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Towards an Integrated Stratigraphy of the Gramame Formation (Maastrichtian), CIPASA Quarry, Pernambuco-Paraíba Basin, NE Brazil

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Abstract

This study presents the integrated biostratigraphic (calcareous nannofossils and foraminifera), petrographic, geochemical and ichnological analyzes of the Gramame Formation (Maastrichtian) at the CIPASA Quarry section, in the Pernambuco-Paraíba Basin, northeastern Brazil.

A high resolution calcareous nannofossil biostratigraphic study has been carried out, allowing to subdivide the studied section into three subzones of Maastrichtian age: CC25A, CC25B, and CC25C. Each biostratigraphic unit was further characterized by petrographic, geochemical and ichnological parameters.

During the Maastrichtian the area was characterized by a dry and warm climate with low influx of terrigenous sediments. These conditions were fundamental to the widespread development of a carbonate ramp system in an outer neritic to bathyal setting, with deposition of alternating calcareous mudstones and argillaceous mudstones of the Gramame Formation.

The Gramame Formation belongs to the transgressive system tract of second-order type, characteristic of a Passive Margin Sequence. The studied section consists of part of a third order deposicional cycle, which is arranged in a transgressive systems tract and a highstand systems tract. The lowstand systems tract was not characterized.
Keywords: Maastrichtian; Pernambuco-Paraíba Basin; NE Brazil, calcareous nannofossils; foraminifera

1 Introduction

The Pernambuco-Paraíba Basin is located on the northeastern Brazilian continental margin. Almost all the current geological knowledge about the basin derives from the investigation of outcrops along the coast. The scarce subsurface studies indicate that the basin has a sedimentary record over 3,000m thick, comprising rocks ranging in age from the Aptian to Holocene. The Gramame Formation consists mainly of alternating calcareous mudstones and argillaceous mudstones. Sedimentological analyses point out to a quiet, warm water depositional environment with moderate (below wave-base) depth. There are over two dozen known outcrops of the Gramame Formation in the Pernambuco-Paraíba Basin.

The CIPASA Quarry, located in the Catolé Farm, Caaporã Municipality, in the southern Paraíba State, nearby the Paraíba/Pernambuco state border, yields one of the most representative outcropping sections of the Gramame Formation. The quarry is approximately 85km far from Recife, with access through the BR-101 (70km) and PB-044 (15km) highways (Figure 1). The

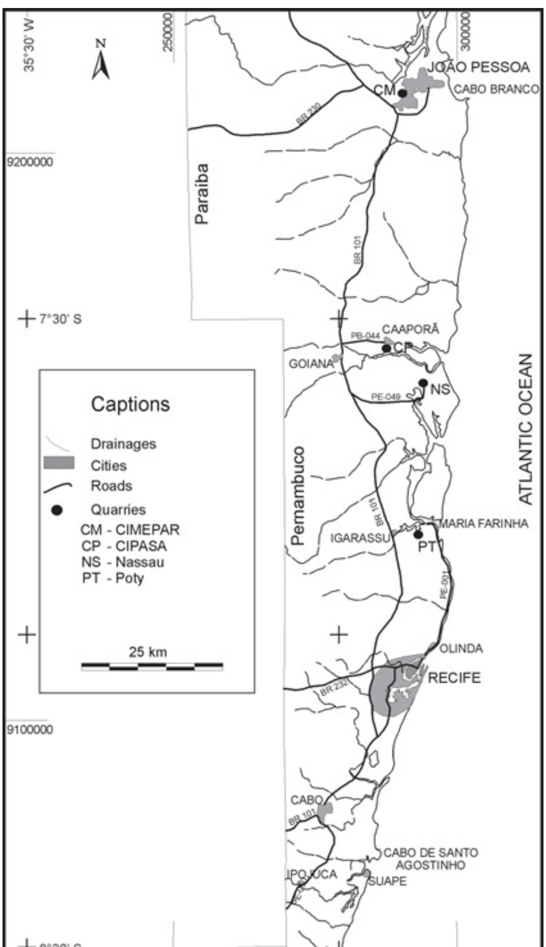

Figure 1 Map of the Pernambuco-Paraíba Basin, northeastern Brazil, showing the location of the main outcrops of the Gramame Formation (Maastrichtian).

