

# A pithonellid bloom in the Cenomanian-Turonian boundary interval from Cerritos in the western Valles–San Luis Potosí platform, Mexico: Paleoenvironmental significance

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## ABSTRACT

A calcisphere (Pithonellid) acme is recorded from Cerritos, western Valles–San Luis Potosí platform, Mexico. The abundance of these microfossils appears to constitute a global event in the Cenomanian-Turonian boundary. Their large quantity is interpreted as an indicator of changes in primary productivity during transgressive episodes. The pithonellids *Bonetocardiella conoidea* (Bonet, 1956), *Pithonella sphaerica* (Kaufmann, 1865), and *P. ovalis* (Kaufmann, 1865) are associated with the r and r-k strategists planktic foraminifera *Muricohedbergella delrioensis* (Carsey, 1926), *M. planispira* (Tappan, 1940), *Heterohelix moremani* (Cushman, 1938), *Heterohelix reussi* (Cushman, 1938), *Macroglobigerinelloides caseyi* (Bolli, Loeblich and Tappan, 1957), *Whiteinella archaeocretacea* Pessagno, W. cf. *W. aprica* (Loeblich and Tappan, 1961), *W. brittonensis* (Loeblich and Tappan, 1961), *W. baltica* (Douglas and Rankin, 1969) and *W. paradubia* (Sigal, 1952), which are also considered to be indicators of high nutrient content in unstable paleoenvironments. The abundance of pithonellids occurred at the base of the *Whiteinella archaeocretacea* Partial Range zone. This great temporal abundance in the material could be related to the environmental changes caused by the drowning of the Valles–San Luis Potosí platform, as nutrient supply increased in the latest Cenomanian, which is linked to a sea-level transgression that occurred on a global scale. In this interval, the occurrence of benthic foraminifera *Gavelinella* spp., *Lingulogavelinella* sp., *Dorothia* sp. and roveacrínids is also recorded.

This sequence overlies an extinction level of the platform benthic foraminifera dated as late Cenomanian.

The calcispheres *Bonetocardiella conoidea* (Bonet, 1956), *Pithonella sphaerica* (Kaufmann, 1865) and *P. ovalis* (Kaufmann, 1865) show a pithonelloid wall type as well as an inner space (pericoel) of the cyst, in-filled with sparry cements.

Key words: pithonellids, Cenomanian-Turonian boundary, Valles–San Luis Potosí platform, Mexico.

## RESUMEN

Un gran florecimiento de calcisferas (pithonélidos) se registró en Cerritos, localidad situada en la parte occidental de la plataforma Valles–San Luis Potosí. La abundancia de estos microfósiles parece constituir un evento global en el límite Cenomaniano-Turoniano. Su gran cantidad es interpretada como indicador de cambios en la productividad primaria durante episodios transgresivos. Los pithonélidos *Bonetocardiella conoidea* (Bonet, 1956), *Pithonella ovalis* (Kaufmann, 1865) y *P. sphaerica* (Kaufmann, 1865) están asociados a foraminíferos planctónicos estratégicos r o r-k como *Muricohedbergella delrioensis* (Carsey, 1926), *M. planispira* (Tappan, 1940), *Heterohelix moremani* (Cushman, 1938), *Heterohelix reussi* (Cushman, 1938), *Macroglobigerinelloides caseyi* (Bolli, Loeblich y Tappan, 1957), *Whiteinella archaeocretacea* Pessagno, W. cf. *W. aprica* (Loeblich y Tappan, 1961), *W. brittonensis* (Loeblich y Tappan, 1961), *W. baltica* Douglas y Rankin, 1969 y *W. paradubia* (Sigal, 1952), los cuales son considerados también como indicadores de altos contenidos de nutrientes en paleoambientes inestables.

La abundancia de pithonélidos ocurrió en la Zona de Alcance Parcial *Whiteinella archaeocretacea*. Su abundancia temporal en nuestro material pudiera estar relacionada a los cambios ambientales causados durante la inundación de la plataforma Valles-San Luis Potosí, incrementándose el aporte de nutrientes en el Cenomaniano más tardío. En este intervalo se registró la presencia de foraminíferos bentónicos como *Gavelinella* spp., *Lingulogavelinella* sp., *Dorothia* sp. y roveacrínidos.

Esta secuencia está sobreyaciendo a un nivel de extinción de los foraminíferos bentónicos de plataforma datado como Cenomaniano medio-tardío.

Las calcisferas *Bonetocardiella conoidea* (Bonet, 1956), *Pithonella ovalis* (Kaufmann, 1865) y *P. sphaerica* (Kaufmann, 1865) muestran una pared de tipo pithonelloideo así como la presencia de un espacio interno (pericoel) del quiste relleno de cemento de esparita.

Palabras clave: pithonélidos, límite Cenomaniano-Turoniano, plataforma Valles-San Luis Potosí, México.

## INTRODUCTION

The drowning of the Valles-San Luis Potosí carbonate platform in the K-T boundary is associated with paleoenvironmental changes such as fluctuations in salinity and high primary productivity (Omaña *et al.*, 2010). In this interval, in the Cerritos section we observed a flood of calcispheres (pithonellids) accompanied by r-strategists planktic foraminifera.

The term “calcisphere” originated as a general term for indeterminate calcareous spherical fossils from the Carboniferous limestone from Flintshire, Wales. Williamson (1880, p. 521) wrote: “I propose for the objects under consideration the generic name Calcisphaera, as not involving any premature hypothesis respecting their nature.”

The pithonellids commonly named “calcispheres” are calcite spheres, sphaeroid, ovoid and ellipsoidal with 20–180 µm in diameter and an aperture ranging in size from 3 to 8 µm. They are studied in thin sections with transmitted light microscopy and also have been studied with scanning electron microscope (SEM) (Banner, 1972; Bolli, 1974; Masters and Scott, 1978; Krasheninnikov and Basov, 1983; Keupp, 1979, 1987, 1992; Wendler *et al.*, 2002a; Wendler and Bown, 2013).

Spherical and elongate single-chambered forms, approximately 40–100 µm from the Swiss Alps (Seewerkalk, central Switzerland), were described by Kaufmann (1865) under the names of *Lagena ovalis* and *L. sphaerica*. Lorenz (1902) recognized that Kaufmann’s species *sphaerica* and *ovalis* could not belong to the genus *Lagena*, so he included them in a newly created genus *Pithonella*.

Sujkowski (1931) described abundant *Pithonella* from the Turonian deposits of the Polish Carpathians, probably *Pithonella ovalis*. Later, Colom (1955) studied the Jurassic-Cretaceous pelagic sediments of the western Mediterranean zone and Atlantic area, which he named *Pithonella ovalis* (= *Lagena ovalis* Kaufmann, 1865).

Bonet (1956) made the first attempt in Mexico to describe and interpret the biostratigraphic value of small spherical to ovate incertae sedis Calcisphaerulidae from Jurassic and Cretaceous limestone, for purposes of petroleum exploration.

Andri (1972) found a rich association of calcispheres in the Tuscany region, Italy, and recognized their stratigraphic and paleogeographic significance.

According to Masters and Scott (1978), the study of these microfossils increased in significance when Bonet (1956) suggested a potential stratigraphic value for the Mesozoic calcispheres.

In the literature, calcispheres have been interpreted as different taxonomic groups; benthic foraminifera (Colom, 1955), or unilocular foraminifera (Bignot and Lezaud, 1964), incertae sedis (Bonet, 1956; Bolli, 1974; Villain, 1977), free-floating, detached parts of a benthonic alga (Bein and Reiss, 1976), planktic ciliate organisms (Banner, 1972), or ciliate protozoa (Trejo, 1983). Wall and Dale (1968) suggested for the first time the possibility of the interpretation of calcispheres as calcareous dinocysts. Later, Keupp (1979, 1987) demonstrated the same relationship with the Mesozoic calcispherulids. Wendler *et al.* (2002b, p. 226) proposed that *Pithonella ovalis* and *P. sphaerica* represent skeletons produced by dinoflagellates with a vegetative-coccoid life stage.

