Calcareous Nannoplankton Biostratigraphy in the Jurassic-Cretaceous boundary (Callovian to Berriasian) in a Southeast Tethyan Platform.

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Key Words
Nannofossils, Tampico-Misantla Basin, Upper Jurassic, Jurassic-Cretaceous Limit, Rio Apulco superficial section.

Abstract

Calcareous Nannoplankton had a high diversification interval during the Jurassic/Cretaceous boundary. We studied the Nannoplankton assemblage found in a land section near a platform zone at the southeastern portion of the Tethys, located today at Northern Puebla, México. The age of the samples spans from Upper Callovian to Upper Berriasian (161 to 132 Ma). 12 species of Calcareous Nannofossils where recorded. We found 4 index species valuable for biostratigraphy correlation. The dominant taxon was *Cyclagelosphaera margerelii* Noël, 1965. Four bioevents, one biozone and two sub-zones defined in previous studies, where recognized. The distribution, significance and paleoenvironmental implications of the recovered nannofossils where discussed and comparisons were made with other Tethyan Realm studies from a Placolith/Nannolith relation perspective. The abundance and diversity of nannoflora was poor in the Callovian to Oxfordian stages, becoming moderate in the Kimmeridgian and higher for the Tithonian to Berriasian stages. In the Upper Tithonian the Nannofossil appears accordingly to black shale sediments. A restricted to neritic paleoenvironment was interpreted in the Callovian to Oxfordian, neritic to basin during Kimmeridgian and from basin to abyssal for the Tithonian to Berriasian stages. The correlation and paleoenvironmental reconstruction potential of the Tampico Misantla Basin Calcareous Nannofossil in the Tethyan Realm was recognized.

Introduction

Nannofossil biostratigraphy isn't a usual theme for investigation in the central region of Mexico, mainly because the common sites for petroleum exploration are in the southeast states of the country, like Tabasco and Campeche. Given the lack of information about Calcareous Nannofossil biostratigraphy from the Jurassic-Cretaceous boundary in the study area (Rio Apulco´s section, northern Puebla), our paper shows some findings about Nannofossil biostratigraphy in these regions and aims to establish the biostratigraphy for the Callovian-Berriasian interval (Upper Jurassic-Lower Cretaceous) in the study area and correlate them with other studies from nearby sites.
The publication and access to biostratigraphy papers in our country has been limited by the petroleum companies that confidentially label them. Still we can find pioneer works within this field, like those from Trejo (1960), Stradner & Papp (1961), Trejo (1969), Abers (1981), Rodríguez (1981), Pierce (1985), Macías (1985), and Flores-Lopez (1987). The nearest location site to our study site is that of López-Caballero et al. (2007) but they work with Ammonites. A summary of Mexican micropaleontology could be found in Gio-Argáez & Yunuen-Rodríguez, (2003). There are unpublished papers about micropaleontology in the study area, like the work from Ornelas et al. (1997) where they describe the Foraminifera, Calpionelidae, Tintinidae and Radiolarian content of the study area sediments. The nannofossil biostratigraphy of this superficial section was described in a degree thesis by Avila (2005).

Rio Apulco superficial section.

The Río Apúlco section located in northeastern Puebla, on the banks of the river of the same name, on the central part of the Tampico-Misantla geological province is located at 19.96 N, 97.4 E. The nearest populated sites are Mazatepec, Cuetzalan and Hueyapan (Figure 1). The stratigraphic series of Tampico-Misantla basin rest on a basement described as "plutonic, igneous rocks, granodiorites and tonalites and in his lowest level by metamorphic and sedimentary rocks represented by red and blackened clastic lithology". Quezadas-Flores (1961) assigned a Permo/Triassic age by the analysis of the basement magmatic-tectonic relation. The Río Apúlco section is composed at this base with the Tepéxic formation, which is overlain by the Santiago, Taman, Pimienta and Tamaulipas Inferior formations. The ages of these formations span from the Callovian to Berriasian stages (Figure 1).The region we studied in the Tampico-Misantla basin was a marine setting with a variable sea level (Aguilera, 1972), located in the south-eastern portion of the proto-Atlantic, at the connection between Tethys and Proto-Pacific oceans. We present a Hypothetical paleomap with the localization of the study area in Tithonian times, about 150 million years (My) ago modified from Bornemman et al. (2003) (Figure 5).

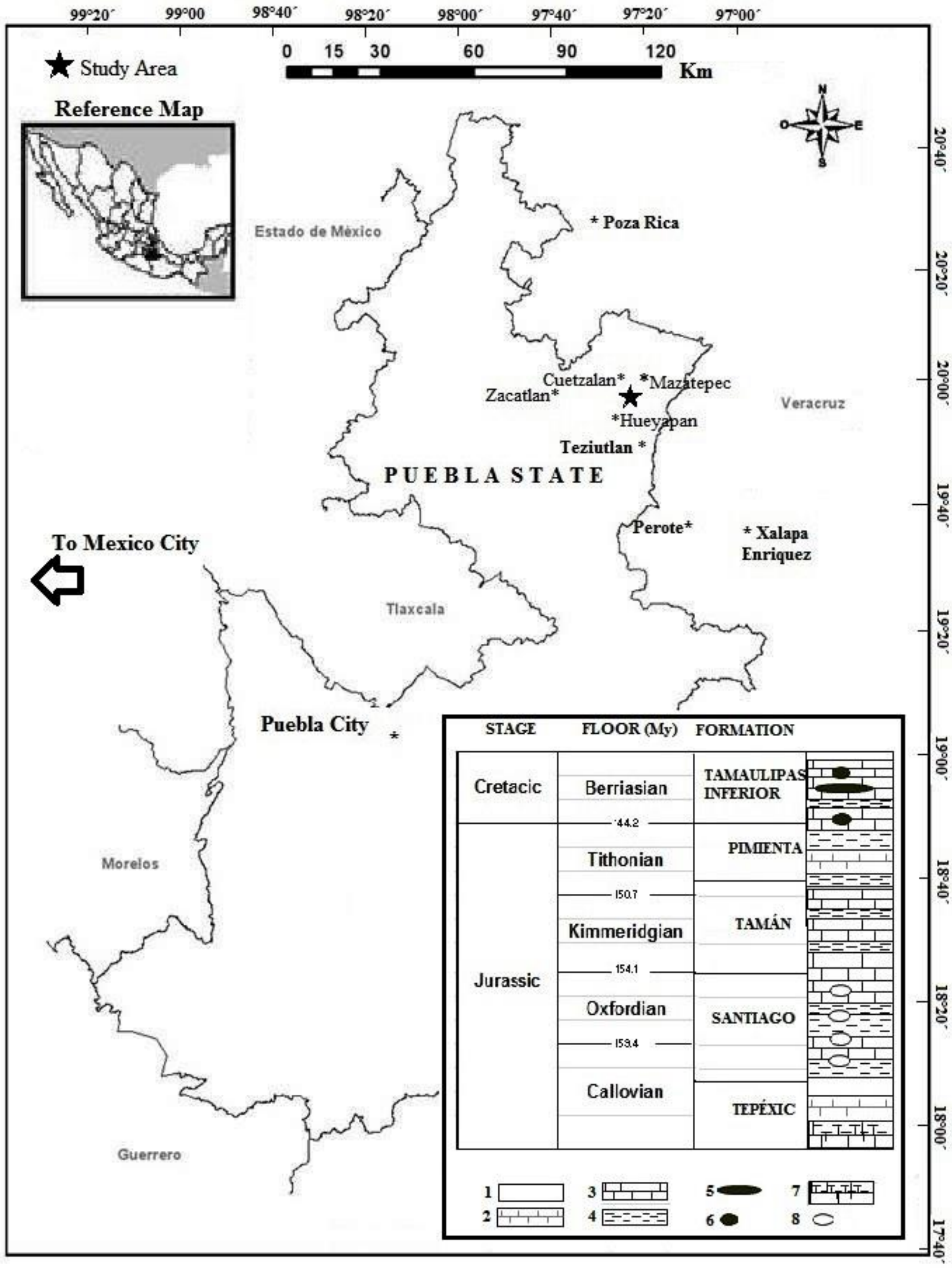

Figure 1. Location map of the studied section, in northern Puebla, México; modified from INEGI (2010). On the right bottom a simplified stratigraphic succession of the section modified from Ornelas et al (1997). Simbology: 1) Claystone, 2) Clayed Limestone, 3) Limestone,4)Lutite, 5) Pedernal band, 6) Pedernal lent;,7) Calcareous sandstone, 8) Calcareous nodule.