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quarry outcropping section is approximately 36m high and subdivided into four working benches, a result from the active mining exploration by the Votorantin cement factory, which constantly expose fresh, unweathered rock sections.

2 Calcareous Nannofossils

Calcareous nannofossils provide one of the best stratigraphic controls in the area, which resulted in a high-resolution biochronostratigraphic framework of regional application.

Based upon the obtained results, the studied section is assigned to the *Arkhangelskiella cymbiformis* Zone (CC25) with three subzones, all of Maastrichtian age (Perch-Nielsen, 1985) (Figure 2). The nannofossil assemblage is rich, well diversified and preserved, composed of typical Cretaceous genera such as *Ahmuellerella, Ceratolithoides, Cretarhabdus, Cribrosphaerella, Eiffellithus, Gartnerago, Helicolithus, Kamptnerius, Lithraphidites, Loxolithus, Manivitella, Microrhabdulus, Micula, Prediscosphaera, Retecapsa, Rhagodiscus, Staurolithites, Tegumentum, Tetrapodorhabdus, Watznaueria* and *Zeugrhabdotus.*

Subzone CC25A, the oldest recognized in the outcrops, is characterized by common *Lithraphidites praequadratus* and *Arkhangelskiella cymbiformis.* The presence of *L. praequadratus* was used because the Last Occurrence Datum (LOD) of *Reinhardtites levis* (the bioevent that marks the base of this subzone), was not observed. The top is marked by the First Occurrence Datum (FOD) of *L. quadratus.* Subzone CC25A occurs in the CIPASA quarry in the interval 0-25.6m. The calcareous nannofossil richness oscillates from 12 to 51 species per sample. Additionally, the LOD of *Gartnerago segmentatum* is recorded at 17m. This bioevent has been used by Mortimer (1987) and Antunes (1998) as a biostratigraphic datum.

Subzone CC25B, occurs in the interval 25.6-32.0m and is recognized between the successive FOD's of *Lithraphidites quadratus* and *Micula murus,* respectively. The calcareous nannofossil richness oscillates from 12 to 48 species per sample.

Subzone CC25C extends from the FOD of *Micula murus* to that of *Nephrolithus frequens.* It occurs in the CIPASA in the interval 32.0-36.5m. The calcareous nannofossil richness oscillates from 36 to 48 species per sample.

