Cour. Forsch.-Inst. Senckenberg | 244 | 47–59 | 8 Figs., 3 Pls. | Frankfurt a. M., 29. 12. 2003

# Biofacies development related to upwelling systems based on high-resolution biostratigraphic studies in southwest Venezuela

8 figures and 3 plates

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## Abstract

New studies show evidence of repetitive upwelling events taking place in the southwestern Tethys margin from the Turonian through the Maastrichtian. On the basis of comparative analyses of sedimentological and biotic characteristics, seven subcropping sections from along the northern border of the Barinas Basin, southwestern Venezuela are interpreted environmentally. Zones II and III of the upwelling model (JONES et al. 1983) were found to be represented by the sections.

The presence of laminated dark shales, phosphate pellets, abundant fish debris, glauconite, diatoms, radiolaria, dinoflagellates, and biogenic chert, support the upwelling model within a continental shelf, with the upwelling centre located over the mid-inner shelf.

The following biofacies are established: Planktic Foraminifers Biofacies (Key Association LCL) associated to light yellow glauconitic wackestones-mudstones, suggesting high productivity and well oxygenated marine conditions; Buliminids and Planktic Foraminifers, Diatoms, Radiolaria and Calcareous Nannoplankton Biofacies in dark grey calcareous shales with wackestones-mudstones (Key Association DCS) that we associated with Zone III; Diatoms, Radiolaria and Dinoflagellate Biofacies in dark grey shales and dolomites interstratified with yellow-brown sandstones and black phosphorites, indicative of Zone II, see fig. 5 (Key Association LSS); and Fish debris Biofacies in phosphorites and dark grey shales, associated with Zone III (Key Association P).

Low diversity and high abundance assemblages, typical of opportunistic species characterise the microfaunal associations. These assemblages are considered survivors of anoxic to dysoxic conditions due to the upwelling. The subsequent high productivity conditions, associated to high salinity and low oxygen level of the water mass, result in high mortality which is reflected by the presence of fish debris and phosphate nodules.

The biofacies succession shows a tendency of the upwelling to have changed from more distal during the Turonian-Coniacian to more proximal environments during the Santonian-Maastrichtian.

**Keywords:** Tethys, Upper Cretaceous, Venezuela, nannofossils, dinoflagellate cysts, foraminifera

## Resumen

Nuevos estudios muestran evidencia de repetitivos eventos de upwelling que ocurrieron en el margen suroccidental de Thetys, desde el Turoniense hasta el Maastrichtiense. Basado en los análisis comparativos de características sedimentológicas y biológicas, han sido interpretadas las zonas II y III del modelo de upwelling (JONES et al. 1983). Estos estudios se realizaron en siete secciones de subsuelo, ubicadas a lo largo del flanco sur andino de la cuenca de Barinas, Venezuela suroccidental.

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La presencia de lutitas oscuras laminadas, pelets de fosfato, y abundantes restos de peces, glauconita, diatomeas, radiolarios y dinoflagelados, asi como abundante chert biogénico, soportan el modelo de upwelling dentro de una plataforma continental, estando el centro del upwelling localizado entre la plataforma interna y media.

Se establecieron las siguientes biofacies:
*Biofacies de Foraminíferos Planctónicos*, asociados con calizas glauconíticas de tipo wackestone – mudstone de color amarillo claro, lo cual sugiere condiciones marinas de alta productividad y buena oxigenación (Asociación Clave LCL); *Biofacies de Buliminidos, Foraminíferos Planctónicos, Diatomeas, Radiolarios y Nanoplancton Calcáreo*, asociada con lutitas grises oscuras calcáreas y calizas de tipo wackestone-mudstone, la cual se asocia a la zona III (JONES ET AL.1983), (Asociación Clave DCS); *Biofacies de diatomeas, radiolarios y dinoflagelados* asociados a lutitas oscuras siliceas laminadas, con intercalaciones de areniscas marrón claro y fosforitas oscuras, dolomitas, la cual se asocia a la zona II (Asociación Clave LSS) *Biofacies de restos de peces*, asociadas con fosforitas y lutitas gris oscuro, la cual se asocia *con la* zona III (Asociación Clave P).

Conjuntos de baja diversidad y alta abundancia típicos de especies oportunistas, son características en estas asociaciones. Estos conjuntos se consideran sobrevivientes de condiciones anóxicas a disóxicas, generadas por el upwelling.

Las condiciones de alta productividad, asociadas con alta salinidad y bajos niveles de oxígeno de la masa de agua, resultan en alta mortalidad reflejadas por la presencia de abundantes restos de peces y nódulos de fosfato.

La localización del upwelling como lo indica la sucesión de biofacies, muestra una tendencia que va desde zonas más distales durante el Turoniense-Coniaciense hasta zonas más proximales durante el Santoniense-Maastrichtiense.

## Zusammenfassung

Neue Untersuchungen belegen, daß sich am im der Tethys Südrand vom Turon bis zum Maastricht Auftriebsbedingungen eingestellt haben. Auf der Grundlage vergleichender Analysen sedimentologischer und paläontologischer Charakteristika wurden sieben Profile am nördlichen Rand des Barinas-Becken, SW Venezuela, interpretiert, welche die Zonen II und III des Auftriebs-Modells (JONES et al. 1983) repräsentieren.

Das Vorhandensein von laminierten dunklen Tonmergeln, phosphatischen Pellets, zahlreichen Fischresten, Glaukoniten, Diatomeen, Radiolarien, Dinoflagellaten und biogenem Kieselschiefer unterstützt das Auftriebs-Modell innerhalb eines kontinentalen Schelfs, wobei das Auftriebs-Zentrum im mittleren Innenschelf liegt.

