



Issues in the identification of the Aptian/Albian boundary in South Atlantic basins and beyond

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Abstract: The use of taxonomic-phylogenetic criteria established for planktonic foraminifera in the 2000's and the definition of the Albian Global Stratotype Section Point (GSSP-Alb) have resulted in a major change in the interpretation of the carbonate sections overlying the giant layer of salt present in basins of the South Central Atlantic (CSA) and their equivalent strata in the Equatorial South Atlantic (ESA), and interior of northeastern Brazil (BNE). These post-salt carbonates have long been considered Albian in age, but they contain a planktonic foraminifera association characteristically Aptian. Great conflicts arise, however, when this faunal association is compared with biostratigraphic successions based on other fossil groups or with lithostratigraphic and geochronological data. Controversies similar to those observed at sites 363 and 364 of the Deep Sea Drilling Project (DSDP) leg 40, drilled almost 45 years ago, have resurfaced. Thus, it is paradoxical that the remarkable disappearance of large species of planktonic foraminifera, associated with the top of the *Paraticinella rohri* Zone (of the upper Aptian), occurred stratigraphically above a typical Albian calcareous nannofossil succession (as the First Stratigraphic Occurrences of *Hayesites albiensis*, *Tranolithus orionatus*, *Axopodorhabdus biramiculatus*, and *Eiffellithus turrisieffelli*) or the FOs of three known species of pelagic calcispheres, all assumed to be of Albian age. Another notorious conflict lies in the fact that these carbonates rest directly on the salt layer onlapping the South Atlantic Middle Barrier (SAMB), where trachyandesite has been dated at 113.2 ± 0.1 Ma, identical to the value established for the GSSP-Alb. Detailed examination of 16 stratigraphic sections from around the world shows that the difficulties of fully applying the GSSP-Alb criteria are not limited to the CSA, ESA, and BNE basins. The explanation of these controversies may lie in the specific conditions of the water mass of the primitive South Atlantic that may have influenced morphological alterations or affected the temporal amplitude of taxa. But until geochronological, biostratigraphic and lithostratigraphic incompatibilities can be clarified, it is here recommended to use the base of the evaporitic layer as the reference for the Aptian/Albian transition in CSA, ESA, and BNE basins.

Keywords:

- South Atlantic basins;
- biochronostratigraphic and geochronological conflict;
- planktonic foraminifera;
- calcareous nannofossils;
- Albian Global Boundary Stratotype Section and Point

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Résumé : Problèmes liés à l'identification de la limite Aptien/Albien dans les bassins sud-atlantiques et au-delà.- L'utilisation de critères taxinomiques et phylogénétiques établis pour les foraminifères planctoniques dans les années 2000 et la définition du Point Stratotypique Mondial de l'Albien (PSM Albien) ont entraîné un changement majeur dans l'interprétation des dépôts à dominante calcaire postérieurs à l'énorme accumulation salifère présente dans l'Atlantique Centre-Sud (CSA), ainsi que dans celle des couches équivalentes de l'Atlantique Sud équatorial (ESA) et de l'intérieur du nord-est du Brésil (BNE). Ces "carbonates post-salifères" ont longtemps été considérés comme d'âge albien alors qu'ils recèlent une association de foraminifères planctoniques caractéristique de l'Aptien. Toutefois, des désaccords apparaissent quand cette association faunistique est comparée à des successions biostratigraphiques datées à partir d'autres groupes fossiles ou fondées sur des données lithostratigraphiques et géochronologiques. Des controverses similaires à celles observées dans l'interprétation des sites 363 et 364, Leg 40 du Deep Sea Drilling Project (DSDP), forés il y a près de 45 ans, refont surface. Paradoxalement, l'événement remarquable que constitue la disparition de grandes espèces de foraminifères planctoniques au sommet de la Zone à *Paraticinella rohri* (de l'Aptien supérieur) survient stratigraphiquement après une série d'apparitions de nannofossiles calcaires typiquement albiens (tels que les espèces *Hayesites albiensis*, *Tranolithus orionatus*, *Axopodorhabdus biramiculatus* et *Eiffellithus turriseiffelli*) ou après l'apparition de trois espèces de calcisphères pélagiques, toutes considérées comme d'âge albien. Un autre conflit notoire réside dans le fait que ces carbonates reposent directement sur la couche de sel, elle-même superposée à la Barrière Médiane de l'Atlantique Sud (SAMB), où une trachyandesite a été datée à $113,2 \pm 0,1$ Ma, soit une valeur identique à celle qui est retenue dans l'Échelle des Temps Géologiques 2020 pour le PSM Albien. L'examen détaillé de 16 coupes stratigraphiques provenant de différentes localités dans le monde montre que les difficultés de l'application stricte des critères du PSM Albien ne se limitent pas aux bassins CSA, ESA et BNE. Il se peut que les réponses à ces controverses résident dans les conditions particulières de la masse d'eau de l'Atlantique Sud primitif, induisant des altérations morphologiques ou encore dans l'amplitude temporelle des taxons. Mais jusqu'à ce que les incompatibilités géochronologiques et bio-lithostratigraphiques soient clarifiées, il est recommandé d'utiliser la base de la couche évaporitique comme référence pour la limite Aptien/Albien dans les bassins CSA, ESA et BNE.

Mots-clés :

- bassins de l'Atlantique Sud ;
- conflits biochronostratigraphiques et géochronologiques ;
- foraminifères planctoniques ;
- nannofossiles calcaires ;
- Point Stratotypique Mondial de l'Albien

1. Introduction

Sedimentary basins in the South Atlantic Ocean situated along the continental margins of Africa and South America, as well as some interior basins in the Brazilian Northeast (BNE), contain key elements for understanding Early Cretaceous evolution of the Central South Atlantic (CSA) and Equatorial South Atlantic (ESA). During this time, basins in the CSA lay between two barriers transverse to the main axis of Gondwana break-up: to the south, the Florianópolis High/São Paulo Plateau/Walvis and Frio Ridge, here referred to as the South Atlantic Middle Barrier (SAMB); and to the north, the Exception Zone (EZ), as defined by BARBOSA *et al.* (2008). Water masses of numerous sedimentary basins throughout the ESA in the area extending from the EZ to the Guinea Plateau/Demerara Rise (HEINE & BRUNE, 2014) were also connected to interior basins (Fig. 1).

This paper discusses the chronostratigraphy of the first marine deposits in the CSA, ESA, and BNE based on a broad survey of the geological literature. Concepts, consistencies, and inconsistencies in 16 geological sections containing the Aptian-Albian boundary, including several from elsewhere, were examined, with special attention given to the biochronology of ammonites, planktonic foraminifera, calcareous nannofossils, pithonellids, colomelliids, and palynomorphs. Lithostratigraphic units and geochronological information for these basins have also been analyzed in the search for additional elements for calibration with Albian Global Stratotype Section Point (GSSP-Alb).

Many oil fields have been discovered in the CSA, ESA, and BNE basins over the last half-century. However, interest in the area increased in the last decade because of the discovery of the Pre-Salt hydrocarbon province along the southeastern Brazilian margin, one of the largest such discoveries of the 21st century (JONES & CHAVES, 2011; PETERSON, 2019). Thus, given its economic importance, it is imperative that the age of the evaporites and overlying carbonates be precisely known. It is these carbonates that comprise the main focus of this study.

2. Geological context

The break-up of Gondwana during the Early Cretaceous led to the development of a relatively common sedimentary succession in the basins from both sides of the CSA and ESA. During this time, a large sedimentary pile formed in these basins associated with the rift, sag, and drift phases of break-up (MILANI *et al.*, 2007). In the rift phase, non-marine siliciclastic sediments were deposited, including black shales, together with grainstones, rudstones, and interlayered volcanic rocks (Fig. 2). Lacustrine deposits formed during this period allowed creation of a local chronostratigraphic scheme, whose stages were defined mostly by ostracod bioevents (SCHALLER, 1969; VIANA *et al.*, 1971). Yet five decades later, the equivalence between these units and international ones remains uncertain (ANTUNES *et al.*, 2018).

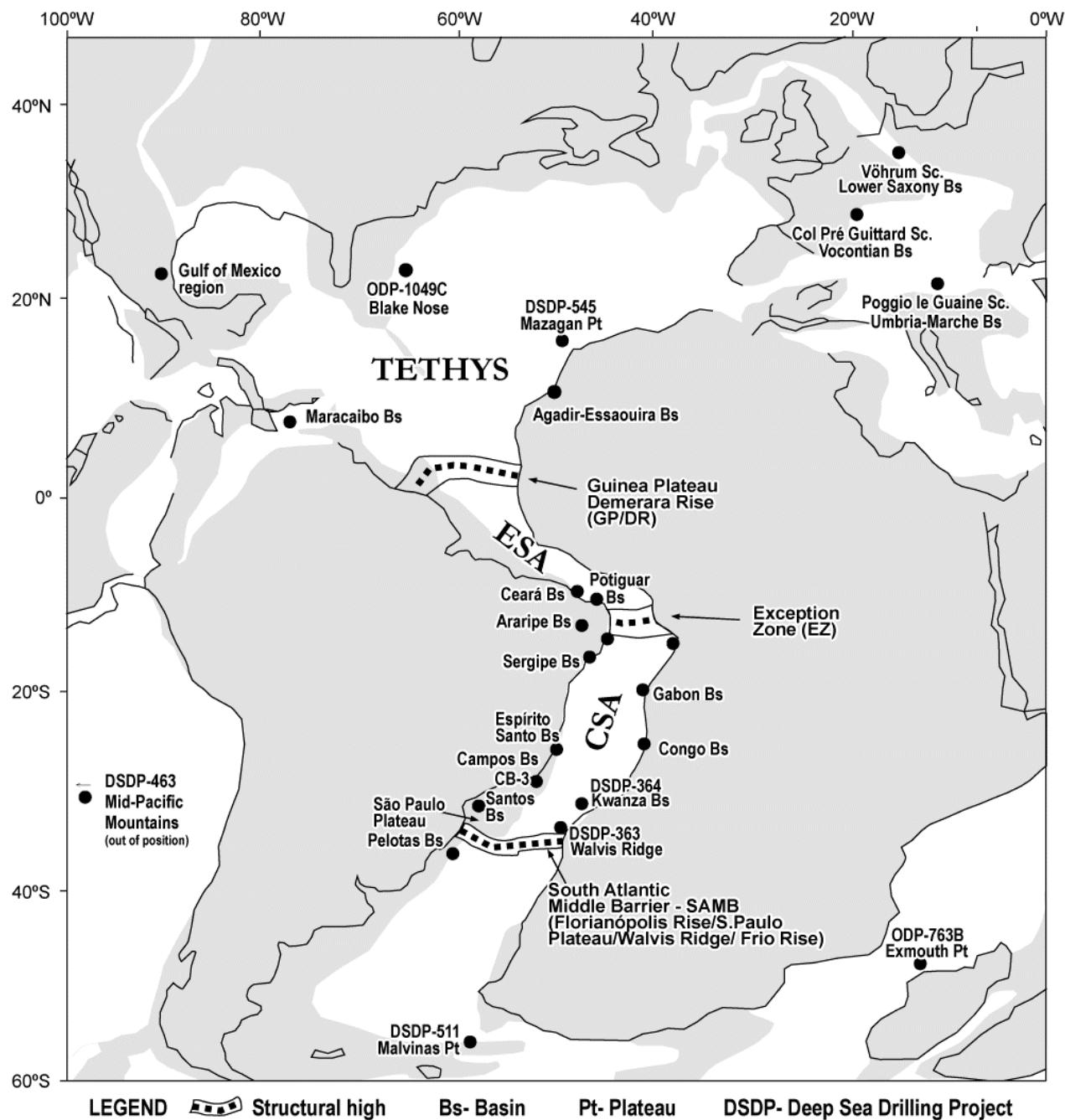


Figure 1: Location of the basins and sections analyzed in the Central South Atlantic (CSA) and Equatorial South Atlantic (ESA), as well as in other regions around the world. Paleogeography is for 113 Ma ago (modified from <http://www.odsn.de>).

The youngest of these local stages, the Alagoas Stage, is a siliciclastic package covered by microbial carbonates-travertines and a very thick and widespread salt layer, which comprises the sag sequence and marks the beginning of the establishment of marine conditions in the CSA. The evaporitic package is dominated by halite and anhydrite, deposited during a time span of ~600 ka to 1 Ma (e.g., DIAS, 1998, 2005; FRANÇA *et al.*, 2007; MOREIRA *et al.*, 2007; WINTER *et al.*, 2007), or as short as 530 ka according to RODRIGUES *et al.* (2018). This layer is around 2,000 m thick and is spread over an area of approximately 1,500 km by 500 km area, limited to the south by the SAMB and to the north by the EZ (Fig. 1). Scattered co-

eval evaporites, though not as thick, can also be seen in offshore and onshore deposits of the ESA (ASMUS & CAMPOS, 1983; REGALI, 1989). DIAS (1998, 2005) created the useful term Ibura Event to unify analysis of all marine incursions responsible for the almost "instantaneous" deposition of these salts, which have distinct lithostratigraphic designations in each basin.

Marine carbonates deposited in shallow waters and open seas are the main components at the beginning of the drift phase in the CSA; they can also be found in basins of the ESA and BNE (MILANI *et al.*, 2007). Until the 2010's, these carbonates were dated as Albian in the synthetic stratigraphic charts of Brazilian basins published by Pe-

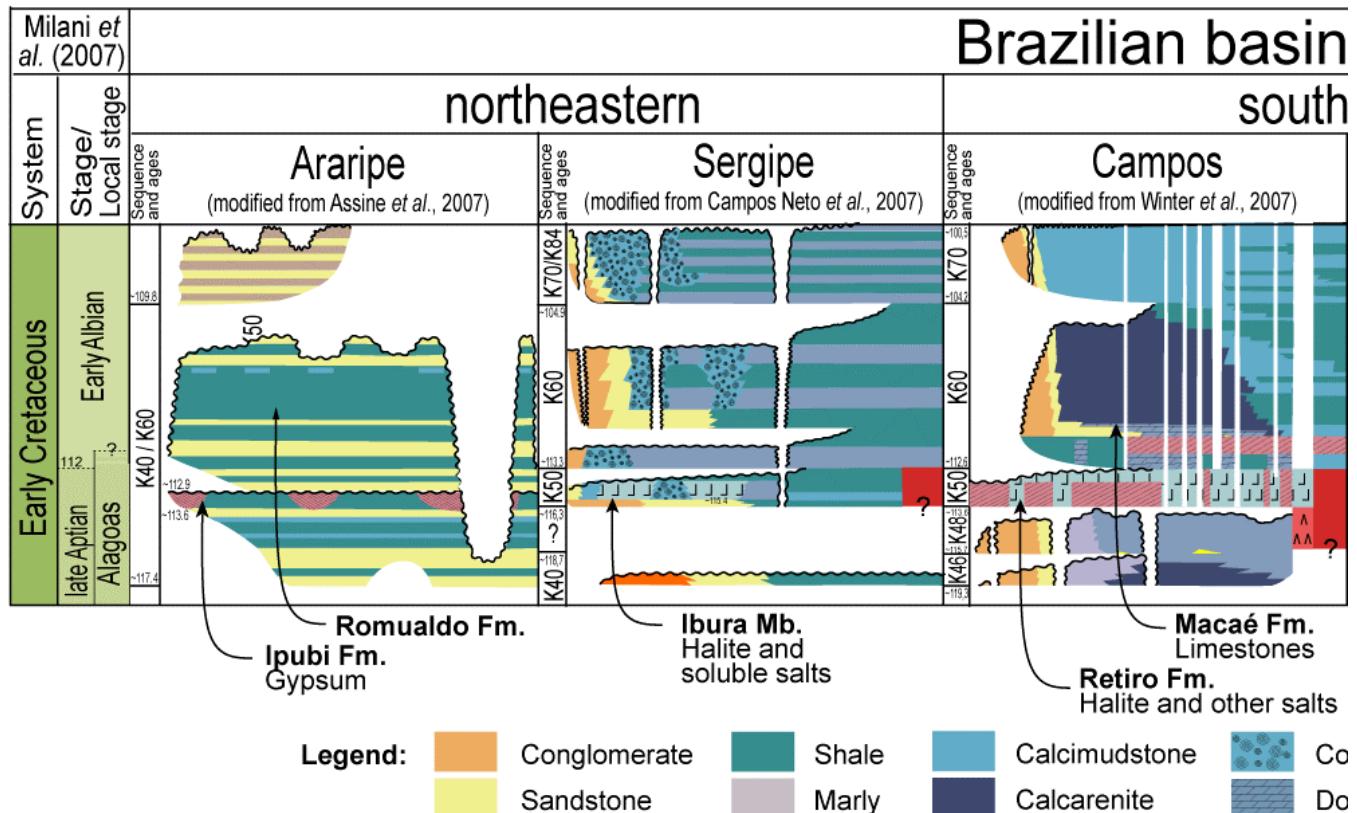
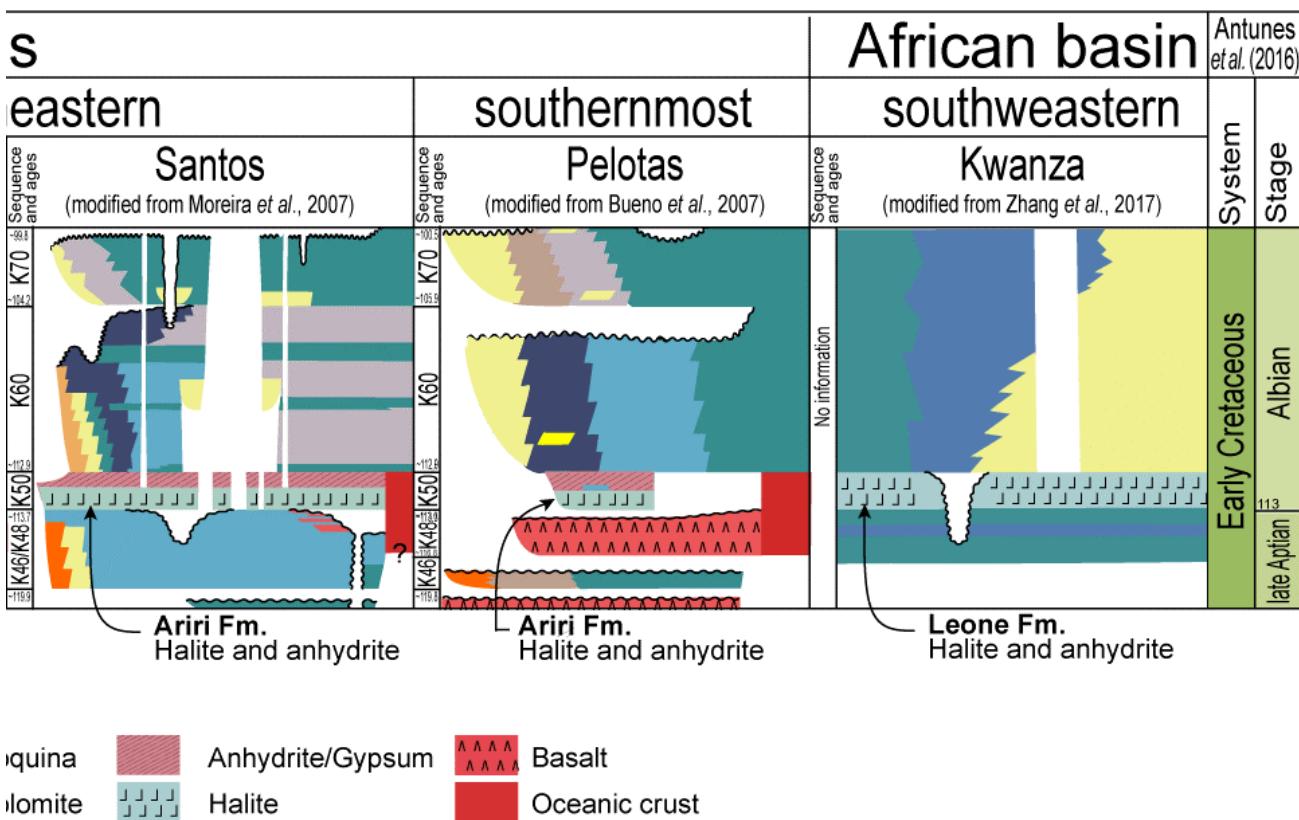


Figure 2: Stratigraphic chart for the Araripe (located in the BNE), Sergipe, Campos, Santos, Pelotas and Kwanza basins during the late Aptian-Early Albian. For the Brazilian basins, stratigraphic adjustment was made considering geochronological interpretations and the position of the sequence boundaries described by MILANI et al. (2007), who used the geological time scale of GRADSTEIN et al. (2004). The right column illustrates the alternative proposal by ANTUNES et al. (2018), who suggested the base of the Ibura evaporite as the marker for the Aptian-Albian boundary.

trobras (FEIJÓ, 1994; MILANI et al., 2007). Since then, this entire carbonate section has been reclassified as Aptian because of biochronostratigraphic revisions mainly affecting planktonic foraminifera in the Santos, Campos, and Espírito Santo basins (LIMA et al., 2018; VIVIERS et al., 2018; SANJINÉS et al., 2022). This was the result of both the application of taxonomic-phylogenetic criteria established for this protist group (HUBER & LECKIE, 2011) and the definition of the GSSP-Alb (KENNEDY et al., 2017). However, this interpretation conflicts with other renowned regional or global chronostratigraphic data, particularly that of calcareous nannofossils at Site 364, Kwanza Basin (BRUNO et al., 2020). Moreover, in the extreme south of the CSA, the salt layer onlaps volcanic rocks in the Florianópolis High, where a trachyandesite was dated by the Ar/Ar method at 113.2 ± 0.1 Ma (MIZUSAKI, 1993, fide DIAS et al., 1994), almost identical to the value established in the Geological Time Scale 2020 - GTS2020 (GALE et al., 2021) for the base of the Albian (GSSP-Alb). Because of this, ANTUNES et al. (2018) proposed an alternative solution by adopting the Ibura evaporite as marking the Aptian-Albian boundary for basins in the CSA, ESA, and BNR, which justifies the chronostratigraphic discrepancies between the two extreme columns illustrated in Figure 2.