Materials and Methods

The samples were obtained from the Rio Apúlco section in accordance to lithological change by mechanical fracture at 10 to 50 cm intervals by Ornelas et al. (1997). From all the samples collected by them, we used 83 samples taken from the paleontology storage room of the Mexican Petroleum Institute (IMP) for this study; the stratigraphic position of each sample is defined according to Ornelas et al. (1997), for details see Fig. 2.
For the Nannofossil study, the samples where processed by standard technique as suggested by Taylor & Hamilton (1982).
For the quantification and taxonomic first approach of Calcareous Nannoplankton (CN) we use a Carl Zeiss polarizing microscope (PM) whit gypsum plate using a 100x oil objective. For definitive taxonomic identification and microphotography we use a PM Olympus BX51 microscope equipped with Olympus CBO40-ZOOM digital camera. A smear slide for each sample was processed and a Nannofossil was counted in 50 fields of observation in each sample at 1250x using polarized light microscopy (PLM) and natural light microscopy (NLM) making 5 horizontal transects of 10 fields above the central blur obtained on every smear slide.
The abundance classes where based on Bown and Young (1998) and adapted to 50 fields of observation for this study, considering as common (C) from 5 to 49 nannofossil per sample (the same for individual species or total nannofossil abundance), scarce (S) from 2 to 4 nannofossil and rare (R) where there is only 1 nannofossil in a sample.
The taxonomy in this study is based mainly on Perch-Nielsen (1985), Bown and Copper (1998) and Bown et al.(1998); further taxonomic information was derived from the following papers: Trejo (1960, 1969), Nöel (1965), Boudreaux (1967), Bukry (1969), Thierstein (1971,1973,1976), Farinacci (1976), Wise and Wind (1977), Aita and Okada (1986), Jakubouski (1986), Bown (1987), Bown and Cooper (1989), Bralower et al. (1989), Kaenel & Bergen (1996), Melinte (1997), Bown et al. (1998), Burnett et al.(1998), Concheryo & Wise (2001) and in Lozar and Tremolada (2003). The classification of nannofossil was based upon Bown and Young (1997). The biozones used in this study are from Thierstein (1976), Roth et al.(1982, 1986), Bralower et al. (1989), Kaenel et al. (1996) and Casellato (2010).

Results

Systematic Paleontology

We present taxonomic features of CN species found in this study; we revised and compared them from several studies to avoid taxonomic uncertainty.
Kingdom Chomista Cavalier-Smith, 1981
Phylum Haptophyta Hibberd ex Cavalier-Smith, 1986
Class Prymnesiophyceae Hibberd, 1976
Family Eoconusphaereceae Kristan-Tollman, 1988
Genus *Conusphaera* Trejo 1969
***Conusphaera mexicana* Trejo,1969 ssp. *mexicana* Bralower,1989**

(Pl. I, No. 1)

1965 Particule calcaire Noël, pl. 28, Figs. 7 & 9.
1969 *Conusphaera mexicana* sp. nov. Trejo, pl.I, Figs.1 & 2; pl. II, Figs. 1 & 2.
1976 *Conusphaera mexicana* Thierstein , pl. II, Figs.26 & 27.
1986 *Conusphaera mexicana* Aita & Okada, pl. 8, Fig.12.
1985 *Conusphaera mexicana* Perch-Nielsen, pl. 31.Figs.4-7.
1989 *Conusphaera mexicana mexicana* ssp. nov.. Bralower et al., pl.VII, Figs.16-20.
1996 *Conusphaera mexicana mexicana* Kaenel & Bergen, pl.6,Figs.14-16.
1997 *Conusphaera mexicana mexicana* Melinte, pl.33II, Fig.1.
1998 *Conusphaera mexicana mexicana* Bown & Cooper , pl.4.16, Figs.3-4.
2001 *Conusphaera mexicana mexicana* Concheryo & Wise , pl.4, Figs.4-5.
2007 *Conusphaera mexicana mexicana* Casellato, pl.4, Figs- 1-2.

Description: Nannolith with conical shape, typically with 4 to 12 μm length and a maximum width less than his maximum length. Composed externally of 22 costillae with an helicoidally orientation and an axial channel in his center which can be seen with Polarized Light Microscopy (PLM) (Trejo, 1969; Bralower *et al.,* 1989)

Discussion: In the section studied a great number of Conuspherids present crystallization, however, all the specimens present the central channel and some little elongate structures (maybe costillae) almost parallel to the axial cannel. The distinction between this species and *C. mexicana* ssp. *minor* is his length, longer than 4 μm.

Synonym: *Conusphaera mexicana* Trejo 1969

Dimension: From 4 to 12 μm of total length, maximum width always less than his total length (Bralower *et al.*, 1989).

Stratigraphic range: Lower Tithonian to Hauterivian (Bown & Cooper, 1989)

***Conusphaera mexicana* Trejo,1969 ssp. *minor* Bown y Cooper, 1989**

(Pl. I, No. 2)

1986 *Conusphaera sp.* cf. *C. mexicana* Aita & Okada, pl.8, Figs.13a &13b.

1989 *Conusphaera mexicana minor* ssp. nov.; Bown & Cooper, pl.5.2, Figs.10-12.
1996 *Conusphaera mexicana minor* Kaenel & Bergen, pl. 6, Figs.10-13.
1997 *Conusphaera mexicana minor* Melinte, pl.33.II, Figs. 3 & 4.
1998 *Conusphaera mexicana minor* Bown y Cooper, pl. 4.16, Figs.5-6.

Description: Conical shaped nanolith with an axial channel conformed by numerous internal plaque covered by external plaques. It is distinguished from *C. mexicana* Trejo, 1969 by its length of less than 4μm. This Nannofossil has a squared shape and its lateral walls are less parallel than in *C. mexicana* Trejo, 1969 (Bown & Cooper, 1989).

Discussion: In this study, the total length of the nannolith found was from 2 to 3.8 μm. Some of them presented a grade of dissolution on the external wall, till their conical shape was altered.

Synonym: *Conusphaera mexicana* Trejo 1969

Dimension: Less than 4 μm in length.

Stratigraphic range: Upper Kimmeridgiano to Upper Tithonian (Trejo, 1969; Bralower *et al.*, 1989).

Order Watznaueriales Bown, 1987

Family Watznauerazeae Rood et al. 1971

Genus: *Cyclagelosphaera* Noël, 1965

***Cyclagelosphaera margerelii* Noël, 1965**

(Pl. I, No. 3)

1965 *Cyclagelosphaera margerelii* sp. nov. Noël pl.17, Figs.4-9; pl.18, Figs.1 & 2; pl. 20, Figs. 2-4.
1977 *Cyclagelosphaera margerelii* Wise & Wind, pl.88, Fig. 10.
1985 *Cyclagelosphaera margerelii* Perch-Nielsen, Fig. 40.18.
1986 *Cyclagelosphaera margerelii* Aita & Okada, pl. 8, Fig.2.
1998 *Cyclagelosphaera margerelii* Bown & Cooper, pl. 4.15, Fig. 6
2001 *Cyclagelosphaera margerelii* Concheryo & Wise, pl.1, Fig. 1.
2007 *Cyclagelosphaera margerelii* Casellato, pl.8, Figs.5-7.

Description: Conformed of two discs joined by a central tube of a size proportional to the size of the Coccolith. The upper disc, oriented to the right, is made of 19 to 25 calcareous laminae and a proximal plaque with smaller laminae. There is a tube in its central part above calcite crystals from the bottom of the axial opening, or just above the upper border of the tube. This crystal appears to be in a random arrangement. The exemplars with a central tube well defined are relatively rare (Noël, 1965).