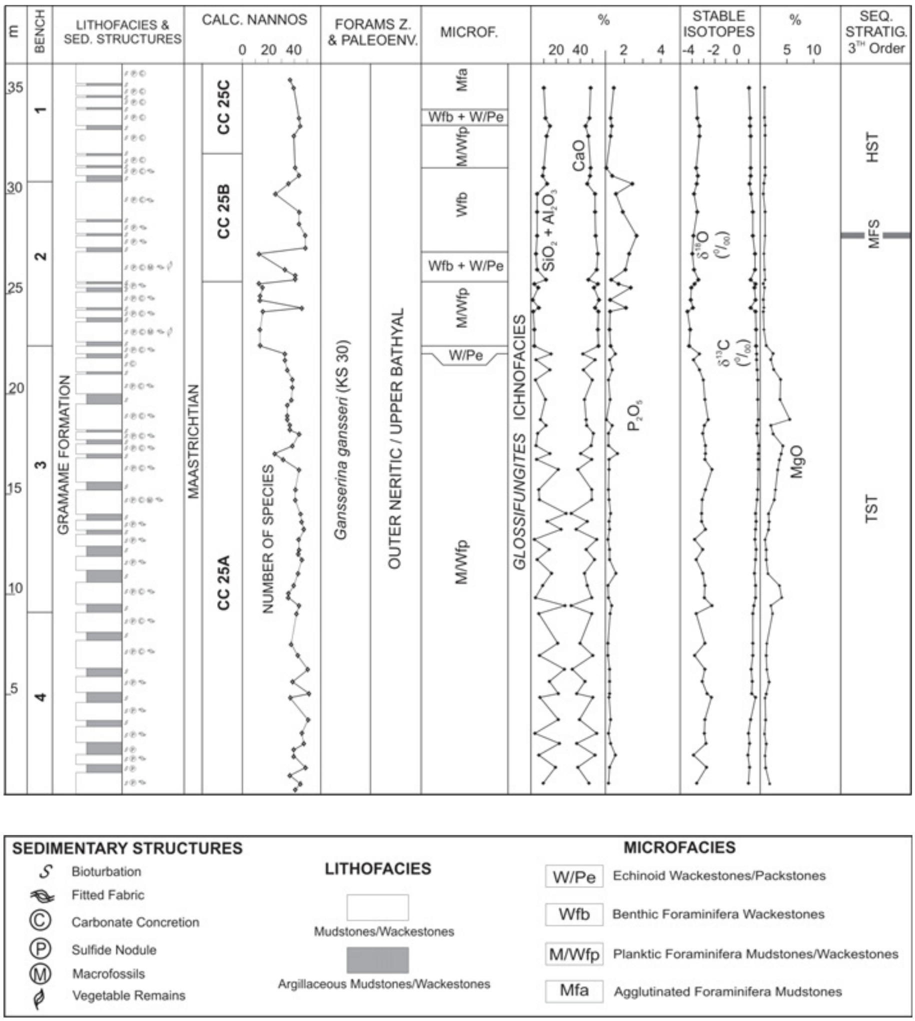

Figure 2 Key stratigraphic features of the CIPASA Quarry (modified from Lima, 2002).

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3 Foraminifera

Biostratigraphic investigations carried out for foraminifera in thin sections, indicates that the whole studied section is assigned to the *Gansserina gansseri* Zone (biozone KS 30 of Sliter, 1999) (Figure 2). The foraminiferal assemblage is rich and diversified, composed of typical Cretaceous genera such as *Archaeglobigerina, Gansserina, Globigerinelloides, Globotruncana, Globotruncanella, Globotruncanita, Guembelitria, Hedbergella, Heterohelix, Planoglobulina, Pseudoguembelina, Pseudotextularia* and *Rugoglobigerina*.

Biozone KS 30 is recorded throughout the CIPASA Quarry, in the interval 0-36.5m. Foraminiferal richness oscillates from 5 to 16 species per sample.

The planktonic foraminifera are composed of common rugose and rugose/pustulose, non-keeled and keeled (with a low-trochospire) assemblages, such as *Gansserina gansseri, Globotruncana aegyptiaca, Globotruncanella havanensis, G. petaloidea, Rugoglobigerina macrocephala, R. rugosa,* and sporadic non-rugose keeled (with a moderately high trochospire) morphotypes, such as *Globotruncana arca* and *Globotruncanita stuartiformis,* together with common heterohelicids *(Heterohelix globulosa, Pseudoguembelina* spp., *Pseudotextularia elegans).* Common but low-diversified calcareous-benthic foraminifera, chiefly composed of *Gavelinella, Siphogenerinoides,* and nodosariids, occur sparsely along the section. The planktonic and benthic foraminiferal assemblages suggest that the studied section was deposited on an outer neritic to upper bathyal setting of a pelagic carbonate ramp system (*cf.* Koutsoukos 1989, 1992; Koutsoukos & Hart, 1990) (Figure 2).

4 Trace Fossils

The ichnological assemblage is formed mainly by the ichnogenus *Thalassinoides.* The trace is a three-dimensional burrow system consisting of smooth-walled cylindrical to sub-cylindrical components, with 0.5 to 5.0cm in diameter. Enlarged Y-shaped junctions are common. Vertical components are irregular-walled and occur in the limestone levels. Horizontal components are regular-walled and occur in the marlstone levels. Deposits from overlying layers fill the burrow system. The ichnogenus *Thalassinoides* is almost universally interpreted as combined feeding-dwelling structures of decapode crustaceans (*e.g.* crabs, shrimps). Sometimes the bioturbation activity is so intense that the stratified boundaries are completely destroyed.

The extremely low diversity and high populational density of the ichnogenus *Thalassinoides* suggest oxygen depleted bottom-water conditions. The wall type and infill of the burrow system suggest that the substrate was firm, with low to moderate energy, when colonization occurred. This firmground suite of traces characterized by *Thalassinoides* indicate the substrate-controlled *Glossifungites* Ichnofacies to the Gramame Formation (Figure 2).