3. The conceptualization of the Albian

The Concise Geologic Time Scale 2016 (CGTS2016), by OGG et al. (2016), integrates the detailed studies carried out by KENNEDY et al. (2000), PETRIZZO et al. (2012), and KENNEDY et al. (2014) in outcrops of the Col de Pré-Guittard, France, which were key for the proposal of that area as the Albian Global Stratotype Section Point (PETRIZZO et al., 2016; KENNEDY et al., 2017; GPS coordinates [according to GRANIER, 2017]: $44^{\circ}30' 28.3''\text{N}$ $5^{\circ}17'50.1''\text{E}$, not $44^{\circ}29' 47.78''\text{N}$ $5^{\circ}18' 42.36''\text{E}$). Differently from previous suggestions (e.g., BRÉHÉRET et al., 1986; HART et al., 1996; OWEN, 2002) and the geological time scales from 2004 and 2012 (GTS2004 and GTS2012; OGG et al., 2004 and 2012; respectively), the CGTS2016 discarded the option of using the First Stratigraphic Occurrence (FO) of the calcareous nannofossil *Prediscosphaera columnata* as the datum for the base of the Albian. A perceived diachronism regarding the FO of *P. columnata* contributed to this decision after Bown (in KENNEDY et al., 2000) recognized three morphological categories for the species based on their outlines: elliptical-subcircular, subcircular, and circular.



The new datum used to indicate the base of the Albian was the FO of the planktonic foraminifera *Microhedbergella renilaevis* (Fig. 3). This bioevent occurs during the notable biotic turnover around the Aptian-Albian boundary that strongly affected the evolution of these protists, led to a drastic decrease in both foraminifera abundance as well as the planktonic/benthic ratio and occurred during the last 1 Ma of the Aptian (HUBER & LECKIE, 2011). Another important factor is that the FO of *M. renilaevis* in Col de Pré-Guittard occurs in the Killian anoxic level and is accompanied by other, stratigraphically close black shale layers: the JACOB Level, below, and the PAQUIER and LEENHARDT levels, above, as described by BRÉHÉRET (1983). The age inferred for the GSSP-Alb was 113.1 ± 0.3 Ma by the $^{238}\text{U}/^{206}\text{Pb}$ method, as determined in zircon from volcanic ash at Vöhrum, Germany (SELBY *et al.*, 2009). Distant about 1000km from Col Pré-Guittard, the Vöhrum section does not contain planktonic foraminifera, so that support for the chronocorrelation between the two outcrops came from ammonite associations and the FO of *Prediscosphaera columnata* (subcircular category) a few centimeters above the ash layer (MUTTERLOSE *et al.*, 2003).

In the updated version of the Geological Time Scale (GTS2020) of GALE *et al.* (2021), a few alterations were introduced to the Albian, of which the three most notable were: changing the age of the GSSP-Alb from 113.1 ± 0.3 to 113.2 ± 0.3 ; not indicating limits for Albian substages; and promoting changes in the succession of ammonite zones. More noteworthy still was the change in age from 126.3 to 121.4 Ma for the base of the Aptian, maintaining the magnetic polarity-Chron M0 as datum. This clearly impacted the ages of the data that subdivide this stage. We mainly follow the GTS2020 in this paper but adopt the CGTS 2016 criteria for identification of Albian substages where necessary.

4. The Aptian-Albian boundary in CSA, ESA, and BNE sedimentary basins

Here we summarize data from numerous studies that attributed Aptian and/or Albian ages to the marine sections of sedimentary basins of the CSA, ESA, and BNE. We also discuss lithological units having potential chronostratigraphic value and absolute ages of volcanic and sedimentary rocks that provide geochronological references for geological interpretations of these basins.

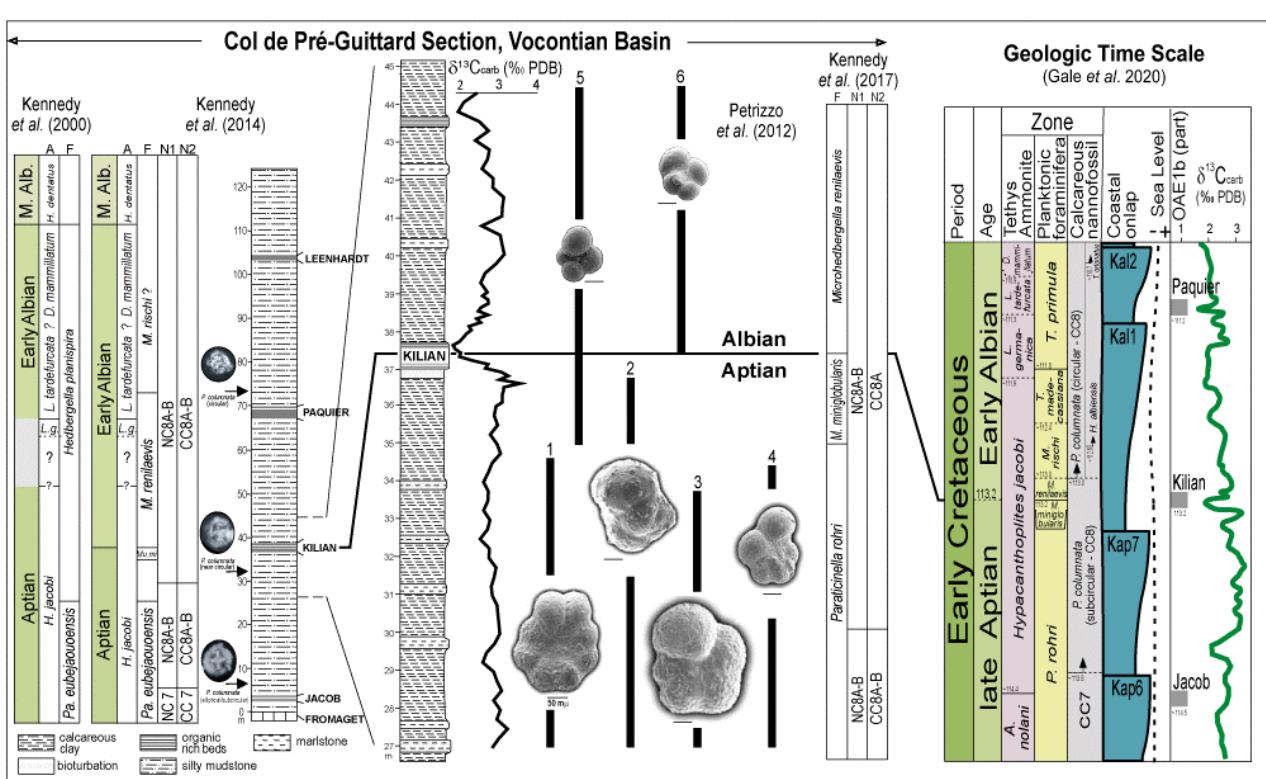


Figure 3: The GSSP-Alb major stratigraphic data (modified from PETRIZZO et al., 2012; KENNEDY et al., 2017), FOs of the *Prediscosphaera columnata* varieties: elliptical-subcircular, subcircular, and circular (modified from Bown, in KENNEDY et al., 2000, 2014). $\delta^{13}\text{C}_{\text{carb}}$ curve and stratigraphic amplitude of some planktonic foraminifera: 1) *Paraticinella eubejaouaensis* (=*P. rohri*), 2) *Pseudoguembelitria blakenensis*, 3) *Hedbergella infracretacea*, 4) *H. aptiana*, 5) *Microhedbergella miniglobularis*, and 6) *M. renilaevia* (modified from PETRIZZO et al., 2012); scale bar is = 30 μm , except for *P. eubejaouaensis*). And the CGTS2020, showing the biostratigraphic units defined with planktonic foraminifera and calcareous nannofossils; main black shale layers (JACOB, KILIAN, PAQUIER, and LEENHARDT); coastal onlap and sea level curves; and the $\delta^{13}\text{C}_{\text{carb}}$ reference curve.

4.1. Biostratigraphic support for chronostratigraphic interpretations

4.1.1. Ammonites, planktonic foraminifera, calcareous nannofossils, pithonellids, and colomiellids

The pioneering studies with ammonites illustrated the difficulty in attributing ages for the oldest, post-salt marine sediments of the CSA, ESA, and BNE basins, sometimes dating them as late Aptian, sometimes as Early or younger Albian (e.g., BEURLEN, 1961, *fide* SCHALLER, 1969; KENNEDY & COOPER, 1975; WIEDMANN & NEUGEBAUER, 1978; BOLLI, 1978; BOLLI et al., 1978a, 1978b; REYMENT & DINGLE, 1987). The most recent paper by BENGTSON et al. (2018) for the Sergipe Basin (Fig. 1) attributed an Aptian age to the association zones marked by *Epicheloniceras* and *Eodouvilleiceras*. They chronocorrelate these units with the *Parahoplites melchioris* Zone, *Epicheloniceras martini* Zone, and the basal portion of the *Hypacanthoplites jacobi* Zone, which are part of the standard international zonation scheme of the GTS2020. They are equivalent to the planktonic foraminifera from the *Leopoldina cabri* (upper part) to *Microhedbergella miniglobularis* zones; to almost the entire range of *Chiastozygus litterarius* (CC7) and to the lower part of *Prediscosphaera columnata* (CC8), among the calcareous nannofossils. BENGT-

SON et al. (2018) also consider the *Douvilleiceras mammillatum* Interval Zone as being Early Albian, corresponding to the upper part of the *H. jacobi* and *D. mammillatum* zones. They are equivalent to the *Microhedbergella renilaevia* and the lower part of the *Ticinella primula* zones in the planktonic foraminiferal biostratigraphic succession, and to a large part of *Prediscosphaera columnata* Zone. This set of zones comprises almost the entirety of the upper Aptian and the Lower Albian. However, because of doubts regarding species provincialism, lack of good outcrops, and uncertain stratigraphic positioning of many recovered specimens, BENGTSON et al. (2018) regarded as "tentative" their calibration between the Sergipe Basin ammonites and the standard international scheme.

Although late Aptian planktonic foraminifera have been reported in the South Atlantic in scattered occurrences (Ceará Basin, DELLA FÁVERA et al., 1984; Deep Sea Drilling Project - DSDP Leg 40, Sites 363-364, Kwanza Basin, CARON, 1978) between 1980 and 2000, many studies in the CSA basins and also some in the ESA basins involving this protist group attributed an Albian age to the post-salt carbonate section (e.g., AZEVEDO et al., 1987; KOUTSOUKOS, 1987; VIVIERS, 1987; VIVIERS & BEURLEN, 1987; DIAS-BRITO et al., 1990; AZEVEDO, 2001). This concept ended up enshrined in the stratigraphic charts of these basins.

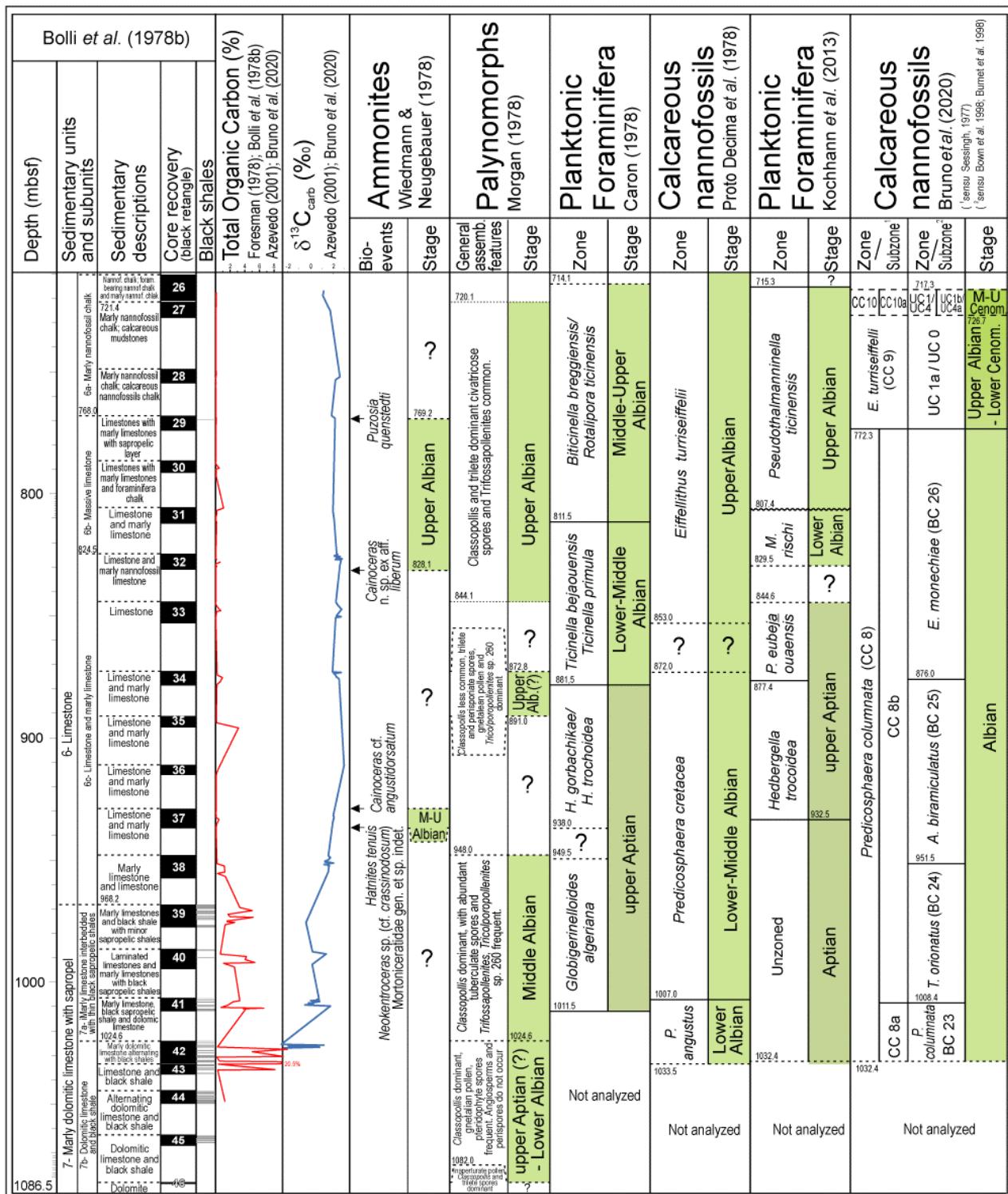


Figure 4: Biochronostratigraphic interpretations for DSDP-364, based on different fossil groups, alongside results for TOC and $\delta^{13}\text{C}_{\text{carb}}$ (Supplementary data).

However, in important work involving cores and outcrops of the Sergipe Basin, KOUTSOUKOS (1989, 1992) identified zones of planktonic foraminifera attributed to the Aptian in the basal portion of carbonates covering evaporites of the Ibura Event: the composite zones *Globigerinelloides barri*-*Hedbergella* (*H.*) *gorbachikae* and *Globigerinelloides* ex. gr. *maridalensis*-*Hedbergella* (*H.*) *similis*, both associated with the upper-

most Aptian. Above these, the composite zone *Globigerinelloides cushmani*-*Ticinella bejaouensis* and the acme zone *Ticinella bejaouensis* were considered to be Early Albian. One year later, KOUTSOUKOS and BENGTSON (1993) made the first attempt to integrate foraminifera and ammonite zonations for the Sergipe Basin, recognizing it as a provisional proposal for the Aptian-Albian interval as well.

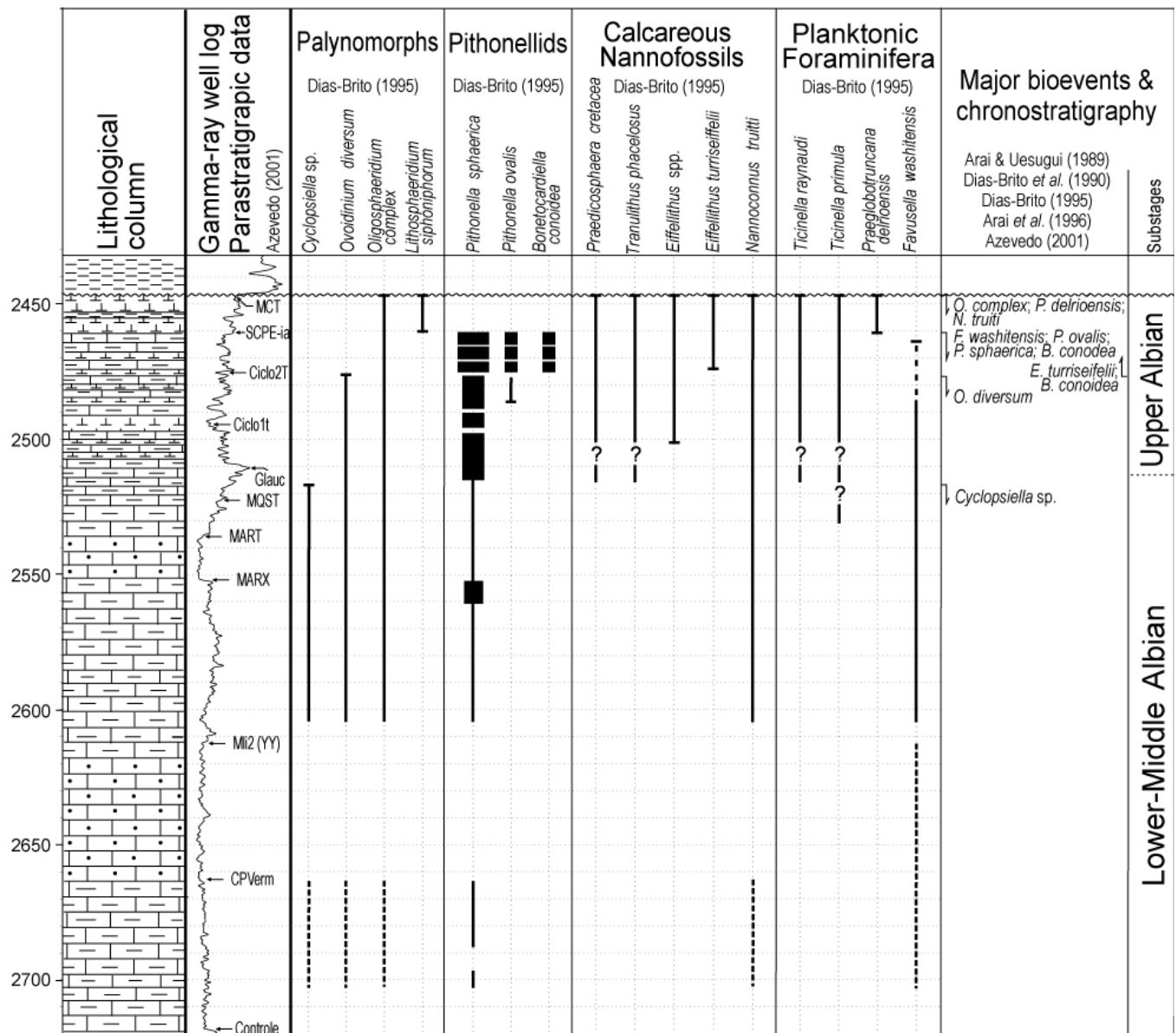
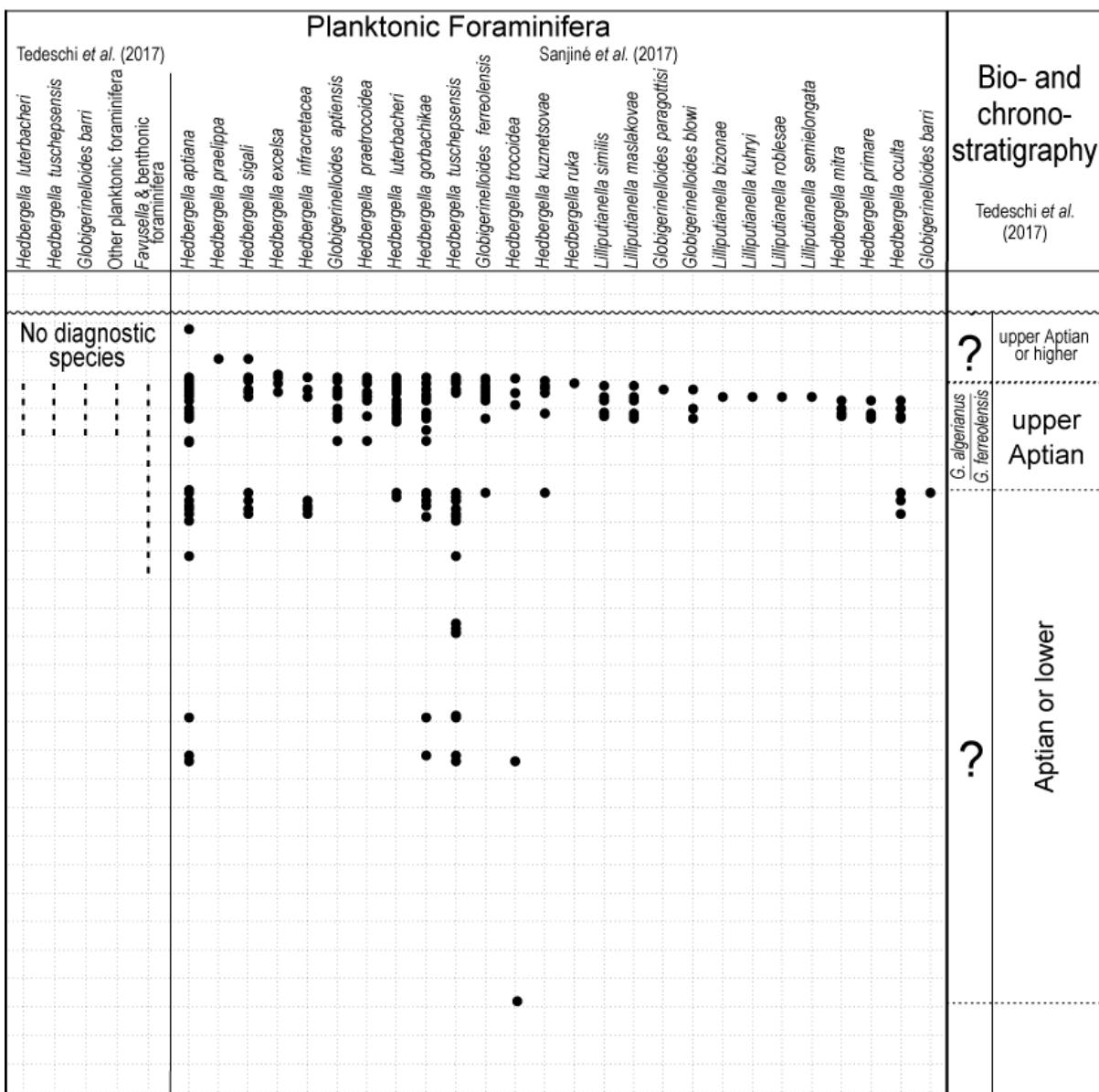