Masters and Scott (1978) proposed that the wall microstructure allows to recognize three families of Mesozoic calcispheres: Cadosinidae Wanner, 1940; Stomiospheridae Wanner, 1940, and Bonetocardiellidae n. family.

Rehánek and Cecca (1993) regarded the stomiospherids and cadosinids Wanner, 1940 as calcareous dinoflagellate cysts and they are assigned by these authors to the subfamily Orthopithonelloideae Keupp (1987). Stomiospherids and cadosinids seem to be a distinct group of “calcispheres” as has been previously noted by other authors (Colom, 1955; Bignot and Lezaud, 1964), while the subfamily Pithonelloideae

Keupp (1987) includes *Pithonella sphaerica* (Kaufmann, 1865), *Pithonella ovalis* (Kaufmann, 1865), and *Bonetocardiella conoidea* (Bonet, 1956).

The calcareous dinoflagellates are now affiliated with the family Thoracosphaeraceae Schiller (Elbrächter *et al.*, 2008) and the pithonellids have been included in the Suborder Peridinniinae Autonym and Family Thoracosphaeraceae Schiller, 1930 (Wendler *et al.*, 2013a).

Dias Brito (2000) indicated that the pithonellids have been interpreted as benthic foraminifera, proloculi of foraminifera, planktonic foraminifera, calcareous algal spores, chlorophycean algal zoospores, unicellular algae, benthic algal oogonia, oolitic structures, protozoa, planktonic protists, planktonic ciliate organisms, benthic elements, planktonic algal cysts, phytoplanktonic microorganisms and calcareous dinoflagellate cysts. They have been cited in the literature as fissurinas, lagenas, oligosteginids, oolinas, orbularinas, orbularinas, pithonellids, pithonelloids, stomiospheras and calcisphaerulids (*non sensu* Bolli, 1974).

Versteegh *et al.* (2009) proposed the term Calcitarcha including all calcareous microfossils with a central cavity for which the biological affinities remain unknown, including the extinct Cretaceous pithonellids.

Wendler *et al.* (2012) carried out a cathodoluminescence spectroscopy study from the well preserved and diagenetically altered Turonian foraminifera and calcispheres (*Pithonella ovalis*, *P. lamellata*).

Wendler and Bown (2013) reported on the biomineralization architecture of the unsuspected complexity in calcareous walls of extinct dinoflagellates (pithonellids) from a Tanzanian microfossil-lagerstätte. They observed large circular and subangular openings (archoepyles), and their associated covering plates called opercula give evidence for the dinoflagellate affinity of pithonellids.

Fossil pithonellid calcispheres are widely distributed in the world. They have been reported from several localities in Spain (Azéma, 1966; Castro and Martínez-Gallego, 1980), France (Bignot and Lezaud, 1964), England (Banner, 1972; Wilkinson, 2011), Italy (Andri, 1972), Pakistan (Masters and Scott, 1978), Israel (Hamaoui, 1965; Bein and Reiss, 1976), Algeria and Tunisia (Colom, 1955; Colom *et al.*, 1954, Dali-Resort, 1989; Villain, 1992), the Morocco Basin (Pflaumann and Krasheninnikov, 1978), and Ivory Coast (Chierici, 1984). In America, these microorganisms have been studied in the Gulf Coast of the United States (Masters and Scott, 1978; Olsson and Youssefnia, 1979), in Mexico (Bonet, 1956; Bonet and Trejo, 1958; Trejo, 1960; Ice and McNulty, 1980; Ornelas, 1984), in Brazil (Krasheninnikov and Basov, 1983; Berthou and Bengtson, 1989; Dias-Brito 1985, 1992, 2000, 2002), and in Chile (Martínez-Pardo *et al.*, 1994).

Several examples of episodic pithonellid blooms have been recorded in Cretaceous successions related to stressful conditions; but the most remarkable occurred in the Cenomanian-Turonian boundary. Hart (1991) found that an abundant flood of calcispheres was recorded in the early Turonian. This author comments that the International Geoscience Program (Global Biological Events) has focused attention on extinction levels and other biological phenomena.

In the latest Cenomanian-earliest Turonian, a very widespread occurrence of abundant calcispheres is known in many localities, including former Yugoslavia (Gusic and Jelaska, 1990), Germany (Neuweiler, 1989), and Portugal (Hart *et al.*, 2005). In the Sopeira Basin (Spain), an unusual amount of calcispheres were recorded in the *Whiteinella archaeoretacea* Zone (Caus *et al.*, 1993); their presence reveals intense primary productivity.

In Mexico, Aguilera-Franco and Allison (2004) recorded an abundance peak of calcispheres in the Morelos-Guerrero platform which occurred in the lower part of the *Whiteinella archaeoretacea* zone during platform drowning.

Wendler *et al.* (2010a) stated that “the calcispheres are the second most abundant calcareous microfossils of Cretaceous rocks and show significant and temporal blooms, the most important of which is in the late Cenomanian-early Turonian global known calcisphere bio-event associated with OAE2.”

The objective of this work is to document the occurrence of a rich calcisphere level and the associated r- and k-r planktic foraminifera in order to emphasize its paleoenvironmental significance in the late Cenomanian-early Turonian boundary interval. In addition, we present some taxonomic notes on some of the pithonellids.

## GEOLOGICAL SETTING

The section studied is located east of San Luis Potosí city (Figure 1). It lies on the western part of the Valles–San Luis Potosí platform (VSLPP). The VSLPP is part of an extensive carbonate platform system that rimmed the ancestral Gulf of Mexico during late early Cretaceous. It is one of “the largest isolated carbonate platforms (200 by 300 km), which began to develop in Early Cretaceous and reached maximum growth during the Albian, when it evolved to a rimmed shelf margin” (Wilson and Ward, 1993).

During the Early Cretaceous, a remarkable tectonic stability in the Gulf of Mexico Basin, characterized by decreased terrigenous influx, permitted the development of stable shelves, ramps and platforms bordering the deep central part of the Gulf of Mexico Basin, which became the site of widespread carbonate deposition, particularly during the Albian-Cenomanian (Salvador, 1991). In late Cenomanian-early Turonian, the carbonate platform was drowned as result of a great, global transgression (Haq *et al.*, 1987; Hallam, 1992; Voigt, 2006).

In the eastern part of the VSLPP, the top of the El Abra Formation is marked by the pelagic deposit of the Tamasopo (lower member) and Agua Nueva formations of Turonian age (Bazañez *et al.*, 1993), interpreted as a drowning event.

The drowning in the western part of the VSLPP occurred in the upper part of the El Abra Formation with the hemipelagic–pelagic Soyatal deposit in the Cenomanian-Turonian boundary interval (CTBI) (Omaña *et al.*, 2010, 2013).

## MATERIAL AND METHODS

A limestone and marly limestone section was measured and sampled in detail from outcrops located on the road cut between the cities of San Luis Potosí and Cerritos, geographical coordinates 22°01'00" N–100°57'00" W, in the western part of the Valles–San Luis Potosí platform (Figure 1b, c).

The samples were collected at an average interval of 4 to 5 m. For micropaleontological and microfacies analysis, thin sections were prepared, both parallel and perpendicular to stratification.

The micropaleontological examination of 50 thin sections (17 samples) of limestone and marly limestone was carried out in order to identify and describe the pithonellids whose structure is masked by effects of diagenesis.

The associated microfossils (benthic and planktic foraminifera and roveacrinids) are also reported. Good foraminiferal preservation allowed precise identification that enabled foraminiferal taxonomic attribution and an accurate age assignment. In addition, a microfacies study was performed to infer the paleoenvironment using the lithology and faunal characteristics (the pithonellids bloom event and the associated microfossils).