5 Petrography

Macroscopicaly the lithofacies of the Gramame Formation in the CIPASA Quarry consists mainly of alternating **mudstones/wackestones (M/W)** and **argillaceous mudstones/wackestones (M/Wa)** (Figure 3 A-B).

The M/W lithofacies consists of light grey tabular beds with thickness oscillating from 0.2 to 1.9m. Top and base are irregular due to intense bioturbation, whereas internally is massive or intensely bioturbated. In addition, macrofossil fragments (molluscs), vegetable remains, sulfide nodules, carbonate concretions and fractures filled with calcite can be observed. The amount of clay is low to very low. This lithofacies presents itself as a positive feature in the outcrop profile. The weathered surfaces are commonly pale cream with the local development of karst features.

The M/Wa lithofacies consists of deep grey tabular beds with thickness oscillating from 0.1 to 0.6m. Top and base are irregular due to intense bioturbation. Macrofossils fragments (molluscs), pyrite and carbonate nodules can also be observed. The amount of clay is high to very high. This lithofacies presents itself as a negative feature in the outcrop profile. The weathered surfaces are pale cream in colour.

The main sedimentary structures are rhythmic bedding, meteorological tidal channels, bioturbations, fitted fabric, stylolites and karstic features. There also occur sparse dolomitization, and mineralizations of phosphates and sulfides (pyrite, chalcopyrite and arsenopyrite) (Figures 3, 4). Sedimentological analyses suggest a quiet, warm water depositional environment with moderate (below wave-base) depths.

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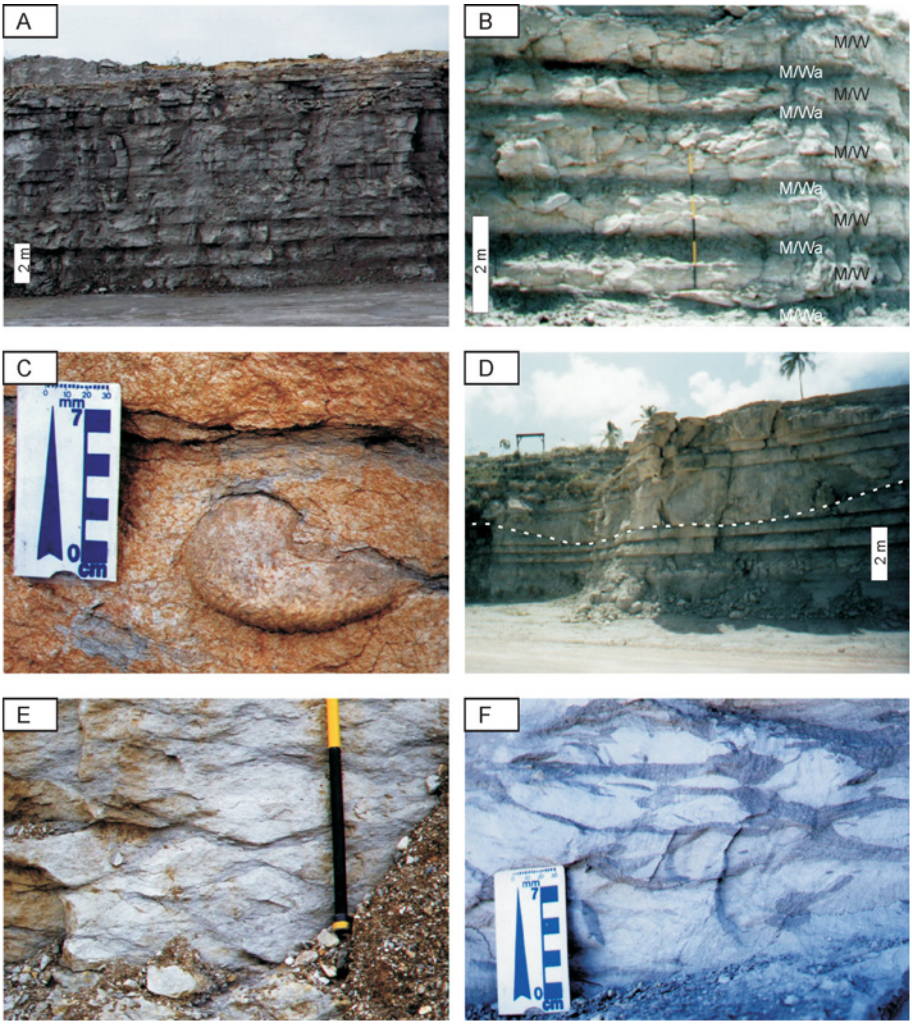