Figure 5: Cored carbonate section of the 3-BO-3-RJS well, with the distribution record for different fossil groups. In TEDESCHI *et al.* (2017)' and SANJINÉS *et al.* (2022)' papers this well was designated BO-3 and CB-01, respectively. The geophysical profile and parastratigraphic data are from AZEVEDO (2001). The depths were recorded with reference to the drilling floor ship level (+12m), to standardize the set of information.

Analyzing post-salt carbonates on the African side of the CSA, CARON (1978) dated the lower section of Site 364 as Aptian, based on recognition of the planktonic foraminiferal *Globigerinelloides algerianus* Zone and the *Hedbergella gorbachikae-Hedbergella trocoidea* composite zone (Fig. 4). This author placed the base of the Lower-Middle Albian in a distinct stratigraphic horizon defined by the FOs of *Ticinella bejaouaensis*, *T. roberti*, and *T. primula*, occurring alongside *Globigerinelloides bentonensis*, *G. texomaensis*, *Ticinella raynaudi*, and *Clavehedbergella simplicissima*, species that are currently associated with younger ages (YOUNG *et al.*, 2022b).

For calcareous nannofossils in the same section, PROTO-DECIMA *et al.* (1978) noted the FOs of *Parhabdolithus angustus* (= *Rhagodiscus angustus*), *Hayesites albiensis*, *Tranolithus orionatus*, and *Prediscosphaera cretacea* (= *P. columnata*) in the *G. algerianus* Zone. They identified the *P. angustus* and *P. cretacea* zones as being Early Albian and Early-Middle Albian in age in stratigraphic levels that CARON (1978) had considered early Aptian. Further adding to the controversy, PROTO-DECIMA *et al.* (1978) also observed that the FO of *Podorhabdus albianus* (= *Axopodorhabdus biramiculatus*), another typical Albian species, was observed in the composite zone *Hedbergella gorbachikae-Hedbergella trocoidea*, which CARON (1978) had associated with the late Aptian.



Conflicting biochronostratigraphies were also observed at Site 363, Leg 40 - DSDP between planktonic foraminifera and calcareous nannofossil events, the former suggesting Aptian ages and the Early-Middle Albian ones (CARON, 1978; PROTO-DECIMA *et al.*, 1978). During the integration of biochronostratigraphic data from sites 363 and 364, an Early Albian age was indicated for the carbonates at the base of both sections via better adjustment of the calcareous nannofossils with the classical zonation observed in Southern France (BOLLI, 1978; BOLLI *et al.*, 1978a, 1978b).

With the discovery by DIAS-BRITO (1985) of the equivalence of the semiquantitative distribution of pithonellids from Site 363 and those observed in the Campos Basin, the Albian interpretation adopted by BOLLI (1978) became the reference for the southeastern and eastern Brazilian margin (Fig. 5). A few years later, DIAS-BRITO *et al.* (1990) consolidated a biostratigraphic zonation using data from the different planktonic fossils found throughout the thick post-salt interval con-

tinuously sampled in the core of the 3-BO-3-RJS well from the Campos Basin. The carbonate section was subdivided into a lower unit of Early to Middle Albian age and a younger one dated as Late Albian. Finally, DIAS-BRITO (2000) published a comprehensive study on the worldwide spatial and stratigraphic distribution of pithonellids in the Cretaceous, where he demonstrated that several species found in the CSA did indeed first appear in the Albian.

DIAS-BRITO (1994) also highlighted the affinity that many of the post-salt carbonate facies had with those described in Albian sections from the Gulf of Mexico with emphasis on the presence of *Colomia recta* and *C. mexicana* in well 1-SPS-6 in the Santos Basin (Fig. 1). These taxa do not yet have well-defined ranges but are frequently considered to be markers for the end of the Aptian and beginning of the Albian, an interpretation adopted in the biostratigraphy for the basins of the southeastern margin of Brazil using colomelliids and pithonellids (DIAS-BRITO, 1999).



More recently, with the support of isotopic data of $^{87}\text{Sr}/^{86}\text{Sr}$, CAETANO-FILHO *et al.* (2017) reached the same conclusion for the chronostratigraphic positioning of *C. recta* in a distal section of the Campos Basin, where this species was also observed in strata immediately above the salt layer.

DUPONT (1996) studied planktonic foraminifera and other microfossils from dozens of wells drilled in the Gabon Basin (Fig. 1) and tentatively associated the *Hedbergella* cf. *sigali* – *Globigerinelloides* aff. *maridalensis* composite subzone and the lower portion of the *Hedbergella* *occulta* subzone with the Aptian. The presence of *Colomiella recta* also contributed to this chronostratigraphic interpretation, with the author also highlighting the affinity among fossil assemblages from Gabon, the Gulf of Mexico and the Sergipe Basin.

Corroborating the observations of CARON (1978), DUPONT (1996) noted the co-occurrence of *Ticinella bejaouensis*, *T. roberti*, and *T. primula*. Currently, the taxa designated as *T. bejaouensis* and *T. eubejaouensis* (or, later, *Paraticinella eubejaouensis*), are considered synonymous with *T. roberti* and *Paraticinella rohri*, respectively, with both having distinct, incompatible amplitudes: *P. rohri* is associated with the latest Aptian, while the FO of *T. roberti* lies in the Early-Middle Albian and its Last Stratigraphic Occurrence (LO) in the Late Albian (MOULLADE *et al.*, 2002; PREMOLI-SILVA *et al.*, 2009; HUBER & LECKIE, 2011; ANDO *et al.*, 2013; KENNEDY *et al.*, 2017). This nomenclatural problem resulted in the choice of the *T. primula* FO as the datum for the base of Middle Albian by some (e.g., LECKIE, 1984; CARON, 1985; BRÉHÉRET *et al.*, 1986; SLITER, 1989), and for other authors, to indicate the uppermost part of the Lower Albian (e.g., LUCIANI *et al.*, 2004; HUBER & LECKIE, 2011; CGTS2016 - OGG *et al.*, 2016).

Recently, new planktonic foraminifera and calcareous nannofossil studies in the basal section at Site 364 by KOCHHANN *et al.* (2013) and BRUNO *et al.* (2020), respectively, confirmed the incompatibility between these two fossil groups in light of the biochronostratigraphic patterns in the CGTS 2020 and the GSSP-Alb.

KOCHHANN *et al.* (2013) identified the *Hedbergella trocoidea* Zone and *Paraticinella eubejaouensis* (= *P. rohri*) Zone, both associated with the upper Aptian (Fig. 4). The top of the latter also coincides with the extinction of other long-lived species having large tests that marks the beginning of the biotic turnover recognized just before the end of the Aptian in the GSSP-Alb. According to KOCHHANN *et al.* (2013), the *Microhedbergella rischi* Zone and *Pseudothalmanninella ticinensis* Zone represent strata from the Lower and Upper Albian, respectively, with an expressive gap indicated by the absence of the Middle Albian. Approximately 13 m of the drill core were not recovered, thereby impeding possible identification of the *Microhedbergella miniglobularis* and *M. renilaevi* zones or of other biotic events associated with the turnover, which could have better de-

fined the Aptian-Albian boundary, according to the GSSP-Alb.

KOCHHANN *et al.* (2013) indicated the FO of *Paraticinella eubejaouensis* four meters above the level at which CARON (1978) observed the FO of *T. bejaouensis*, *T. roberti*, *T. primula*, and other taxa attributed to the Middle-Upper Albian (Fig. 4). KOCHHANN *et al.* (2013) revised the taxonomic description of *T. primula*, considering it to be closer to that of *T. madecassiana* (*Microhedbergella rischi* trans. *madecassiana*). In addition, they stated that "CARON's figures of *T. cf. T. roberti* and *T. praeticinensis* do not yield a typical 'ticinellid wall structure', being [t]herein considered *Murico-hedbergella astrepta* and *M. praelibyca*, respectively". They did not, however, discuss the taxa *G. bentonensis*, *G. texomaensis*, *T. raynaudi*, and *C. simplicissima* described by CARON (1978), also associated with a Middle-Upper Albian, which they would be present in the interval in which *Paraticinella eubejaouensis* occurs.

Studying calcareous nannofossils, BRUNO *et al.* (2020) identified in core 42, lower portion of Site 364, the circular morphotype of *Prediscosphaera columnata* (Fig. 4; Supplementary data, no. 2). The presence of all the biozones described by BOWN *et al.* (1998) characterizing the Albian (BC24 to BC27 zones) suggests that continuous sedimentation took place during this time interval, which contradicts the hypothesis of the hiatus described by KOCHHANN *et al.* (2013). The extinctions of large planktonic foraminifera at the top of the *P. eubejaouensis* Zone are coeval to the *Eiffellithus monechiae* (BC26) Zone, whose base coincides with the beginning of the Late Albian, according to the CGTS2016 (GTS2020 did not indicate the limits of the Albian substages). Thus, once more, while studies with foraminifera classify the interval as Aptian, calcareous nannofossils point to an Albian age.

As commented before, since 1990, the cored section of the 3-BO-3-RJS well has become the biochronostratigraphic reference for the basins of the southeastern margin of the CSA for studies on associations of planktonic foraminifers, calcareous nannofossils, pithonellids. As it could not be otherwise, there was object of studies by TEDESCHI *et al.* (2017) and SANJINÉS *et al.* (2022). TEDESCHI *et al.* (2017) were the first to propose a zonation scheme following the taxonomic-phylogenetic criteria of HUBER and LECKIE (2011) for a well drilled on the Brazilian margin. Based on the presence of the *Globigerinelloides ferreolensis*-*G. algerianus* zones, these authors dated a major part of a thick interval recovered from core CB-3 (the nickname adopted by TEDESCHI *et al.*, 2017, and AZEVEDO, 2001, to 3-BO-3-RJS) as late Aptian (Fig. 5). Below this, the presence of *Favusella* ex. gr. *washitensis* and *Lenticulina* ex. gr. *nodosa* was considered as indicative of an Aptian age or older. Lacking marker species for the uppermost part of the well, TEDESCHI *et al.* (2017) used isotopic correlations to attribute an Aptian age to almost the entirety of these post-salt carbonates.



SANJINÉS *et al.* (2022) analyzed this section, which they designated as CB-01 [*], in great detail (Fig. 5), where they described an association of planktonic foraminifera, reproducing what they observed in a wide set of wells in the Santos, Campos, and Espírito Santo basins. Above the salt, following an unspecified interval, they identified the *Globigerinelloides ferreolensis*-*G. algerianus* and *Hedbergella infracretacea*-*Paraticinella rohri* composite zones, formally defined by the LOs of these species or of coeval species (Fig. 5). The top of both zones are located in the uppermost section of the post-salt carbonates, characterized by the dominance of pelagic and hemipelagic sediments that until then were exclusively associated with the Upper Albian. In the stratigraphic charts of the Santos and Campos basins, these rocks comprise the Itanhaém and Outeiro formations, respectively (MOREIRA *et al.*, 2007; WINTER *et al.*, 2007).

According to SANJINÉS *et al.* (2022), a mixed Aptian-Albian fauna was registered "immediately above the Aptian section that could be related to rework[ing] or, eventually, misidentification. Depending on new research or integrations with [other] (bio)stratigraphic methods, it could represent an unconformity or even a condensed section. Due to this undetermined interval, the *P. rohri* Zone is probably not complete, and the Lower-Middle Albian biozones were not characterized". Therefore, to date, the species that define the *Microhedbergella miniglobularis* and *Microhedbergella renilaevensis* zones have not been recorded in the southeastern basins of the CSA. This regional unconformity, which would compartmentalize the K70 Sequence encompassing these fine carbonates, has not been recognized in the stratigraphic charts of the Santos and Campos basins (MOREIRA *et al.*, 2007, and WINTER *et al.*, 2007, respectively).

As in CARON (1978), DUPONT (1996), and KOCH-HANN *et al.* (2013), the paper by SANJINÉS *et al.* (2022) records a high number of species classified as *conferatum* (cf.), *affinis* (aff.) or doubtful (?). This supports the idea that perhaps conditions in the primitive CSA, a restricted sea with lagoonal circulation (AZEVEDO, 2001, 2004) favors morphological variation and greater longevity for the species that came to occupy that environmental niche. At any rate, SANJINÉS *et al.*'s (*op cit.*) observation of coexisting species having seemingly incompatible ranges in core samples from CB-01 (=3-BO-3-RJS), such as *Hedbergella tuschepensis* or *H. mitra* versus *H. gorbacikae* or *H. trochoidea*, attests to the potential that CSA sections hold for contributing to the improvement of the geological range of many planktonic foraminifera.

It is important to mention the remarkable discovery of a planktonic foraminifera assemblage in the Romualdo Formation at the Sobradinho Site, Araripe Basin (MELO *et al.*, 2020), a Cretaceous *Konservat-Lagerstätten* [**] (Figs. 1-2, 6). The Romualdo Formation overlies thin evaporites of the Ipubi Formation related to the thick salt packets of the Ibura Event (ASMUS & CAMPOS, 1983; AS-SINE, 2007).

At the Sobradinho Site, almost all species have their LOs associated with the late Aptian *Paraticinella rohri* Zone. However, MELO *et al.* (2020) identified *Microhedbergella miniglobularis* in the assemblages, a species ranging from latest Aptian to Early Albian. This creates a paradox, considering that in the GSSP-Alb, *M. miniglobularis* does not coexist with *P. rohri* and other large species whose LOs define the *P. rohri* Zone (Fig. 3). Reworking and redeposition of these large foraminifera into a younger stratigraphic level may explain this observation. This, however, is unlikely, given the anoxic/dysoxic environment, not the least propitious to sedimentary remobilization, in which these planktonic fossils were deposited. Alternatively, the FO of *M. miniglobularis* may well appear earlier at Sobradinho than indicated in the GSSP-Alb. The fact that this same stratigraphic inversion is also recorded at Site 511 (HUBER & LECKIE, 2011) and Poggio le Guaine, Italy (COCCIONI *et al.*, 2014) is coherent with this interpretation.

MELO *et al.* (2020) found *M. miniglobularis* in great abundance at the Sobradinho Site, even though their illustrations do not allow for indisputable differentiation from other, older taxa, for example, the Praehedbergellidae. In this respect, it is important to note that *Praehedbergella* and *Microhedbergella* are considered as parts of a distantly related homeomorphic lineage. Furthermore, Sobradinho specimens are larger than expected for *M. miniglobularis* and exhibit great morphological affinity to *Praehedbergella tatinæ*, whose last occurrence was near the end of the Aptian (BANNER & DESAI, 1988). Therefore, in the present study, we consider the entire planktonic foraminifera assemblage described by MELO *et al.* (2020) at the Sobradinho Site as belonging to the *Paraticinella rohri* Zone.

Another important study has been carried out in core section SER-03 in the onshore portion of the Sergipe Basin (FAUTH *et al.*, 2022). For the first time in the CSA, FO of *Microhedbergella renilaevensis* is indicated accompanied by an ideal succession of Lower Albian planktonic foraminifera—the FOs of *M. rischi*, *Ticinella madecassiana*, and *T. primula*. Below the *M. renilaevensis* datum, there is an interval with low $\delta^{13}\text{C}_{\text{carb}}$ values preceded by a strong positive excursion, where occurs the FO of *Prediscosphaera columnata*? (subcircular).

[*] This deduction was possible because the sections designated as CB-3 by AZEVEDO (2001) and TEDESCHI *et al.* (2017) and Cb-01 by SANJINÉS *et al.* (2022) comprise a continuous core, the interval of which is similar to 3-BO-3-RJS, the original name of this well when drilled.

[**] The term *Konservat-Lagerstätten* was coined by A. SEILACHER, in 1970, to deposits known for the exceptional preservation of fossilized organisms or traces (<https://en.wikipedia.org/wiki/Lagerstätte>, accessed: 2022/11/15).



FAUTH *et al.* (2022) also described the FOs of *Braarudosphaera batilliformis*, *B. africana*, *B. regularis*, and *B. pseudobatilliformis*, and *Nannococonus quadriangulus apertus*, *N. quadriangulus quadriangulus* and *N. troelsenii* below to the *M. renilaevensis* datum.

FAUTH *et al.* (2022) indicated an age of latest Aptian to Early Albian for the SER-03 section, based on astronomical cyclicity analysis, using these planktonic foraminifera and calcareous nannofossils as references for time calibration. Furthermore, we were not identified any exclusive Aptian planktonic foraminiferal taxon below FO of *M. renilaevensis*.

The list of species of other fossil groups that have their LOs close to the Aptian-Albian boundary presented by LIMA *et al.* (2018) created new controversies. The calcareous nannofossils *Braarudosphaera batilliformis*, *B. pseudobatilliformis*, and *Nannoconus troelsenii*, considered to be restricted to the Aptian by ALVES *et al.* (2017), were observed in Albian strata at Site 364 (BRUNO *et al.*, 2020) and in the SER-03 section FAUTH *et al.* (2022). Without detailing their stratigraphic positions, ALVES *et al.* (*op cit.*) also reported the presence of *Nannoconus bucheri*, *N. circularis*, *N. globulus*, *Micrantholithus hoschulzii*, and *Rhagodiscus achylostaurion*, all of which, except for the last, have amplitudes not extending beyond the Aptian (YOUNG *et al.*, 2022a). Likewise, other species considered Aptian by LIMA *et al.* (2018) also reach the Albian, such as *Colomiella recta* and *C. mexicana* and the crinoid *Microcalamoides diversus* (DIAS-BRITO, 1995, 1999; DIAS-BRITO & FERRE, 2001; LEÓN-FRANCISCO *et al.*, 2013; MADHAVARAJU *et al.*, 2013; FEKETE *et al.*, 2017). Additional taxa with poorly defined ranges were also added to this list (e.g., *Cadosina ex gr. semiradiata*, and *Colomisphaera heliosphaera* (YOUNG *et al.*, 2022a; <https://paleobotany.ru/> accessed: 2022/12/06).

