. & Souza E.M. (2006).- Eventos tectônicos and sedimentares nas Bacias de Pernambuco and da Paraíba: Implicações no quebramento do Gondwana and correlação com a Bacia do Rio Muni.- *Geociências*, UNESP, São Paulo, vol. 25, no. 1, p. 117-126.

Lima Filho M.F., Viana M.S.S & Mabesoone J.M. (1996).- Tectonic and stratigraphic relationships between the Afrobrazilian and Araripe-Potiguar depressions (NE Brazil). *In*: Anais do 39º Congresso Brasileiro Geologia, Salvador.- Sociedade Brasileira de Geologia, São Paulo, vol. 7, p. 402-404.

Lima M.R. (1978, unpublished).- Palinologia da Formação Santana (Cretáceo do Nordeste do Brasil).- PhD thesis, Universidade de São

Paulo, 335 p. DOI: https://doi.org/10.11606/T.44.1978.tde-16112015-153709

Lowenstein T.K., Timofeeff M.N., Brennan S.T., Hardie L.A. & Demicco R.V. (2001).- Oscillations in Phanerozoic seawater chemistry: Evidence from fluid inclusions.- *Science*, vol. 294, p. 1006-1088.

Luft-Souza F., Fauth G., Bruno M.D.R., Mota M.A.D.L., Vázquez-García B., Santos Filho M.A & Terra G.J.S. (2022).- Sergipe-Alagoas Basin, Northeast Brazil: A reference basin for studies on the early history of the South Atlantic Ocean.- *Earth-Science Reviews*, vol. 229, article 104034, 25 p.

Mabesoone J.M. & Tinoco I.M. (1973).- Palaeoecology of the Aptian Santana Formation (northeastern Brazil).- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 14, no. 2, p. 97-118.

Machado L.L. (2022, unpublished).- Ostracodes não-marinhos de Cretáceo Inferior da Bacia do Parnaíba, Formação Codó (poço 2-CO-1-MA): Taxonomia, bioestratigrafia e inferências paleoambientais.- PhD Thesis, Universidade do Vale do Rio dos Sinos, São Leopoldo, 163 p. URL: http://repositorio.jesuita.org.br/handle/UNISINOS/9548

Magnavita L.P., Davison I. & Kusznir N.J. (1994).- Rifting, erosion, and uplift history of the Recôncavo-Tucano-Jatobá Rift, northeast Brazil.- *Tectonics*, vol. 13, no. 2, p. 367-388. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/93TC02941

Maia M.F.B. (2012, unpublished).- Revisão da estratigrafia do intervalo Aptiano-Albiano da Bacia de Pernambuco Nordeste do Brasil.- MSc Thesis, Universidade Federal de Pernambuco, Recife, 215 p. URL: https://repositorio.ufpe.br/handle/123456789/12133

Martins G.S. (2016, unpublished).- Evolução tectono-estratigráfica dos evaporitos Horizonte e Paripueira na porção alagoana da Bacia de Sergipe-Alagoas e suas implicações na abertura do Oceano Atlântico Sul.- MSC Thesis, Universidade do Estado do Rio de Janeiro, 226 p. URL: https://www.bdtd.uerj.br:8443/handle/1/7140

Mascle J., Blarez E. & Marhino M. (1988).- The shallow structure of the Guinea and Ivory Coast-Ghana transform margins: Their bearing on the Equatorial Atlantic Mesozoic evolution.- *Tectonophysics*, vol. 155, p. 193-209.

Mascle J., Lohmann G.P., Clift P.D. & Shipboard Scientific Party (1996a).- Introduction. *In*: Mascle J., Lohmann G.P. & Clift P.D. (eds.).- *Proceedings of the Ocean Drilling Program*, *Scientific Results*, Washington - DC, vol. 159, p. 5-15. URL: http://www-odp.tamu.edu/publications/159_IR/VOLUME/CHAPTERS/ir159_01.pdf

Mascle J., Lohmann G.P., Clift P.D. & Shipboard Scientific Party (1996b).- Principal Results. *In*: Mascle J., Lohmann G.P. & Clift P.D. (eds.).- *Proceedings of the Ocean Drilling Program*, *Scientific Results*, Washington - DC, vol. 159, p. 297-314. URL: http://www-odp.tamu.edu/publications/159_IR/VOLUME/CHAPTERS/ir159_09.pdf

Matos R.M.D. (1992).- The Northeast Brazilian Rift System.- *Tectonics*, vol. 11, no. 4, p. 766-791. DOI: https://doi.org/10.1029/91TC03092

Matos R.M.D. (1999).- History of the northeast Brazilian rift system: Kinematic implications for the break-up between Brazil and West Africa. *In*: Cameron N.R., Bate R.H. & Clure V.S. (eds.), The oil and gas habitats of the South Atlantic.- *Geological Society*, *Special Publications*, London, vol. 153, p. 55-73.

Matos R.M.D (2021).- Magmatism and hotspot trails during and after continental break-up in the South Atlantic.- *Marine and Petroleum Geology*, vol. 129, article 105077, 24 p.