Figure 3 Features of the CIPASA Quarry. A. View of the outcrop section (bench 4). B. Detail showing the rhythmic bedding of Mudstones/Wackestones (M/W) and Argillaceous Mudstones/ Wackestones (M/Wa) lithofacies (bench 4). C. Cephalopod internal mold within the M/W lithofacies (bench 2). D. Meteorological tidal channel (Bench 3). E. Nodular fitted fabric in the M/W lithofacies (bench 2). F. Brecciated fitted fabric in the M/W lithofacies (bench 1).

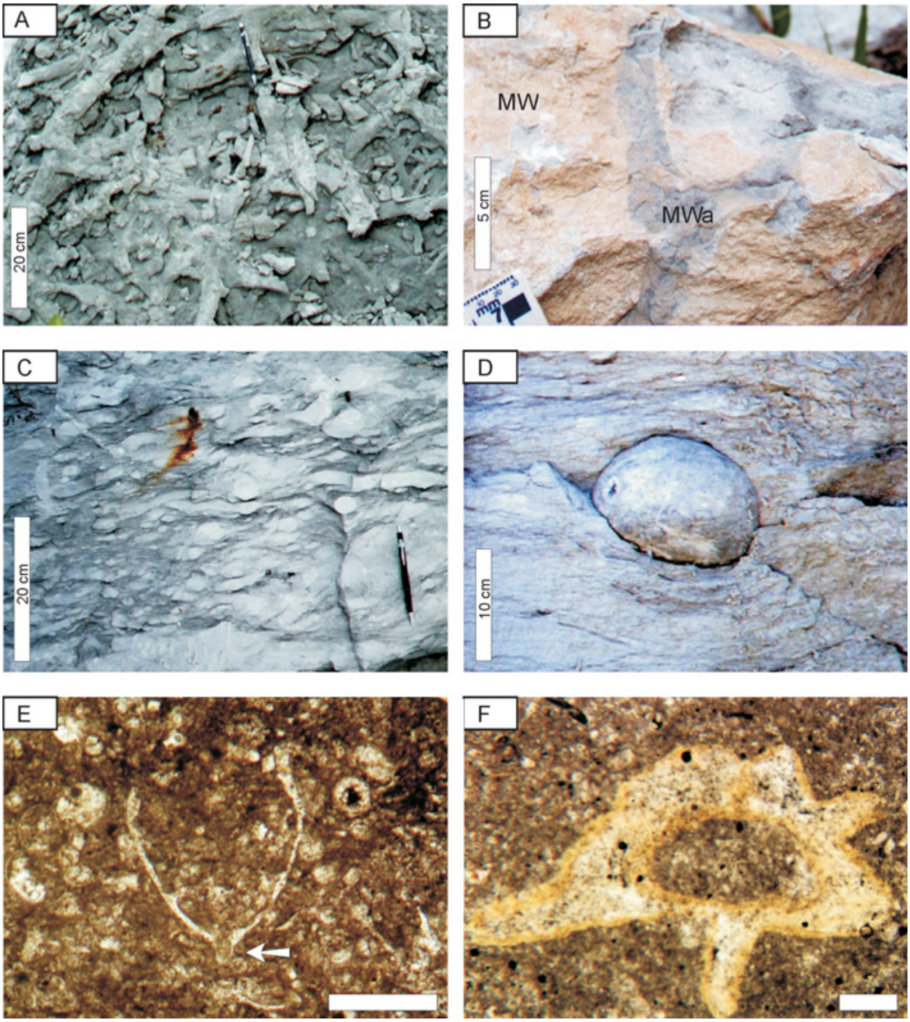

Figure 4 Features of CIPASA Quarry. A. Top view of *Thalassinoides* isp. horizontal burrow systems. The weathering removed the M/Wa matrix-lithofacies leaving the borrow system filled with M/W lithofacies as a positive feature. B . Lateral view of