4.1.2. Palynomorphs

Pollen, spores, dinoflagellate cysts, and other palynomorphs are all found in strata of local Alagoas age, which are tentatively correlated with the late Aptian-Early Albian interval (e.g., SCHALLER, 1969; ANTUNES *et al.*, 2018). These deposits are transition from a continental to a marine environment in the CSA, ESA, and BNE basins. The palynozones subdividing the sedimentary record of this period in the inner Brazilian basins and in the marginal basins of northeastern and equatorial Brazil are distinct from those of the marginal basins of southeastern and eastern Brazil. REGALI & VIANA (1989), ARAI *et al.* (1989), DINO *et al.* (1999), and AZEVEDO (2001) provide a summary of this discussion, including information on basins from the African margin.

The most relevant taxa for correlations and for attempts to delineate the Aptian-Albian boundary

are elaterite pollen (particularly *Elateropollenites jardinei*), the gymnosperm pollen *Sergipea variverrucata*, and the dinoflagellates that make up the *Subtilisphaera* spp. ecozone.

Elaterite pollen first appeared at the end of the Aptian and became widely dispersed during the Albian (DINO *et al.*, 1999). *E. jardinei* is the taxon the range of which is best calibrated with international chronostratigraphy; its FO has been observed in South American and African basins postdating the beginning of the Albian (ATTA-PETERS, 2013). As discussed by DIAS-BRITO *et al.* (1987), *E. jardinei* is not mentioned among the palynomorphs in the type-section of the local Alagoas stage, which was defined in a subsurface section of the Sergipe Basin (SCHALLER, 1969).

The LO of *Sergipea variverrucata*, an endemic species described by REGALI *et al.* (1974), marks the top of the zone of the same name that makes up part of the Alagoas stage. For REGALI and VIANA (1989), this bioevent occurred in the late Aptian and was followed, upwards, by the FO of *E. jardinei* and *Cretaceiporites polygonalis*, which mark the beginning of the Albian. ARAI *et al.* (1989), in a different interpretation, place the LO of *S. variverrucata* at the Aptian-Albian boundary. Above this horizon, the FO of *E. jardinei* would already lie within Lower Albian strata.

The correlation of *S. variverrucata* with planktonic foraminifera in marine deposits of the Sergipe Basin (KOUTSOUKOS, 1989) allowed it to be associated with the later portion of the Aptian (REGALI & SILVA SANTOS, 1999). Nevertheless, the recent identification of the *Paraticinella rohri* Zone at the Sobradinho Site, Araripe Basin (MELO *et al.*, 2020), impacts the interpretations of REGALI and VIANA (1989) and reinforces the chronostratigraphic solution proposed by ARAI *et al.* (1989). As demonstrated by ARAI and ASSINE (2020), at Sobradinho *S. variverrucata* extends above the limit of the *P. rohri* Zone (Fig. 6), noting that this biostratigraphic unit occurs shortly before the FO of *Microhedbergella renilaevensis*, the GSSP-Alb datum.

The *Subtilisphaera* spp. ecozone was first described in the Ceará Basin by REGALI (1989) and is notable for the high number of cysts it contains members of this dinoflagellate genus. The rocks containing these cysts were considered late Aptian in age. Since then, this ecozone has been observed in many other basins, particularly in the BNE, including as far south as the Aptian-Albian of the Espírito Santo Basin (MICHELS *et al.*, 2018). This evidence of dinoflagellate blooms lies either directly upon or slightly above the Ibura evaporites, although in some basins, *Subtilisphaera* spp. blooms are also noted in younger, Albian strata (ARAI, 2009, 2014; CARVALHO *et al.*, 2016; MICHELS *et al.*, 2018). This ecozone has also been found in Senegal, Morocco, and Venezuela (ARAI, 2014, and papers cited therein).

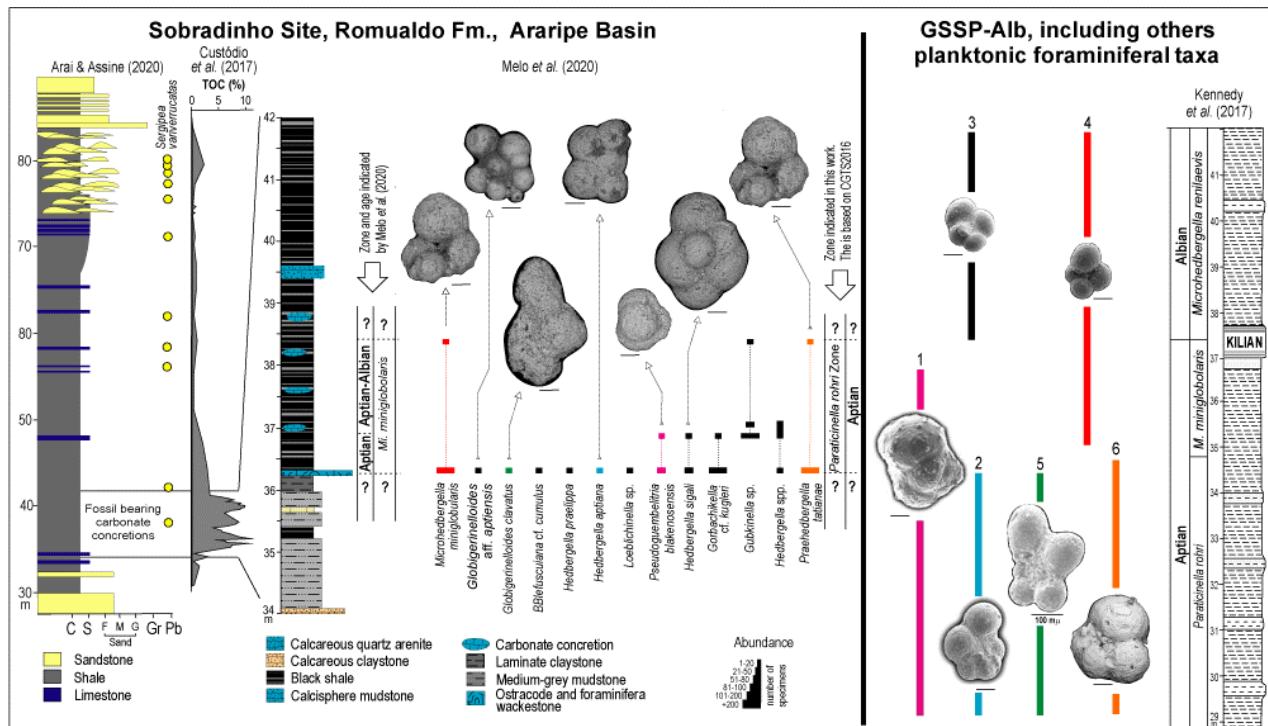


Figure 6: Stratigraphic data for the Romualdo Formation, Sobradinho Site, Araripe Basin, and for Col de Pré Guitard, GSSP-Alb, with modifications. For the Araripe Basin are displayed the range of *Sergipea variverrucata* (ARAI & ASSINE, 2020), the TOC profile (CUSTÓDIO *et al.*, 2017), and the planktonic foraminifera succession (MELO *et al.*, 2020). For GSSP-Alb are shown some of the planktonic foraminifera registered by KENNEDY *et al.*, 2014): *Pseudoguembelitria blakenensis* (1), *Hedbergella aptiana* (2), *Microhedbergella renilaevius* (3) and *M. miniglobularis* (4). The ranges of the taxa *Globigerinelloides clavatus* (5) and *Praehedbergella tatianae* (6) are from the Mikrotax Catalogue (URL: <https://mikrotax.org/pforams/index.php?id=110128>, accessed: 2021/01/31) and BANNER and DESAI (1988), respectively. The scale bar = 30 µm, except for *G. clavatus*, which represents 100 µm. To the right, in the central column, the specimen classified as *M. miniglobularis* by MELO *et al.* (2020) is represented under the taxonomic designation *H. tatianae*.

These anomalous, episodic *Subtilisphaera* blooms have been associated with restricted shallow marine and mixohaline environments (e.g., REGALI, 1989; ARAI *et al.*, 1994; CARVALHO *et al.*, 2016; HELMOND *et al.*, 2014). According to CARVALHO *et al.* (2016), the phenomenon would have been related to a "humid period, increased freshwater input, a high rate of nutrient supply, and the formation of a pycnocline separating slightly less saline surface waters from higher saline deeper waters. These conditions would have impeded vertical circulation". In the drill cores from the Sergipe Basin studied by these authors, the two intervals in which *Subtilisphaera* dominate exhibits moderate to high ratios of amorphous organic matter versus phytoclasts, particularly the older one, which led these authors to associate these conditions with restricted marine environments and reduced terrigenous influence.

This accords well with the occurrence of the *Subtilisphaera* ecozone immediately or slightly above the evaporitic layers. Hence, it can be considered a good marker for the end of the evaporite event apparently caused by the arrival of lower salinity waters carrying the nutrients that allowed these dinoflagellate blooms and led to stratification of the water body. Therefore, more than just representing an environmental anomaly, this ecozone also has chronostratigraphic value for not

only basins in the CSA, ESA, and BNE, but, potentially, for basins on the margins of southern Tethys as well.

In the basins of the eastern and southeastern Brazilian margins, other palynomorphs subdivide the post-salt carbonate section and the overlying marls and shales. These are the classic biozones *Cyclopsiella* sp. (Early-Middle Albian), *Hystrichosphaeridium maranhensis* and Din D/Din H (Late Albian), and *Classopollis major* (Cenomanian), all defined by the LO of their respective homonyms. Their stratigraphic positions were indicated by considering the well-defined ranges of other fossil groups observed in the cored section of 3-BO-3-RJS (UESUGUI, 1976, *fide* ARAI, 1992; DIAS-BRITO *et al.*, 1990; DIAS-BRITO, 1995; ARAI *et al.*, 1996; AZEVEDO, 2001). Palynological analyses made by MORGAN (1978) at Site 364 also contributed to establishing the age of these post-salt limestones as Albian (Fig. 4).

Therefore, with current palynological knowledge it is not possible to assert with certainty that marine Aptian strata are present above the evaporites on both margins of the meridian portion of the CSA, ESA, and BNE. Inferences of an Aptian age for the post-salt limestones are mainly a corollary of the correlation between palynozones and the planktonic foraminiferal biounits identified by KOUTSOUKOS (1989). Thus, palyno-



morphs are inserted as coadjuvants within the controversies regarding the chronostratigraphic attributions of these protists and other fossil groups that have internationally recognized ranges.

4.2. Lithological units and absolute dating as markers for the base of the Albian

The option of indicating lithological horizons to define chronostratigraphic boundaries is incorporated in the North American Commission on Stratigraphic Nomenclature - NASC (2005). A relevant example of here is the KILIAN Level, an organic-rich shale comprising the main lithological datum associated with the GSPP-Alb (Fig. 3).

According to TISSOT *et al.* (1980), HERBIN *et al.* (1987), and BEGLINGER *et al.* (2012), there is but a single notable organic-rich layer in the basins of the CSA, ESA, and BNE. Exceptions to this occur in the Sergipe-Alagoas, Gabon, and Kwanza basins, where other similar layers have been identified in the Albian (BEGLINGER, *op cit.*). At Site 364, Kwanza Basin, the most organic-rich layer, with more than 20% Total Organic Carbon (TOC), occurs in the lower portion of the drill core, where black shales intercalated with dolomites overlie the Ibura evaporites (Fig. 4). TOC values greater than 2% are found in recurring layers in the overlying first 50 meters, above which TOC values become extremely low throughout the Albian (KUMAR *et al.*, 1977; AZEVEDO, 2001; BRUNO *et al.*, 2020). In the Campos and Santos basins, rocks with TOC values greater than 2% in the post-salt limestones are rare, other than those that immediately overlying the Ibura salts (AZEVEDO, 2001).

For chronocorrelation purposes, the most efficient lithological datum for basins in the CSA, ESA, and BNE is the base of the Ibura Event (Fig. 2). The age indicated for this stratigraphic horizon is related to the definition of the Curumim Formation, Pelotas Basin (DIAS *et al.*, 1994). This lithostratigraphic unit is formed by trachyandesites, covered discordantly by both Portobelo carbonates and Ariri evaporites (Figs. 2, 7). Its type-section is in the 1-SCS-2 well. These volcanic rocks are attributed to the Alagoas Stage on the basis of Ar/Ar dating of a sample from the 1-SCS-1 well at the northern end of the Pelotas Basin (MIZUSAKI, 1993, *fide* DIAS *et al.*, 1994). In both 1-SCS-1 and 1-SCS-2, there is no salt layer, and the Portobelo carbonates cover the volcanics discordantly. The complete stratigraphic succession defining the stratigraphic relationships between the three lithological units occurs in well 1-SCS-3B, chosen by DIAS *et al.* (1994) as type-sections for the Ariri (evaporites) and Portobelo (carbonates) formations. This succession is covered by fine-grained sediments exhibiting a greater terrigenous influence that defines the Atlântida Formation, chronoequivalent to pelagic and hemipelagic carbonates in which SANJINÉS *et al.* (2022) recorded the diverse fauna of planktonic foraminifera assigned to the Aptian in the Santos, Campos, and Espírito Santo basins.

DEMERCIAN (1996) showed that both the evaporitic and carbonate layers thin towards the volcanic high on the southern edge of the São Paulo Plateau and its extension to the continent, the Florianópolis High. Based on this, DIAS (1998) pointed out the onlap character of the base of the evaporitic package onto the volcanic high making up the SAMB, even noting the difficulty of seismic resolution in layers of anhydrite, more frequent in the limits of the occurrence of the salt over the Florianópolis High. Although lacking direct evidence, this information contains the basic elements that led DIAS (1998) to estimate an age for evaporite deposition between 113 and 112 Ma, a little younger than that of the trachyandesite in 1-SCS-1-SC. In 2007, Petrobras updated the stratigraphic maps of all Brazilian basins, establishing the age obtained by MIZUSAKI (1993, *fide* DIAS *et al.*, 1994) and published by DIAS *et al.* (1994) as a geochronological reference for the salt base in the CSA basins (e.g., BUENO *et al.*, 2007; FRANÇA *et al.*, 2007; MOREIRA *et al.*, 2007; WINTER *et al.*, 2007).

SZATMARI and MILANI (2016) describe the particularities and succession of Pre-Salt volcanic events in the offshore portion of the basins of the southeast margin of the CSA (Fig. 7). They cite an age of 115.7 ± 1 Ma obtained by the Ar-Ar method for a thick basalt flood sampled in the Santos Basin (GOMES *et al.*, 2016 - Petrobras Internal Report). Keeping in mind the limited number of radiometric age determinations, SZATMARI and MILANI (2016) proposed that "volcanic activity in the CSA, as in the North Atlantic (KEEN *et al.*, 2012), started almost simultaneously, about 10 Ma after the start of the rifting process; it peaked at about 135 to 130 Ma, and continued alternating with sedimentation until about 113 Ma, shortly before the beginning of the salt deposition". Recently, SZATMARI *et al.* (2021) reaffirmed the 113 Ma Ar-Ar age for the volcanic rocks below the evaporites of the Santos Basin. However, they also report a 110.64 ± 0.34 Ma age for an intra-salt unconformity at the carnallite/sylvinitic contact in the Sergipe Basin, suggesting that salt deposition took longer than previously thought. Figure 8 shows the stacking of some of these volcanic events identified in deep water wells drilled in the Santos and Campos basins.

LAWSON *et al.* (2022) recently offered further geochronological elements favoring an age assignment of 113 Ma to the base of the salt. Although focusing on the Pre-Salt carbonates (Barra Velha Fm, Santos Basin), these authors provide a good review of the complexity involved in dating the evaporites that cover them. They register that one "of the main challenges in developing a robust understanding of these basins is the total absence of reliable time markers to place any environmental constraints into temporal context. This has led to significant uncertainty on the age of key sequences within the stratigraphy. The Ariri Formation that represents the Santos Basin equiv-

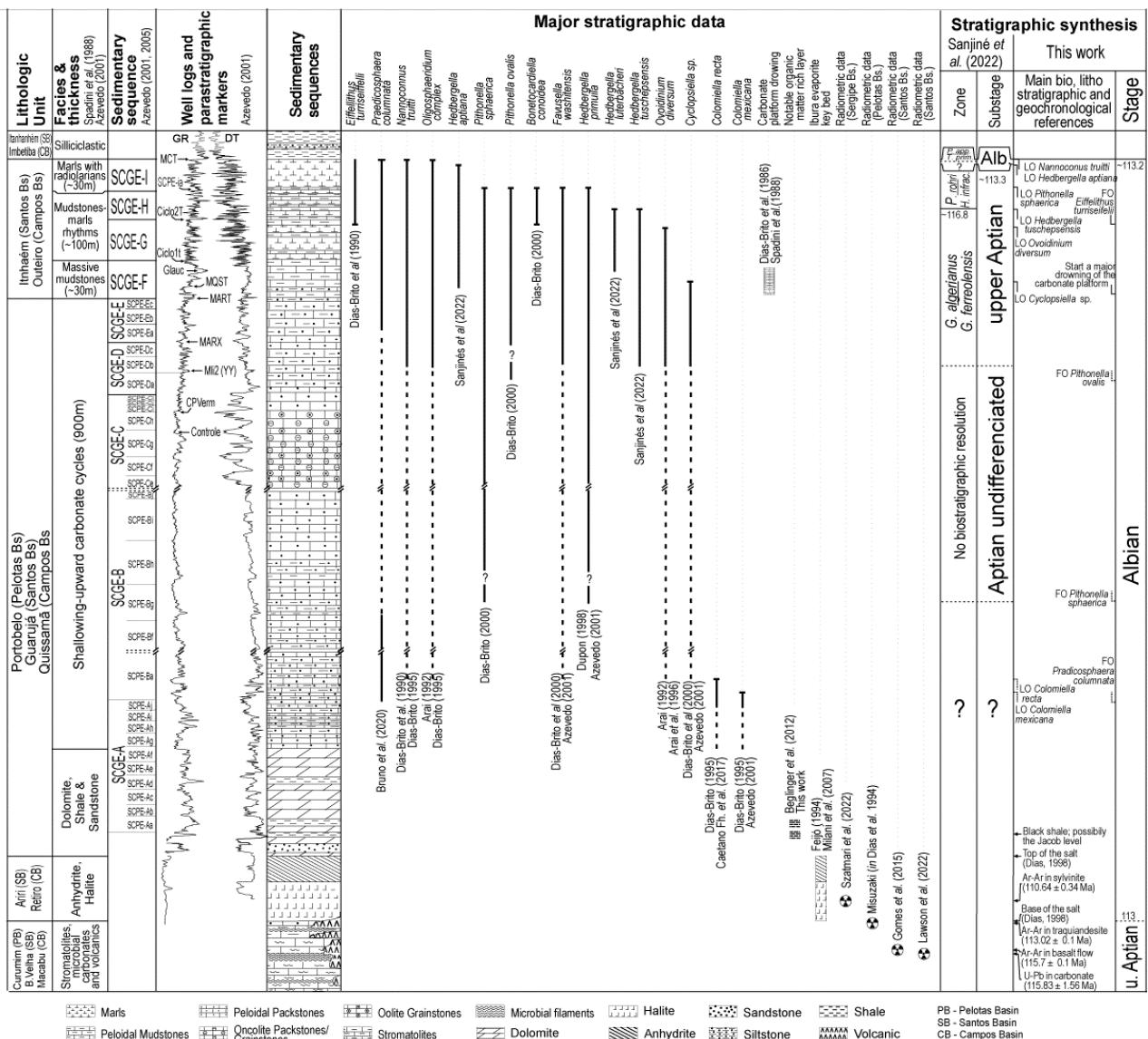


Figure 7: Schematic stacking of sedimentary succession and other geological parameters with respect to the Pelotas, Santos, Campos and Kwanza basins. The most relevant stratigraphic data justify the discrepancies between the solution proposed by SANJINÉS *et al.* (2022) and the one offered in this work. 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 para-stratigraphic data are from AZEVEDO (2001) and the ages from CGTS2020.

alent of the regional evaporite sequence, for example, has been proposed to be as young as 111 Ma based on an Ar-Ar age of sylvinites of 110.64 ± 0.3 Ma from the Sergipe Basin (SZATMARI *et al.*, 2021). Further, evaporites unconformably overlying volcanic rocks dated to 113.2 ± 0.1 Ma in the northern Pelotas Basin (DIAS *et al.*, 1994; DAVISON, 2007). However, biostratigraphic data from the DSDP Site 364 suggest that the first marine deposition above these evaporites occurred during the late Aptian prior to 113 Ma (KOCHHANN *et al.*, 2013). This has been further supported by the study of SANJINÉS *et al.* (2022), who also report upper Aptian aged fauna in the stratigraphy immediately overlying the evaporites in numerous wells within the Santos, Campos, and Espírito Santo basins offshore Brazil. Alternatively, these evaporites have been proposed to be as old as 120-125 Ma and associated with the Aptian Ocean Anoxic Event (OAE) 1a (TEDESCHI *et al.*, 2017)".