Matos R.M.D, Krueger A., Norton N. & Casey K. (2021a).- The fundamental role of the Borborema and Benin-Nigeria provinces of NE Brazil and NW Africa during the development of the South Atlantic Cretaceous Rift system.- *Marine and Petroleum Geology*, vol. 127, article 104 872, 30 p.

Matos R.M.D., Norton I., Casey K. & Krueger A. (2019).- An orthogonal zone between the Equatorial and South Atlantic margins: Relevance and control in the evolution of the Afro-Brazilian basins. *In*: 16º International Congress of the Brazilian Geophysical Society.- SBGf - Sociedade Brasileira de Geofísica- Rio de Janeiro, p. 1-6.

Matos R.M.D, Walter E., Medeiros W.E., Jardim de Sá E.F., Almeida C.B., Norton I. & Córdoba V.C. (2021b).- A solution to the Albian fit challenge between the South American and African plates based on key magmatic and sedimentary events late in the rifting phase in the Pernambuco and Paraíba basins.- *Marine and Petroleum Geology*, vol. 128, article 105038, 31 p.

Matsumoto H., Kuroda J., Coccioni R., Frontalini F., Sakai S., Ogawa N.O. & Ohkouchi N. (2020).- Marine Os isotopic evidence for multiple volcanic episodes during Cretaceous Oceanic Anoxic Event 1b.- *Scientific Reports*, vol. 10, no. 12601, 10 p. URL: https://www.nature.com/articles/s41598-020-69505-x

Matt S. & Johns W.E. (2007).- Transport and Entrainment in the Red Sea Outflow Plume.- *Journal of Physical Oceanography*, Washington - DC, vol. 37, no. 4, p. 819-836. DOI: https://doi.org/10.1175/JPO2993.1

McAnena A., Flögel S., Hofmann P., Herrle J.O., Griesand A., Pross J., Talbot H.M., Rethemeyer J., Wallmann K. & Wagner T. (2013).- Atlantic cooling associated with a marine biotic crisis during the mid-Cretaceous period.- *Nature Geoscience*, vol. 6, p. 558-561.

McNulty C.L. (1985).- Micropaleontological stratigraphic framework for the Cretaceous black lime wackestone-mudstone facies of the Gulf of Mexico. *In*: Proceedings of the 4th Annual Research Conference of the Gulf Coast.- SEPM, Tulsa - OK, p. 1176-1191.

MICHELS F.H., SOUZA P.A. de & PREMAOR E. (2018).- Aptian-Albian palynologic assemblages interbedded within salt deposits in the Espírito Santo Basin, eastern Brazil: Biostratigraphical and paleoenvironmental analysis.- *Marine and Petroleum Geology*, vol. 91, p. 785-799.

MILANI E.J., RANGEL H.D., BUENO G.V., STICA J.M., WINTER W.R., CAIXETA J.M. & PESSOA NETO O. da C. (2007).- Bacias sedimentares brasileiras – Cartas estratigráficas.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 183-205.

MONIER-CASTILLO A., LÓPEZ-PALOMINO I., ROMO-RAMÍREZ J.R., RAMÍREZ A.P. & CONTRERAS-CRUZ D. (2018).- Micropaleontological study of Lower Cretaceous rocks (Barremian- Albian) near La Soledad, Nuevo León, northeastern Mexico.- *Paleontología Mexicana*, México, CDMX, vol. 7, no. 1, p. 57-72.

MOREIRA J.L.P., MADEIRA C.V., GIL J.A. & MACHADO M.A.P. (2007).- Bacia de Santos.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 531-549.

MOULIN M., ASLANIAN D., RABINEAU M., PATRIAT M. & MATIAS L. (2012).- Kinematic keys of the Santos-Namibe basins. *In*: MOHRIAK W.U., DANFORTH A., POST P.J., BROWN D.E., TARI G.C., NEMČOK M. & SINHA S.T. (eds.), Conjugate divergent margins.- *Geological Society*, *Special Publications*, London, vol. 369, no. 1, p. 91-107.

MOULIN M., ASLANIAN D. & UNTERNEHR P. (2010).- A new starting point for the South and Equatorial Atlantic Ocean.- *Earth-Science Reviews*, vol. 98, no. 1-2, p. 1-37.

MOULLADE M. & GUÉRIN S. (1982).- Le problème des relations de l'Atlantique Sud et de l'Atlantique Central au Crétacé moyen : Nouvelles données microfauniques d'après les forages D.S.D.P.- *Bulletin de la Société géologique de France* (7e Série), Paris, t. XXIV, no. 3, p. 511-517.

MOULLADE M., WATKINS D.K., OBOH-IKUENOBE F.E., BELLIER J.- P., MASURE E., HOLBOURN A.E.L., ERBACHER J., KUHNT W., PLETSCH T., KAMINSKI M.A., RAUSCHER R., SHAFIK S., YEPES O., DEJAX J., GREGG J.M., SHIN I.C. & SCHULER M. (1998).- Mesozoic biostratigraphic, paleoenvironmental, and paleobiogeographic synthesis, Equatorial Atlantic. *In*: MASCLE J., LOHMANN G.P. & MOULLADE M. (eds.).- *Proceedings of the Ocean Drilling Program*, *Scientific Results*, vol. 159, p. 481-490. URL: http://www-odp.tamu.edu/publications/159_SR/CHAPTERS/CHAP_35.PDF

MOURA J.A. (1988).- Ostracods from non-marine Early Cretaceous sediments of the Campos Basin, Brazil.- *Developments in Palaeontology and Stratigraphy*, vol. 11, p. 1207-1216.