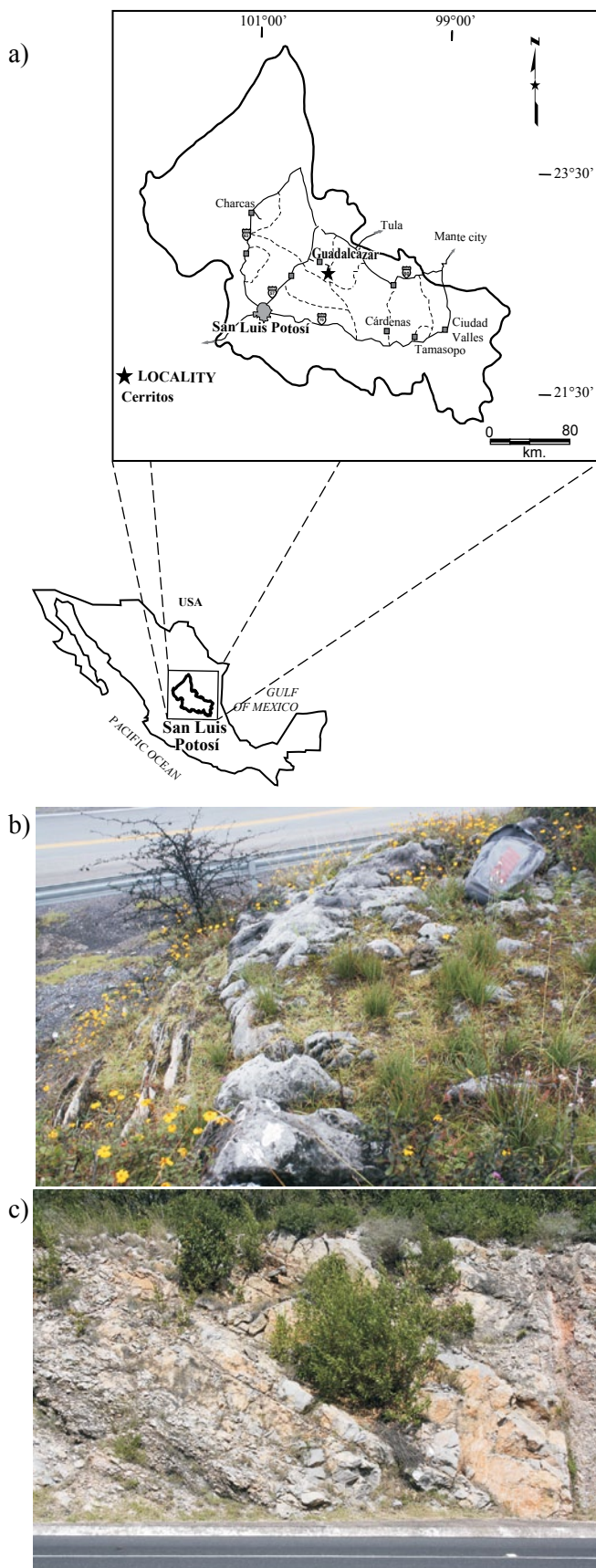


Figure 1. a) Location of the study section. Images from the San Luis Potosí–Cerritos road showing El Abra Limestone (b) and Soyatal Formation (c).



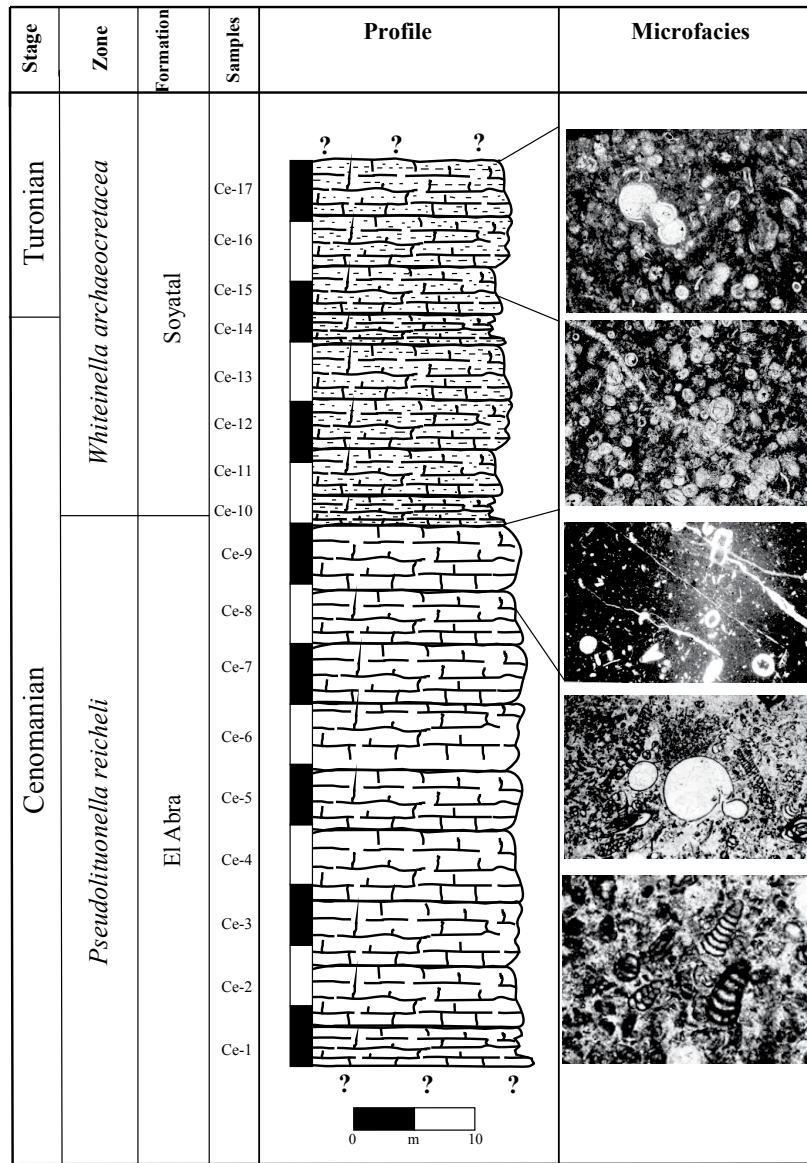


Figure 2. Stratigraphic column of the Cerritos section with microfacies images.

## RESULTS AND DISCUSSION

### Lithofacies and microfacies

The Cerritos section is exposed on a road cut, east of the city of San Luis Potosí (Figure 1a). At this locality, the section consists of 45 m of grey massive limestone of the upper part of the shallow-water deposit of El Abra Formation (Figure 1b).

Upwards, the lithology consists of 30 m of successive 30–40 cm beds of cream marly limestone of the Soyatal Formation (Figure 1c) that marks a change to pelagic sedimentation.

In the present study four microfacies were identified (Figure 2). For El Abra shallow-water deposit two microfacies are described.

Microfacies 1. Benthic foraminiferal, algal packstone-grainstone, rich in pellets and pseudopellets. The percentage of components locally exceeds 50%, forming a grain-supported fabric (Figure 3 a-c). The groundmass, mostly sparry cement, shows small remains of an original micritic matrix. This microfacies type could be compared with Standard Microfacies Type (SMF) 18 “bioclastic grainstones and

packstones with abundant benthic foraminifera or calcareous green algae” (Wilson, 1975; Flügel, 2004).

The depositional environment of this microfacies suggests a shallow marine environment above the normal wave base, within the euphotic zone in the open marine interior platform, corresponding with Facies Zone 7 (ZF 7) of Flügel (2004). The fossil assemblage indicates precipitation in shallow subtidal zones with normal salinity, stable temperature conditions and good oxygenation of the seawater.