Lawson *et al.* (2022) conclude that we "have constrained the depositional age of the upper Barra Velha Fm to be 115.83 ± 1.56 Ma through isotope dilution U-Pb dating. This age is consistent with overlapping laser ablation U-Pb ages of 114.46 ± 4.72 Ma and 109.73 ± 9.26 Ma from two separate carbonate platforms in the Santos Basin". These values would rule out in advance the age indication proposed by Tedeschi *et al.* (2017) for the evaporitic layer, of the order of 120 to 125 Ma, fundamentally supported by isotopic correlation. Considering the margin of error, the age of 115.83 ± 1.56 Ma for the sediments of the upper portion of the Pre-Salt carbonates, but not their top, is more compatible with the 113.2 ± 0.1 Ma measured in the trachyandesite of the 1-SCS-1 than the value of 116.8 Ma (according to GTS2020) of the top of the *Globigerinelloides ferreolensis-Globigerinelloides algerianus* composite biozone (Sanjinés *et al.*, 2022). The top of this

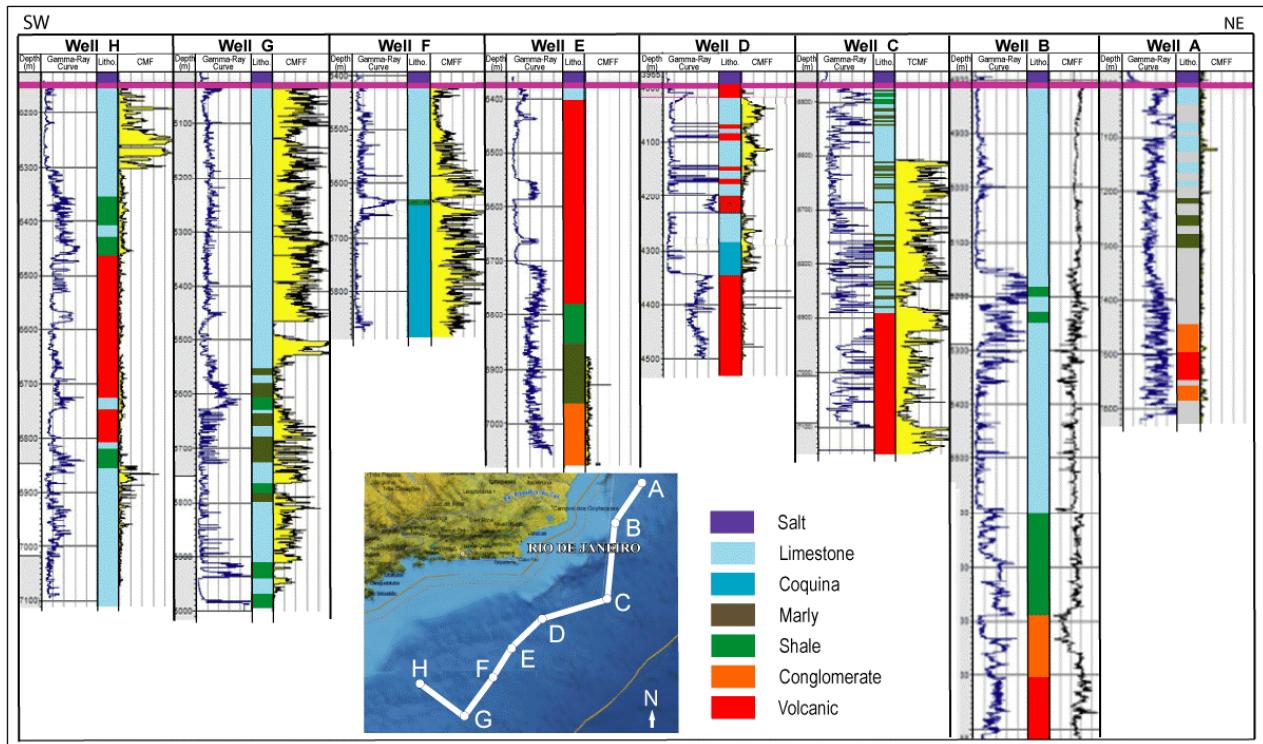


Figure 8: Well section illustrating the Pre-Salt reservoir from the Campos and Santos basins. Well D is notable for the presence of a volcanic layer overlain by the Ibura Event (modified from MATIAS *et al.*, 2015).

biozone is almost 1,000 m above the evaporite layer and it is estimating a time interval of the order of 6 Ma among these horizons. This value considers the minimum time suggested for deposition of the salt bed (~0.5 Ma, according to RODRIGUES *et al.*, 2018) as well as the 5.5 Ma attributed to 55 short eccentricity cycles (~100 ka each one) recognized by AZEVEDO (2001, 2005) in the Quissamã Formation (41 cycles) and Outeiro Formation (14 cycles) in well 1-RJS-135, type-section of the Macaé carbonates in the Campos Basin (RANGEL *et al.*, 1984; Fig. 7).

Despite controversies over the age of the salt, the unique character of the Ibura evaporite led ANTUNES *et al.* (2018) suggest using the base of the salt as the datum to the Aptian-Albian transition for the CSA basins. It is arguably one of the most notorious lithological data in these basins, deposited over a short period of time with its base onlapping upon trachyandesite sampled in the SAMB, dated at 113.2 ± 0.1 Ma. As already shown, support also comes from biostratigraphic successions involving other groups of fossils, such as pelagic calcispheres and calcareous nannofossils, which attest to the Albian age for post-salt carbonates. The recognition at Site 364 of the FO of *Prediscosphaera columnata* (circular) just above the salt and black shale layer permits associating these organic-rich accumulations with the JACOB Level, which by this interpretation would also be Early Albian age. It is always worth recalling that *Prediscosphaera columnata* was for a long time considered as a potential marker to define the base of the Albian.

An important additional argument derives from the fact that sea level remained low with only

small-magnitude oscillations for almost 20 Myr, from the late Barremian to the late Aptian (HAQ, 2014). At the end of the Albian this changed as the sea level rose rapidly to reach its apex, an episode of global eustatic elevation represented in CSA by the fine sediments in the upper portion of the post-salt carbonates, traditionally related to Late Albian in age (e.g., DIAS-BRITO & AZEVEDO, 1986; SPADINI *et al.*, 1988; SPADINI & PRAÇA, 1989; SPADINI, 1992).

5. Discussion

Figure 7 shows a schematic sedimentary succession with the major data that justify the two quite different chronostratigraphic interpretations. Information on the evaporitic package and the carbonate section comes from the 1-RJS-135 well and is complemented by data from sections in the Pelotas, Santos, Campos, and Kwanza basins.

The papers by TEDESCHI *et al.* (2017) and SANJINÉS *et al.* (2022) show that, unlike previous thinking, it is not just the lower part of the post-salt carbonate section, but practically the entire section that would be Aptian in age according to more recent international biochronostratigraphic charts and GSSP-Alb criteria. In this scenario, only a thin Upper Albian section would have been preserved in the southeastern part of the CSA. Yet, even if doubts about the presence of putative Aptian planktonic foraminifera and even ammonites (according to the GSSP-Alb criteria) in the CSA, ESA, and BNE basins, are overcome, other new ones present themselves. For example, how does one explain the subversion in the successions of different fossil groups, or even among LO's of species of the same group, as in the case



of the planktonic foraminifera? Or, the "incompatible" radiometric ages obtained by MIZUSAKI (1993, *fide* DIAS *et al.*, 1994), SZATMARI *et al.* (2021) and LAWSON *et al.* (2022)? Some speculative answers might include bioprovincialism in the South Atlantic; or an inappropriately old age indication for the GSSP-Alb, where a younger value should be considered? It is more important for the moment, however, to know if these "stratigraphic anomalies" also occur elsewhere on the globe.

Analysis of 16 sedimentary sections from different regions of the world [Only papers showing sections with the planktonic foraminifera reviewed according to the taxonomic and phylogenetic revisions of HUBER and LECKIE (2011) were considered] allowed us to observe and evaluate relationships between biostratigraphic, chemostratigraphic and lithologic data regarding the latest Aptian-Early Albian (Fig. 9). The stratigraphic reference used for the dataset was the FO of *Microhedbergella renilaevis*, as well as, whenever possible, the position of the other events indicated in the GTS 2020. Among these, the LOs of large planktonic foraminifera (~*Paraticinella rohri* Zone), indicative of the last portion of the Aptian, deserves to be highlighted. When conflicting geological information presented itself, biostratigraphic references were chosen to define stratigraphic positioning rather than other data, such as black shale beds or carbon isotope events. Supplementary data inform the stratigraphic position and the studies supporting the succession in each section in Figure 9.

The initial aim of indexing the stratigraphic relationships between different datasets was to evaluate the chronostratigraphic consistency of the FO of *Prediscphaera columnata*. Throughout the development of the numerous Geologic Time Scales (from the 90s to GTS2012), the FO of this species was always considered relevant, either as a secondary datum, or as a reference to informally define the Aptian-Albian boundary. After BOWN (*in* KENNEDY *et al.*, 2000) showed that *P. columnata* consisted of elliptical-subcircular, subcircular, and circular morphological categories, the idea that its FO was diachronous became the norm. The erratic distribution of these morphotypes points to the high degree of subjectivity in this taxonomic option, with a strong impact on biochronostratigraphic interpretations. Not even in neighboring outcrops, such as those in European sections (Fig. 9, columns 3-7), can the synchronicity that was once attributed to the FO of *P. columnata* be observed (e.g., BRÉHÉRET *et al.*, 1986; HART *et al.*, 1996; OWEN, 2002; OGG *et al.*, 2004, 2012).

On the other hand, if one groups these three morphotypes into one taxon, *Prediscphaera columnata* (*sensu lato*), it is possible to confirm the value of the FO of this species as a chronostratigraphic datum, present in 11 of the 16 analyzed sections (Fig. 9, columns 4-10, 12-15). This morphotype group is part of the *P. spinosa*-*P. columnata* s.l. plexus, which has a wide, global distribution, with the FOs of these taxa being separated by the

JACOB Level, as recognized in the GSSP-Alb (e.g., HERRLE & MUTTERLOSE, 2003; KENNEDY *et al.*, 2017). *P. columnata* s.l. is found outside of this stratigraphic level only at Site 463 (Fig. 9, column 1) and Vöhrum (Fig. 9, column 3). In the composite section for the southeastern Brazilian margin (Fig. 9, column 16), it was recorded in well-core samples that recovered just part of the Albian, which did not allow precise identification of its full stratigraphic range (DIAS-BRITO *et al.*, 1990; ANTUNES, 1996; Fig. 5). A hiatus prevents the analysis of the FO of *P. columnata* s.l. at Site 763B, from the Ocean Drilling Program, ODP (Fig. 9, column 2), and there is no information about calcareous nannofossils for the Linderos section (Fig. 9, column 11).

Worthy of note are the FOs of *P. columnata* s.l. in the Vöhrum outcrop (Germany), in the composite section of the Vocontian Basin (France), in the Agadir-Essaouira Basin (Morocco), and at sites 463 (Pacific) and 364 (CSA). At Site 463 (Fig. 9, column 1) and in Vöhrum (Fig. 9, column 3), *P. columnata* s.l. occurs at later stratigraphic levels than expected. The Vöhrum outcrop was a candidate reference-section for the base of the Albian Stage (OWEN, 2002). It has an ash layer dated as 113.1 ± 0.3 Ma (SELBY *et al.*, 2009) that is today used to mark the beginning of the Albian in the GSSP-Alb. MUTTERLOSE *et al.* (2003) identified the FO of *P. columnata* s.l. a few centimeters above this tuff, which defines its position in Figure 9. It occurs in an assemblage containing few specimens, amid the low specific diversity of calcareous nannofossils in the Boreal region.

In the composite section for the Vocontian Basin described by HERRLE & MUTTERLOSE (2003), the only *P. columnata* morphotype identified is circular and occurs slightly above the JACOB Level (Fig. 9, column 6). Its stratigraphic position is distinct from those described by KENNEDY *et al.* (2000) and KENNEDY *et al.* (2014) for the Col de Pré Guittard (Fig. 9, columns 5-7). In the Moroccan sections (Fig. 9, column 8), HASSANEIN (2016) did not observe any stratigraphic ordering between the FOs of the *P. columnata* s.l. varieties as described by BOWN (*in* KENNEDY *et al.*, 2000). Finally, as already mentioned, BRUNO *et al.* (2020) found the circular morphotype of this species in Core 42, Site 364, not much more than dozens meters above the inferred salt layer for the area (Fig. 9, column 14). Towards the top of the section are the FOs of *H. albiensis*, *T. orionatus*, *A. biramiculatus*, *E. monechiae*, and *E. turrieffelli*, which perfectly follows the characteristic stratigraphic succession of calcareous nannofossil data for the Albian (BOWN *et al.*, 1998). Except the FO *E. turrieffelli*, the other ones bioevents occur beneath the LO of the large planktonic foraminifera considered as being a reference for the upper portion of the Aptian (CGTS2020), thereby conflicting with the standard established for the GSSP-Alb (Figs. 3-4, 9).

This striking biochronostratigraphic discrepancy appears to extend far beyond Site 364, with *Hayesites albiensis*, *Tranolithus orionatus*, *Axopo-*



dorhabdus biramiculatus, and even *Eiffellithus turriseifelli* occurring below the turnover of large planktonic foraminifera in North Atlantic and South Atlantic sections (Fig. 9, columns 9-10, 13-14). However, in the Pacific, European, Agadir-Essaouira Basin and the Site 511 sections (Fig. 9, columns 2, 4-6, 8, 12) these taxa follow the standard succession and occur above this turnover. As the only exception in the South Atlantic, the succession observed in the 511 confirming the thesis of the isolation of the waters of the CSA in relation to the southernmost waters of this ocean.

This phenomenon needs to be understood. Maybe it points to precocious phylogenetic evolution of the nannoplankton in the CSA, or maybe it can be explained taphonomically, or even by a sampling constrains. It must be considered that the set of North Atlantic and South Atlantic sections used samples that came from deep wells and the European, Agadir-Essaouira Basin sections were studied outcrop samples. However, the presence of *Hayesites albiensis* and *Tranolithus orionatus* at the 763 and 511' drilled sections in their predicted stratigraphic positions in the GTS 2020 rules out a sampling constrains influence and reinforcing the idea that evolutionary or taphonomic particularities should have been the cause of theses biochronostratigraphic regional discrepancies.

The succession of stratigraphic data for the ESA and BNE basins (Fig. 9, column 15) incorporates a lot of information from outcrops, particularly regarding the planktonic foraminifera, palynomorphs, and geochemical information from the Sobradinho Site, Araripe Basin (Fig. 6). The planktonic foraminifera are here interpreted as belonging to the *Paraticinella rohri* Zone and occur in a black shale layer with high TOC values (CUSTÓDIO *et al.*, 2017; MELO *et al.*, 2020), making it chronocorrelative to the JACOB Level. Furthermore, CUNHA & KOUTSOUKOS (1998) associated the FO of *P. columnata s.l.* with the *G. ex gr. maridalensis* - *H. (H.) similis* Zone (KOUTSOUKOS, 1989; KOUTSOUKOS & BENGTSON, 1993), suggesting that this calcareous nannofossil species may have occurred below the LO of the large planktonic foraminifera in Sergipe Basin. In turn, the completed biostratigraphy succession of planktonic foraminifera described by FAUTH *et al.* (2022) in a well also drilled in the Sergipe Basin assures perfect adjustment with the Albian succession shown in the GTS2020.

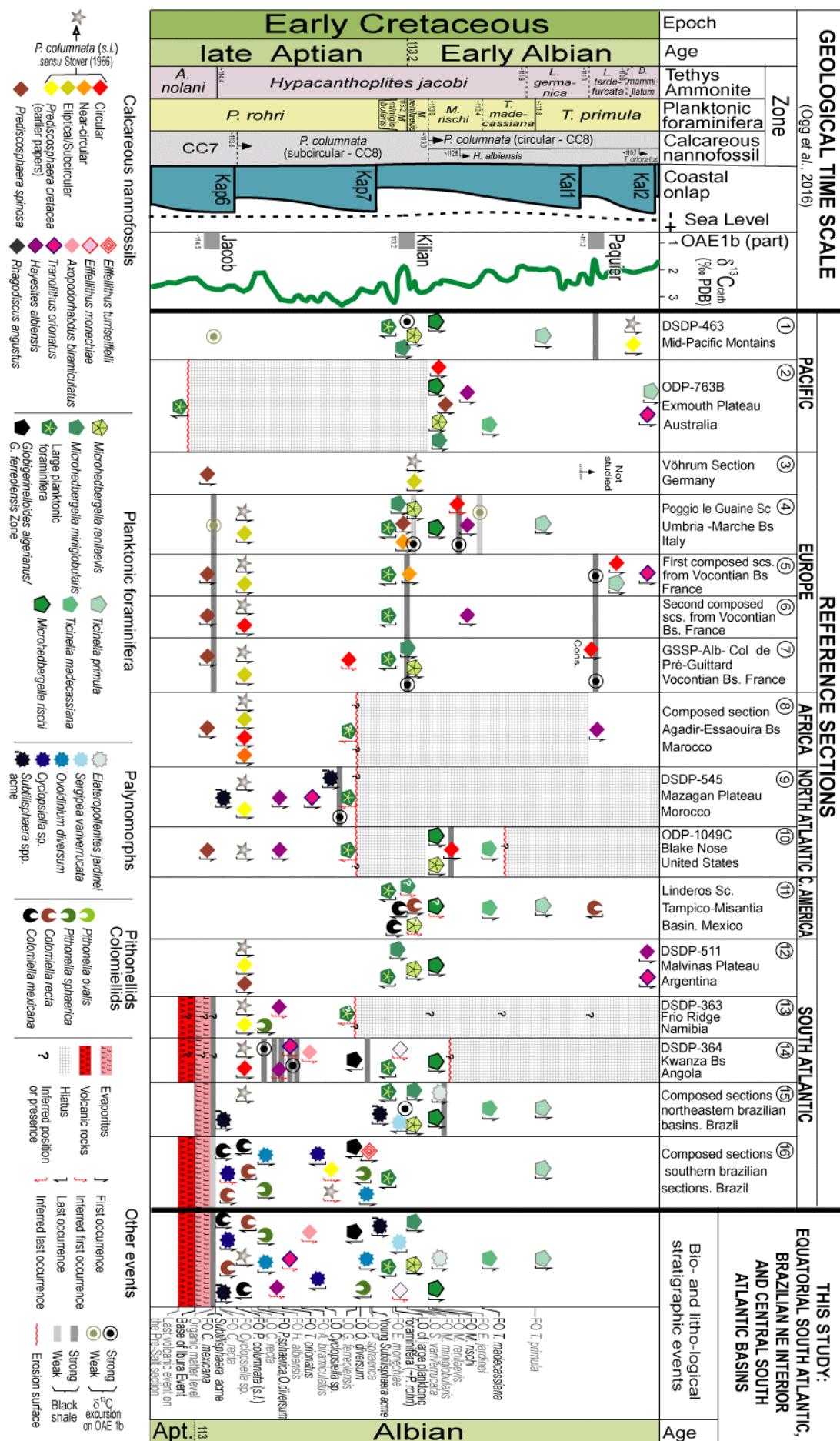
The composite section for the southeastern Brazilian basins (Fig. 9, column 16, and Fig. 7) is based, mainly, on information from drill cores 3-BO-3-RJS from the Campos Basin and 1-SPS-6 from the Santos Basin, the latter of which did not reach the Ibura evaporites. The former provided most information related to the calcareous nannofossils, palynomorphs, and pithonellids, and 1-SPS-6 furnished the data related to the colomeliids (DIAS-BRITO *et al.*, 1990; DIAS-BRITO, 1994,

1995, 1999, 2000). TEDESCHI *et al.* (2017) and SANJINÉS *et al.* (2022) complete the dataset with their reports of large planktonic foraminifera (\sim *Paraticinella rohri*) and species related to *Globigerinelloides algerianus*-*G. ferreolensis* Zone in the CSA's upper portion of the post-salt carbonates.