MUTTERLOSE J., BORNEMANN A., LUPPOLD F.W., OWEN H.G., RUFFELL A., WEISS W. & WRAY D. (2003).- The Vöhrum section (northwest Germany) and the Aptian/Albian boundary.- *Cretaceous Research*, vol. 24, p. 203-252.

NATLAND J.H. (1978).- Composition, provenance, and diagenesis of Cretaceous clastic sediments drilled on the Atlantic continental rise off southern Africa, DSDP Site 361- Implications for the early circulation of the South Atlantic. *In*: BOLLI H.M., RYAN W.B.F., MCKNIGHT B.K., KAGAMI H., MELGUEN M., SIESSER W.G., NATLAND J.H., LONGORIA J.F., PROTO DECIMA F., FORESMAN J.B. & HOTTMAN W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 1025-1061. URL: http://deepseadrilling.org/40/volume/dsdp40_30.pdf

NEVES I.A., MENDONÇA FILHO J.M. & SOUZA I.V.A.F. (2007, unpublished).- Aplicação da palinofácies na caracterização paleoambiental da Formação Codó, Cretáceo da Bacia do Parnaíba.- Dissertation Universidade Federal do Rio de Janeiro, 41 p. URL: https://pantheon.ufrj.br/bitstream/11422/4246/1/NEVE%2c%20I.A.pdf

NÚÑEZ-USECHE F., BARRAGÁN R., CANET C. & LÓPEZ-MARTÍNEZ R. (2016).- Record of upper Aptian – lower Albian environmental perturbation in northeastern Mexico.- *Journal of South American Earth Sciences*, vol. 70, p. 298-307

OGG J.G., OGG G.M. & GRADSTEIN F.M. (2016).- Cretaceous. *In*: OGG J.G., OGG G.M. & GRADSTEIN F.M. (eds.), A concise geologic time scale 2016.- Elsevier, p. 167-186.

OJEDA H.A.O. (1981).- Estrutura, estratigrafia e evolução das bacias marginais brasileiras.- *Revista Brasileira de Geociências*, São Paulo, vol. 11, no. 4, p. 257-273. URL: http://bjg.siteoficial.ws/1981/n4/ojeda.pdf

OLIVEIRA L.C.V., BOTELHO NETO J. & COSTA L.A.R. (1993, unpublished).- Porção norte da Plataforma de Regência, Bacia do Espírito Santo: Caracterização bioestratigráfica e contribuição à interpretação geológica.- Petrobrás/CENPES, internal report, Rio de Janeiro, 51 p.

PAZ J.D.S. & ROSSETTI D.F. (2001).- Reconstrução paleoambiental da Formação Codó (Aptiano), borda leste da Bacia do Grajaú, MA. *In*: O Cretáceo na Bacia de São Luís-Grajaú.- Coleção Friedrich KATZER, Museu Paraense Emílio GOELDI, Belém, p. 77-100.

PEDERSEN T.F. & CALVERT S. (1990).- Anoxia vs. productivity: What controls the formation of organic- carbon-rich sediments and sedimentary rocks?- *AAPG Bulletin*, Tulsa - OK, vol. 74, no. 4, p. 454-466.

PEREIRA M.J. & FEIJÓ F.J. (1994).- Bacia de Santos.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 219-234.

PESSAGNO E.A. Jr & DIAS-BRITO D. (1996).- O silexito a radiolários do sul da Bacia Sanfranciscana, Brasil: Idade, origem e significado. *In*: Boletim do 4º Simpósio sobre o Cretáceo do Brasil, Água de São Pedro.- UNESP, Rio Claro, vol. 4, p. 213-222.

PETRI S. (1987).- Cretaceous paleogeographic maps of Brazil.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 59, p. 117-168.

PHILIP J. (1982).- Paléobiogéographie des rudistes et géodynamique des marges mésogéennes au Crétacé supérieur.- *Bulletin de la Société géologique de France* (7e série), Paris, t. XXIV, no. 5-6, p. 995-1006.

PLETSCH T., DAOUDI L., CHAMLEY H., DECONINCK J. & CHARROUD M. (1996).- Palaeogeographic controls on palygorskite occurrence in mid-Cretaceous sediments of Morocco and adjacent basins.- *Clay Minerals*, Cambridge (UK), vol. 31, no. 3, p. 403-416.

PLETSCH T., ERBACHER J., HOLBOURN A.E.J., KUHNT W., MOULLADE M., OBOH-IKUENOBE F.E., SÖDING E. & WAGNER T. (2001).- Cretaceous opening history of the Equatorial Atlantic Gateway: The view from the West African continental margin (ODP Leg 159).- *Journal of South American Earth Sciences*, vol. 14, no. 2, p. 147-174.