Discussion: Some of the discolith found in this study have crystallization, mainly in the Upper Tithonian to Lower Berriasian interval.

Dimensión: 5 to 15 μm (Nöel, 1965); 4 μm (Rood et al. 1971).

Stratigraphic range: Upper Bajocian to Paleocene (Perch-Nielsen, 1985; Burnett *et al.*, 1998).

Familia NANNOCONACEAE Deflandre, 1959

Genus *Nannoconus* Kamptner, 1931

***Nannoconus* sp. Kamptner 1931**

(Pl. I, No. 7)

Description: Nannofossil with elongated-conical trapezoidal shell form, pyriform, globular or rectangular with 4 to 25 and in some cases 50 μm in length. It is composed of little hyaline calcite crystals in radial positions and almost perpendicular to the outer wall disposed in a single cap with an internal vertex who extinct individually under PLM. These same crystals are disposed in remnant spiral that cut in a 45 degree its longitudinal axis. Its cavity could be a cylindrical tube sometimes closed to the spheroidal depending on the species and having communication to the exterior by two openings opposing each other, the basal and the apical one. It has an elongated conical shape form with a rounded base; presents a longitudinal opening almost invisible, same that in smaller exemplars can be of 1 μm width. Maximum width is approximately half of its total length (Trejo, 1960).

Discussion: The Nannoconidae present moderate to good preservation in the section studied, just a few of the specimens found present a degree of recrystallization and fragmentation.

Type species: *Nannoconus steinmannii* Kamptner, 1931.

Stratigraphical range: Tithonian to Campanian (Perch-Nielsen, 1985a).

***Nannoconus steinmannii* Kamptner, 1931 ssp. *minor* Deres & Archéritéguy, 1980**

(Pl. I, No 4)

1960 *Nannoconus steinmannii* Trejo, pl.1 & 3, Figs. 3 a, c-f.
1965 *Nannoconus steinmannii* Noël, pl. 24, Fig. 8; pl. 25, Fig. 9.
1985 *Nannoconus steinmannii ssp. minor* Perch-Nielsen, Fig. 45.40.
2007 *Nannoconus steinmannii ssp. minor* Casellato, pl.8, Figs.7-8.
2010 *Nannoconus steinmannii ssp. minor* Casellato, pl.5, Figs.10-11.

Description: Conical form with wide base and an axial channel wider than in *N. steinmannii* Trejo, 1960 and a length almost the same as its maximum width (Perch-Nielsen, 1985a).

Discussion: The specimens were present mainly in the Middle Tithonian; the first Nannofossil from the Lower Tithonian was in very poor conservation and recrystallized.

Dimension: 4 to 6 μm.

Stratigraphic range: Upper Tithoniano to Valanginian (Perch-Nielsen, 1985a).

Nannoconus steinmannii* Kamptner, 1931 ssp. *steinmannii

(Pl. I, No. 5)

1960 *Nannoconus steinmannii* Trejo. pl.1 & 3, Fig. 3 b.
1965 *Nannoconus steinmannii* Noël, pl.24, Figs. 1 & 9.
1971 *Nannoconus colomii* Thierstein, pl.II, Fig. 28.
1985 *Nannoconus steinmannii* Perch-Nielsen, Figs. 5.1, 8.79 & 45.39.
1997 *Nannoconus steinmannii* Melinte, pl.33.II, Fig. 5.
1998 *Nannoconus steinmannii steinmannii* Bown et al., pl.5.14, Fig. 21-22.
2007 *Nannoconus steinmannii steinmannii* Casellato, pl.8, Figs. 9-10.
2010 *Nannoconus steinmannii steinmannii* Casellato, pl.6, Figs. 6-7.

Description: Conic and elongated shape, with a rounded base and with a maximum width approximately half of its maximum length. Its central cavity has a longitudinal conduct used to present a very small size (Trejo, 1960).

Discussion: The nannoconus presented in the section studied appeared with moderate to high preservation. They were abundant in the Middle and Upper Tithonian.

Synonyms: *Nannoconus colomii, Nannoconus steinmannii*

Dimension: 7-21.5 μm in length and 5-11μm in width.

Stratigraphic range: Upper Tithonian to Upper Hauterivian (Trejo, 1960) or Barremian (Perch-Nielsen, 1985a).

***Nannoconus compressus* Bralower & Thierstein, 1989 *in* Bralower et al. 1989**
(Pl. I, No. 6)

1989 *Nannoconus compressus* Bralower et al., pl. VIII, Figs. 7-12.
1998 *Nannoconus compressus* Bown y Cooper, pl.4.16, Figs. 11-12.
2007 *Nannoconus compressus* Casellato, pl. 2, Fig. 4.

Description: Oval and elongated form. Have no axial channel. Adjacent wall structures are strongly closed. Rounded ends and outer wall are shapely defined. It could be distinguished from *N. infans* Bralower, 1989 by its longer shape. (Bralower *et al.,* 1989).

Discussion: Some of the specimens observed are fragmented and even recrystallized, but most keep visible features to place them in the species level.

Dimension: 3 to 8 μm long and 2 to 4 μm in width.

Stratigraphic range: Middle Tithonian (Bralower *et al.*, 1989).

Family POLYCYCLOLITHACEAE Forchheimer, 1972

Genus Polycostella Thierstein, 1971

***Polycostella beckmannii* Thierstein, 1971**

(Pl. I, No. 8)

1971 *Polycostella beckmannii* sp. nov. Thierstein, pl. II, Figs. 5-16.
1976 *Polycostella beckmannii* Thierstein , pl. 2, Figs. 29-30.
1985 *Polycostella beckmannii* Perch-Nielsen, Fig.55.27-32.
1986 *Polycostella beckmannii* Aita & Okada, pl.8, Fig.11.
1998 *Polycostella beckmannii* Bown y Cooper, pl.4.16, Figs. 18-19.
2007 *Polycostella beckmannii* Casellato, pl.4, Figs. 3-6.

Description: Nannolith with globular shape, consist of a flat conic pile of radially organized protuberant elements that conform 6 to 8 wrinkles in distal view (Thierstein, 1971; Perch-Nielsen, 1985a).

Discussion: In accordance with Thierstein (1971) this type of species can be distinguished from *P. senaria* by its always convex external margin. *P. beckmannii* has a short and well defined stratigraphical range, so it is an excellent marker species for the Tithonian. Some authors consider *P. beckmannii* to be reminiscent of other Nanofossil, (Kaenel & Bergen, 1996) but this has not been determined yet. In the present study almost all of the specimens presents defragmentation and poor preservation, also some present deformation (Lamina I foto 20).

Dimension: 3.5 to 6 μm.

Stratigraphical range: Middle Tithonian (Bown y Cooper, 1998) to the base of Berriasian (Thierstein, 1971;1976)

Orden WATZNAUERIALES Bown, 1987

Familia WATZNAUERACEAE Rood et al. 1971

Género Watznaueria Reinhardt, 1964

Watznaueria *sp.*

(Pl. I, No. 12)

Description: Elliptic Coccolith with a distal shield conformed by a diagonally located laminae and joining a proximal shield trough a central tube. The central zone can be opened and closed with a calcareous elements bridge of variable form that joined the walls of the central tube. The degree of opening in the central zone determinates the species (Burky, 1969).

Discussion: The *Watznaueria* sp specimens found presented a high degree of recrystallization in the central area and distal shield, also a great number of them are fragmented so it was not possible to distinguish the species, just to the genus level.

Synonyms: *Actinosphaera* Noel, 1965; *Colvillea* Black, 1964 (*Colvillea* Bojer & Hooker, 1834);*Trematolithus* Black, 1966, *Esgia* Worsley, 1971 *Maslovella* Tappan y Loeblich, 1966; *Ellipsagelosphaera* Nöel, 1965; y *Calolithus* Nöel, 1965 (Rood *et al.*, 1971; Perch-Nielsen, 1985a).