Microbiofacies analyses carried out on core samples from well 1-SPS-6 by DIAS-BRITO (1994, 1995) demonstrated the similarity between the faunas and floras of the lower portion of the post-salt carbonates of the Guarujá Formation and the Tamaulipas Formation, Mexico. Based on this affinity, DIAS-BRITO (1995) placed the FO of *Colomiella mexicana* in the uppermost portion of the upper Aptian and the FO of *C. recta* at the base of the Lower Albian. These occur at a much lower stratigraphic level than the Itanhaém Formation, where TEDESCHI *et al.* (2017) and SANJINÉS *et al.* (2022) recognized the LO of the large planktonic foraminifera in the southeastern Brazilian basins (Fig. 7). GUTIÉRREZ-PUENTE *et al.* (2021), on the other hand, observed the FO of both *Colomiella* species slightly before the LO of *P. rohri* and in the middle of the *Microhedbergella* Zone, though it bears mentioning that his taxonomic description of the foraminifera was based on thin-sections (Fig. 9, column 11).

The bioevents shown in the right column of figure 9 are based on the calcareous nannofossils, planktonic foraminifera, pithonellids, and colomeliids observed at sites 363 and 364 and in the composite sections of the northeastern and southeastern Brazilian basins (Fig. 9, columns 13-16). Also shown in that column are volcanic events, evaporites, and intercalations between organic shales and dolomites, with the two latter being widespread in the meridional portion of the CSA. Volcanic rocks, the salt and black shales bed are indicated at sites 363 and 364 based on geophysical and geochemical evidence (BOLLI *et al.*, 1978a, 1978b). The last column on the right side of Figure 9 registers the chronostratigraphic proposal put forward in this study, which uses the 113 Ma age for the base of the Albian, coinciding with initiation of the Ibura Event. There were not indicated formal subdivision to Albian Age according to the GTS2020 decision, and because of the difficulty in reconciling established planktonic foraminifera biochronostratigraphic positions with those of calcareous nannofossils.

► **Figure 9:** Biostratigraphic, chemostratigraphic and lithological events for the latest Aptian-Early Albian interval. The columns to the left are from CGTS2020; the ones at the center are the 16 analyzed sections; to the right is an idealized section for the CSA, ESA and BNE encompassing the chronostratigraphic and geochronological limits suggested in this study. The highlighted black shales and $\delta^{13}\text{C}$ excursions are limited to three OAE1b levels; the carbon isotopic data where tentatively differentiated among strong (2‰) and weak (between 1 and 2‰) oscillations. Bibliographic references and reference sections can be found in Supplementary data.





The results obtained from the 16 sections do not support the idea that the KILIAN and PAQUIER layers are chronostratigraphically consistent on a global scale. Besides occurring in Col de Pré-Guitard, organ-rich shales are also present in isolated levels in Teronne outcrops (KENNEDY *et al.*, 2000) and in Tardendol and l'Arboudeysse (HERRLE & MUTTERLOSE, 2003), all within the Vocontian Basin (Fig. 9, columns 5-7). The KILIAN Level was not observed in either Site 463, Vöhrum, and Linderos sections (Fig. 9, columns 1, 3, 11, respectively), or in any of the South Atlantic sections (Fig. 9, columns 12-16). An erosional hiatus does not permit speculation regarding its presence at Site 763B, Agadir-Essaouira, Site 545, Site 1049C, or Site 363 (Fig. 9, columns 2, 8-10, 13).

In Poggio le Guaine, Site 545, Site 1049C, Site 364, and the composite section of Northeastern Brazilian basins (Fig. 9, columns 4, 9-10, 14-15), the occurrence of horizons rich in organic matter are not compatible with the succession of bio-events associated with the KILIAN Level in the GSSP-Alb. In Poggio le Guaine, this organic layer is situated above the FO of *M. renilaevi* (COCCIONI *et al.*, 2014). At Site 1049C and in the composite section of Northeastern Brazilian basins the black shales are located above the FO of *M. rischi*, while at Site 545 these deposits are located below the LO of the large planktonic foraminifer, associated with the *P. rohri* Zone, whose top coincides with an erosional surface (HUBER & LECKIE, 2011; TRABUCHO ALEXANDRE *et al.*, 2010). At the upper section of Site 364, the only horizon with TOC greater than 2% also occurs below the disappearance of these protists (Fig. 4).

The PAQUIER Level is observed in sections of the Vocontian Basin, where it was first described (Fig. 9, columns 5-7), but its presence in Poggio le Guaine, Umbria-Marché Basin, is controversial. Differently from what is seen in the GSSP-Alb, the FO of *Hayesites albiensis* occurs within the upper part of this black shale, named the Urbino Level (Fig. 9, column 4). The fourth organic-rich horizon in Poggio le Guaine was attributed by COCCIONI *et al.* (2014) to the LEENHARDT Level, but is within the *Microhedbergella rischi* Zone, hence below the FO of *Ticinella primula*, opposite the order of events defined in the CGTS2020. This illustrates the limited spatial distribution of the PAQUIER Level, even in Europe, which is only accompanied by an occurrence of a layer rich in organic matter at Site 463 (Fig. 9, column 1). However, this layer does not extend to Site 763B (Fig. 9, column 2), also drilled in the Pacific, nor to the Moroccan sections (Fig. 9, column 8) or to South Atlantic sections where hiatuses are absent (Fig. 9, columns 12, 15-16).

The JACOB Level is present in almost all European sections (Fig. 9, columns 4-7) and apparently has chronostratigraphic equivalents in sections of the CSA (Fig. 9, columns 13-14, 16) and in the inner Brazilian basins (Fig. 9, column 15), having organic-rich layers overlying the Ibura evaporites.

Its presence is inferred at Sites 363 and 364 (Fig. 9, columns 13-14) based on undirected geological evidence (BOLLI *et al.*, 1978a, 1978b). It does not occur at sites 463, 545, 1049C, and 511 (Fig. 9, columns 1, 9-10, 12), nor in the Agadir-Essaouira and Linderos outcrops (Fig. 9, columns 8, 11). An eroded interval inhibits inferring its presence at Site 763B (Fig. 9, column 2).

The results from Site 463 in the Pacific (Fig. 9, column 1) demonstrate the lack of correlation between organic-rich layers and expressive $\delta^{13}\text{C}_{\text{carb}}$ excursions (MATSUMOTO *et al.*, 2020). Despite the excellent correlation of carbon isotope values with the Poggio le Guaine outcrop, the TOC values for the section at Site 463 are too low in all but one organic-rich horizon, tentatively associated with the PAQUIER Level. $\delta^{13}\text{C}_{\text{carb}}$ excursions are also present at the Site 545 section (Fig. 9, column 9) and in the many horizons with high TOC values at Site 364 (FORESMAN, 1978; AZEVEDO, 2001; BRUNO *et al.*, 2020; Fig. 9, column 14). However, the anomalous condition observed in this well is not seen in its neighboring section, Site 363 (Fig. 9, column 13), which suggests that local paleogeographic factors, instead of global ones, influenced deposition of these black shales. In turn, the absence of important $\delta^{13}\text{C}_{\text{carb}}$ negative excursion in the JACOB Level, in contrast to what occurs in the KILIAN and PAQUIER levels in European sections (Fig. 9, columns 5, 7) and is consolidated in the CGTS2020's $\delta^{13}\text{C}_{\text{carb}}$ curve, demonstrates the difficulty in understanding the effective modeling agents of carbon isotope fractionation during the formation of these black shales.

The information presented in Figure 9 demonstrates the difficulty in applying the model established by the GSSP-Alb to other regions of the world outside of the Vocontian Basin. Although the planktonic foraminifera succession indicated in the GSSP-Alb has proved to be widely applicable, adjustments are required with other fossil groups, particularly with calcareous nannofossils. The peculiarities of this situation justify the proposal of ANTUNES *et al.* (2018) to adopt the base of the salt as the Aptian-Albian boundary, with an age of around 113 Ma, for the basins of the CSA, ESA, and BNE. Until the significant biochronological incompatibilities of key taxa for these stratigraphic stages are resolved, it is their proposal that best aligns with the geochronology indicated in the GTS2020 (113.2 ± 0.3 Ma).

6. Conclusion

A "Scientific Revolution" presented itself to researchers of the fauna and flora preserved in the earliest marine sediments in the South Central Atlantic (CSA), Equatorial South Atlantic (ESA), and interior of northeastern Brazil (BNE), with the identification of a diversified assemblage of planktonic foraminifera of Aptian age, according the Albian Global Stratotype Section Point (GSSP-Alb). This assembly extends up to the uppermost portion of the post-salt carbonates, hitherto considered to be of Albian age. As happens when a chal-



lenge to "normal science" presents itself, it was necessary to test the new information against already established information involving the same research object (KUHN, 1962). In this case, information on planktonic foraminifera was integrated with biochronostratigraphic data from different fossil groups, lithostratigraphic data, and geochronological data. This revealed a paradoxical conflict among this information, a problem particularly notable in the CSA, ESA, and BNE basins but not exclusive to this region of the world.

The analysis of 16 sections from sedimentary basins at different localities showed the difficulty in recognizing numerous markers data in the GSSP-Alb. For example, the diagnostic datum for the Aptian-Albian boundary, the first occurrence (FO) *Microhedbergella renilaevis*, did not show up as frequently as did the disappearance of the large planktonic foraminifera, the most globally consistent event observed among this protist group in the analysed sections. The few sure occurrences of the KILIAN, PAQUIER and LEENHARDT levels observed in this study exhibited limitations as global stratigraphic markers. Only the JACOB level appears to occur below the consistent FO of *Prediscosphaera columnata s.l.* on a global scale. The use of an expanded taxonomic concept for this calcareous nannofossil confirms its stratigraphic value as a candidate for marking the base of the Albian, as suggested a few years ago.

In relation to the CSA, ESA, and BNE basins, the controversy between the biochronostratigraphy offered by planktonic foraminifera in relation to those indicated by calcareous nannofossils and pithonellids has been presented in detail. This problem was first recorded about 45 years ago in the Initial Report on Leg 40 of the Deep Sea Drilling Project (DSDP). At stratigraphic levels below the disappearance of the large planktonic foraminifera (~*Paraticinella rohri* Zone), forms recognized as having much younger and exclusively Albian amplitudes occur, such as *Hayesites albensis*, *Tranolithus orionatus*, and *Axopodorhabdus biramiculatus*, among the calcareous nannofossils, and *Pithonella sphaerica*, *P. ovalis*, and *Bonetocardia conoidea*, among the pithonellids. Moreover, the description of successions of Aptian planktonic foraminifera in wells showing no indication of reworking documents the coexistence of species traditionally considered as from different time intervals, once again reinforcing the need to review many of the LOs recorded in chronostratigraphic tables.

These divergences would be less relevant were it not for the 113.2 ± 0.1 Ma age determined on trachyandesite samples overlain by the Ibura evaporites in the Florianópolis High in the CSA, which is almost same age indicated for the GSSP-Alb by the GTS2020. More recent drilling in the Campos and Santos basins has recognized Pre-Salt strata intercalated with basic volcanic flows, also covered by the salt layer. The youngest of these volcanic rocks confirm the 113 Ma age for the base of this salt. Thus, in order to build a glo-

bally consistent chronostratigraphy, the geochronology dictates for the GGSP-Alb cannot fail to consider the many possibilities of volcanic flows close to the base of the salt limit CSA sections.

Changing the focus, for now, from the international GSSP-Alb definition, we recommend adopting the base of the salt of the Ibura Event as the reference for the Aptian-Albian boundary in the CSA, ESA, and BNE basins. Of unequivocal stratigraphic value, it is easily recognizable and coeval in these basins, contrary to the suggested criteria for the GSSP-Alb, whose many limitations have been discussed above. Furthermore, the magnitude of the processes leading to salt formation, as well as those succeeding it during the opening and expansion of the South Atlantic Ocean, likely left records in other parts of the globe, that merit proper exploration.

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Supplementary data

1. Information from the studied sections

mbsf = meters below surface; FO = first occurrence datum; LO = last occurrence datum; Bs = basin; Sc = section.

1.1. Site 463-DSDP, Mid-Pacific Mountains

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>P. cretacea</i> (= <i>P. columnata</i>)	#55-1	480.70	CEPÉK (1981); ROTH (1981)
PAQUIER black shale (top)	#56-1	490.95	DEAN <i>et al.</i> (1981)
FO <i>T. primula</i>	#58-3	513.54	MATSUMOTO <i>et al.</i> (2020)
FO <i>M. rischi</i>	#59-3	522.83	MATSUMOTO <i>et al.</i> (2020)
$\delta^{13}\text{C}_{\text{carb}}$ excursion - KILIAN Level	#60-1	529.33	MATSUMOTO <i>et al.</i> (2020)
FO <i>M. renilaevis</i>	#60-2	529.56	MATSUMOTO <i>et al.</i> (2020)
LO <i>M. miniglobularis</i>	#60-2	530.19	MATSUMOTO <i>et al.</i> (2020)
LO Large planktonic foraminifers (~LO <i>P. rohri</i>)	#60-2	530.19	MATSUMOTO <i>et al.</i> (2020)
$\delta^{13}\text{C}_{\text{carb}}$ excursion - JACOB Level	#62-1	538.64	MATSUMOTO <i>et al.</i> (2020)

Comments: The $\delta^{13}\text{C}_{\text{carb}}$ excursions related to the JACOB and KILIAN levels are dissociated from any organic-rich layer; the black shale occurring in this section has been associated with the PAQUIER Level but is not accompanied by any relevant oscillation in $\delta^{13}\text{C}_{\text{carb}}$.

1.2. Site 763B-ODP, Exmouth Plateau Australian

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>T. primula</i>	#34R-1	494.22	HUBER & LECKIE (2011)
FO <i>T. orionatus</i>	#34X-1	494.28	BRALOWER & SIESSE (1992)
FO <i>T. madecassiana</i>	#35R-5	509.69	HUBER & LECKIE (2011)
FO <i>H. albensis</i>	#36R	517.80	BRALOWER & SIESSE (1992)
FO <i>P. spinosa</i>	#37X-2	524.29	BRALOWER & SIESSE (1992)
FO <i>M. miniglobularis</i>	#37R-3	525.74	HUBER & LECKIE (2011)
FO <i>M. renilaevis</i>	#37R-3	525.74	HUBER & LECKIE (2011)
FO <i>P. columnata</i>	#37X-5	528.75	BRALOWER & SIESSE (1992)
FO <i>M. rischi</i>	#37R-5	529.45	HUBER & LECKIE (2011)
Unconformity	#37R-5	between 529.45 and 530.23	HUBER & LECKIE (2011)
LO large planktonic foraminifera (~LO <i>P. rohri</i>)	#37R-5	530.23	HUBER & LECKIE (2011)

Comments: Supported by HUBER and LECKIE (2011), the last occurrence (LO) of *P. transitoria* is adopted as the datum for the large planktonic foraminifera (*P. rohri* Zone), covered by the *M. rischi* Zone, which characterizes a hiatus; the absence of *P. spinosa* and the JACOB Level determined the position of the base of the hiatus; occurrences of *M. renilaevis*, *M. miniglobularis*, *P. spinosa* and *P. columnata* were considered as reworked or in a stratigraphic position above their first occurrences (FOs); the section has low TOC values (< 2%), and no $\delta^{13}\text{C}_{\text{carb}}$ information was found.



1.3. Vöhrum Sc., Lower Saxony Basin, Germany

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>P. columnata</i> (subcircular)	Vo 15	2.15	MUTTERLOSE <i>et al.</i> (2003)
Ash layer	Vo 15	2.12	MUTTERLOSE <i>et al.</i> (2003)
FO <i>P. spinosa</i>	Vo 1	0.1	MUTTERLOSE <i>et al.</i> (2003)

Comments: No planktonic foraminifera were recovered in the section and the palynomorphs present have no chronostratigraphic value; the section has low TOC values (< 1.3%) and no $\delta^{13}\text{C}_{\text{carb}}$ information was obtained.

1.4. Poggio le Guaine Sc., Umbria-Marche Basin, Italy

Event	Depth (mbsf)	Reference
<i>T. primula</i>	21	COCCIONI <i>et al.</i> (2014)
Black shale (top)	18	COCCIONI <i>et al.</i> (2014)
$\delta^{13}\text{C}_{\text{carb}}$ excursion	17.71-18	COCCIONI <i>et al.</i> (2014)
Black shale (base)	17.71	COCCIONI <i>et al.</i> (2014)
Urbino black shale (top)	16.37	COCCIONI <i>et al.</i> (2014)
FO <i>H. albiensis</i>	16.3	COCCIONI <i>et al.</i> (2014)
$\delta^{13}\text{C}_{\text{carb}}$ excursion (Urbino)	16.12-16.37	COCCIONI <i>et al.</i> (2014)
Urbino black shale (base)	16.12	COCCIONI <i>et al.</i> (2014)
FO <i>P. columnata</i> (circular)	15.5	COCCIONI <i>et al.</i> (2014)
FO <i>M. rischi</i>	10.8	COCCIONI <i>et al.</i> (2014)
Black shale (top)	8.37	COCCIONI <i>et al.</i> (2014)
$\delta^{13}\text{C}_{\text{carb}}$ excursion	7.97-8.37	COCCIONI <i>et al.</i> (2014)
Black shale (base)	7.97	COCCIONI <i>et al.</i> (2014)
FO <i>M. renilaevi</i>	7.6	COCCIONI <i>et al.</i> (2014)
FO <i>P. spinosa</i>	6.5	COCCIONI <i>et al.</i> (2014)
FO <i>P. columnata</i> (near-circular)	6.5	COCCIONI <i>et al.</i> (2014)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	6.5	COCCIONI <i>et al.</i> (2014)
FO <i>M. miniglobularis</i>	6.42	COCCIONI <i>et al.</i> (2014)
FO <i>P. columnata</i> (subcircular)	4	COCCIONI <i>et al.</i> (2014)
113/JACOB black shale (top)	3.55	COCCIONI <i>et al.</i> (2014); SABATINO <i>et al.</i> (2015)
$\delta^{13}\text{C}_{\text{carb}}$ excursion (JACOB)	3.47-3.55	COCCIONI <i>et al.</i> (2014); SABATINO <i>et al.</i> (2015)
113/JACOB black shale (base)	3.47	COCCIONI <i>et al.</i> (2014); SABATINO <i>et al.</i> (2015)

Comments: A biostratigraphic inversion was observed in this section, with the FO of *M. miniglobularis* preceding the LO of *P. rohri*; the black shale associated to the KILIAN level identified by COCCIONI *et al.* (2014) occurring a few meters above the FO of *M. renilaevi*, outside of the position defined by the GSSP-Alb; the same problem occurs with the Urbino Layer, with high TOC values, considered by these authors as being chronocorrelated to the PAQUIER Level even though it is located below the FO of *H. albiensis*; the occurrence of another horizon rich in organic matter above, but below the FO of *T. primula* (indicated as being 2 m above the studied section), makes it impossible to chronocorrelate it with the LEENHARDT Level.