POPOFF M. (1988).- Du Gondwana à l'Atlantique Sud : Les connexions du fossé de la Bénoué avec les bassins du Nord-Est brésilien jusqu'à l'ouverture du golfe de Guinée au Crétacé inférieur.- *Journal of African Earth Sciences (and the Middle East*), vol. 7, no. 2, p. 409-431.

POROPAT S.F. & COLIN J-P. (2012).- Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: An overview.- *Gondwana Research*, vol. 22, p. 772-798.

POULSEN C.J., GENDASZEK A.S. & JACOB R.L. (2003).- Did the rifting of the Atlantic Ocean cause the Cretaceous thermal maximum?- *Geology*, Boulder - CO, vol. 31, no. 2, p. 115-118.

PREMOLI-SILVA I. & BOERSMA A. (1977).- Cretaceous planktonic foraminifers - DSDP Leg 39 (South Atlantic). *In*: SUPKO P.R., PERCH-NIELSEN K., NEPROCHNOV Y.P., ZIMMERMAN H.B., MCCOY F., KUMAR N., THIEDE J., BONATTI E., FODOR R., BOERSMA A., DINKELMAN M.G. & CARLSON R.L. (eds.), Leg 39 of the cruises of the Drilling Vessel Glomar Challenger. Amsterdam, Netherlands to Cape Town, South Africa. October-December 1974.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XXXIX, p. 615-642. URL: http://deepseadrilling.org/39/volume/dsdp39_40.pdf

RANGEL H.R., MARTINS F.A.L., ESTEVES F.R. & FEIJÓ F.J. (1994).- Bacia de Campos.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 203-217.

RAT T. (1987).- The Iberian Cretaceous: Climatic implications.- 3rd International Cretaceous Symposium (Cretaceous of the Western Tethys), Tübingen, Proceedings, p. 17-25.

REGALI M.S.P. (1989a).- A idade dos evaporitos da plataforma continental do Ceará, Brasil, e sua relação com os outros evapflororitos das bacias nordestinas.- *Boletim do IG-USP*, São Paulo, Publicação Especial, vol. 7, p. 139-143. DOI: https://doi.org/10.11606/issn.2317-8078.v0i7p139-143

REGALI M.S.P. (1989b).- Primeiros registros da transgressão neo-aptiana na Margem Equatorial Brasileira. *In*: Anais do 11º Congresso Brasileiro de Paleontologia, Curitiba.- Sociedade Brasileira de Paleontologia, vol. 1, p. 275-293.

REGALI M.S.P. & VIANA C.F. (1989).- Sedimentos do NeoJurássico-EoCretáceo do Brasil: Idade e correlação com a escala internacional.- Editora Gávea, Petrobrás, Rio de Janeiro, 95 p.

ŘEHÁKOVÁ D. & MICHALÍK J. (1993).- Observations of ultrastructure of the upper jurassic and lower cretaceous calpionellid tests.- *Geologica Carpathica*, Bratislava, vol. 44, no. 2, p. 75-79.

RISACHER F. & FRITZ B. (2000).- Bromine geochemistry of salar de Uyuni and deeper salt crusts, Central Altiplano, Bolivia.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 495, p. 163-170.

SAINT-MARC P. & N'DA V. (1997).- Biostratigraphie et paléoenvironnements des dépôts crétacés au large d'Abidjan (Golfe de Guinée).- *Cretaceous Research*, vol. 18, p. 545-565.

SALARD-CHEBOLDAEFF M. & BOLTENHAGEN E. (1992).- La palynologie des évaporites d'Afrique équatoriale et ses rapports avec le paléoenvironnement.- *Journal of African Earth Sciences (and the Middle East)*, vol. 14, no. 2, p. 191-195.

SAMES B., WAGREICH M., CONRAD C.P. & IQBAL S. (2020).- Aquifer-eustasy as the main driver of short-term sea-level fluctuations during Cretaceous hothouse climate phases. *In*: WAGREICH M., HART M.B., SAMES B. & YILMAZ I.O. (eds.), Cretaceous climate events and short-term sea-level changes.- *Geological Society*, *Special Publications*, London, vol. 498, p. 9-38.

SANJINÉS A.E.S., VIVIERS M.C., COSTA D.S., ANJOS-ZERFASS G.S., BURLEN G. & STROHSCHOEN O. (2022).- Planktonic foraminifera from the Aptian section of the southeastern Brazilian Atlantic margin.- *Cretaceous Research*, vol. 134, article 105141, 16 p.

SANTOS A., MOTA M.A.L., KERN H.P, FAUTH G., PAIM P.S.G., NETTO R.G., SEDORKO D., LAVINA E.L.C., KRAHL G., FALLGATTER C., SILVEIRA D.M., AQUINO C.D., SANTOS M.O., BAECKER-FAUTH S. & VIEIRA C.E.L. (2022).- Earlier onset of the Early Cretaceous Equatorial humidity belt.- *Global and Planetary Change*, vol. 208, article 103724, 14 p.