Microfacies 2. Worn algal (gymnocodacean) packstone. A large amount of gymnocodacean algae, such as *Permocalculus* Elliot, is embedded in a fine-grained matrix. The foraminiferal community is reduced to small forms of *Nezzatinella picardi* (Henson), miliolids, textularids such as *Praechrysalidina* sp., and rotalids. This change could be related to an increase in nutrient supply (Figure 3d). This microfacies is similar to SMF 10 of Wilson (1975), suggesting an open sea shelf environment of Facies Zone 7. The main components have been transported from high-energy to low-energy environments, and a variation in the water energy can be interpreted from the increase

in size of the bioclasts and groundmass grains (microsparite). This microfacies corresponds to Facies Zone 7 (interior platform, open marine environment) of Wilson (1975) and Flügel (2004).

Up-section, the lithology changes to marly limestone of the hemipelagic-pelagic Soyatal Formation (Figure 2) represented by the following microfacies:

Microfacies 3. Calcsphere-rich packstone-wackestone. This microfacies contains a flood of pithonellids embedded in a micritic matrix (Figure 4 a-d; Figure 5 a, b, e) that locally varies to microsparitic cement. The population of pithonellids can reach 50% of the components in a mud- to grain-supported fabric. In addition to the

calcspheres, opportunistic planktic foraminifera are also present; hedbergellids, heterohelicids, whiteinellids (Figure 4a-d) and small benthic foraminifera such as *Dorothia* sp., *Gavelinella* spp., *Lingulogavelinella* sp. and roveacrinids (Figure 5 c, d, f, g, h, i). A microlamination or some orientation of the components is not recognizable, but it resembles an unsorted accumulation of microfauna in the micritic groundmass. This microfacies could be similar to the Standard Microfacies Type 2 and 3 (wackestone to packstone with larger calcspheres and foraminifera) of Wilson (1975) and Flügel (2004) in a Facies Zone 2 to 3 (deep shelf), but its depositional environment is certainly evidence of an initial drowning event.

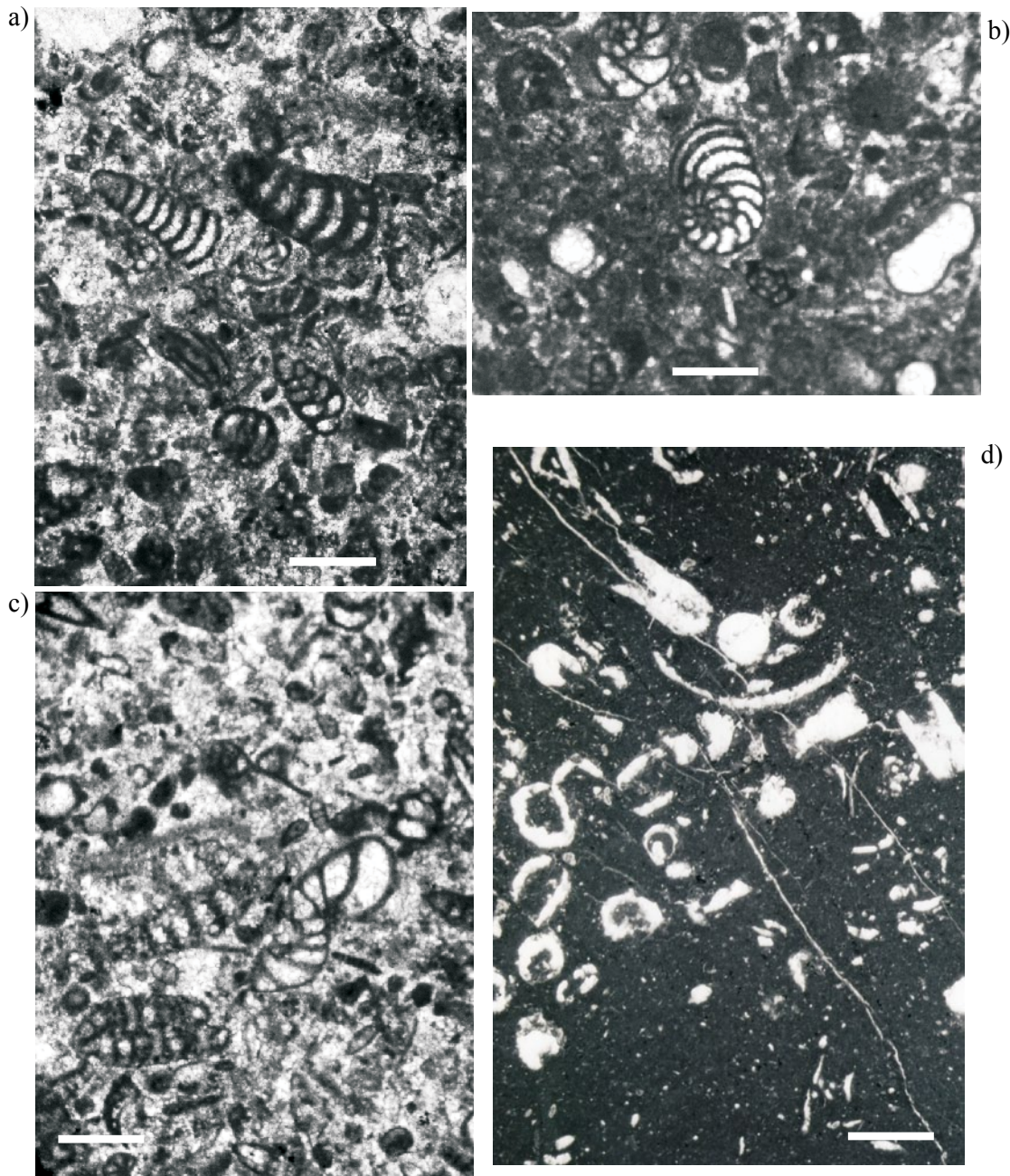


Figure 3. Benthic foraminiferal algal packstone-grainstone, rich in pellets and pseudopellets (El Abra Formation). Scale bar = 200  $\mu$ m. a) Benthic foraminiferal algal packstone-grainstone with *Pseudolituonella reicheli* (Sample C-4); b) Benthic foraminiferal algal packstone-grainstone with *Peneroplis parvus* (Sample C-6); c) Benthic foraminiferal algal packstone-grainstone with *Trochospira* sp. and *Cuneolina* sp. (Sample C-6); d) Worn algal (gymnocodacean) packstone. (Sample C-8).



Microfacies 4. Planktic foraminiferal wackestone. This microfacies is characterized by a dark grey, micritic matrix (up to 70%), within which are small bioclasts, foraminifera and a few calcispheres (maximum 40%). The component assemblage is characterized by a lower population of pithonellids but it is also associated with small and large globular foraminifera, which are characteristic of a stressed environment because they had wider ecological tolerance (Figure 5 a, b, e; Figure 6 a-d). This microfacies resembles a Standard Microfacies 3 (SMF 3, pelagic mudstone-wackestone), and its depositional environment can be considered to be Facies Zone 1 to 3, which shows variations to even deeper water environments.

#### Age

Age was assigned using the benthic foraminifera in the shallow-water deposit of El Abra Formation. The overlying pelagic deposit

(Soyatal Formation) that contains the pithonellid bloom was dated with planktic foraminifera.

The upper part of El Abra Formation was dated as mid-late Cenomanian age (*Pseudolituonella reicheli* Assemblage Zone), based on the stratigraphic range of the nominal fossil and other benthic foraminifera such as *Daxia cenomana* Cuvillier and Szakall, *Nezzazata simplex* Omara, *Pseudocyclammina rugosa* (d'Orbigny) *Peneroplis parvus* de Castro, *Dicyclina schlumbergeri* Munier-Chalmas, *Minouxia inflata* Gendrot, *Montcharmontia apenninica* de Castro, *Nezzatinella picardi* (Henson). This zone consists of an interval recognized by the abundance and diversity of the benthic foraminifera; however, the benthic association was affected in two steps. First, the bulk of genera disappears, reducing the foraminiferal community to small forms of miliolids, textularids, and rotalids. Gymnocodaceans such as *Permocalculus* Elliot are abundant.