Type species: *Watznaueria barnesae* (Black, 1959) Perch-Nielsen, 1968.

Stratigraphic range: Bajocian to Maastrichtian Superior (Perch-Nielsen, 1985a)

Watznaueria britannica **(Stradner, 1963) Reinhardt, 1964**

(Pl. I, No. 9)

1965 *Ellipsagelosphaera lucassi* sp. nov. Noël, pl.11, Figs. 1-6.
1976 *Watznaueria britannica* Thierstein, pl.IV, Figs. 24-25.
1977 *Watznaueria britannica* Wise & Wind, pl. 88, Fig. 8.
1985 *Ellipsagelosphaera britannica* Perch-Nielsen, Figs.5.26-28/40.6-9.
1986 *Watznaueria communis* Aita & Okada, pl.8, Fig. 7.
1998 *Watznaueria britannica* Bown & Cooper, pl.4.15, Figs. 25-26.
2001 *Ellipsagelosphaera britannica* Concheryo & Wise, pl.3, Fig.2a.
2003 *Watznaueria britannica* Lozar & Tremolada, pl.1, Fig. 12.
2007 *Watznaueria britannica* Casellato, pl.7, Figs. 10-12.
2010 *Watznaueria britannica* Casellato, pl.2, Figs. 1-2.

Description: Elliptic shaped Coccolith made of two discs, the upper one composed of concentric calcareous elements that spin in a sense and the lower one composed of a single row of calcite laminae. The internal borders of both discs are joined by a central bridge of elements (Noël, 1965).

Discussion: With its bigger size, and a clear and bright appearance under PLM, this cocolith was easy identified. Most of the specimen found in this study present good to excellent preservation. Thus we agree with the reports that said "genus *Watznaueria* have an excellent potential of paleontological conservation and preservation" (Perch-Nielsen, 1985).

Synonims: *Ellipsagelosphaera lucasii, E. communis, W. communis, E. frequens, E. britannica.*

Dimension: 4 to 9μm.

Stratigraphic range: Bajocian to Lower Maastrichtian (Bown y Cooper, 1998).

Watznaueria fossacincta **Black, 1971**

(Pl. I, No. 10)

1985 *Ellipsagelosphaera fossacincta* Perch-Nielsen, Fig. 40.31.
1998 *Watznaueria fossacincta* Bown & Cooper, pl. 4.15, Fig. 27.
2007 *Watznaueria fossacincta* Casellato, pl.7, Figs. 3-4.

Description: This Coccolith has the same characteristics of *W. britannica* but lack the central bridge that holds the intern borders of the discs. This feature is easily seen using PLM (Bown & Coper, 1998).

Discussion: As with the *W. britannica,* this placolith looks shiny and bright under PLM, so it was easy to identify those specimens in the present study.

Synonims: *Ellipsagelosphaera fossacincta, E. keftalrempti.*

Dimension: 4 to 9 µm

Statigraphic range: Lower Bajocian to Maastrichtian (Bown y Cooper, 1998).

***Watznaueria manivitiae* Bukry, 1973**

(Pl. I, No. 11)

1998 *Watznaueria manivitiae* Bown & Cooper , pl. 4.15, Fig. 28.
2010 *Watznaueria manivitiae* Casellato, pl. 2, Figs. 5-6.

Description: Semielliptical Coccolith conformed by two cycle calcite discs. It can be distinguished under PLM by a little opening, almost closed in its central zone, and by presenting a distal almost circular shield.

Discussion: Two specimens of *W. manivitiae* show a degree of recrystallization, but the one in the Upper Tithonian was moderately conserved (Pl.1, No.11).

Dimension: 4 to 9 µm

Stratigraphic range: Callovian to Maastrichtian (Bown & Cooper, 1998).

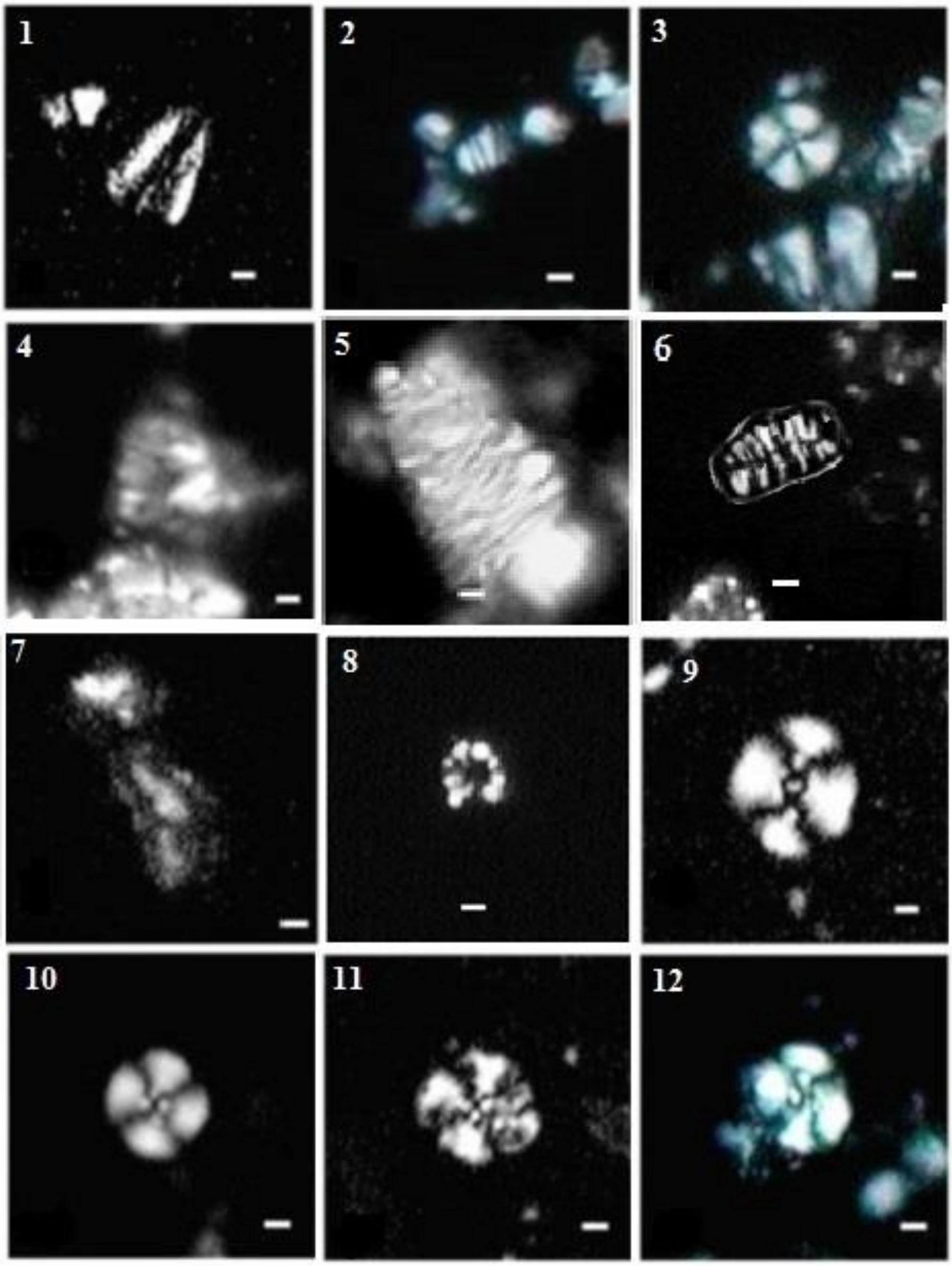

Plate 1. Reference bar = 1μm. Crossed Nichols Polarized Light Micrographs of 1) *Conuspahera mexicana* Trejo, 1969 ssp. *mexicana* Bralower, 1989, 2)*Conuspahera mexicana* Trejo, 1969 ssp. *minor* Bown & Cooper,1989, 3) *Cyclagelospahera margerelii* Nöel, 1965, 4) *Nannoconus steinmannii* Kamptner, 1931 ssp *minor* Deres y Archéritéguy 1980, 5) *Nannoconus steinmannii* Kamptner, 1931 ssp *steinmannii*, 6) *Nannoconus compressus* Bralower & Thierstein, 1989, 7) *Nannoconus* sp. Kamptner, 1931, 8) *Polycostella beckmannii* Thierstein, 1971, 9) *Watznaueria británnica* (Stradner, 1963) Reinhardt, 1964, 10) *Watznaueria fossacincta* Black, 1971, 11) *Watznaueria manivitiae* Bukry, 1973, 12) *Watznaueria* sp. Reinhardt, 1964.