SANTOS C.F. (1999).- Ocorrência de foraminíferos em depósitos lacustres barremianos da Bacia do Recôncavo. *In*: Boletim do 5º Simpósio sobre o Cretáceo do Brasil.- UNESP, Rio Claro, p. 401-409.

SAUNDERS C., JAMES R. & BRADLEY C. (2018).- Assessing the diachroneity of the South Atlantic salt province to De-risk exploration.- *Neftex Exploration Insights*, vol. 3, p. 22-27.

SCHALLER H. (1969).- Revisão estratigráfica da Bacia de Sergipe/Alagoas.- *Boletim Técnico da Petrobrás*, Rio de Janeiro, vol. 12, no. 1, p. 21-86.

SCHEIBNEROVÁ V. (1978).- Aptian and Albian benthic foraminifers of Leg 40, sites 363 and 364, Southern Atlantic. *In*: BOLLI H.M., RYAN W.B.F., MCKNIGHT B.K., KAGAMI H., MELGUEN M., SIESSER W.G., NATLAND J.H., LONGORIA J.F., PROTO DECIMA F., FORESMAN J.B. & HOTTMAN W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 741-757. URL: http://deepseadrilling.org/40/volume/dsdp40_17.pdf

SCHOLLE P. (1996).- Oceanography 3 CD number PC D2704, picture number 256.- SEPM CD No. 5

SCHRÖDER S., IBEKWE A., SAUNDERS M., DIXON R. & FISHER A. (2015).- Algal-microbial carbonates of the Namibe Basin (Albian, Angola): Implications for microbial carbonate mound development in the South Atlantic.- *Petroleum Geoscience*, vol. 22, no. 1, p. 71-90. DOI: https://doi.org/10.1144/petgeo2014-083

SCOTCHMAN I.C., GILCHRIST G., KUSZNIR N.J., ROBERTS A.M. & FLETCHER R. (2010).- The breakup of the South Atlantic Ocean: Formation of failed spreading axes and blocks of thinned continental crust in the Santos Basin, Brazil and its consequences for petroleum system development. *In*: VINING B.A. & PICKERING S.C. (eds.), Petroleum geology: From mature basins to new frontiers.- *Petroleum Geology Conference Series*, Geological Society, London, vol. 7, p. 855-866.

SCOTESE C.R. (2014).- Atlas fo Early Cretaceous paleogeographic maps. *In*: Paleomap atlas for ArcGis, vol. 2, The Cretaceous, Map 23-31.- MollweideProjection, Paleomap Project, Evanston - IL. DOI: http://dx.doi.org/10.13140/2.1.4099.4560

SELBY D., MUTTERLOSE J. & CONDON D.J. (2009).- U-Pb and Re-Os geochronology of the Aptian/Albian and Cenomanian/Turonian stage boundaries: Implications for timescale calibration, osmium isotope seawater composition and Re-Os systematics in organic-rich sediments.- *Chemical Geology*, vol. 265, nos. 3-4, p. 394-409.

SILVA-SANTOS R. (1991, unpublished).- Fósseis do Nordeste do Brasil: Paleoictiofáunula da Chapada do Araripe.- Editora Universidade do Estado do Rio de Janeiro, Departamento de Biologia Animal e Vegetal, 64 p.

SOARES E.F., ZALÁN P.V., FIGUEIREDO J. de J.P. de & TROSDTORF I. Jr (2007).- Bacia do Pará-Maranhão.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2., p. 321-329.

SOARES JÚNIOR A.V., HASUI Y., COSTA J.B.S. & MACHADO F.B. (2011).- Evolução do rifteamento e paleogeografia da Margem Atlântica Equatorial do brasil: Triássico ao Holoceno.- *Geociências*, São Paulo, UNESP, vol. 30, no. 4, p. 669-692. URL: https://www.periodicos.rc.biblioteca.unesp.br/index.php/geociencias/article/view/5593

SOHL N.F. (1987).- Cretaceous gastropods: Contrast between Tethys and the temperate provinces.- *Journal of Paleontology*, Cambridge (UK), vol. 61, no. 6, p. 1085-1111.

SOUSA JÚNIOR G.R., SANTOS A.L.S., LIMA S.G., LOPES J.A.D., REIS F.A.M., SANTOS NETO E.V. & CHANG H.K. (2013).- Evidence for euphotic zone anoxia during the deposition of Aptian source rocks based on aryl isoprenoids in petroleum, Sergipe-Alagoas Basin, northeastern Brazil.- *Organic Geochemistry*, vol. 63, p. 94-104.

SOUZA-LIMA W., PIERINI C., FISCHER C.M. & SILVA B.O. (2021).- Paleogeografia da seção Cretácea Neoaptiana do Nordeste da Bacia de Sergipe-Alagoas, Brasil.- *Geociências*, São Paulo, UNESP, vol. 40, no. 2, p. 397-406. DOI: https://doi.org/10.5016/geociencias.v40i02.15394

SPADINI A.R. (1982).- Calcários de granulação fina da Formação Macaé, Bacia de Campos. *In*: Anais do Congresso Brasileiro de Petróleo, 2, Rio de Janeiro.- Instituto Brasileiro de Petróleo, Rio de Janeiro (Trab. no. 18).