Thalassinoides isp. vertical burrows. C. *Thalassinoides* isp. borrow system distribution, from intense in the M/Wa lithofacies to sparse or moderate in the M/W lithofacies. D. Subsphaeric carbonate concretion within the M/W lithofacies (bench 2). E. Microcrinoid longitudinal section, M/Wfp microfacies (scale bar = 200 μm). F. Transverse section of a vertebra fragment in the M/Wfp lithofacies (scale bar = 200 μm).

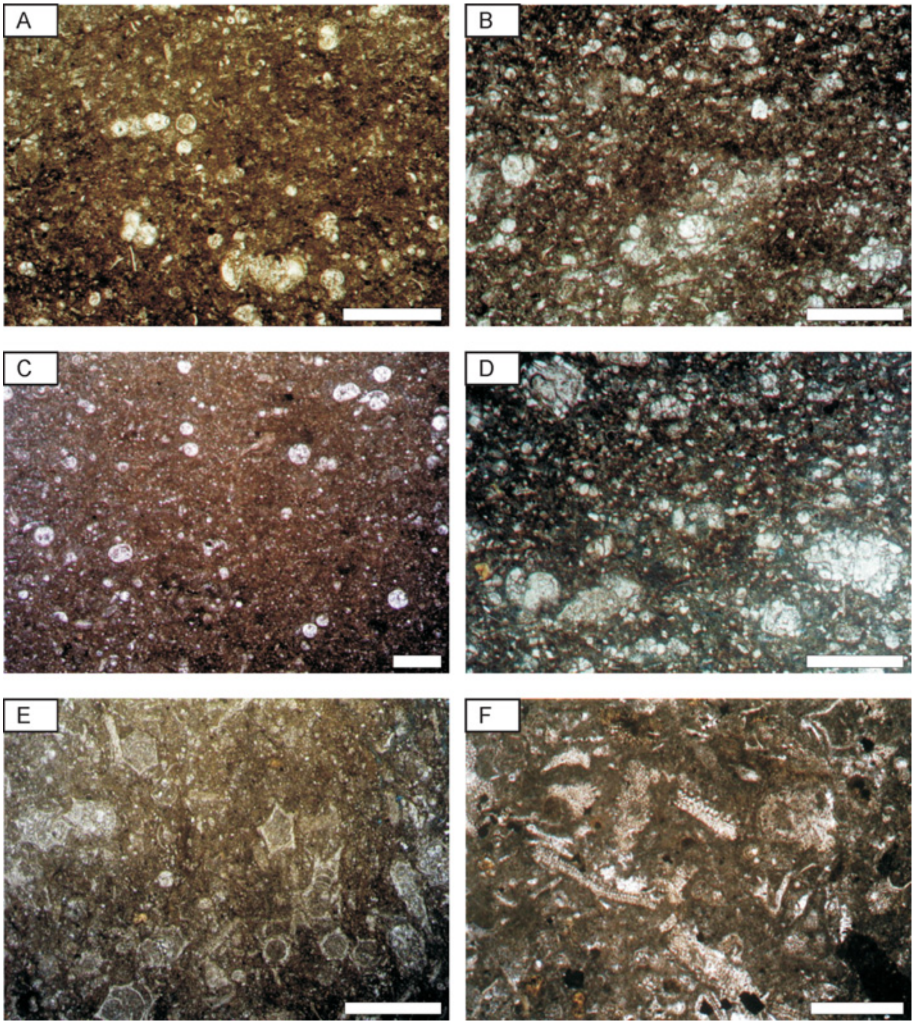

Figure 5 Microfacies types of the Gramame Formation. A-B. Planktic Foraminifera Mudstones/ Wackestones (M/Wfp). C. Radiolarian Mudstones (Mr). D. Agglutinated Foraminifera Mudstones (Mfa). E. Benthic Foraminifera Wackestones (Wfb). F. Echinoid Wackestones/Packstones (W/Pe). Scale bar = 500 µm.