Nannofossil abundance

Quantitative analysis of 82 samples reveals that 482 Nannofossil were present in the Rio Apulco superficial section. CN quoted in this study is listed in Table 1, its stratigraphic distribution in Figure 2.

The Nannofossil assemblage recognized in the Rio Apulco superficial section was poor and almost absent from the Callovian to the Oxfordian stages, there appears to be only specimens of *Cyclagelosphaera margerelli*. From the Kimmeridgian to Lower Tithonian stages appear two important nannofossil taxa: *Conusphaera* sp. and *Watznaueria* sp; then from the Middle to the Upper Tithonian appear two more species: *Polycostella beckmannii* and *Nannoconus* sp.

The dominant specie of all the section studied was *C. margerelli*, with 2 specimens in the Callovian, 53 in the Oxfordian, 38 in the Kimmeridgian, 3, 37 and 58 specimens in the Lower, Middle and Upper Tithonian respectively and 1 Nannofossil in the Berriasian, for a total of 192 Nannofossil. *C. mexicana spp mexicana, C. margerelli, N. steinmannii spp steinmannii,W. Britannica, W. fossacincta* and *Watznaueria sp*. reach the top of abundance in the Upper Tithonian. Five species: *C. mexicana* spp. *minor, N. compressus, N, steinmanni spp minor, Nannoconus sp.* and *P.beckmanni* reach theirs in the Middle Tithonian. Just *W. manivitiae* presents no changes in its distribution (for details see Table 1).

Specie / Stage	*Consuphaera mexicana minor*	*Consuphaera mexicana mexicana*	*Cyclagelosphaera margerelli*	*Nannoconus compresus*	*N. steinmannii minor*	*N. steinmannii steinmannii*	*Nannoconus sp*	*Polycostella beckmanni*	*Watznauweria britannica*	*Watznaueria fossacincta*	*Watznaueria manivitae*	*Watznaweria sp*	% Placolith	% Nannolith	Total of specimens
Berriasian	1	-	1	3	2	4	3	-	2	4	-	-	35	65	20
U. Tithonian	4	11	58	3	3	14	8	4	15	15	1	27	71	29	163
M. Tithonian	35	5	37	17	11	12	10	24	3	3	1	2	29	71	160
L. Tithonian	18	10	3	-	3	-	-	-	2	-	-	3	21	79	39
Kimmeridgian	4	-	38	-	-	-	-	-	1	-	1	1	91	9	45
Oxfordian	-	-	53	-	-	-	-	-		-	-	-	100	0	53
Callovian	-	-	2	-	-	-	-	-		-	-	-	100	0	2
Total by sp.	62	26	192	23	19	30	21	28	23	22	3	33	57	43	482
Total by Genus	88		192	93				28	81						

Table 1. Number of Nannofossil per stages founded in the study area, included by species, by genus and total.

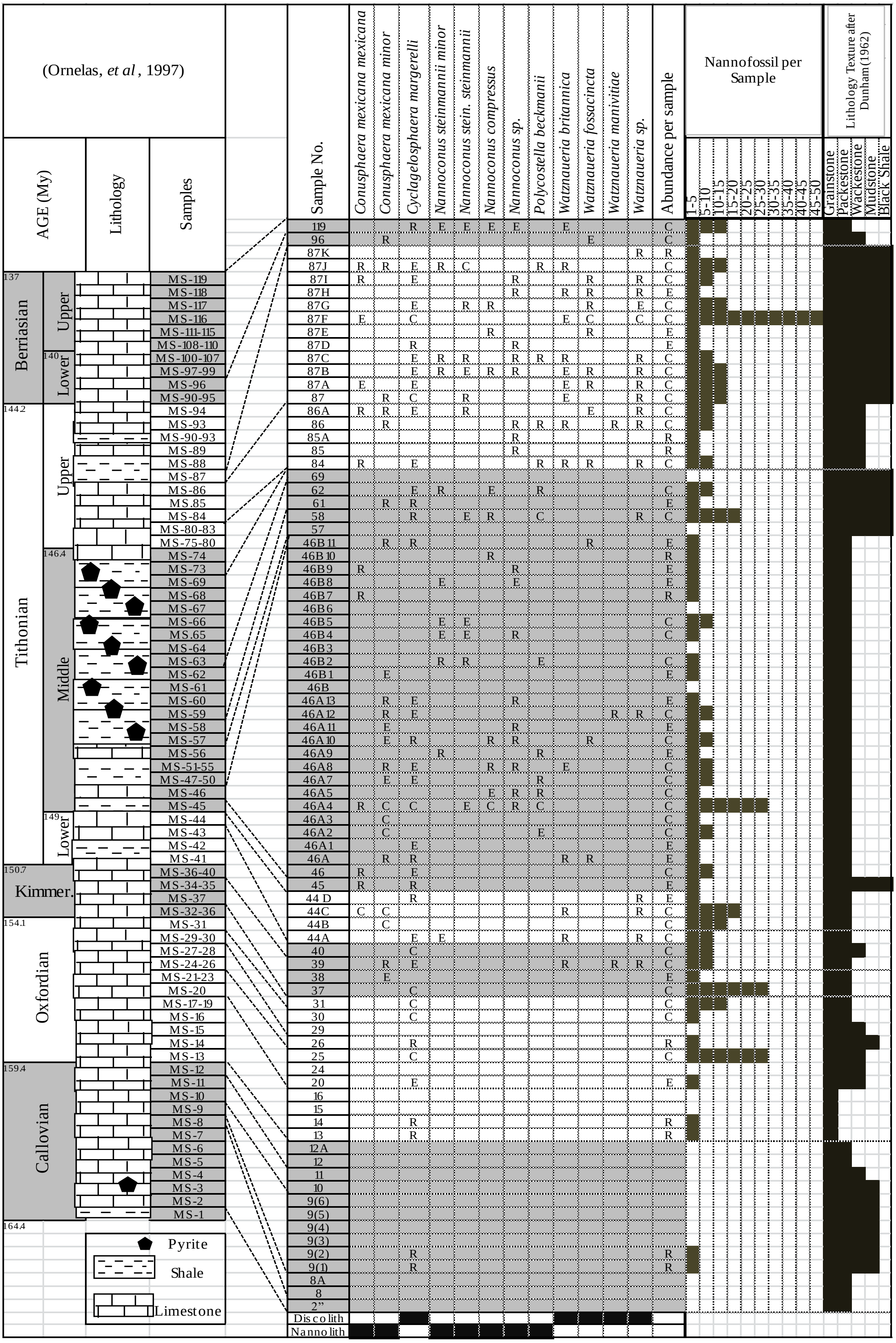

Figure 2. Nannofossil per sample found in this study with reference to the age and lithology from Ornelas *et al* (1997). The samples labeled as MS are the those sampled byOrnelas et al.(1997), the samples in the center column are the studied in this work. C is Common (5 to 49 Nannofossil per sample),E means Scarse from "*Escaso*" in Spanish (2 to 4 Nannofossil per sample) and R means Rare (1 Nannofossil per sample). A lithology texture from the Dunham (1962) classification is included.