Folgende Biofazies-Typen wurden aufgestellt: Planktische Foraminiferen Biofazies (Assoziation LCL), assoziiert mit hellgelben glaukonitischen Wacke-/Mudstones, die auf eine hohe Produktivität und gut durchlüftete marine Bedingungen hinweisen; Biofazies mit Buliminiden und planktischen Foraminiferen, Diatomeen, Radiolarien und kalkigem Nannoplankton in dunkelgrauen kalkigen Tonmergeln mit Wacke-/Mudstones (Assoziation DCS), die wir mit der Zone III assoziieren; Biofazies mit Diatomeen, Radiolarien und Dinoflagellaten in dunkelgrauen Tonmergeln und Dolomiten mit eingeschalteten gelbbraunen Sandsteinen und schwarzen Phosphoriten, die auf Zone II (Abb. 5) hinweisen, (Assoziation LSS); und Biofazies mit Fischresten in Phosphoriten und dunkelgrauen Tonmergeln, assoziiert mit Zone III (Assoziation P).

Die Vergesellschaftungen werden durch geringe Diversität und hoher Häufigkeit, die typisch für opportunistische Arten sind, charakterisiert. Sie gelten als Überlebende anoxischer bis dysoxischer Bedingungen, die während des Auftriebs herrschten. Die nachfolgenden Bedingungen hoher Produktivität im Zusammenhang mit hoher Salinität und niedrigem Sauerstoffgehalt der Wassermassen ergeben eine hohe Sterblichkeit, die sich im Vorhandensein von Fischresten und Phosphatkügelchen widerspiegelt.

Die Biofaziesabfolge legt eine Entwicklung des Auftriebs nahe, sich von einer mehr distalen Position während des Turon-Coniac zu einer mehr proximalen Position während des Santon-Maastricht verlagert zu haben.

**Schlüsselworte:** Tethys, Oberkreide, Venezuela, Nannofossilien, Dinoflagellatenzysten, Foraminiferen

## Introduction

We present recent biostratigraphic studies from the Southwestern Venezuelan Cretaceous which show evidence of several upwelling events. The lithology and the abundance and diversity of nannofossils, foraminifera, dinoflagellates, and other fossils, show that the zones II, III, and IV of the upwelling model of JONES et al. (1983) are represented.

The coastal upwelling model of JONES et al. (1983) that we used, relates to the effect of longshore winds due to Ekman forcing transport surface waters away from the coastline (seaward) inducing subsurface waters to flow upward to replace these removed surface waters (fig. 1). It explains the response in space and time of plankton to nutrient fields generated during an upwelling event.

This model describes the biological responses and the patterns which may change rapidly (on scales of hours to days). Normally, we are not able to see these patterns preserved in modern sediments, at least not in the detail suggested by the diagram, because the zones are constantly shifting in response to wind conditions. None the less, we

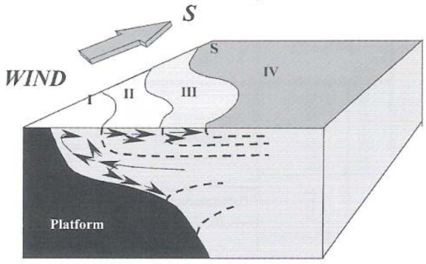



**Fig. 1:** Upwelling model modified from JONES ET AL. (1983). I Intense Upwelling; II Abundant Diatoms and Radiolaria; III Diatoms, Foraminifera, Nannoplankton and Dinoflagellates; IV Decreased biomass, mixed phytoplankton and zooplankton.

can predict a gentle gradient away from persistent upwelling plumes, with the area directly beneath the plume usually richer in diatoms and radiolaria. However, we have to consider that the combination of sedimentation