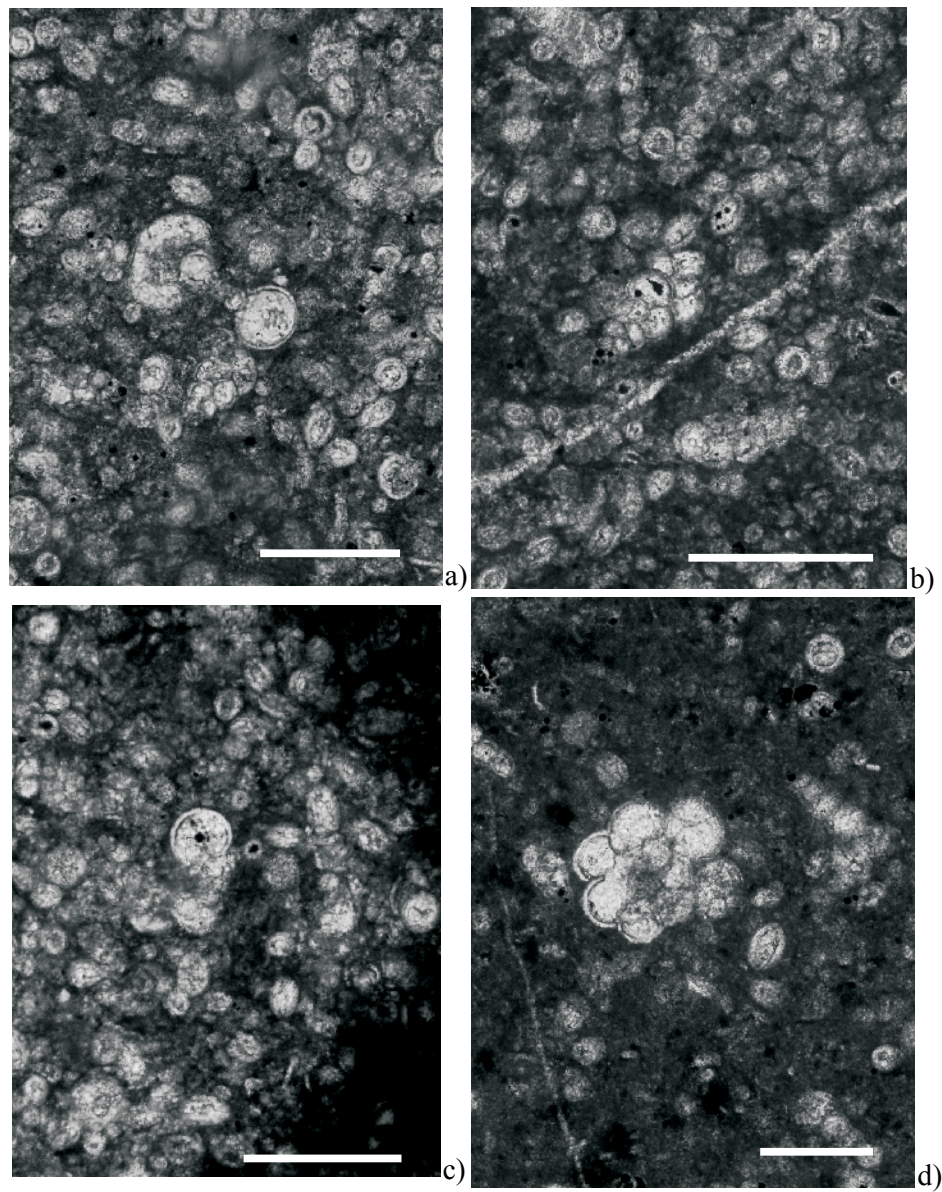


Figure 4. Calcisphere-rich packstone-wackestone (Soyatal Formation). Scale bar 200  $\mu\text{m}$ . a) Packstone-wackestone of pithonellids with *Macroglobigerinelloides caseyi* (Sample C-10-1); b) Packstone-wackestone of pithonellids and *Heterohelix moremani* (Sample C-10-4); c) Packstone-wackestone of pithonellids and *Muricohedbergella delrioensis* (Sample C-10-1); d) Packstone-wackestone of pithonellids and *Whiteinella paradubia* (Sample C-13).



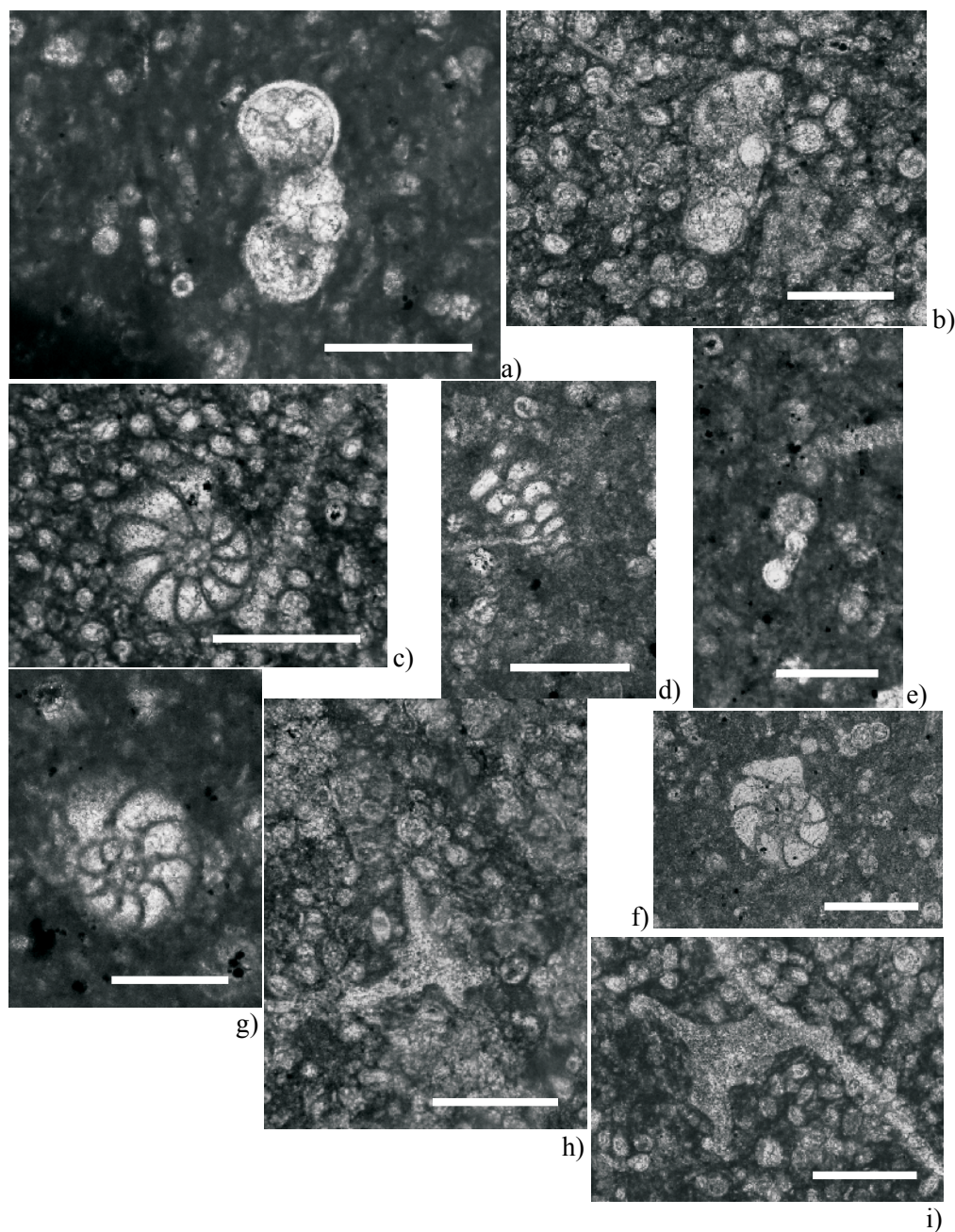


Figure 5. Packstone-wackestone of pithonellids, planktic, benthic foraminifera and roveacrinids (Soyatal Formation). Scale bar 200  $\mu\text{m}$ . a) Packstone-wackestone of pithonellids and *Whiteinella baltica* (Sample C-13); b) Packstone-wackestone of pithonellids and *Whiteinella praehelvetica* (Sample C-13); c), g) *Gavelinella* spp. (Sample C-13); d) *Dorothia* sp. (Sample C-13); e) *Muricohedbergella planispira* showing a large umbilicus and the chambers slowly enlarging (Sample C-10). f) *Lingulogavelinella* sp.; h) and i) Roveacrinids (Sample C-13).