Petrographically the Gramame Formation in the CIPASA Quarry consists of the following microfacies:

Planktonic foraminifera mudstones/wackestones microfacies (M/Wfp), with frequent occurrence of planktonic foraminifera. The planktonic/benthic foraminifera ratio is high. Radiolarians, calcisphaerulids, agglutinated foraminifera and echinoids fragments also occur (Figure 5 A-B).

Radiolarian mudstones microfacies (Mr), characterized by the common occurrence of radiolarians. The planktonic/benthic foraminifera ratio is still high. Calcisphaerulids are frequent while agglutinated foraminifera and echinoids fragments are rare or absent (Figure 5C).

Agglutinated foraminifera mudstones microfacies (Mfa), characterized by the common occurrence of agglutinated foraminifera. The planktonic/benthic foraminifera ratio is still high. Calcisphaerulids are frequent while radiolarians and echinoids fragments are rare or absent (Figure 5D).

Benthic foraminifera wackestones microfacies (Wfb), characterized by the common occurrence of calcareous benthic foraminifera. The planktonic/benthic foraminifera ratio is low. Echinoids fragments are frequent while radiolarians, agglutinated foraminifera and calcisphaerulids are rare or absent (Pl. 3 E).

Echinoid wackestones/packstones microfacies (W/Pe), with the abundant occurrence of echinoids fragments. The plankontic/benthic foraminifera ratio is low. Radiolarians, agglutinated foraminifera and calcisphaerulids are rare or absent (Figure 5F).

In the CIPASA Quarry, the M/Wfp is the main microfacies type, while the others present a very sparse distribution. The Wfb and W/Pe microfacies usually occur macroscopically as an undifferentiated bed.

Chemical and petrographic analyses indicate two intervals strongly affected by diagenetic dolomitization processes. The first one is from 6.0 to 11.0m, whereas the second is from 13.5 to 22.0m (Figure 2).

6 Chemostratigraphy

The $\delta^{18}O$ and $\delta^{13}C$ stable isotope curves, based on bulk rock samples, show a strong positive correlation with the Mg curve, which indicates that the isotope record has been heavily altered by diagenetic processes, and thus can not be longer considered as a primary oceanographic signal (Figure 2).

The Ca and Si curves show clear opposite behaviors, which indicates a strong negative correlation between Ca and Si (and others lithophile elements) (Figure 2). The Ca and Si curves also show three different trends that are approximately correlated to calcareous nannofossils subzones.

Chemical analysis also shows high phosphate concentrations, about 1.5%, at the interval 24.0-31.0m (Figure 2).

According to the chemical and petrographical data, during the Maastrichtian the Pernambuco-Paraíba Basin was subject to hot and dry climatic conditions with very low siliciclastic input, which gave rise to the development of a pelagic carbonate ramp setting.

7 Sequence Stratigraphy

Within Subzone CC25B, a marked positive anomaly of the P_2O_5 values is observed, which is related to sediment accumulation enriched with authigenic phosphates. This level is associated with a maximum flooding surface, characterized by low sedimentation rates, due to the increasing distance or drowning of source areas in response to a relative sea level rise (Lima, 2002).

The entire section corresponds to a third order sequence organized into a Transgressive Systems Tract (TST) succeeded by a Highstand Systems Tract (HST), with thicknesses up to 35 m and duration of over 4.6 Ma (Figure 3).