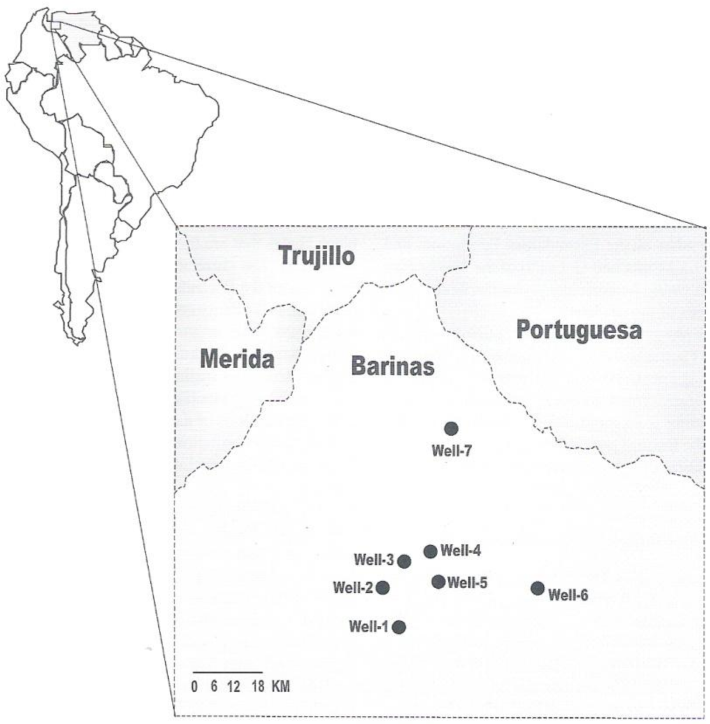



**Fig. 2:** Location map of the studied area.

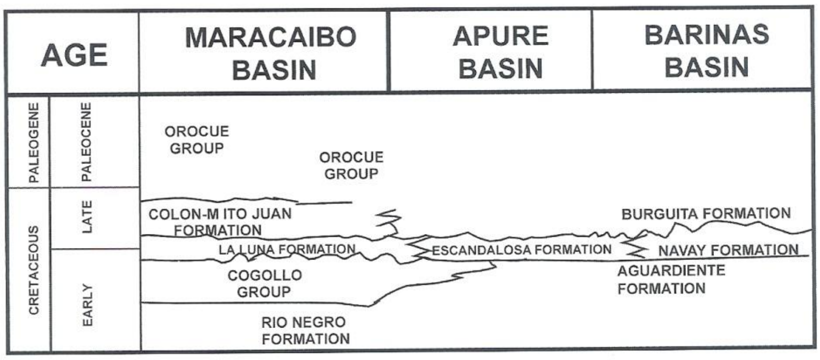



**Fig. 3:** Generalised stratigraphic relations of the Upper Cretaceous Units in Western Venezuela (From information in KISSER 1989; COONEY & LORENTE 1997).

and diagensis in the upper few meters of the seafloor can greatly modify the original plankton input, even though it is possible that such patterns might be preserved in shallow water platform conditions as we show in this paper.

The studied area is the Barinas-Apure Basin, southern Venezuela (fig. 2). The tectonic history of the basin is characterised by a preliminary phase (Jurassic to Late Cretaceous) of progressive evolution. This is related to an extension of the Caribbean-Tethyan passive margin at the edge of the South American plate, attributed to the fragmentation of Pangaea. In the Barinas-Apure Basin, this initial phase is represented by transgressive facies of the Guayacan Member of the Escandalosa Formation, and the Members La Morita and Quevedo of the Navay Formation, which would be correlated with the world-wide eustatic changes of the sea level.

This initial phase was followed by collision and obduction of the Pacific Volcanic Arc with the South American plate, during Late Cretaceous-Paleogene time (fig. 7). The collision transformed the passive margin into an active belt, creating a foreland basin with an associated forebulge in the Barinas area, where regressive facies of the Burguita Formation were deposited (PARNAUD et al. 1995), (fig. 3).

## Geological Framework

The tectonic history of the Barinas-Apure Basin, from the Jurassic to the late Cretaceous, is marked by a progressive evolution starting with an extension of the Caribbean-Tethyan passive margin. A diachronic extensive marine invasion beginning at the end of the Albian reached the southwestern area of the basin during the Turonian, which had been emerged probably in Paleozoic times. This marine invasion correlates well with the transgression during the Late Cretaceous registered in Europe and North America, characterised by the abundance of "black shale facies" that makes this stratigraphic interval one of the richest in source rocks worldwide. The maximum transgression and anoxia occurred between the Turonian and the Campanian.

In western Venezuela, this time interval corresponds to the Escandalosa, Navay and La Luna Formations. The Navay Formation is a lateral equivalent of La Luna Formation in the Barinas-Apure Basin, and this initial phase is represented by the transgressive facies of the Guayacan Member of the Escandalosa Formation and by the La Morita and Quevedo Members of the Navay Formation. The La Luna Formation consists of 50 to 100 m thick black shales that are the richest source rocks of western Venezuela. The correlation chart is given in fig. 3. The thickness of the Escandalosa Formation varies from 150 to 427 m. It is mainly composed of quartzitic glauconitic sandstones with minor amounts of black calcareous shales. KISSER (1989) described this unit in subcrops of the Barinas-Apure Basin. The Guayacan Member is characterised by grey bioclastic, very fossiliferous limestones with intercalations of dark grey shales and siltstones.

The Navay Formation has two well differentiated units in the area known as La Morita and Quevedo Members (fig. 4).

The La Morita Member consists of 150-180 m of dark grey shales, locally calcareous shales with phosphatic pellets and fish remains in some levels. The Quevedo Member consists of 180 to 210 m of siliceous, light-coloured shales (white to cream) in outcrops but dark grey to light brown in subcrops, with variable amounts of intercalated cherts as well as fossils and phosphatic remains (spines, and other fish remains).

This initial phase was followed by the collision and obduction of the Pacific Volcanic Arc with the South American Plate, during Late Cretaceous-Paleogene time. The collision transformed the passive margin into an ac-