SPADINI A.R., ESTEVES F.R. & AZEVEDO R.L.M. (1987).- O ritmito do Albiano Superior da Formação Macaé, Bacia de Campos: Um marco estratigráfico com significado paleoambiental e cronoestratigráfico. *In*: Anais do 10º Congresso Brasileiro de Paleontologia, Rio de Janeiro.- Sociedade Brasileira de Paleontologia, vol. 2, p. 1027-1041.

SPADINI A.R., ESTEVES F.R., DIAS-BRITO D., AZEVEDO R.L.M. & RODRIGUES R. (1988).- The Macaé Formation, Campos Basin, Brazil: Its evolution in the context of the initial history of the South Atlantic.- *Revista Brasileira de Geociências*, São Paulo, vol. 18, no. 3, p. 261-272.

SPENCER R.J. & HARDIE L.A. (1990).- Control of seawater composition by mixing of river waters and mid-ocean ridge hydrothermal brines. *In*: SPENCER R.J. & CHOU I-M. (eds.), Fluid-mineral interactions: A tribute to H.P. EUGSTER.- *The Geochemical Society*, *Special Publication*, Alexandria - VA, vol. 19, no. 2, p. 409-419.

SULEIMAIN A.A. (2016, unpublished).- Formation and fill of continental rift basins: An integrated study based on the Bornu Basin, onshore NE Nigeria.- PhD Thesis, Department of Earth Science and Engineering, Imperial College, 374 p.

SZATMARI P. & MILANI E.J. (2016).- Tectonic control of the oil-rich large igneous-carbonate-salt province of the South Atlantic rift.- *Marine and Petroleum Geology*, vol. 77, p. 567-596.

SZATMARI P., LIMA C.M., FONTANETA G., LIMA N.M., ZAMBONATO E., MENEZES M.R., BAHNIUK J., COELHO S.L., FIGUEIREDO M., FLORENCIO C.P. & GONTIJO R. (2021).- Petrography, geochemistry and origin of South Atlantic evaporites: The Brazilian side.- *Marine and Petroleum Geology*, vol. 127, article 104805, 31 p.

TAGLIARI C.V, FONTANELLI P.R., BRANDÃO J.R. & PAIM P.S.G. (2013).- Evolução geológica das sequências mistas (siliciclásticas and carbonáticas) sob influências da tectônica que envolve o embasamento e da halocinese durante o Albiano - Plataforma de Regência - Bacia do Espírito Santo.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 21, no. 1, p. 149-174.

TAVARES T., MEISTER C., DUARTE-MORAIS M.L & DAVID B. (2007).- Albian ammonites of the Benguela Basin (Angola): A biostratigraphic framework.- *South African Journal of Geology*, Johannesburg, vol. 110, p. 137-156.

TEDESCHI L.R., JENKYNS H.C., ROBINSON S.A., SANJINÉS A.E.S., VIVIERS M.C., QUINTAES C.M.S.P. & VAZQUEZ J.C. (2017).- New age constraints on Aptian evaporites and carbonates from the South Atlantic: Implications for Oceanic Anoxic Event 1a.- *Geology*, Boulder - CO, vol. 45, no. 6, p. 543-546.

TERRA G.J.S & LEMOS V.B. (1999).- Algas Solenoporáceas do Albo-Cenomaniano das Bacias do Nordeste do Brasil.- Implicações paleoecológicas e paleobiogeográficas. *In*: Boletim do 5º Simpósio sobre o Cretáceo do Brasil e 1º sobre el Cretácico de América del Sur.- Rio Claro - SP - Brasil, vol. 1, p. 23-28.

TORSVIK T.H., ROUSSE S., LABAILS C. & SMETHURST M.A. (2009).- A new scheme for the opening of the South Atlantic Ocean and the dissection of an Aptian salt basin.- *Geophysical Journal International*, vol. 177, p. 1315-1333.

TRABUCHO ALEXANDRE J.T., IZAA R., GILST K.V., LÓPEZ J.P.R. & BOER P.L. de (2011).- The sedimentary expression of oceanic anoxic event 1b in the North Atlantic.- *Sedimentology*, vol. 58, p. 1217-1246.

TRABUCHO ALEXANDRE J.T., TUENTER E., HENSTRA G.A, ZWAN K.J. van der, WAL R.S.W. van de, DIJKSTRA H.A. & BOER P.L. de (2010).- The mid-Cretaceous North Atlantic nutrient trap: Black shales and OAEs.- *Paleoceanography*, vol. 25, no. 4, article PA4201, 14 p. DOI: https://doi.org/10.1029/2010PA001925

TREJO M. (1975).- Los tintinidos mesozoicos de Mexico.- *Mémoires du Bureau de Recherches Géologiques et Minières*, Orléans, vol. 86, p. 95 -104.

TUCKER M.E. & DIAS-BRITO D. (2017).- Petrologia sedimentar carbonática - Iniciação com base no registro geológico do Brasil.- UNESP-IGCE-UNESPetro, Rio Claro, Obra 3, 208 p.