Upwards, in the lower part of the Soyatal Formation, we recorded a mass occurrence of pithonellids such as *Pithonella sphaerica*, *P. ovalis*, and *Bonetocardiella conoidea*, which are associated with opportunistic foraminifers (r-strategists) such as *Muricohedbergella delrioensis*, *M. planispira*, *Heterohelix moremani*, *H. reussi*, *Macroglobigerinelloides caseyi*, or r-k intermediate strategists for example *Whiteinella archaeocretacea*, *W. baltica* W. cf. *W. brittonensis*, and *W. paradubia* (Figure 5). This assemblage is dated as latest Cenomanian-earliest Turonian age (*Whiteinella archaeocretacea* Partial Range Zone) = “zone à grosses globigérines” (Sigal, 1955, 1977).

#### Cenomanian-Turonian boundary

The C-T boundary is marked by the first occurrence (FO) of the ammonite *Watinoceras devonense* at the base of level 86 in the Pueblo Colorado as the Global Standard Section and Point (GSSP). Among the planktic foraminifera, the first occurrence (FO) of *Helvetoglobotruncana helvetica* is above the ammonite index in level 89, and the transitional forms between *Whiteinella praehelvetica* and *Helvetoglobotruncana helvetica* are found in beds 85–87 (Kennedy et al., 2000, p. 98). These foraminiferal events show that the Cenomanian-Turonian Boundary in the section could be placed within the *Whiteinella archaeocretacea* Partial Range zone.



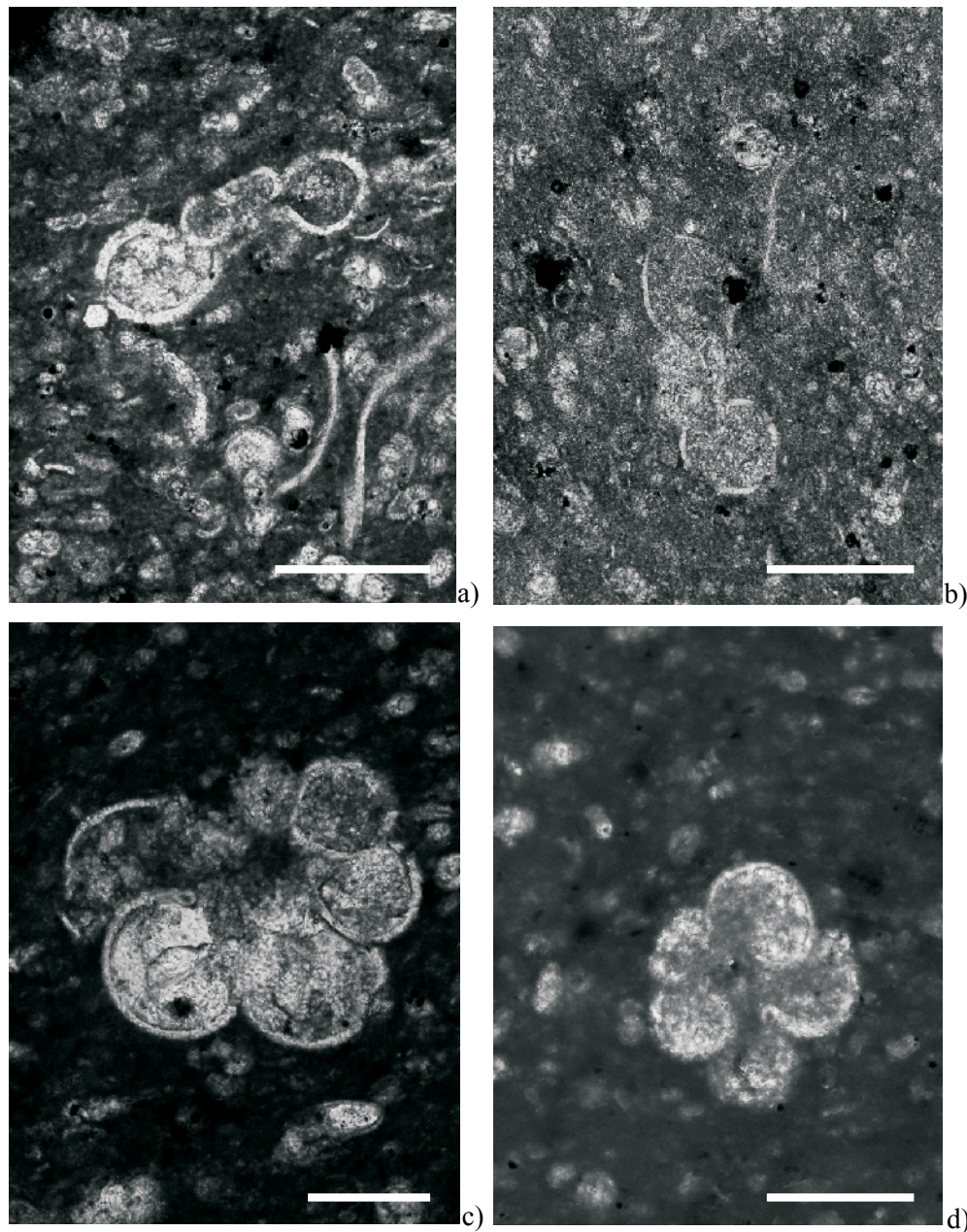


Figure 6. Planktic foraminiferal wackestone (Soyatal Formation) (Sample C-16). Scale bar 200  $\mu\text{m}$ . a) *Whiteinella* cf. *W. aprica*, axial section showing a low trochospire nearly symmetrical, wide umbilicus (Sample C-16); b) *Whiteinella* cf. *W. archaeocretacea*, subaxial section showing a test slightly convex-concave, with the globular chambers rapidly increasing in size, wide umbilicus. (Sample C-16); c) *Whiteinella paradubia* equatorial section showing the last whorl with six chambers and the portici (Sample C-16); d) *Whiteinella brittonensis*, transverse section showing a moderate high trochospire asymmetrical, with five globular chambers in the last whorl, and pustulose wall.

In the study section, it is difficult to locate the exact position of the boundary because ammonites are absent; however, taking into account the foraminiferal events in the Pueblo Colorado (GSSP), we can infer that the Cenomanian-Turonian could also be within the *Whiteinella archaeocretacea* Zone Partial Range zone. This agrees with the view of Caron *et al.* (2006) who stated that “while the ammonites defined precisely the boundary C-T boundary, the changes in the planktic foraminifera are less indicative over a broad interval of time coeval with the contemporaneous oceanic environmental perturbation”. This planktic turnover correspond to the traditional ‘zone à grosses globigérines’ of Sigal (1977) defined as *Whiteinella archaeocretacea*

Partial Range zone of Robaszynski and Caron (1995).

The long stratigraphic range of the pithonellids has little biostratigraphical significance and we used them as a complementary data for dating. *Pithonella ovalis* is frequently recorded in the Albian, but the stratigraphic range reported is Albian to Maastrichtian (Bonet, 1956; Andri, 1972; Dias-Brito, 2000), while Keupp (1987) gives a range for this species from the upper Barremian to Maastrichtian.

According to Bignot and Lezaud (1964) this species is very abundant from Albian to Coniacian, and rare in Santonian, and extinction occurred in Maastrichtian.

*Pithonella sphaerica* has the longest stratigraphic range, spanning



from the upper Barremian to Maastrichtian (Keupp, 1987).