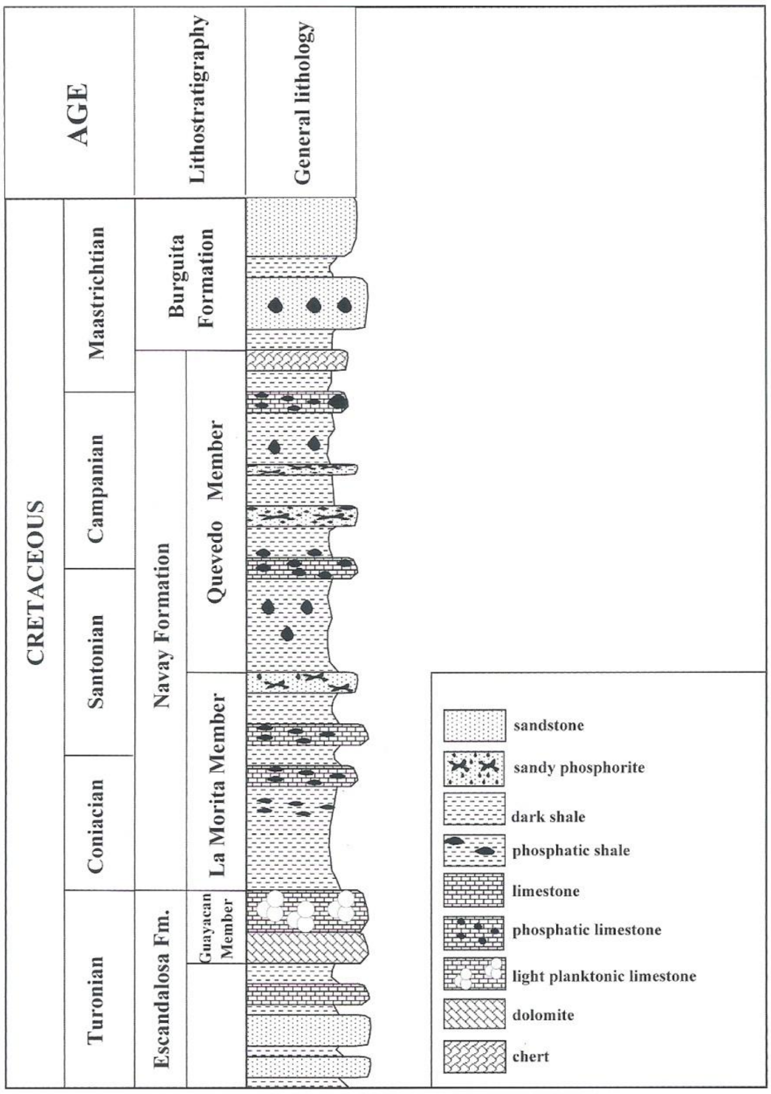



**Fig. 4:** Stratigraphic column in the studied area of the Barinas Basin.

tive belt, creating a foreland basin with an associated forebulge in the Barinas area, where the regressive facies of the Burguita Formation were deposited (PARNAUD et al. 1995). The Burguita Formation consists of more than 350 m of light grey, fine grained micaceous sandstones and siltstones that may be glauconitic and calcareous, with dark grey shale intercalations in surface sections (RENZ 1959) and an average thickness of 73 m in subsurface sections FEO-CODECIDO (1972). This variation in thickness is due to differential erosion.

## Methods

High resolution stratigraphical, biostratigraphical and lithological analyses of the Turonian-Maastrichtian section were carried out on cuttings and core samples from all the rock types (limestones, phosphorites, sandstones, and shales) in seven subcropping sections (wells 1 to 7 in figs. 5, 6). These analyses included the study of foraminifera, calcareous nannoplankton, and palynology.

Standard methods were used for sample preparation of loose residues for foraminiferal studies. Thin sections of selected rock chips were also prepared for petrographic studies in order to identify the foraminifera embedded in the sediment which otherwise are difficult or impossible to detect in loose samples and are extremely important for chronostratigraphy. Lithological descriptions and sedimentological observations were made of all the samples. In total, foraminifera analyses of washed residues and thin-sections as well as calcareous nannoplankton and palynological analyses were performed on 200 cutting samples and 14 core samples; the counts also included other groups observed in the samples, such as diatoms and radiolaria. Geochemical analyses (TOC and Rock Eval pyrolysis) were carried out on 140 cutting samples. For the maceration of palynological samples, the conventional methodology used in our laboratories and described in BARSS et al. (1993) was applied. For the palynological analysis all palynomorphs observed were counted. The preparation of samples for calcareous nannoplankton studies followed the conventional method used in our laboratories: It includes a desegregation of the sample and then the suspension of this material using distilled water and finally the concentration of the suspended material used for the slide. As for the abundance of nannofossils this was based on the counts of all the specimens observed on one slide for each sample. For the analysis of nannoplankton a nannofacies methodology was applied (DURÁN 1996). This is based on semi-quantitative counts of all the elements present in the slide in addition to nannofossils, such as minerals (e.g., glauconite, pyrite), coal and various types of organic matter, and other biological components indicative of marine environments (dinoflagellates, diatoms, foraminifera). With this method it is possible to establish palaeoenvironmental tendencies, based on abundance peaks of terrestrial and marine components.

## Results

Low diversity and high abundance assemblages typical of opportunistic species characterise the microfaunal associations. Those assemblages are considered survivors of anoxic to partially anoxic conditions due to the upwelling. The high-productivity conditions and associated increased salinity and low oxygen level of the water mass resulted in a high mortality reflected by the presence of fish debris and phosphate nodules.

This palaeontological and lithological evidence indicates a coastal upwelling system within a broad continental shelf, similar to the West African margin. The evolution of the upwelling shows an offshore migration of the zones, from the Turonian through the Coniacian – Santonian interval, with a maximum preserved productivity in the Turonian interval.

There is a change in the nature of the platform sedimentation from phosphate-rich to silica-rich from the Coniacian to the Maastrichtian, indicating variations in the palaeoceanography of the latest Cretaceous south western Tethys platform, probably related to the closing of the Barinas Basin Gulf.