UESUGUI N. (1987).- Posição estratigráficas dos evaporitos da Bacia de Sergipe-Alagoas.- *Revista Brasileira de Geociências*, São Paulo, vol. 17, no. 2, p. 131-134.

UMEJI O.P. (2013).- The South and Central Benue Trough: Stratigraphic revisions.- Proceedings of University of Jos PTDF Chair Endowment Fund Seminar, April 2012, p. 145 -181.

VALENÇA L.M.M., NEUMANN V.H. & MABESOONE J.M. (2003).- An overview on Callovian-Cenomanian intracratonic basins of Northeast Brazil: Onshore stratigraphic record of the opening of the Southern Atlantic.- *Geologica Acta*, Barcelona, vol. 1, no. 3, p. 261-275.

VIANA C.F., GAMA E.G. Jr, SIMÕES I.A., MOURA J.A., FONSECA J.R. & ALVES R.J. (1971).- Revisão estratigráfica da Bacia do Recôncavo/Tucano.- *Boletim Técnico da Petrobrás*, Rio de Janeiro, vol. 14, no. 3-4, p. 57-92.

VIANA M.S.S. (1998).- The Proto-Atlantic Albian way and its influence on the South American-African life. *In*: Proceedings of 3rd Annual Conference IGCP Project 381, Comodoro Rivadavia, Argentina, November 17 - 20, 1998.- *Boletin de la Asociación Paleontológica del Golfo San Jorge*, 2 (Edición Especial), Ano I, p. 32-34.

VIEIRA R.A.B, MENDES M.P., VIEIRA P.E, COSTA L.A.R, TAGLIARI C.V., BACELAR L.A.P. & FEIJÓ F.J. (1994).- Bacia do Espírito Santo e Mucuri.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 8, no. 1, p. 191-202.

VIVIERS M.C. (1986).- Bioestratigrafia e evolução paleoambiental do meso-neocretáceo da Bacia de Santos, Brasil. *In*: Anais do 34º Congresso Brasileiro de Geologia, Goiânia.- Sociedade Brasileira de Geologia, São Paulo, vol. 1, p. 50-64.

VIVIERS M.C., SANJINÉS A.E.S., COSTA D.S., ANJOS-ZERFASS G.S., BEURLEN G. & STROHSCHOEN O. (2018).- Aptian planktonic foraminifera occurrence in the southeastern Brazilian marginal basins. *In*: Anais do 49º Congresso Brasileiro de Geologia, Rio de Janeiro.- Sociedade Brasileira de Geologia, São Paulo, p. 2027 (abstract). URL: http://cbg2018anais.siteoficial.ws/resumos/7442.pdf

WAGNER T., HERRLE J.O., DAMSTÉ J.S.S., SCHOUTEN S., STÜSSER I. & HOFMANN P. (2008).- Rapid warming and salinity changes of Cretaceous surface waters in the subtropical north Atlantic.- *Geology*, Boulder - CO, vol. 36, no. 3, p. 203-206.

WAGNER T., WALLMANN K., STÜSSER I., HERRLE J.O. & HOFMANN P. (2007).- Consequences of moderate 25,000 yr lasting emission of light CO2 into the mid-Cretaceous ocean.- *Earth and Planetary Science Letters*, vol. 259, p. 200-211.

WARREN J.K. (2010).- Evaporites through time: Tectonic, climatic and eustatic controls in marine and nonmarine deposits.- *Earth-Science Reviews*, vol. 98, p. 217-268.

WENDLER J.E. & WENDLER I. (2016).- What drove sea-level fluctuations during the mid-Cretaceous greenhouse climate?- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 441, no.3, p. 412-419.

WENDLER J.E., WENDLER I., VOGT C. & KUSS J. (2016).- Link between cyclic eustatic sea-level change and continental weathering: Evidence for aquifer-eustasy in the Cretaceous.- *Palæogeography*, *Palæoclimatology*, *Palæoecology*, vol. 441, no. 3, p. 430-437.

WIEDMANN J. & NEUGEBAUER J. (1978).- Lower Cretaceous ammonites from the South Atlantic Leg 40 (DSDP): Their statrigraphic value and sedimentological properties. *In*: BOLLI H.M., RYAN W.B.F., MCKNIGHT B.K., KAGAMI H., MEL-

GUEN M., SIESSER W.G., NATLAND J.H., LONGORIA J.F., PROTO DECIMA F., FORESMAN J.B. & HOTTMAN W.E. (eds.), Leg 40 of the cruises of the Drilling Vessel Glomar Challenger. Cape Town, South Africa to Abidjan, Ivory Coast. December 1974-February 1975.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. XL, p. 709-734. URL: http://deepseadrilling.org/38_39_40_41/volume/dsdp40_12.pdf

WIEGAND G.E. (1984).- Cretaceous Nannofossils from the Northwest African Margin, Deep Sea Drilling Project Leg 79. *In*: HINZ K. & WINTERER E.L. (eds.), Leg 79 of the cruises of the Drilling Vessel Glomar Challenger. Las Palmas, Grand Canary Island, to Brest, France. April-May 1981.- *Initial Reports of the Deep Sea Drilling Project*, Washington - DC, vol. LXXIX, p. 563-578. URL: http://deepseadrilling.org/79/volume/dsdp79_21.pdf

WINTER W.R., JAHNERT R.J. & FRANÇA A.B. (2007).- Bacia de Campos.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 511-529.