Lithology, texture and CN

The dominant lithology from Callovian to Kimmeridgian was limestone, but the Dunham texture index presented a different pattern for each stage: the Callovian presented mostly mudstone, the Oxfordian mostly wackestone-packestone and the Kimmeridgian presented packestone. In the Tithonian the lithology changes drastically: In the Lower Tithonian there where shales and limestones intercalated, the Dunham texture index presented mostly packestone. In the Middle Tithonian shales and packestone were predominant with presence of pyrite and some levels of limestone in the bottom; and in the Upper Tithonian limestone and shale intercalated with Mudstone-black shale texture lithology. For the Berriasian a limestone lithology with wackestone-packestone texture was present. For details see Figure 2 and Table 1.

Stage: Floor		Stage: Age	Polarity	Thierstein (1976)	Roth et al (1982)	Bralower et al (1989): Zone	Bralower et al (1989): Subzone	Bralower et al (1989): bioevents	Kaenel, et al (1996)	Cassellato (2010)	This Study
Berriasian		137	CM16			*NK-2*	NK-2A/ 2B				
			CM17	*P. beckmanii*		*NK-1*					
		144.2	CM18	*C. chiastia*	*N. colomii*		NJ-KC / D			*N. steinmannii*	
Tithonian	U	146.4	CM19	*N. colomii*		*M. chiastus*	NJ-KB	*P. beckmanii*	*P. beckmanni*		*P. beckmanni*
	M		CM20		*Nannoconus sp /*	*NJ-K*	NJ-KA			*N. infans*	*Nannoconus sp/*
		148.9		*P. beckmanii*	*P. beckmanii*		*P. beckmanii (NJ-20B)*	*P. beckmanii*	*P. beckmanii*		*P. beckmanii*
	L	150.7	CM21	*C. mexicana*	*C. mexicana*	*C. mexicana*		*N. compressus*	*C. mexicana*	*P. beckmanii*	*C. mexicana*
Kimmeridgian						*NJ-20*	*H. cuvilleri (NJ-20A)*	*C. mexicana minor*		*C. mexicana minor*	*C. mexicana minor*
			CM22				*P. embergeri*		*Z. embergeri*		
		154.1					*NJ-19B*				
Oxfordian				S. bigotti		*V. stradneri*					
					V. stradneri	*NJ-19*					
										L. sigilatus	
		159.4		*P. escaigii*	*C. margerelii* Subzone					*C. wiedmannii*	
Callovian											*C. margerelii*
					S. hexum						
					S. bigotii						
		164.4		*S. bigotti*					*S. bigotti*		

Figure 3. Calcareous Nannoplankton bioevents reported in this study and his correlation with Polarity Time Scale from Bralower et al. (1989) and other previous reports: Thierstein (1976), Roth (1982,1986), Bralower et al. (1989), Kaenel et al. (1996) and Casellato, (2010). Age is based on Ornelas et al (1997).

The samples with more than 20 CN of any of the species found in the study can help to distinguish the low and high abundant samples and to understand its relation to the lithology, these samples are in stratigraphic order:

- Sample No. 25 - Middle Oxfordian - with 27 specimens of *C. margerelli* and limestone/wackestone lithology.
- Sample No 37 –Kimmeridgian- with 29 *C. margerelli* and limestone/packestone lithology.
-Sample No. 46A4 - Middle Tithonian- with 27 specimens *of C. mexicana minor, C. mexicana mexicana, C. margerelli, N. steinmannii steinmannii, N. compressus, Nannoconus sp.* and *P. beckmannii* and shale/packestone lithology.

Sample 87F -Upper Tithonian- with 49 specimens of *C. mexicana mexicana, C. margerelli, W. britannica*, *W. fossacincta* and *Watznaueria* sp. and limestone/black shale lithology. If we focus on the Upper Tithonian peak of abundance (Sample No. 87F) we could see that all species are placolith and reach their highest abundance in this sample. This was noticed previously by Erba (2004) who report "a positive correlation between the abundance of placolith species, the presence of organic black shale, the depletion of limestone sediments and Oceanic Anoxic Events" (OAE). For details see Figure 2.

In the Middle Tithonian, in the Sample No. 58 we could see the highest abundance of *P. beckmannii* correlated again with black shale lithology and in this case the presence of pyrite, probably associated with OAE.

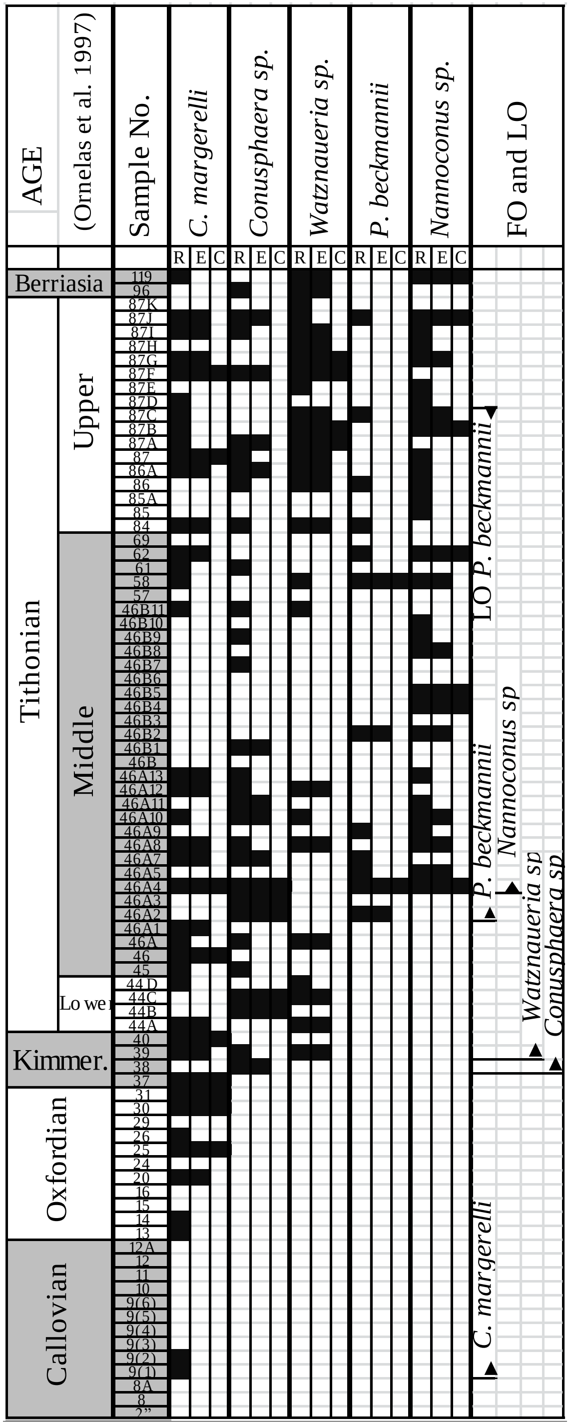

Figure 4. Relative abundance of principal Genus founded in the Rio Apulco superficial section with the Age of the samples after Ornelas et al.(1997) and the LO (last occurrence) and FO (first occurrence) of the main index taxa.

Nannofossil biostratigraphy

The FO of *Conusphaera mexicana* spp *minor* was found in the Kimmeridgian aged sample No. 38, coinciding with previous reports from Bralower et al (1989) and Casellato (2010). The FO of *Conusphaera mexicana* spp *mexicana* was found in the Lower Tithonian, event that had been reported at the same stratigraphic level by several authors (Thierstein, 1976; Roth et al, 1982; Bralower et al, 1989; Kaenel et al, 1996; Casellato, 2010).

Another bio-event of importance reported in this study corresponds to the FO of *C. margerelli* that was found at the Upper Callovian, in the same stratigraphical level reported previously by Roth et al. (1983). The Nannoconids have been reported to appear in the Lower (Bralower et al. 1989), Middle (Casellato, 2010) and Upper (Thierstein, 1976, Perch-Neielsen, 1985) Tithonian sediments in the Tethys Realm. We found its FO in the base of the Middle Tithonian, close to the base of the CM20 Polarity Time Scale and NJ20B *P. beckmannii* subzone from Bralower et al (1989); this also coincides with Roth et al. (1982) results.