Based upon the lithological descriptions, foraminifera, diatoms, radiolaria, fish fragments, nannoplankton, dinoflagellates, and phosphate contents, four biofacial key associations were identified. Three of these associations are correlative to the Jones Model for upwelling in the northern Andean Turonian-Maastrichtian section. The key associations are characterised as follows (representative microfossils are shown in pls. 1-3):

### Key Association P "Phosphorites" = Biofacies 1

Lithology: dark grey shales and phosphorites. The biological association is mainly composed of fish teeth, bone fragments, scales, phosphate nodules, scarce buliminid forams and some specimens of *Astacolus* sp., *Quadrum* sp., *Watznaueria* sp., and *Micula* spp. nannoplankton platform assemblages, associated with P>G (Peridinioids > Gonyaulacoids) dinoflagellate assemblages. The TOC varies from 0.81-2.80%. We correlate this association with upwelling **Zone III** (JONES et al. 1983).

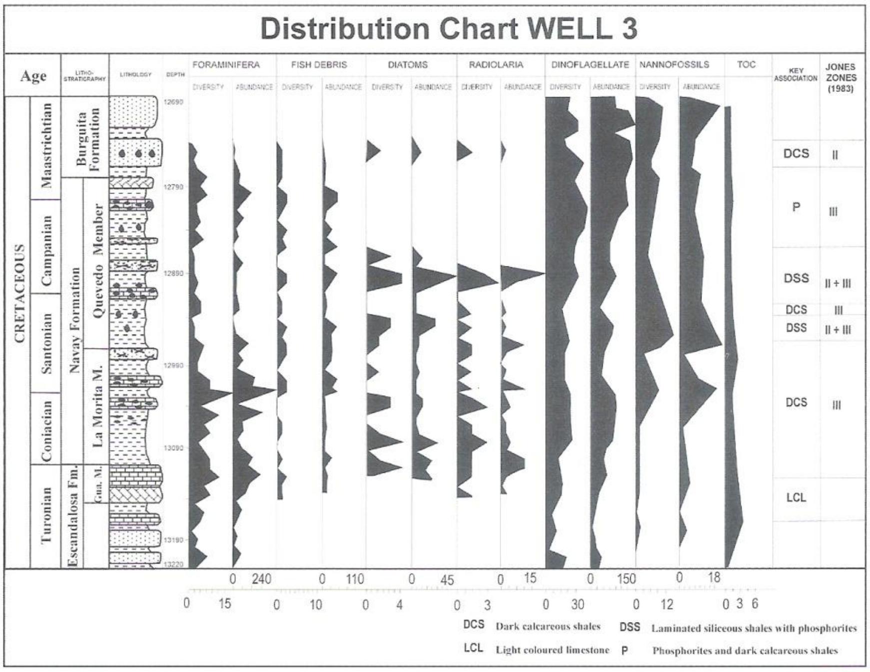
### Key Association DCS "Dark Calcareous Shales" = Biofacies 2

Lithology: dark grey mainly laminated shales and partially dolomitised limestones.

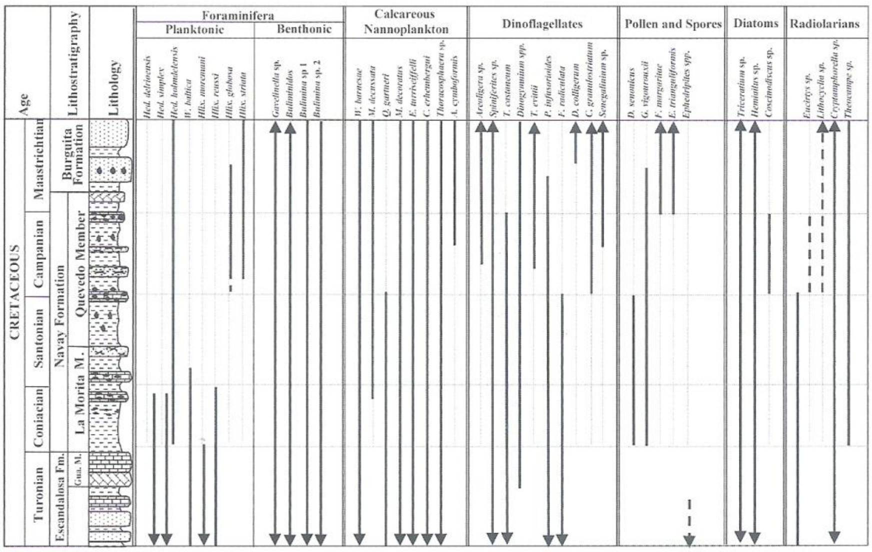
The biological association contains abundant benthic and planktic forams represented by buliminids and some specimens of *Gavelinella* sp., *Gyroidina* sp., *Heterohelix* sp., and *Hedbergella* sp.; low diversity assemblages of diatoms and radiolaria; diagenetically deteriorated very poor *Micula* spp. nannoplankton assemblages alternating with P>G (Peridinioids > Gonyaulacoids) dinoflagellate assemblages and phosphate nodules. The TOC varies from 0.21-4.6%. We correlate this association with upwelling **Zone III** (JONES et al. 1983).

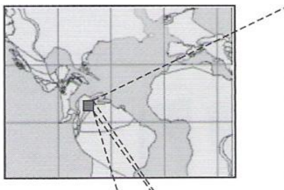
**Fig. 5:** Abundances and diversity patterns of the fossil groups studied, the TOC variation, the associated key associations and their correspondence with the upwelling model of JONES at al. (1983). Lithology as for fig. 4.

**Fig. 6:** Range chart of the most relevant species of the different fossil groups used in this study. Lithology as for fig. 4.