This species, together with *P. ovalis*, is reported to be very abundant in upper Albian-Coniacian deposits (Dias-Brito, 2000).

Andri (1972) indicated that *P. sphaerica* is present from mid-Albian to Turonian. This author recorded the first occurrence of *Pithonella ovalis* and *P. sphaerica* in the late Cenomanian with planktic foraminifera; however, although its presence in the Coniacian has not often been verified, it is widely distributed from the Santonian to Maastrichtian (Dias-Brito, 2000).

*Bonetocardiella conoidea* is considered to be the form with the shortest stratigraphic distribution, spanning from the Albian to Turonian (Bonet, 1956), Albian-Cenomanian (Andri, 1972), and it is assumed that the extinction of this species occurred in early Turonian (Dias-Brito, 2000).

### Paleoecology and paleoenvironment

The pithonellids were thermophilic planktic organisms that inhabited the surface waters and are associated with fine-grained carbonates which were deposited in shelf to shallow bathyal environments. Therefore the distribution of these fossils was controlled by both latitudinal and facies-environmental factors (Dias-Brito, 2000).

In the study material, the great abundance of *Pithonella ovalis*, *P. sphaerica* and *Bonetocardiella conoidea* is related to the Valles-San Luis Potosí platform drowning when the shallow-water deposit of El Abra Formation was interrupted by the marly limestone sedimentation of the hemipelagic Soyatal deposit.

The lithological change from shallow-water marine carbonates to hemipelagic, deeper sediments is interpreted as a drowning unconformity, as has been described by Schlager (1989). The flooding of the platform has been reported by the other authors in several localities.

The long term sea level rise has been reported (Hallam, 1992; Miller et al., 2005; Morth et al., 2007; Gale et al., 2008), and widespread drowning of Mediterranean platforms has been recorded for the Cenomanian-Turonian Boundary Interval (CTBI) on the global scale (Philip and Airaud-Crumière, 1991; Drzewiecki and Simó, 1997; Caus et al., 1993, 1997, Hart et al., 2005; El-Sabbagh et al., 2011), which is coeval with the drowning event of the Valles-San Luis Potosí platform.

An increased abundance of *Pithonella ovalis* related to transgressive episodes has been reported by Zügel (1994). His conclusion is based on the abundance of this species during the Turonian sea level maximum. A relationship between *P. ovalis* increase and transgression has been observed in the late Cenomanian at several localities (Villain, 1975; Keupp, 1987; Dali-Ressot, 1987; Hart, 1991; Hilbrecht et al., 1996; Wendler et al., 2002b).

Pearce et al. (2009) observed an abundance pattern of calcispheres which reaches a maximum in the transgressive sediments within the latest Cenomanian at Eastbourne (England).

The calcispheres (pithonellids) appear to have been an opportunistic group, their abundance probably reflecting an increased nutrient supply, and a marked increase of them coincides with the decline in organic-walled dinoflagellate cysts (Jarvis et al., 1988, p. 65).

Wendler et al. (2002b) stated that the distribution of pithonellids in the shelf depends on water depth or the availability of nutrients.

The pithonellids show temporal changes in abundance related to nutrient availability; thus *Pithonella sphaerica* has been interpreted as a species indicative of eutrophic conditions (Wendler et al., 2002b). The pithonellids (calcispheres) have also been regarded as productivity indicators (Caus et al., 1993, 1997; Noël et al., 1995; Drzewiecki and Simó, 1997; Gale et al., 2000; Drzewiecki and Simó, 2000; Wilmsen, 2003; Wendler et al., 2010b).

In the analyzed material, the pithonellids are associated with small simple morphologies of r-strategists planktic foraminifera which are restricted to surface-dwelling species such as *Heterohelix*, *Globigerinelloides* and *Muricohedbergella* (Hart, 1980a), 1999; Jarvis et al., 1988; Leckie, 1987; Leckie et al., 1998; Leckie et al., 2002; Keller and Pardo, 2004).

The low salinity tolerance of hedbergellids such as *Muricohedbergella delrioensis*, *H. Muricohedbergella planispira*, and low oxygen-tolerant heterohelicids *Heterohelix reussi*, *Heterohelix moremani* have been documented (Hart, 1980b, 1999; Leckie, 1987; Leckie et al., 1998, 2002; Keller and Pardo, 2004).

In the study material, the pithonellids could be regarded as opportunistic forms by their association with small morphology r-strategists planktic foraminifera, which are cosmopolitan ecological opportunistics and adapted to eutrophic environments as documented by Leckie (1987), Premoli Silva and Sliter (1994) and Coccioni and Luciani (2004) and Caron et al. (2006).

The r-k strategists planktic foraminifera with globular chambers such as whiteinellids also indicate stressed environments with increased surface productivity and salinity changes (Keller et al., 2001; Keller and Pardo, 2004; Gebhardt et al., 2010). These shallow environments are often characterized by high nutrients due to terrigenous runoff and low salinity due to fresh water influx.

Wendler et al. (2013b) pointed out that the value of  $\delta^{13}\text{C}$  of biserial species such as *Heterohelix moremani* could reflect the opportunistic character of the species that lived in surface waters. These authors also measured the  $\delta^{18}\text{O}$  value in *Pithonella sphaerica*, which indicates surface water temperatures, but the value of  $\delta^{13}\text{C}$  is very high. The disparity of these values reflects differences in cyst types and related differences in metabolism, probably involving photosynthetic activity.

Kohring et al. (2005) stated that the morphological features of cysts provide important information about the paleoenvironment; distinctive characters of the dinoflagellates cysts can be used for paleoecological interpretations.

We found small and scarce benthic foraminifera such as *Gavellinella*, *Lingugavellinella* and *Dorothia* sp. associated with the pithonellids (Figure 4 c, d, f, g); their occurrence indicates low oxic-dysoxic bottom conditions during the Cenomanian-Turonian boundary interval as was reported by Hart (1980b) and Gebhardt et al. (2010). The bloom of pithonellids is also associated with the roveacrinids (pelagic crinoids).

With respect to paleoenvironmental conditions of these microfossils, Ferré et al. (2005) indicate that "the roveacrinids seem to have thrived in such environments, where they frequently developed abundant opportunistic populations that fed on calcisphere blooms."

### Paleobiogeography

During the late Cenomanian, carbonate platforms developed extensively along the northern and southern borders of the Tethyan Realm on the passive margins of the Eurasian, African and American plates (Philip and Airaud-Crumière, 1991).

A sea-level rise and warmer global climate in the Cenomanian-Turonian boundary interval marked a shift along flooded continental margins and in newly-created or expanded epicontinental seas. The Valles-San Luis Potosí was flooded in the latest Cenomanian and this transgression also facilitated an increase of nutrients that enabled the development of opportunists such as the calcispheres and r- and r-k strategists planktic foraminifera.

In the Cerritos section, we recorded an assemblage composed of the calcispheres *Bonetocardiella conoidea*, *Pithonella ovalis*, and *P. sphaerica*, and opportunistic r and r-k strategists planktic foraminifera such as heterohelicids, hedbergellids, and whiteinellids as has been reported in other areas of the Mediterranean region.

The distribution of pithonellids is limited to 40° N and S of the equator, which corresponds to the Cretaceous tropical belt (Kauffman and Johnson, 1988); thus the pithonellids are considered to be typical Tethysian fossils (Bignot and Lezaud, 1964; Andri, 1972; Masters and Scott, 1978; Dias-Brito, 2000).

*Pithonella ovalis* and *Pithonella sphaerica* are the most abundant and widely distributed (Figure 7). They have been reported from many localities from Europe such as southern England (Banner, 1972; Hart, 1991; Wilkinson, 2011), Germany (Neuweiler, 1989; Wendler *et al.*, 2002a; Wilmsen, 2003), Portugal (Hart *et al.*, 2005), Spain (Colom, 1955; Azéma, 1966; Castro and Martínez-Gallego, 1980; Caus *et al.*, 1993, 1997; Drzewiecky and Simó, 1997, 2000), France (Bignot and Lezaud, 1964), Italy (Andri, 1972), and former Yugoslavia (Gusic and Jelaska, 1990).