1.5. First composed sections from Vocontian Basin, France (Col de Pré-Guittard and Tartonne sections)

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>T. orionatus</i>	PG29	125.5	P. Guittard Sc, KENNEDY et al. (2000). Biostratigraphic chart. Depth from Fig. 21
FO <i>T. primula</i>	PG17	72.5	P. Guittard Sc, KENNEDY et al. (2000). Depth from Fig. 21
FO <i>P. columnata</i> (circular)	PG17	72.5	P. Guittard Sc, KENNEDY et al. (2000). Biostratigraphic chart.
PAQUIER black shale (top)	below PG16	70	P. Guittard Sc, KENNEDY et al. (2000). Depth from Fig. 21. TOC >2 (Fig. 23)
$\delta^{13}\text{C}_{\text{carb}}$ excursion PAQUIER	PG15-PG16	68-70	P. Guittard Sc, KENNEDY et al. (2000). Smooth negative $\delta^{13}\text{C}$ excursion (Fig. 25)
PAQUIER black shale (base)	above PG15	68	P. Guittard Sc, KENNEDY et al. (2000). Depth from Fig. 21. TOC >2 (Fig. 23)
KILIAN black shale (top)	below PG9	38.5	P. Guittard Sc, KENNEDY et al. (2000). TOC >2 (Fig. 23)
$\delta^{13}\text{C}_{\text{carb}}$ on the KILIAN Level	PG8-PG9	38.5-37.5	P. Guittard Sc, KENNEDY et al. (2000). No $\delta^{13}\text{C}$ excursion detected (Fig. 25)
KILIAN black shale (base)	above PG8	37.5	P. Guittard Sc, KENNEDY et al. (2000). TOC >2 (Fig. 23)
FO <i>P. columnata</i> (near-circular)	PG8	36	P. Guittard Sc, KENNEDY et al. (2000). Biostratigraphic chart
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	PG6	26	P. Guittard Sc, KENNEDY et al. (2000)
FO <i>P. columnata</i> (subcircular)	PG2	6	P. Guittard Sc, KENNEDY et al. (2000)
JACOB level (top)	below PG2	4	P. Guittard Sc, KENNEDY et al. (2000). Low values of TOC (Fig. 23)
$\delta^{13}\text{C}_{\text{carb}}$ on the JACOB Level	PG1-PG2	4-2.5	P. Guittard Sc, KENNEDY et al. (2000). No $\delta^{13}\text{C}$ excursion detected (Fig. 25)
JACOB level (base)	above PG1	2.5	P. Guittard Sc, KENNEDY et al. (2000). Low values of TOC (Fig. 23)
FO <i>P. spinosa</i>	PG1	1	P. Guittard Sc, KENNEDY et al. (2000). Biostratigraphic chart. Depth from Fig. 21
PAQUIER black shale (top)	above TO20	33	Tartone Sc, KENNEDY et al. (2000). High values of TOC (Fig. 24)
$\delta^{13}\text{C}_{\text{carb}}$ on the PAQUIER Level	TO10	33-21.8	Tartone Sc, KENNEDY et al. (2000). Depth from Fig. 24. Smooth negative $\delta^{13}\text{C}$ excursion (Fig. 26)
PAQUIER black shale (base)	TO10	21.8	Tartone Sc, KENNEDY et al. (2000). High values of TOC (Fig. 24)

Comments: KENNEDY et al. (2000)' paper was published before the planktonic foraminifera taxonomic review of HUBER and LECKIE (2011), which justifies the limited number of key species; Col de Pré-Guittard is the section where the JACOB, KILIAN, PAQUIER and LEENHARDT levels were described (BRÉHÉRET et al., 1986), which required the adjustment of the biostratigraphic positions to these lithological data, which justifies the FO *T. primula* outside the expected position in the GTS2020; TOC and $\delta^{13}\text{C}_{\text{carb}}$ information come from samples separated by metric spacing, which may have masked the detection of excursions of this last variable; only the PAQUIER Level recorded relevant variations of $\delta^{13}\text{C}_{\text{carb}}$.

1.6. Second composed sections from Vocontian Basin, France (Serre Chaitieu, Gaubert, Tarendol, Pré-Guittard, Les Oustaus, l'Arboudeysse, and Col de Palluel sections)

Event	Depth (mbsf)	Reference
PAQUIER black shale (top)	281.5	l'Arboudeysse Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
PAQUIER black shale (base)	280.5	l'Arboudeysse Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
FO <i>H. albiensis</i>	244.5	HERRLE & MUTTERLOSE (2003). Depth from Fig. 5
KILIAN bed (top)	241.6	C. P. Guittard Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
KILIAN bed (base)	241.6	C. P. Guittard Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	234.5	Composite lithological column. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
FO <i>P. columnata</i> (circular)	214.5	TARENDOL Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
JACOB black shale (top)	201	Tarendol Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
JACOB black shale (base)	200	Tarendol Sc. Depth from Fig. 5 (HERRLE & MUTTERLOSE, 2003)
FO <i>P. spinosa</i>	194.5	HERRLE & MUTTERLOSE (2003). Depth obtained in Fig. 5

Comments: The sections were studied seeking to establish the succession of calcareous nannofossils in the Vocontian Basin; the circular shape of *P. columnata* was the variety found in the oldest horizon; planktonic foraminifera biostratigraphy was based on MOULLADE et al. (1998) and KENNEDY et al. (2000); no information on $\delta^{13}\text{C}_{\text{carb}}$ values was available.



1.7. Col de Pré-Guittard Sc., GSSP-Alb, Vocontian Basin, France

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>M. rischi</i>		73	KENNEDY et al. (2017). Depth from Fig. 4
PAQUIER black shale (top)		70	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
$\delta^{13}\text{C}$ PAQUIER excursion	25	68-70	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
PAQUIER black shale (base)		68	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
FO <i>P. columnata</i> (circular – consistent)	17	66.6	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
KILIAN bed (top)		37.8	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017).
$\delta^{13}\text{C}$ excursion KILIAN		37-37.8	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
FO <i>M. renilaevis</i>	13	37.4	KENNEDY et al. (2017). Depth from Fig. 4
KILIAN bed (base)		37	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
FO <i>M. miniglobularis</i>	8	35	KENNEDY et al. (2017). Depth from Fig. 4
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	7	34.75	KENNEDY et al. (2017). Depth from Fig. 4
FO <i>P. columnata</i> (circular)	5	29.5	KENNEDY et al. (2017). Depth from Fig. 4
FO <i>P. columnata</i> (subcircular)	3	6	KENNEDY et al. (2017). Depth from Fig. 4
JACOB black shale (top)		201	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
No $\delta^{13}\text{C}$ on the JACOB level		200-201	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
JACOB black shale (base)		200	HERRLE et al. (2004) and OGG et al. (2016). Depth from Fig. 4 (KENNEDY et al., 2017)
FO <i>P. spinosa</i>	PG1	1	Depth from KENNEDY et al. (2000)

Comments: This is the GSSP-Alb's reference section; the position of the FO of *P. spinosa* was based on KENNEDY et al. (2000); the FO *M. rischi* was not found; the names of the black shales with $\delta^{13}\text{C}$ carb excursions were taken from previous studies.

1.8. Composed section from Agadir-Essaouira Basin, Morocco (Ida w Shayq, Tissakatine Center, Anzate, and Tinfoul)

Event	Stratigraphic position	Depth (mbsf)	Reference
LO large planktonic foraminifers (~LO <i>P. rohri</i>) ?	EAB		These sections belong to Oued Tidzi/Tamgo Fms, where the planktonic foraminifera turnover occurs (HASSANEIN, 2016; YAMINA et al. [sic BOURGEOINI et al.], 2002)
FO <i>H. albiensis</i>	ISA25	29.05	Ida w Shayq sc. Above the D4 unconformity (HASSANEIN, 2016)
FO <i>P. columnata</i> (subcircular)	ISA24	28.7	Ida w Shayq sc (HASSANEIN, 2016)
FO <i>P. columnata</i> (near circular)	ISA23	27.9	Ida w Shayq sc (HASSANEIN, 2016)
FO <i>P. columnata</i> (circular)	ISA22	26.6	Ida w Shayq sc (HASSANEIN, 2016)
FO <i>H. albiensis</i>	TKC66a	41	Tissakatine sc. Above the D4 unconformity. Depth from Fig. 3.11 (HASSANEIN, 2016)
FO <i>P. columnata</i> (subcircular)	TKC63a	37	Tissakatine sc. Depth from Fig. 3.11 (HASSANEIN, 2016)
FO <i>H. albiensis</i>	TF16	49.5	Tinfoul sc. Above the D4 unconformity Depth from Fig. 3.13 (HASSANEIN 2016)
FO <i>P. columnata</i> (circular and near-circular)	TF7	28	Tinfoul sc. Depth from Fig. 3.13 (HASSANEIN, 2016)
FO <i>P. spinosa</i>	TF2	16.5	Tinfoul sc. Depth from Fig. 3.13 (HASSANEIN, 2016)

Comments: COT values are low throughout the section; the long-spaced intervals between samples and diagenetic processes around the D4 discontinuity does not permit indicate reliable $\delta^{13}\text{C}$ carb excursions; the LOs large planktonic foraminifers have dubious indications based on lithostratigraphic and ammonites biozones correlations.



1.9. Site 545-DSDP, Mazagan Plateau, Morocco

Event	Stratigraphic position	Depth (mbsf)	Reference
Unconformity	40-6	between 377.06 and 377.11	WIEGAND (1984); HUBER & LECKIE (2011)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	40-6	377.11	HUBER & LECKIE (2011)
Black shale (top)	42	388.8	WAGNER <i>et al.</i> (2008); TRABUCO-ALEXANDRE <i>et al.</i> (2011); MCANENA <i>et al.</i> (2013)
$\delta^{13}\text{C}$ excursion	42	388.8-390.45	HERRLE <i>et al.</i> (2004); WAGNER <i>et al.</i> (2008)
Black shale (base)	42	390.45	WAGNER <i>et al.</i> (2008); TRABUCO-ALEXANDRE <i>et al.</i> (2011); MCANENA <i>et al.</i> (2013)
Acme <i>Subtilisphaera</i> spp.	43-1	401.2	BELOW (1984)
FO <i>T. orionatus</i>	44-1	406.63	WIEGAND (1984)
FO <i>H. albiensis</i>	45-4	422.2	WIEGAND (1984)
FO <i>P. cretacea</i> (= <i>P. columnata</i>)	47-3	439.3	WIEGAND (1984)
Acme <i>Subtilisphaera</i> spp.	48-6	453.2	BELOW (1984)

Comments: An unconformity is indicated in this section based on the absence of several zones in the interval between the disappearance of the large foraminifera (~*P. rohri*) and the FOs of many species related to Late Albian in age (HUBER & LECKIE, 2011); there is also an inversion in the biochronostratigraphic succession, with the FOs of *H. albiensis* and *T. orionatus* preceding the large foraminifera turnover; also the anoxic event has its stratigraphic position marked by biostratigraphic data and cannot be related to any of the OAE1b levels.

1.10. Site 1049C-ODP, Blake Nose, USA

Event	Stratigraphic position	Depth (mbsf)	Reference
Unconformity	11X-2	132.31-132.44	HUBER & LECKIE (2011)
FO <i>T. madecassiana</i>	11cc	134.53	HUBER & LECKIE (2011)
Black shale (top)	12X-2	142.75	Measure on core description (NORRIS <i>et al.</i> , 1998)
No $\delta^{13}\text{C}$ excursion	12X-2	142.75-143.1	HUBER & LECKIE (2011)
Black shale (base)	12X-2	143.1	Measure on core description (NORRIS <i>et al.</i> , 1998)
FO <i>P. columnata</i> s.s.	12	143.2	BROWNING & WATKINS (2008). Depth from Fig. 2
FO <i>M. rischi</i>	12X-4	145.26	HUBER & LECKIE (2011)
FO <i>M. renilaevi</i>	12X-4	145.26	HUBER & LECKIE (2011)
Unconformity	11X-2	145.26-145.29	HUBER & LECKIE (2011)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	12X-4	145.29	HUBER & LECKIE (2011)
FO <i>H. albiensis</i>	12X-5	145.4	BROWNING & WATKINS (2008). Depth from Fig. 2
FO <i>P. columnata</i> s.l.	12X-5	146.4	BROWNING & WATKINS (2008). Depth from Fig. 2
FO <i>P. spinosa</i>	12X-6	146.8	BROWNING & WATKINS (2008). Depth from Fig. 2

Comments: Two unconformities are inferred based on bioevents successions; the first is indicated by the absence of the *M. miniglobularis* Zone and the fact that *M. renilaevi* and *M. rischi* have their local FO happening at the same time; the second unconformity is defined by the presence of Campanian fossils succeeding the *T. madecassiana* Zone (HUBER & LECKIE, 2011); there is also an inversion in the biochronostratigraphic succession, with the FO of *H. albiensis* preceding the disappearance of the large foraminifera (~*P. rohri*); the biostratigraphic information's shows that the anoxic event is not related to any of the OAE1b levels.



1.11. Linderos Section, Tampico-Misantla Basin, Mexico

Event	Stratigraphic position	Depth (mbsf)	Reference
LO <i>Colomiella recta</i>	LIN 66.1	64.5	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
FO <i>T. primula</i>	LIN 51	49	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
FO <i>T. madecassiana</i>	LIN 48.2	46.5	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
FO <i>Colomiella recta</i>	LIN 47.2	45.5	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
LO <i>Colomiella mexicana</i>	LIN 47.2	45.5	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
FO <i>Microhedbergella</i> Zone	LIN 47	45	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	LIN 46.2	44.5	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)
FO <i>Colomiella mexicana</i>	LIN 45.1	43.2	GUTIÉRREZ-PUENTE <i>et al.</i> (2021)

Comments: The taxonomic classification was based exclusively on thin sections; the identification of *Microhedbergella* was limited to the generic level; there is no information about calcareous nannofossils, COT or $\delta^{13}\text{C}_{\text{carb}}$.

1.12. Site 511-DSDP, Malvinas Plateau, Argentina

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>T. orionatus</i>	51-cc	451	WISE (1983)
FO <i>H. albiensis</i>	51-cc	451	WISE (1983)
FO <i>M. rischi</i>	55-4	484.75	HUBER & LECKIE (2011), Table 2
FO <i>M. renilaevius</i>	55-4	485.11	HUBER & LECKIE (2011), Table 2
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	55-5	486.14	HUBER & LECKIE (2011), Table 2
LO <i>M. miniglobularis</i>	55-1	486.7	HUBER & LECKIE (2011), Table 2
FO <i>P. cretacea</i> (= <i>P. columnata</i>)	56-1	491	WISE (1983)
FO <i>P. spinosa</i>	56-1	491	WISE (1983)

Comments: A biostratigraphic inversion is noted here, in which the FO of *M. miniglobularis* precedes the LO of *P. rohri*.

1.13. Site 363-DSDP, Walvis Ridge

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>E. turriseiffelli</i>	#34-3, 41-42	596	PROTO DECIMA <i>et al.</i> (1978)
Unconformity	#34-3, 41-42	596	This study
LO large planktonic foraminifers (~LO <i>P. rohri</i>) ?	#34-3, 41-42	596	This study
FO <i>H. albiensis</i>	#38-1, 90-91	668.41	PROTO DECIMA <i>et al.</i> (1978)
FO <i>P. cf sphaerica</i>	#39-2, 92-94	688.94	BOLLI (1978)
FO <i>P. cretacea</i>	#38-1, 90-91	669.25	PROTO DECIMA <i>et al.</i> (1978)
Black shale	Not drilled		Inferred by BOLLI (1978)
Evaporite layer	Not drilled		Inferred by BOLLI (1978)
Volcanic layer	Not drilled		Inferred by BOLLI (1978)

Comments: An unconformity marks the top of the *H. algeriana*/*T. bejaouensis* zone, defined in CARON (1978); it is indicated by the presence of the FOs of *Effeillitus turriseiffelli* (PROTO DECIMA *et al.*, 1978) and *Clavihedbergella simplisima* (CARON, 1978), Late Albian age.

**1.14. Site 364-DSDP, Kwanza Basin, Angola**

Event	Stratigraphic level	Depth (mbsf)	Reference
FO <i>E. turriseiffelli</i>	#29-4	772.3	BRUNO <i>et al.</i> (2020)
FO <i>P. ticinensis</i>	#31	807.4	KOCHHANN <i>et al.</i> (2013)
Unconformity	#31	807.4	KOCHHANN <i>et al.</i> (2013)
FO <i>M. rischi</i>	#32	829.5	KOCHHANN <i>et al.</i> (2013)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	#33-4	844.6	KOCHHANN <i>et al.</i> (2013)
FO <i>E. monechiae</i>	#34-3	876.0	BRUNO <i>et al.</i> (2020)
LOs <i>H. trochoidea</i> and <i>G. barri</i>	#34	877.4	KOCHHANN <i>et al.</i> (2013)
Black shale	#35-3	895.0	BRUNO <i>et al.</i> (2020)
FO <i>A. biramiculatus</i>	#38.3	951.5	BRUNO <i>et al.</i> (2020)
FO <i>T. orionatus</i>	#41.3	1008.4	BRUNO <i>et al.</i> (2020)
$\delta^{13}\text{C}_{\text{carb}}$ excursion	#41-3	1007.9-1009.2	AZEVEDO (2001); BRUNO <i>et al.</i> (2020)
FO <i>H. albiensis</i>	#42-5	1031.2	BRUNO <i>et al.</i> (2020)
$\delta^{13}\text{C}_{\text{carb}}$ strong negative excursion	#42-1, #42-1	1025.4-1026.9	AZEVEDO (2001); BRUNO <i>et al.</i> (2020)
FO <i>P. columnata</i> (circular)	#42-6	1032.4	BRUNO <i>et al.</i> (2020)
Several black shales	#39-1, #43-1	968.45-1034.6	FORESMAN (1978); BOLLI <i>et al.</i> (1978b); AZEVEDO (2001); BRUNO <i>et al.</i> (2020)
Black shale	#44 - #46	1043.0-1086.5	BOLLI <i>et al.</i> (1978b)
Evaporite layer	Not drilled		Inferred by BOLLI <i>et al.</i> (1978b)
Volcanic layer	Not drilled		Inferred by BOLLI <i>et al.</i> (1978b)

Comments: The incompatibility between the biostratigraphic successions of planktonic foraminifera and calcareous nannofossils, previously recognized in 1978 and confirmed by KOCHHANN *et al.* (2013) and BRUNO *et al.* (2020), makes the chronostratigraphic interpretation for the section difficult; It is elected to follow the stratigraphic positioning of the planktonic foraminifera, to the detriment of the international calcareous nannofossil markers; LOs *H. trochoidea* and *G. barri* are indicating by the *G. ferreolensis/G. algerianus* Zone symbol; sampling gap between *P. eubea-jouensis* (= *P. ROHRI*) and *M. rischi* zones (844.6 and 829.5 mbsf) may have prevented the identification of the *M. miniglobularis* and *M. renilaevi* zones; the *P. ticinensis* Zone, Late Albian in age, rests in an unconformity over the *M. rischi* Zone; the presence of successive black shales levels in the last 120 mbsf of the perforated section is accompanied by at least two $\delta^{13}\text{C}_{\text{carb}}$ excursions.



1.15. Composite section of northeastern Brazilian basins

Event	Stratigraphic position	Position or depth (mbsf)	Reference
LO <i>T. primula</i>	Well SER-03, Sergipe Bs.	117.51	FAUTH <i>et al.</i> (2022)
LO <i>T. madecassiana</i>	Well SER-03, Sergipe Bs.	122.57	FAUTH <i>et al.</i> (2022)
Black shale	Well SER-03, Sergipe Bs.	153.07	FAUTH <i>et al.</i> (2022)
LO <i>E. jardinei</i>	Equatorial South Atlantic, Brazilian northern interior and African basins	Relative position	ARAI <i>et al.</i> (1989); ATTA-PETERS (2013)
FO <i>Microhedbergella rischi</i>	Well SER-03, Sergipe Bs.	168.14	FAUTH <i>et al.</i> (2022)
FO <i>Microhedbergella renilaevis</i>	Well SER-03, Sergipe Bs.	171.55m	FAUTH <i>et al.</i> (2022)
FO <i>Microhedbergella microglobularis</i>	Well SER-03, Sergipe Bs.	171.55m	FAUTH <i>et al.</i> (2022)
$\delta^{13}\text{C}_{\text{carb}}$ positive excursion	Well SER-03, Sergipe Bs.	178.4-176.62	FAUTH <i>et al.</i> (2022)
LO <i>S. variterrucata</i>	Equatorial South Atlantic, Brazilian northern interior and African basins	Relative position	ARAI <i>et al.</i> (1989)
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	Sobradinho Sc., Araripe Bs.	38.4	MELO <i>et al.</i> (2020) and this study
FO Upper acme zone of <i>Subtilisphaera</i> spp.	Well 1-CES-42A, Ceará Bs.	~2330-2600	REGALI (1989)
FO <i>P. columnata</i>	Sergipe Bs.	Relative position	CUNHA & KOUTSOUKOS (1998)
FO Lower acme zone of <i>Subtilisphaera</i> spp.	Well 1-CES-46, Ceará Bs.	~1200-1700	REGALI (1989); ARAI <i>et al.</i> (1994); ARAI (2009, 2014)
Black shale	Sobradinho Sc., Araripe Bs.	~35-42	CUSTÓDIO <i>et al.</i> (2017)
Evaporite layer	Well 1-CES-46, Ceará Bs.	~1700-2400	REGALI (1989)

Comments: The position of the FO of *P. columnata* was defined through stratigraphic correspondence with the *G. ex gr. maridalensis - H. (H.) similis* Zone (KOUTSOUKOS, 1989; KOUTSOUKOS & BENGTSON, 1993); a younger acme of *Subtilisphaera* spp. were recognized by ARAI *et al.* (1994) and ARAI (2009; 2014); alternative interpretation is adopted in this study to indicate the LO large planktonic foraminifers (~LO *P. rohri*), based on MELO *et al.* (2020) informations; the top of the *G. ex gr. maridalensis - H. (H.) similis* Zone (KOUTSOUKOS, 1989; KOUTSOUKOS & BENGTSON, 1993) also support the presence of this bioevent; the stratigraphic position to the youngest level of black shale is dubious.