## Biostratigraphic assemblages in the studied interval





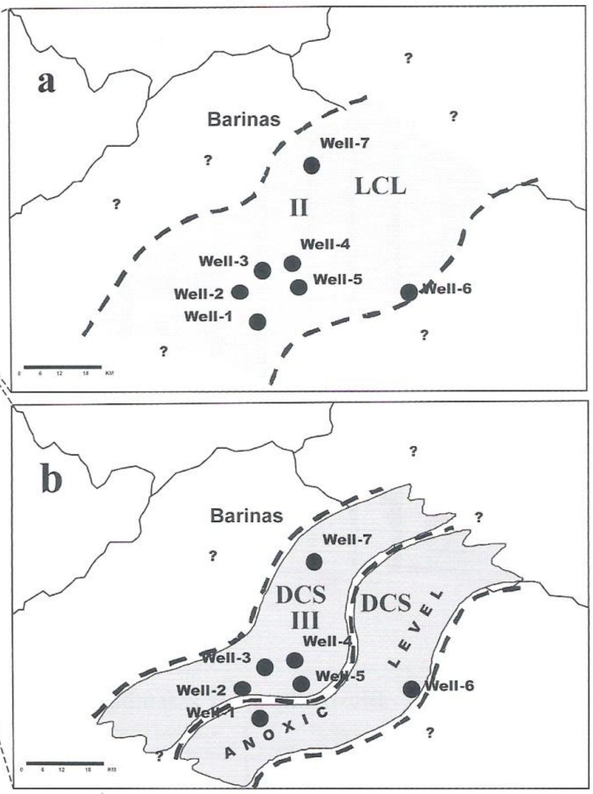



**Fig. 7:** Distribution of the continents during the Late Cretaceous. a) Palaeogeographic map with the distribution of the key associations and its relation to the upwelling system model during the Turonian (Guayacan Member of the Escandalosa Formation). b) Palaeogeographic map with the distribution of the key associations and its relation to the upwelling system model during the Coniacian-Santonian (La Morita Member of the Navay Formation). For further information (Fig. 7, 8): http://odsn.de/odsn/services/paleomap/animation.html.

**Key Association LSS**
**"Laminated Siliceous Shales" = Biofacies 3**

L i t h o l o g y: dark grey mainly laminated shales and bedded chert. The biological association contains predominantly diatoms and radiolaria, scarce planktic and buliminid forams, *Thoracosphaera* sp. and *Watznaueria* sp. nannoplankton associations, and P>G (Peridinioids > Gonyaulacoids) dinoflagellate assemblages. The TOC varies from 0.98-1.61%. We correlate this association with upwelling **Zone II** (JONES et al. 1983).

**Key Association LCL**
**"Light Colour Limestones" = Biofacies 4**

L i t h o l o g y: represented by recrystalised, partially dolomitised light limestones interstratified with black shales. The biological association contains very abundant, low-diversity planktic foraminifera assemblages represented by the genera *Hedbergella* sp., *Heterohelix* sp., and *Whiteinella* sp., with very low-abundance benthic assemblages represented by scarce buliminids alternating with P=G or G>P (Gonyaulacoids > Peridinioids) dinoflagellate assemblages. No nannoplankton or extremely poor *Watznaueria* sp. assemblages were present. The TOC varies from 0.17-4.7%.

No correlation with the model of JONES et al. (1983) was possible. This association represents periods of high productivity under well oxygenated normal marine conditions which alternated with poorly oxygenated periods and the sequence could not be associated with the model (figs. 5, 6).

**Upwelling Evolution in the Barinas Basin**

Based on these key associations, four maps were made in order to show the spatial distribution of the upwelling system in the studied area (figs. 7, 8).

The studied sequence begins within the Turonian, characterised by a light-coloured limestone interstratified with black shales, which corresponds to times of en-

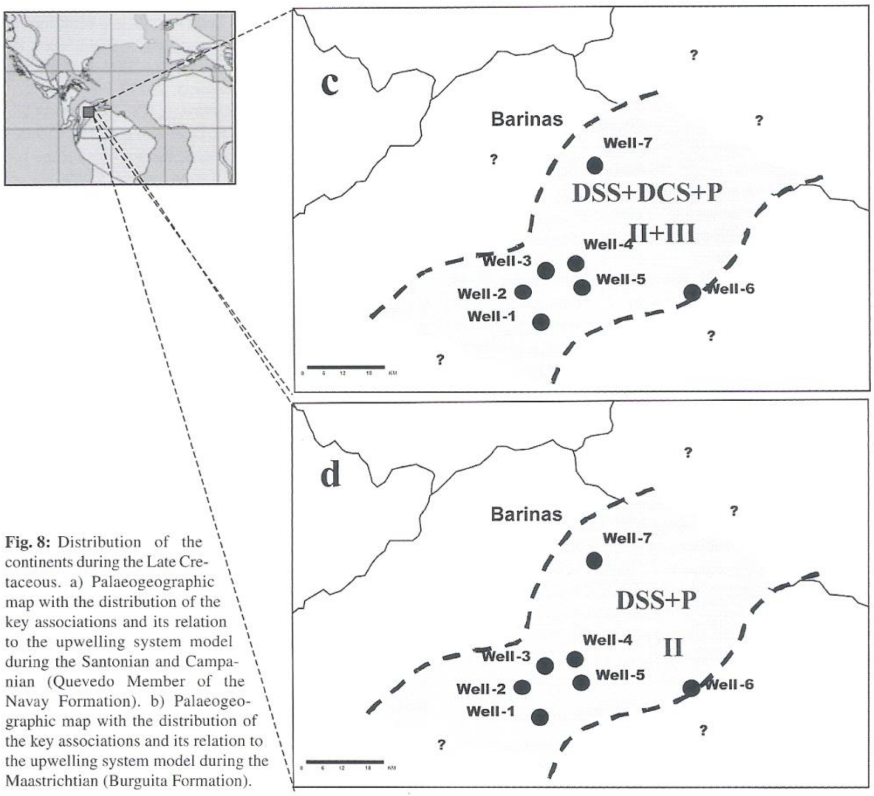



**Fig. 8:** Distribution of the continents during the Late Cretaceous. a) Palaeogeographic map with the distribution of the key associations and its relation to the upwelling system model during the Santonian and Campanian (Quevedo Member of the Navay Formation). b) Palaeogeographic map with the distribution of the key associations and its relation to the upwelling system model during the Maastrichtian (Burguita Formation).