Polycostella beckmannii is a nannolith that has been widely reported in several papers, always restricted to Tithonian sediments. In the section studied we found its FO in the base of the Middle Tithonian, where it had been reported previously by the studies of Roth et al (1982), Bralower et al (1989) and Kaenel et al (1996). Its LO was found at the Upper Tithonian, a fact that had been reported previously by Bralower et al. (1989) and Kaenel et al, (1996), then these two bio-events could serve as correlational between the studied section and the Tethyan Nannofossil Biostratigraphy. For details of the events above please see Figure 3.

The FO patterns of *Conusphaera* sp., *Polycostella beckmannii* and *Nannoconus* sp had been previously reported by Roth et al (1982), Bralower et al (1989) and more recently by Tremolada (2006) and Casellato (2010) (FO and LO column in Figure 4). In this study, the FO of *Watznaueria* sp appeared in the Kimmeridgian stage, while the same has been reported in the Bajocian by Thierstein (1976), Young et al. (2014) and his LO according to the same authors reach the Maastrichtian. However, the *Watznaueria* sp in the present study show a pattern of distribution centered in the Upper Tithonian and its absence from younger sediments may be due to post-depositional burial and dissolution (Tremolada, 2006).

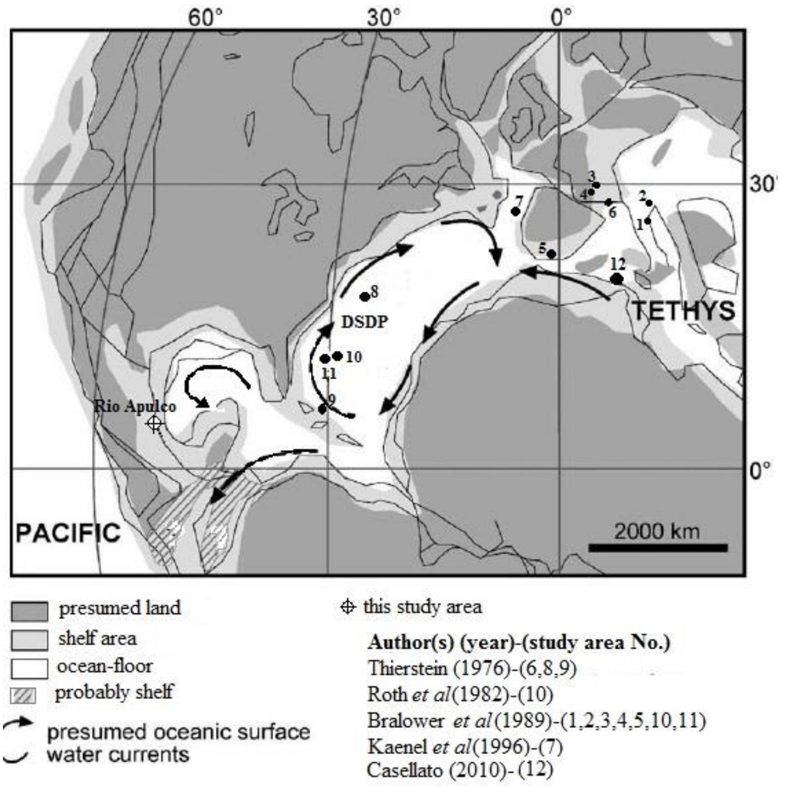

Figure 5. Map of the location of the study area during the Tithonian (150 My ago) with the location of the other CN sites previously studied. Modified from Bronemann et al. (2003).Figure 6. Placolith vs. Nannolith abundance and his correlation with the Long term & Short term Esutatic Curves presented by Handerbol et al (1998) adapted for this study; the arrows shows the nannolith/deeper water conditions; the Polarity Time Scale is modified from Bralower et al (1989), the age of each stage and the lithology are from Ornelas et al (1997); the paleoenvironments are: a) Near-Shore to Platform, a´) Near-Shore Platform with river runoff, b) Plataform to Neritic, c) Batial, d) Batial (Deep basin) and e) Batial to Abysal.

Discussion

The FO of *C. margerelli* in the present work was in the Upper Callovian considering the age previously defined by Ornelas et al, (1997) for the samples of the section studied. This event corresponds with the base of the subzone of *C. margerelli* reported previously by Roth (1986) (Figure 3). The Callovian–Oxfordian range is a stratigraphic interval that lacks useful marker-species (Perch-Nielsen, 1985) and is characterized to "contain poorly preserved coccolith assemblages" (Roth et al, 1982), then this bio-event could be used in further investigations as a good index for determining the Upper Callovian level sediments in any marine or inland section belonging to the Tethys Realm.

In the studied section, the FO of *C. mexicana* spp. *minor* was located in the Kimmeridgian, this bio-event corresponds to previous reports from six land sections (France, Italy and Spain) and Atlantic marine sediment cores (DSDP 391C and 534A campaigns) made by Bralower et al (1989). They found the FO of this same nannolith at the upper part of the CM22n Magnetic Anomaly Polarity, defining the base of their NJ-20 *Conusphaera mexicana* biozone and the NJ-20A *H. cuvilleri* sub-zone. It is a remarkable event that this species appears in the same stratigraphical level as it was reported in other Marine and

Land sections worldwide, the implications of this are of capital importance for the Tethyan Calcareous Nannofossil Biostratigraphy.

The nannolith *C. mexciana* spp. *mexicana* has been recognized as an important bio-marker for Tithonian sediments in both land and marine sections (Thierstein, 1976; Roth, 1982; Bralower et al, 1989; Bown & Cooper, 1998). In this study its FO was found at the base of the Tithonian sediments in accordance to the age previously defined by Ornelas et al, (1997) for the samples studied here. This bio-event corresponds to previous results by Thierstein (1971), Roth et al (1982; 1986), Bralower et al (1989) and Kaenel et al (1996). This is very important not only for the biostratigraphy of calcareous nannoplankton, but also for the chronostratigraphy because it links both fields, defining the base of the CM21 Magnetic Polarity Time Scale that has been used for calibration worldwide (Handerbol et al, 1998) (Figure 3).

The LO of *P. beckmannii* was found in the Upper Tithonian like Bralower et al (1989), Kaenel et al. (1996) and Tremolada et al (2006) was. But this isn't agreeing for other case studies, particularly the Thierstein (1976) scheme, because he proposed its last occurrence in the Lower Berriasian. Roth et al (1982) place this LO in the Tithonian-Berriasian boundary. There is no general agreement for defining this last bio event, among other reasons, the great taxonomic uncertainty about *P. beckmannii*. Here we consider the Bralower et al (1989) scheme as the best for comparing the results in the present work, mainly by its geographic correspondence to the study area. For details see Figures 2, 3 and 5.

The First and Last Occurrences explained above suggest that there is a straight relation between our study area and the DSDP 534A, 105 and 391C study sites from the Northern Atlantic. The location of the Rio Apulco superficial section corresponds to a continental shelf area located southeast of the Tethys around the Late Jurassic (Figure 5). The logical cause may be that the marine currents reach the southeastern Tethys flowing from north to south, a part of the currents continue to southern waters but some of them flow in to the proto-Gulf of México in a circular pattern to finally reach the coast of a probable shelf-tidal zone, in accordance to Bornemann et al. (2003). For details see Figure 5.