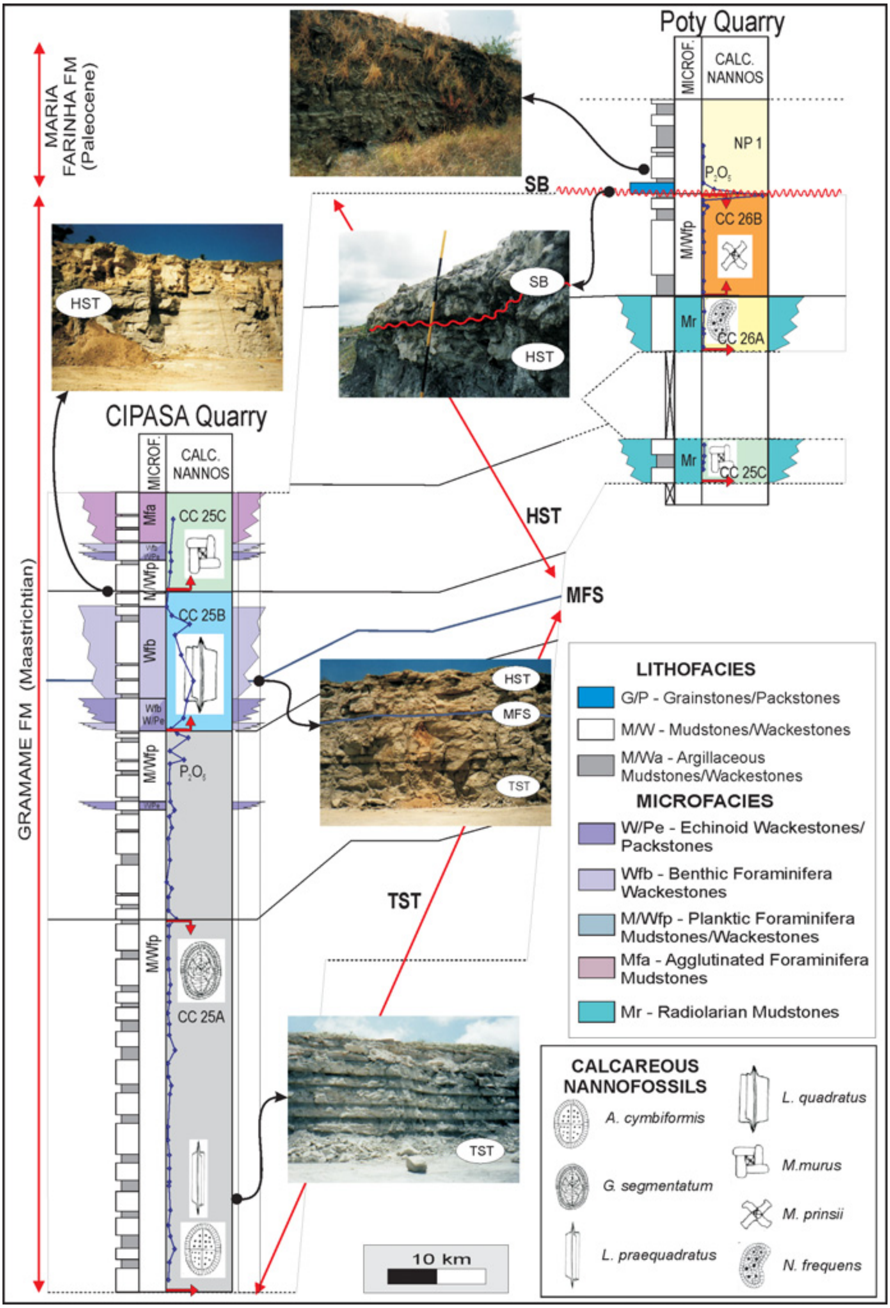

Figure 6 Stratigraphic correlation between the CIPASA and POTY quarries, showing the facies and third-order sequence systems tracts for the Gramame Formation (Maastrichtian).

8 Concluding Remarks

A high resolution calcareous nannofossil biostratigraphic study has been carried out, allowing to subdivide the studied section into three subzones of Maastrichtian age: CC25A, CC25B, and CC25C. Foraminiferal analyses in thin sections assigns the whole section to the KS 30 Zone. Each biostratigraphic unit was further characterized by petrographic (M/Wfp, Mfa, Wfb and W/Pe microfacies), geochemical and ichnological (*Glossifungites* ichnofacies) parameters.

According to the obtained results, during the Maastrichtian the Pernambuco-Paraíba Basin was characterized by a dry and warm climate with low influx of terrigenous sediments. These conditions allowed the widespread development of a carbonate ramp system in an outer neritic to bathyal setting, with deposition of alternating calcareous mudstones and argillaceous mudstones.The CIPASA section consists of part of a third order deposicional cycle, which is arranged in a transgressive systems tract and a highstand systems tract. The maximum flooding surface was recognized by a huge anomaly of the P_2O_5 values, which is related to sediment accumulation enriched with authigenic phosphates.

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