hanced surface water productivity under eutrophic conditions (Key Association LCL). It belongs to the Guayacan Member of the Escandalosa Formation which spreads over all the studied area (fig. 7a). These open marine conditions tend to increase to the southwest according to the lithologic and biostratigraphic features observed in the samples.

During the Coniacian-Santonian (fig. 7b), this limestone was overlain by laminated calcareous dark shales (Key Association DCS), deposited under anoxic to dysoxic (oligotrophic) conditions, with fossil faunas characterised by high abundance, low diversity and small size benthic and planktic foraminifera, corresponding to the La Morita Member of the Navay Formation, which represents one of the most important maximum flooding surfaces defined in the Barinas-Apure Basin (Parnaud et al. 1995). One of the main characteristics of this level is the total anoxia in certain areas of the basin, indicated by total absence of benthic and planktic organisms. This event could be correlated with the global event OAE2 (Oceanic Anoxic Event) (Premoli Silva 1999) which corresponds with the Cenomanian-Turonian boundary, and the authors propose to nominate it OAE2a or Morita Anoxic Event in the Barinas Basin.

During the Santonian-Campanian, the upwelling system shows a sequence of mainly laminated dark siliceous shales intercalated with cherts, phosphorites, thin phosphatic limestones, and sandstones (Key Associations LSS and P), an abundant association of diatoms and radiolaria is present as the major indicators of eutrophic conditions and high productivity (Douglas 1998). It corresponds to the Quevedo Member of the Navay Formation (fig. 8a). This interval is associated with the proximal Zone II with intercalations of phosphoritic facies which are associated with Zone III, located offshore on the shelf.

The Maastrichtian is represented by a sequence mainly characterised by sandstones intercalated with thinly laminated dark shales associated to the proximal Zone II (Key Association LSS). It corresponds to the Burguita Formation.

## Conclusions

- The alternation of four key associations based on faunal and floral assemblages, as well as on lithology and TOC content, characterises the Turonian – Maastrichtian section of the southwest Tethys Sea in the Barinas Basin area of Venezuela.
- The comparison of the associations described in this paper with the description given by JONES et al. (1983) for the upwelling model zones, shows striking coincidences with three of our four key associations: P, DCS and DSS.
- Key association LCL has no similarity with the above mentioned zones, and it has been interpreted as representing the sedimentation from a well oxygenated high-productivity marine water mass, not included in the upwelling model of JONES et al. (1983).
- The evolution of the upwelling in space and time shows a seaward migration of the zones from the Turonian through the Coniacian – Santonian, with a maximum productivity in the Turonian-Santonian interval.
- During the Santonian-Maastrichtian, the presence of siliceous (chert) and phosphatic-rich sediments, both characteristic products of high palaeoproductivity under eutrophic conditions, indicates changes in the palaeoceanography of the latest Cretaceous at the southwestern Tethys platform, probably related to the closing of the connection between the Tethyan Ocean and the Barinas Basin Gulf.

## Acknowledgments

The authors wish to thank PDVSA, Exploration and Production Management for permission to publish the results of numerous analyses conducted in connection with exploration operations. We also wish to thank Max Furrer for valuable help in preparing the manuscript. We are very grateful to Dr. J.Young, Dr. E. Erba and Dr. G. Versteegh for their suggestions and comments during the review of this paper.

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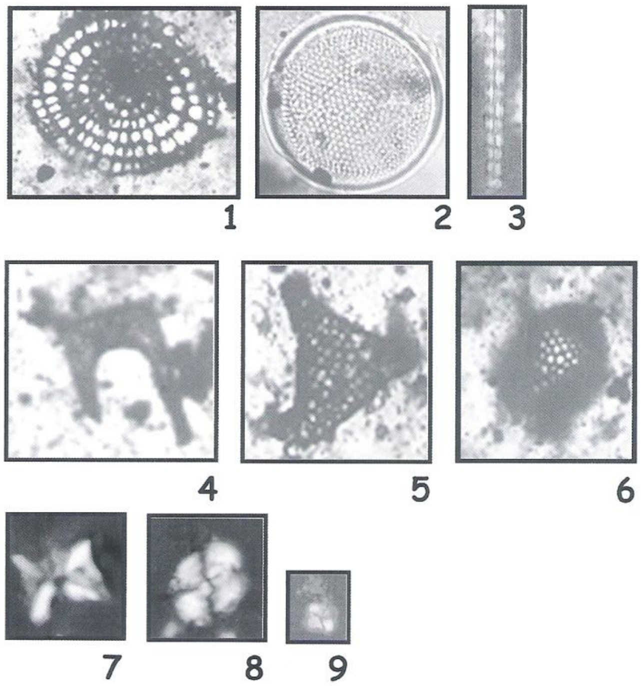
## Plate 1