Paleoenvironmental reconstruction

If we consider the low nannofossil diversity, the variability of the lithology and that *C. margerelii* is a characteristic species of restricted environments (Keupp, 1976 ref. in Perch-Nielsen, 1985) from the Callovian to Oxfordian stages, we have elements to argue that the study area was a near-shore littoral, or even maybe a salt deposition platform (Padilla, 2007) and in its upper part (Upper Oxfordian) a near-shore platform with a bigger runoff of fresh water from rivers than the evaporation index, accumulating more oxygen-rich and clayed sediments (Guzman-Vega et al. 2001). During the Kimmeridgian it continued the subsidence of the proto-gulf of México that keep receiving the orogenic river flow mainly from the southeast and Yucatan platform (Salvador, 1991). The subsidence lead to a deeper water column, permitting the entrance of oceanic currents and the deposition of planktonic species in the sea floor; then we found at this interval Placolith as *Watznaueria* sp. and the first Conusphaerids. The factors that prevailed for the Lower Tithonian was a low energy, deep-basin paleoenvironment (Aguilera, 1972; Gonzalez & Holguín, 1991; Salvador, 1991) and fluctuating from batial to abyssal (Guzman-Vega et al. 2001). In accordance with Thierstein (1976) the *Conusphaera mexicana*,

Nannoconus spp. and *Polycostella beckmannii* appeared restricted to tropical and subtropical paleo-latitudes, and in shelf and epicontinental seas according with Tremolada et al. (2006); then we have a study area with warm water conditions and a high diversity planktonic community that leads to higher deposition rates of several species. From Middle Tithonian to Berriasian stages the paleoenvironment was from batial to abyssal conditions, if we consider that the *Nannoconus* sp had been reported to proliferate in deep marine waters (Busson & Noël, 1991). The analysis of the comparative scheme shown in Figure 6 reveal a pattern that probably could be linking the placolith presence with the swallow water levels in the short term eustatic curve of Handerbol et al (1998) and the nannolith presence with the deeper water lectures in the same curves. There is probably a relation between the long term eustatic curve and the presence of nannolith in the Negative Polarity Chron CM20 during the Upper-Middle Tithonian; other probable links are shown with dashed line arrows in Figure 6.
This pattern of placolith/nannolith prescence and the eustatic level reported previously by Haderbol et al (1998) for the stages studied in this work, confirm the reported relations between nannolith presence with deep water conditions and placolith presence with near shore platform/restricted paleoenvironments (Figure 6).

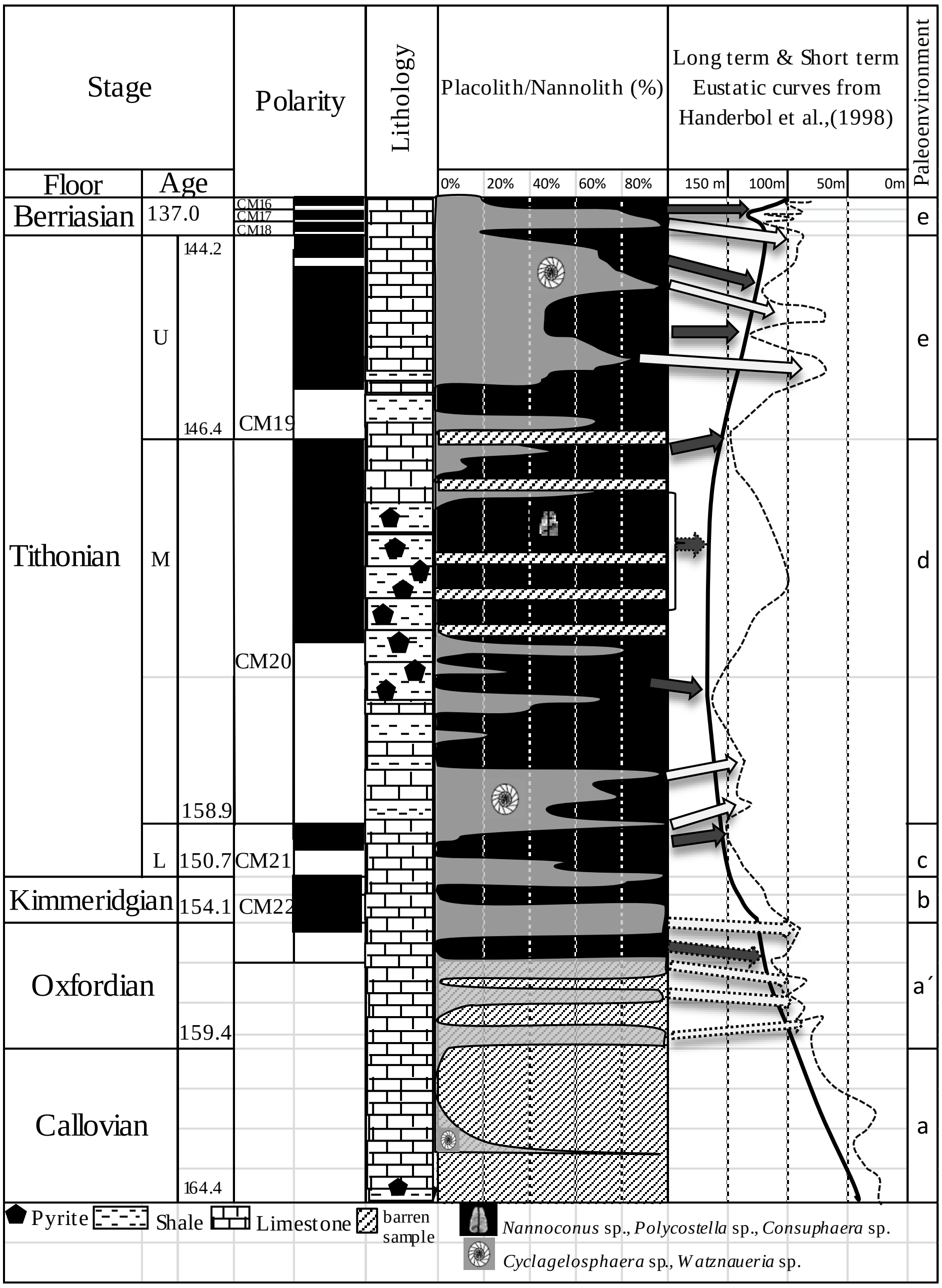

Figure 6. Placolith and Nannolith presence in comparative column with Age and Lithology from Ornelas et al (1997), Polarity Time Scale from Bralower et al (1989 and Long and Short Term Eustatic Curves modified from Handerbol et al (1998)) adapted for this study; the Paleoenvironmental column are expressed from bottom to top as a) Near-Shore Platform, a´)Near-Shore Platform with epicontinental runoff, b) Platform to Neritic, c) Batial, d) Batial (Deep Basin) and e)Batial to Abysal. The white arrows indicate the correlation between Placolith presence in the study area and the shallow water short term eustatic curve of Handerbol et al (1989); the black arrows indicate the correlation of the Nannolith presence with deep water short term eustatic curves; the dashed-line black or white arrows indicate possible correlations either with long and short term eustatic curves.

Conclusions

The FO of *C. margerelli* could be useful in the Upper Callovian - Tithonian interval in the tropical zone (Perch-Nielsen, 1985; Kaenel et al., 1996).

The FO of *Conusphaera mexicana* spp. *mexicana*, *Conusphaera mexicana* spp. *minor* and the FO and LO of *Polycostella beckmannii* found in this study, established a stratigraphic correlation between the Tampico-Misantla Basin Nannofossil Biostratigraphy and the Tethyan Realm study sites, especially those from the Atlantic (Thiestein, 1976; Roth et al, 1982; Bralower et al. 1989) and the East Mediterranean Sea (Kaenel et al, 1996; Casellato, 2010).

These bio-events correspond to the bio-zones of Bralower et al. (1989) for the Upper Jurassic–Lower Cretaceous, reflecting the paleoenvironmental patterns of the Tethys defined by mean of stratigraphic correlation for the Tampico-Misantla Basin Nannofossil Biostratigraphy for the first time.

The Placolith/Nannolith presence in the study area are closely related to the deep of the water column as we demonstrate it in Fig.6 using the Eustatic Curves of Handerbol et al (1998).

The Paleoenvironment in the studied section was restricted to neritic from Callovian to Oxfordian; neritic to basin in the Kimmeridgian and from basin to abyssal from the Tithonian to Berriasian stages.

The correlation with other site studies from the Tethyan Realm and the paleoenvironmental reconstruction potential of the Calcareous Nannofossil found in the Rio Apulco superficial section in Tampico Misantla Basin are of a great biostratigraphic value for future research and aims to establish the Tampico Misantla Basin Calcareous Nannofossil Biostratigraphy for the first time. We recommend to sample complete sections and relate them with multidisciplinary field studies.

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