WU Y., WANG J., WANG, Q., LI H., ZHANG N. & XIAO Y. (2019).- Geochemical features and genetic mechanism of deep-water source rocks in the Senegal basin, West Africa.- *Thermal Science*, Beograd, vol. 23, no. 5, Part A, p. 2641-2649. DOI: https://doi.org/10.2298/TSCI181130153W

ZALÁN P.V. (2007).- Bacias de Bragança-Viseu, São Luís and Ilha Nova.- *Boletim de Geociências da Petrobrás*, Rio de Janeiro, vol. 15, no. 2, p. 341-345.

ZHANG W.B., DUAN T.Z., LIU Z.Q., LIU Y.F., ZHAO L. & XU R. (2017).- Architecture mode, sedimentary evolution and controlling factors of deep-water turbidity channels: A case study of the M Oilfield in West Africa.- *Petroleum Science*, vol. 14, p. 493-506.

Supplementary data

Upwelling intensity dataset for Site 545, DSDP, Mazagan Plateau, coast of Morocco (= Upwelling caused by Western African trade wind, in Figure 11).

Note: Upwelling intensity values from 0 to 4 were obtained by adjusting relative abundances of radiolarians and sponge spicules (LECKIE, 1984) with palygorskite percentages (CHAMLEY & DEBRABANT, 1984). The bold black numbers were obtained from the graph of clay minerals (scanned). Linear interpolation ensured the identification of depths common to the two datasets.

Depth (m)	Sponge spicules	Radiolarians	Linear interpolation for palygorskite %	Upwelling intensity	Depth (m)	Sponge spicules	Radiolarians	Linear interpolation for palygorskite %	Upwelling intensity
354.51			**18.0**		429.55	4.0	3.0	6.8	2.5
355.2	1.0	1.0	18.6	1.0	432.63	4.0	3.0	9.3	2.6
360.97	0.0	0.0	24.0	0.0	436	4.0	4.0	12.0	3.0
362.09	0.0	0.0	**25.0**	0.7	436.94	4.0	4.0	12.8	3.0
363.97	0.0	0.0	29.7	0.8	**440.98**	4.0	4.0	**16.0**	3.1
366.24	1.0	0.0	35.3	1.3	442.54	4.0	4.0	16.6	3.1
367	0.0	0.0	37.2	1.0	445.5	3.0	4.0	17.6	2.8
369.59	0.0	0.0	43.6	1.2	446.08	4.0	4.0	17.8	3.1
370.14	0.2	0.2	**45.0**	1.3	451.98	4.0	4.0	19.9	3.2
372.59	1.0	1.0	40.9	1.8	**452.28**	4.0	4.0	**20.0**	3.2
375.59	2.0	1.0	36.0	2.0	454.74	4.0	4.0	30.1	3.5
376.18	2.0	1.3	**35.0**	2.0	455	4.0	4.0	31.2	3.5
377.9	2.0	2.0	29.8	2.1	455.29	4.0	4.0	32.4	3.5
379.41	4.0	2.0	25.2	2.7	**459.58**	4.0	4.0	**50.0**	4.0
382.57	4.0	3.0	15.6	2.8	459.72	4.0	4.0	49.9	4.0
382.78	4.0	3.1	**15.0**	2.8	464.5	4.0	4.0	47.5	3.9
385.1	4.0	4.0	14.7	3.1	464.84	3.0	4.0	47.4	3.6
389.54	4.0	4.0	14.2	3.0	468.05	3.0	2.0	45.8	2.9
392.25	4.0	4.0	13.9	3.0	**469.57**	2.5	3.0	**45.0**	3.0
395.44	4.0	4.0	13.6	3.0	471.05	2.0	4.0	44.0	3.2
398.48	4.0	0.0	13.2	1.7	474	2.0	2.0	42.1	2.5
402.48	4.0	0.0	12.8	1.7	474.55	2.0	1.0	41.7	2.1
404.64	4.0	0.0	12.5	1.7	476.15	4.0	3.0	40.7	3.4
407.5	4.0	4.0	12.2	3.0	477.48	2.0	4.0	39.8	3.1
407.85	4.0	4.0	12.1	3.0	480.38	2.0	4.0	37.9	3.0
409.14	4.0	4.0	**12.0**	3.0	**481.78**	2.0	4.0	**37.0**	3.0
410.6	4.0	4.0	11.4	3.0	483.5	2.0	4.0	35.9	3.0
422.63	4.0	3.0	6.8	2.5	484.34	2.0	4.0	35.3	2.9
426.5	4.0	3.0	5.3	2.5	487.3	2.0	3.0	33.4	2.6
426.66	4.0	4.0	5.2	2.8	490.45	1.0	4.0	31.3	2.5
427.25	4.0	3.9	**5.0**	2.8	494	1.0	2.0	29.0	1.8