Radiolaria, Diatoms, and Calcareous Nannoplankton

**Fig. 1:** *Lithocyclia* sp., X4000.

**Fig. 2:** . *Coscinodiscus* sp., X12500

**Fig. 3:** *Micrantolithus decoratus*, X11500.

**Fig. 4:** . *Hemiaulus* sp., X4000

**Fig. 5:** *Triceratium* sp., X4000.

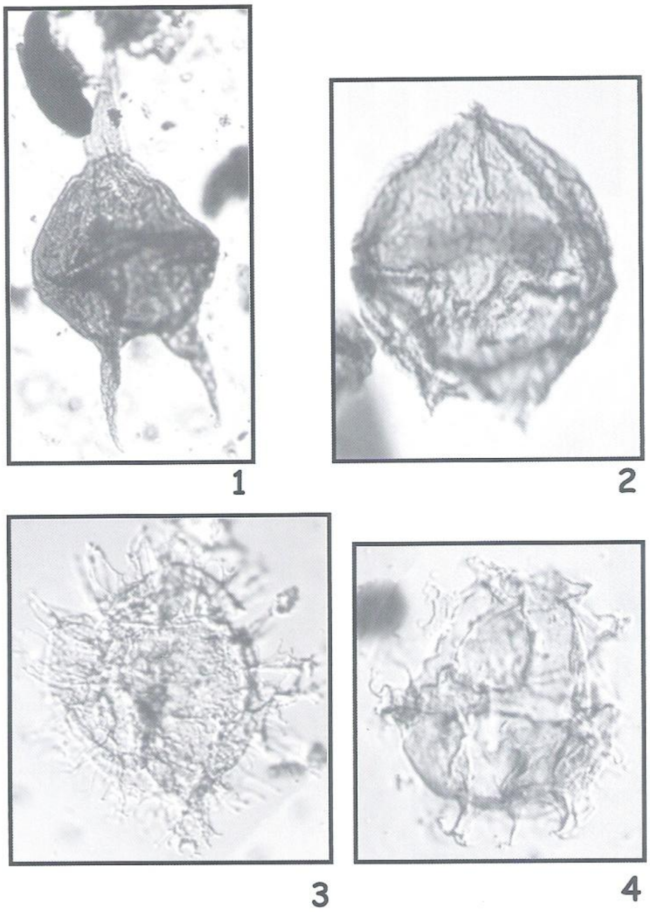
**Fig. 6:** . *Cryptamphorella* sp., X4000

**Fig. 7:** *Micula decussata*, X12500.

**Fig. 8:** *Watznaueria barnesae*, X12500.

**Fig. 9:** *Quadrum gartneri*, X12500.

## Plate 2



Dinoflagellates

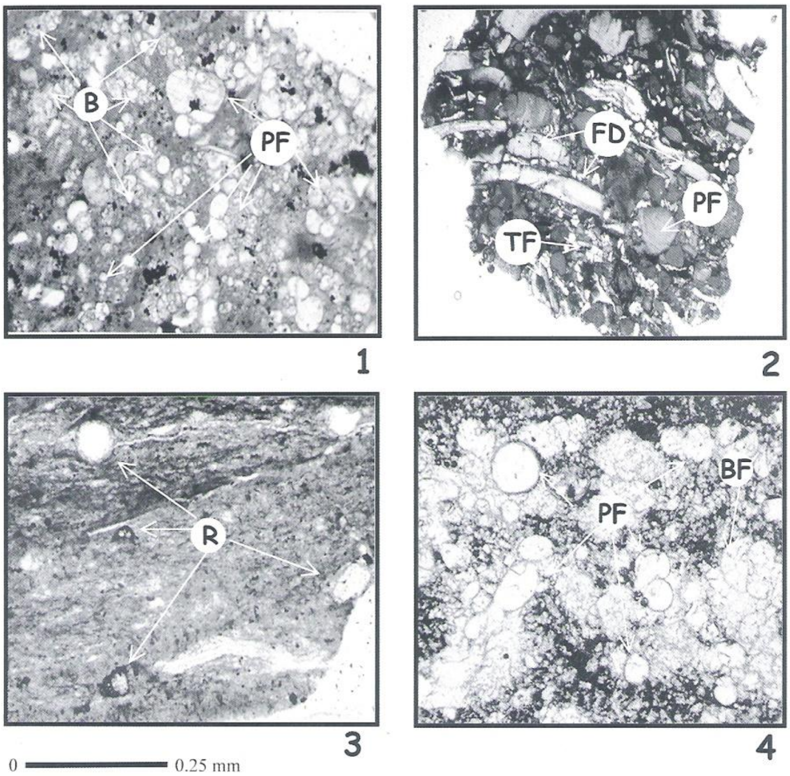
**Fig. 1:** *Cerodinium granulostriatum*, X700.

**Fig. 2:** *Senegalinium* sp., X800.

**Fig. 3:** *Areoligera* sp., X900.

**Fig. 4:** *Spiniferites* sp., X800.

## Plate 3




Microfacies of Navay Formation and Guayacan Member (Escandalosa Formation)

**Fig. 1:** Dark Calcareous Shales (DCS); **B**: Buliminids, **PF**: Planktic Foraminifera.

**Fig. 2:** Phosporites and Dark Calcareous Shales (P); **FD**: Fish Debris, **P**: Phosphates, **TF**: Fish Teeth.

**Fig. 3:** Laminate Siliceous Shales with Phosphates (LSS); **R**: Radiolaria

**Fig. 4:** Light Coloured Limestone (LCL); **PF**: Planktic Foraminifera, **BP**: Benthic Foraminifera.