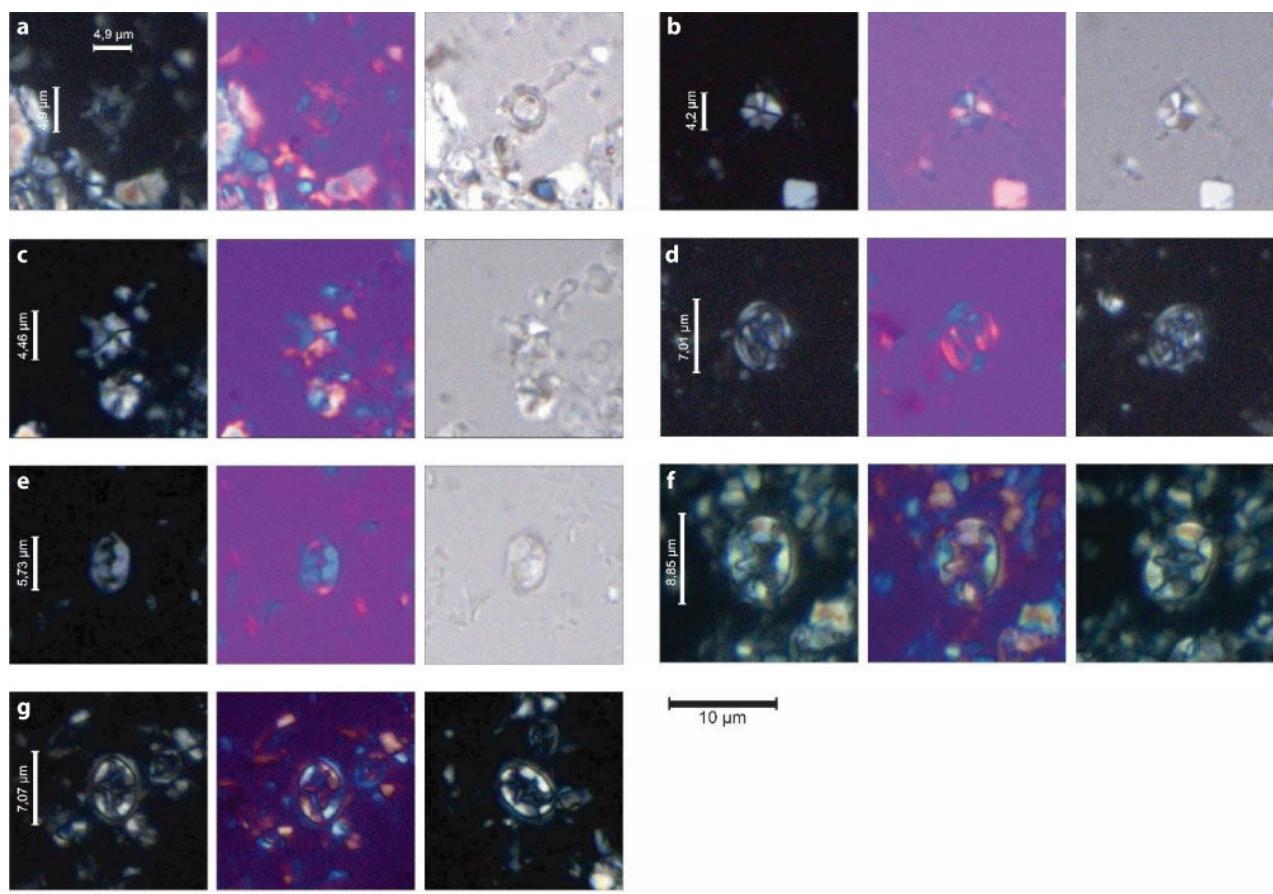
1.16. Composite section of southeastern Brazilian basins

Event	Stratigraphic position	Depth (mbsf)	Reference
FO <i>T. primula</i>	Well 3-BO-3, Campos Bs	Relative position	DIAS-BRITO (1999); SANJINÉ <i>et al.</i> (2022), Fig. 10
LO large planktonic foraminifers (~LO <i>P. rohri</i>)	Well CB-3 (=CB-3), Campos Bs.	2450	TEDESCHI <i>et al.</i> (2017). Depth from Fig. 2
Top of <i>G. algerianus/G. ferreolensis</i> Zone	Well CB-3 (=CB-3), Campos Bs.	2484	TEDESCHI <i>et al.</i> (2017)
FO <i>E. turriseifelli</i>	Well 3-BO-3, Campos Bs.	2473	DIAS-BRITO (1995). Depth from Fig. 92
LO <i>Ovoidinium diversum</i>	Well 3-BO-3, Campos Bs.	2476.6	DIAS-BRITO <i>et al.</i> (1990)
FO <i>P. cretacea</i> (<i>P. columnata</i>)	Well 3-BO-3, Campos Bs.	2515	DIAS-BRITO (1995). Depth from Fig. 92
LO <i>Cyclopsiella</i> spp.	Well 3-BO-3, Campos Bs.	2516,9	DIAS-BRITO <i>et al.</i> (1990)
FO <i>P. sphaerica</i>	Well 3-BO-3, Campos Bs.	2602	DIAS-BRITO (1995). Depth from Fig. 92
FO <i>Ovoidinium diversum</i>	Well 3-BO-3, Campos Bs.	2602	DIAS-BRITO (1995). Depth from Fig. 92
LO <i>Colomiella recta</i>	Well 1-SPS-6, Santos Bs.	5220	DIAS-BRITO (1999)
LO <i>Colomiella mexicana</i>	Well 1-SPS-6, Santos Bs.	5487.7	DIAS-BRITO (1999)
FO <i>Cyclopsiella</i> spp.	Integrate data	Relative position	AZEVEDO (2001)
FO <i>Colomiella recta</i>	Well 1-SPS-6, Santos Bs.	5595	DIAS-BRITO (1999)
FO <i>Colomiella mexicana</i>	Well 1-SPS-6, Santos Bs.	> 5595	DIAS-BRITO (1999)
Black shale	Well X, Santos Bs.	2600-2756	TEDESCHI <i>et al.</i> (2017)
Evaporite layer	Well 1-RJS-117A, Campos Bs	Relative position	RANGEL <i>et al.</i> (1994)
Volcanic layer	Well 1-SCS-1, Santos Bs.	Not informed	MIZUSAKI (1993) <i>fide</i> DIAS <i>et al.</i> (1994)

Comments: There is no information about $\delta^{13}\text{C}_{\text{carb}}$ strong excursions nor high TOC values in the section.



2. Calcareous nannofossils zone markers at Site 364 (BRUNO et al., 2020)



a) *Prediscosphaera columnata* (DSDP Site 364 - depth 1,032.37 mbsf); **b)** *Hayesites albiensis* (DSDP Site 364 - depth 790.41 mbsf); **c)** *Hayesites albiensis* (DSDP Site 364 - depth 1,031.21 mbsf); **d)** *Axopodorhabdus biramiculatus* (DSDP Site 364 - depth 951.47 mbsf); **e)** *Tranolithus orionatus* (DSDP Site 364 - depth 1008.41 mbsf); **f)** *Eiffellithus turriseiffelii* (DSDP Site 364 - depth 772.34 mbsf); **g)** *Eiffellithus monechiae* (DSDP Site 364 - depth 875.96 mbsf).



3. Geochemical data from Site 364-DSDP

Core	Section	Interval (mbsf)	Depth (mbsf)	TOC (%)	Reference	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{18}\text{O}_{\text{carb}}$
26	5	73-77	717.23	0.13	BRUNO <i>et al.</i> (2020)	1.14	-4.17
26	6	115-117	719.15	0.11	BRUNO <i>et al.</i> (2020)	1.06	-3.29
27	2	125-128	722.75	0.13	BRUNO <i>et al.</i> (2020)		
27	3	67-71	723.67	0.08	BRUNO <i>et al.</i> (2020)	1.53	-3.28
27	4	74-77	725.24	0.09	BRUNO <i>et al.</i> (2020)	1.71	-2.89
27	5	66-70	726.66	0.12	BRUNO <i>et al.</i> (2020)		
28	1	69-73	749.19	0.11	BRUNO <i>et al.</i> (2020)		
28	2	70-74	750.7	0.12	BRUNO <i>et al.</i> (2020)		
28	2	130	751.3	0.1	BOLLI <i>et al.</i> (1978a)		
28	2	150	751.5	0.1	BOLLI <i>et al.</i> (1978a)		
28	3	87-91	752.37	0.05	BRUNO <i>et al.</i> (2020)	2.57	-2.90
28	4	18	753.18	0	BOLLI <i>et al.</i> 1978a		
28	4	64-68	753.64	0.10	BRUNO <i>et al.</i> (2020)	2.17	-3.70
28	cc	Bottom of the box	755	0.06	FORESMAN (1978)		
29	1	69-71	768.19	0.09	BRUNO <i>et al.</i> (2020)	1.84	-4.49
29	2	33-37	769.33	0.13	BRUNO <i>et al.</i> (2020)	2.14	-3.37
29	3	67-71	771.17	0.12	BRUNO <i>et al.</i> (2020)		
29	4	15	772.15	0.1	BOLLI <i>et al.</i> (1978a)		
29	4	34-37	772.34	0.10	BRUNO <i>et al.</i> (2020)		
29	cc		774.5	0.09	FORESMAN (1978)		
30	1	66-70	787.16	0.07	BRUNO <i>et al.</i> (2020)		
30	2	94-98	788.94	0.49	BRUNO <i>et al.</i> (2020)		
30	2	130	789.3	0.1	BOLLI <i>et al.</i> (1978a)		
30	2	150	789.5	0.1	BOLLI <i>et al.</i> (1978a)		
30	3	91-94	790.41	0.14	BRUNO <i>et al.</i> (2020)		
30	cc		792	0.1	FORESMAN (1978)		
31	1	27-29	805.28	1.03	FORESMAN (1978)		
31	1	79-82	806.29	0.19	BRUNO <i>et al.</i> (2020)		
31	2	40-42	807.4	0.19	BRUNO <i>et al.</i> (2020)	1.96	-3.25
31	3	41-44	808.91	0.11	BRUNO <i>et al.</i> (2020)		
31	4	52	810.52	0.1	BOLLI <i>et al.</i> (1978a)		
31	4	94-98	810.94	0.18	BRUNO <i>et al.</i> (2020)	2.07	-3.58
32	1	20-21	824.7		AZEVEDO (2001)	2.28	-3.71
32	1	61-61	825.11		AZEVEDO (2001)	2.38	-3.68
32	1	101-102	825.5		AZEVEDO (2001)	2.07	-4.38
32	1	123-127	825.73	0.08	BRUNO <i>et al.</i> (2020)	2.11	-4.08
32	1	143-143	825.93		AZEVEDO (2001)	2.6	-2.17
32	2	40-44	826.4	0.17	AZEVEDO (2001)	2.24	-4.11
32	2	40-44	826.4		BRUNO <i>et al.</i> (2020)	2.33	-3.60
32	2	79-80	826.79		AZEVEDO (2001)	2.77	-2.27
32	2	100-101	827		AZEVEDO (2001)	2.16	-3.52
32	2	120-121	827.2		AZEVEDO (2001)	2.68	-2.11
32	2	126-128	827.27	0.61	FORESMAN (1978)		



Core	Section	Interval (mbsf)	Depth (mbsf)	TOC (%)	Reference	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{18}\text{O}_{\text{carb}}$
32	3	53-56	828.05	0.09	FORESMAN (1978)		
32	3	53-56	828.05	0.09	FORESMAN (1978)		
32	3	90-92	828.4	0.10	BRUNO <i>et al.</i> (2020)		
32	3	130	828.8	0.1	BOLLI <i>et al.</i> (1978a)		
32	3	150	829	0.2	BOLLI <i>et al.</i> (1978a)		
32	4	46-50	829.46	0.07	BRUNO <i>et al.</i> (2020)	2.57	-3.62
32	4	92	829.92	0.1	BOLLI <i>et al.</i> (1978a)		
33	1	107-111	844.57	0.06	BRUNO <i>et al.</i> (2020)	2.21	-4.13
33	2	92-95	845.92	0.34	BRUNO <i>et al.</i> (2020)	2.42	-3.69
33	3	75	847.25	0.7	BOLLI <i>et al.</i> (1978a)		
33	3	93-95	847.43	0.15	BRUNO <i>et al.</i> (2020)	2.72	-2.78
33	4	63-67	848.63	0.15	BRUNO <i>et al.</i> (2020)		
33	5	65-69	850.15	0.07	BRUNO <i>et al.</i> (2020)	2.25	-3.92
33	5	100-101	850.5		AZEVEDO (2001)	2.68	-3.18
33	5	121-121	850.71		AZEVEDO (2001)	2.4	-3.51
33	5	140-141	850.9		AZEVEDO (2001)	2.17	-4.71
33	cc	0-1	851		AZEVEDO (2001)	2.19	-4.62
34	1	100-101	873		AZEVEDO (2001)	1.92	-4.3
34	1	121-121	873.21		AZEVEDO (2001)	2.68	-2.55
34	1	133-136	873.33	0.22	BRUNO <i>et al.</i> (2020)		
34	2	19-20	873.69		AZEVEDO (2001)	2.02	-4.11
34	2	60-61	874.1		AZEVEDO (2001)	2.13	-3.6
34	2	93-96	874.43	0.90	BRUNO <i>et al.</i> (2020)		
34	2	100-101	874.5		AZEVEDO (2001)	2.23	-3.52
34	2	140-141	874.9		AZEVEDO (2001)	2.22	-3.52
34	3	96-99	875.96		BRUNO <i>et al.</i> (2020)	2.50	-3.84
34	3	130	876.3	0.6	BOLLI <i>et al.</i> (1978a)		
34	4	53	877.03	0.3	BOLLI <i>et al.</i> (1978a)		
34	4	92-96	877.42	0.21	BRUNO <i>et al.</i> (2020)		
35	1	114-117	892.14	0.15	BRUNO <i>et al.</i> (2020)		
35	2	46-49	892.96	0.19	BRUNO <i>et al.</i> (2020)		
35	3	99-101	894.99	2.89	BRUNO <i>et al.</i> (2020)		
36	1	125-128	911.25	0.46	BRUNO <i>et al.</i> (2020)	2.94	-2.69
36	3	75-77	913.75	0.13	BRUNO <i>et al.</i> (2020)		
37	1	66-68	929.66	0.10	BRUNO <i>et al.</i> (2020)		
37	1	130	930.3	0.1	BOLLI <i>et al.</i> (1978a)		
37	2	120-122	931.7	0.12	BRUNO <i>et al.</i> (2020)	1.99	-3.76
37	3	45-47	932.45	0.46	BRUNO <i>et al.</i> (2020)	2.05	-3.36
37	4	94-97	934.44	0.15	BRUNO <i>et al.</i> (2020)	1.94	-3.77
37	5	98-101	935.98	0.09	BRUNO <i>et al.</i> (2020)		
38	1	20-21	948.2		AZEVEDO (2001)	1.55	-5.05
38	1	90-93	948.9	0.19	BRUNO <i>et al.</i> (2020)		
38	1	99-100	948.99		AZEVEDO (2001)	1.73	-4.8
38	2	39-40	949.89		AZEVEDO (2001)	1.54	-4.14
38	2	80-81	950.3		AZEVEDO (2001)	1.32	-2.76



Core	Section	Interval (mbsf)	Depth (mbsf)	TOC (%)	Reference	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{18}\text{O}_{\text{carb}}$
38	2	100-101	950.5		AZEVEDO (2001)	1.23	-4.44
38	2	103-105	950.53	0.20	BRUNO <i>et al.</i> (2020)	1.37	-2.68
38	2	120-12	950.7		AZEVEDO (2001)	1.23	-4.41
38	2	140-141	950.9		AZEVEDO (2001)	1.62	-4.8
38	3	20-21	951.2		AZEVEDO (2001)	2	-4.53
38	3	40-41	951.4		AZEVEDO (2001)	1.56	-4.71
38	3	47-49	951.47	1.13	BRUNO <i>et al.</i> (2020)		
38	3	60-61	951.6		AZEVEDO (2001)	1.6	-4.16
38	3	80-81	951.8		AZEVEDO (2001)	1.17	-3.41
38	3	100-101	952		AZEVEDO (2001)	1.59	-4.64
38	3	120-12	952.2		AZEVEDO (2001)	1.54	-4.14
38	3	139-140	952.39		AZEVEDO (2001)	1.65	-4.55
38	4	27-30	952.77		BRUNO <i>et al.</i> (2020)	1.57	-3.86
38	4	143	953.93	1.2	BOLLI <i>et al.</i> (1978a)		
38	5	53-55	954.53	0.28	BRUNO <i>et al.</i> (2020)	1.56	-3.98
38	6	25-28	955.75	1.27	BRUNO <i>et al.</i> (2020)		
39	1	145-148	968.45	3.02	BRUNO <i>et al.</i> (2020)		
39	2	114-119	969.64	4.60	BRUNO <i>et al.</i> (2020)		
39	3	118-122	971.18	1.58	BRUNO <i>et al.</i> (2020)		
39	4	66-69	972.16	1.81	BRUNO <i>et al.</i> (2020)		
39	4	91	972.41	4.7	BOLLI <i>et al.</i> (1978a)		
39	5	89-92	973.89	1.44	BRUNO <i>et al.</i> (2020)		
39	5	127	974.27	1.5	BOLLI <i>et al.</i> (1978a)		
39	5	150	974.5	2.4	BOLLI <i>et al.</i> (1978a)		
39	6	85	975.35	1.4	BOLLI <i>et al.</i> (1978a)		
39	6	99-101	975.49	1.22	BRUNO <i>et al.</i> (2020)	-0.42	-4.58
40	1	142-147	987.42	0.63	BRUNO <i>et al.</i> (2020)	0.15	-3.05
40	2	92-96	988.42	3.85	BRUNO <i>et al.</i> (2020)	1.36	-4.11
40	3	71-75	989.71	3.71	BRUNO <i>et al.</i> (2020)		
40	4	44	990.94	4.9	BOLLI <i>et al.</i> (1978a)		
40	4	66-68	991.16	1.02	BRUNO <i>et al.</i> (2020)		
40	5	63-66	992.63	2.39	BRUNO <i>et al.</i> (2020)	0.12	-5.07
41	1	141-145	1006.41	3.03	BRUNO <i>et al.</i> (2020)		
41	2	19-20	1006.7		AZEVEDO (2001)	0.72	-4.06
41	2	46-50	1006.96	2.26	BRUNO <i>et al.</i> (2020)		
41	2	60-61	1007.1		AZEVEDO (2001)	0.52	-5.15
41	2	79-80	1007.3		AZEVEDO (2001)	0.74	-5.46
41	2	100-01	1007.5		AZEVEDO (2001)	-0.02	-4.98
41	2	141-142	1007.91		AZEVEDO (2001)	0.77	-4.59
41	3	40-41	1008.4		AZEVEDO (2001)	0.03	-5.33
41	3	41-44	1008.41	1.50	BRUNO <i>et al.</i> (2020)	-0.21	-5.47
41	3	80-81	1008.8		AZEVEDO (2001)	0.22	-3.89
41	3	119-120	1009.2		AZEVEDO (2001)	-0.52	-5.14
41	3	130	1009.3	0.7	BOLLI <i>et al.</i> (1978a)		
41	3	150	1009.5	6	BOLLI <i>et al.</i> (1978a)		



Core	Section	Interval (mbsf)	Depth (mbsf)	TOC (%)	Reference	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{18}\text{O}_{\text{carb}}$
41	4	19-20	1009.7		AZEVEDO (2001)	1.73	-3.42
41	4	29-32	1009.79	3.47	BRUNO <i>et al.</i> (2020)		
41	4	32	1009.82	3.8	BOLLI <i>et al.</i> (1978a)		
42	1	137-139	1025.37	0.28	BRUNO <i>et al.</i> (2020)	-2.59	-4.85
42	2	20-21	1025.7		AZEVEDO (2001)	1.15	-5.75
42	2	60-61	1026.1		AZEVEDO (2001)	-1.99	-5.28
42	2	81-84	1026.31	8.91	BRUNO <i>et al.</i> (2020)		
42	2	100-101	1026.5		AZEVEDO (2001)	0.78	-4.06
42	2	140-141	1026.9		AZEVEDO (2001)	-2.37	-5.17
42	3	24-28	1027.24	4.58	BRUNO <i>et al.</i> (2020)		
42	4	75	1029.25	8.4	BOLLI <i>et al.</i> (1978a)		
42	4	100-125	1029.5	0.19	BRUNO <i>et al.</i> (2020)		
42	5	121-125	1031.21	0.54	BRUNO <i>et al.</i> (2020)		
42	6	32	1031.82	22.5	BOLLI <i>et al.</i> (1978a)		
42	6	87-90	1032.37	0.40	BRUNO <i>et al.</i> (2020)		
43	1	130	1034.6	7.4	BOLLI <i>et al.</i> (1978a)		
43	1	150	1034.8	0.3	BOLLI <i>et al.</i> (1978a)		
44	4	10	1047.6	1.2	BOLLI <i>et al.</i> (1978a)		