The occurrence of these microfossils has been documented in Israel (Hamaoui, 1965; Bein and Reiss, 1976) and Jordan (Wendler *et al.*, 2010b). In Africa, they have been reported in Algeria and Tunisia (Colom, 1955; Colom *et al.*, 1954; Dali-Ressot, 1989; Robaszynski *et al.*, 2010; Negra *et al.*, 2011), the Morocco Basin (Pflaumann and Krasheninnikov, 1978), Ivory Coast (Chierici, 1984) and Tanzania (Wendler *et al.*, 2010a). The pithonellids are found in the Himalayan region of India (Bertle and Suttner, 2005).

In America, they have been also recorded in the Gulf Coast of the United States (Masters and Scott, 1978; Olsson and Youssefnia, 1979), in Mexico (Bonet, 1956; Bonet and Trejo, 1958; Trejo, 1960; Bonet and Riva-Palacio, 1970; Ice and McNulty, 1980; Ornelas, 1984; Aguilera Franco and Allison, 2004), in Brazil (Krasheninnikov and Basov, 1983; Berthou and Bengtson, 1989; Dias Brito, 1985, 1992, 2000, 2002), and in Chile (Martínez-Pardo *et al.*, 1994).

It is important to point out that these microfossils reached their acme during the mid-Cretaceous, at the time when the Earth experienced its warmest period, repeated drowning in the tropics, and high biological turnover. The warm temperatures have been widely attributed to high levels of atmospheric greenhouse gases such as carbon dioxide (Norris *et al.*, 2002). Greenhouse conditions are consistent with the increase in oceanic crust production, forming anomalously thick

and extensive oceanic plateaus termed LIPS (large igneous provinces) (Sinton *et al.*, 1998), and the sea level rise (Hallam, 1992; Miller *et al.*, 2005; Morth *et al.*, 2007; Gale *et al.*, 2008) was probably driven by this formation of oceanic crust (Seton *et al.*, 2009).

#### Taxonomic notes

We studied the pithonellids in thin sections from marly limestone samples and we observed morphologic characters such as shape, size, aperture, and wall structure. The wall structure is regarded as the most important feature for the classification of dinoflagellate cysts. It is mostly based on wall crystal orientation, and four types are described: pithonelloid, radial, oblique and tangential (Keupp, 1987; Kohring, 1993; Young *et al.*, 1997), which are illustrated (Figure 8) from the drawing of Kohring *et al.* (2005).

Other significant morphologic characters such as tabulation and archeopyle/operculum morphology have to be included in a systematic study (Fensome *et al.*, 1993).

Streng *et al.* (2004) indicated that the opening of the pithonellid species is too small (12–18%) to represent an archeopyle. The monoplacoid archeopyle of calcareous dinoflagellates measures about 30% of the cyst diameter; moreover, no distinct opercula have been seen in any species with pithonellid wall structure. Although Masters and Scott (1978) described a plug-like structure in pithonellid taxa, this is regarded by Streng *et al.* (2004) to be an artifact due to the irregular form.

Dali-Ressot (1989) gave evidence by SEM analysis of the presence of the operculum in *Pithonella ovalis* and *P. sphaerica*, confirming the taxonomic affinity to calcified dinoflagellate cysts. Wendler *et al.* (2002a) showed an illustration of a specimen of *Pithonella sphaerica* with a distinctive operculum. Later, Wendler *et al.* (2010a) and Wendler and Bown (2013) found abundant and well-preserved Turonian pithonellids in Tanzania and they discovered an operculum-like structure that can be associated with the apical third plate of the peridiniaean tabulation pattern of dinoflagellates.

The numerous thin sections examined contained *Bonetocardiella conoidea*, *Pithonella ovalis* and *P. sphaerica*. They showed diagenetic recrystallization; however, some features were observed.

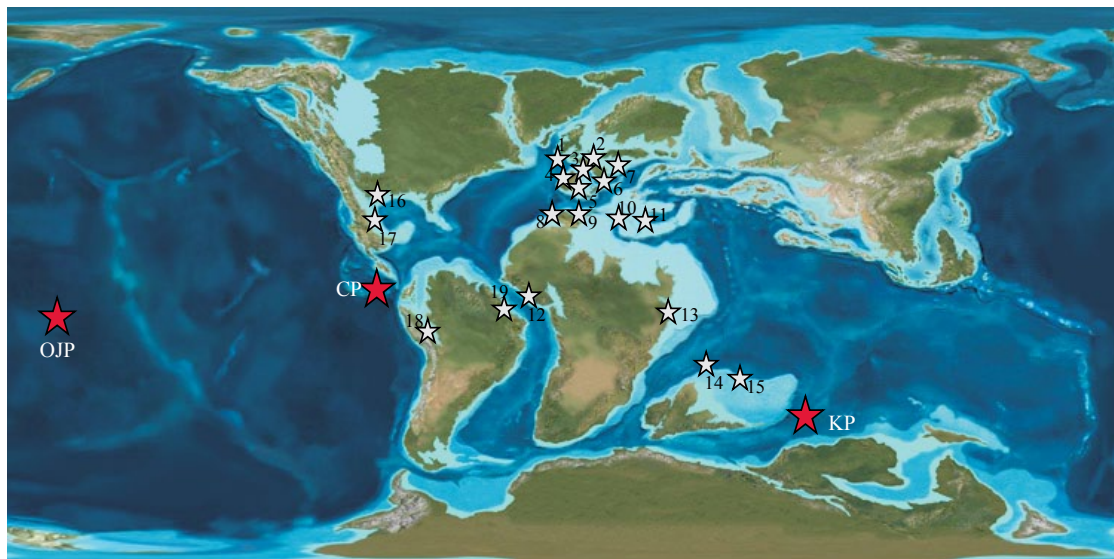


Figure 7. Cenomanian-Turonian paleogeographic map (Blakey, 2002) showing the localities where calcispheres has been reported and the site of the main Large Igneous Provinces in mid Cretaceous: 1. England, 2. Germany, 3. France, 4. Spain, 5. Portugal, 6. Italy, 7. Croatia, 8. Morocco, 9. Tunisia, 10. Lebanon, 11. Israel, 12. Ivory Coast, 13. Tanzania, 14. Pakistan, 15. India, 16. Gulf Coast (USA), 17. Mexico, 18. Chile, 19. Brazil. Large Igneous Provinces: OJP- Ontong Java plateau (94–86 Ma), CP- Caribbean plateau (90–99 Ma), KP- Kerguelen plateau (103–83 Ma).



The study specimens are housed in the Collection of Paleontology of the Institute of Geology (Universidad Nacional Autónoma de México).

According to Wendler *et al.* (2013a) the systematic position of the pithonellids is:

Division Dinoflagellata (Bütschli, 1885) Fensome *et al.*, 1993  
 Subdivision Dinokaryota Fensome *et al.*, 1993  
 Class Dinophyceae Pascher, 1914  
 Subclass Peridiniphyceae Fensome *et al.*, 1993  
 Order Peridiniales, Haeckel, 1894  
 Suborder Peridiniineae Autonym  
 Family Thoracosphaeracea Schiller, 1930  
 Genus *Bonetocardiella* Dufour, 1968

***Bonetocardiella conoidea* (Bonet, 1956)**

(Figure 9 a, b, c)

*Stomiosphaera conoidea* Bonet, 1956, p. 454, pl. XXII, figs. 1, 2; Adams *et al.*, 1967 p. 64, pl. 1, fig. 5a; Dufour, 1968 p. 2, pl. 1, fig. 4.

*Bonetocardiella conoidea* (Bonet, 1956) Andri, 1972 p. 15, pl. 1, figs. 1, 2; Bolli, 1974 p. 822, pl. 7 figs. 1, 2, 3, 9, 10, 11, pl. 2, figs. 1, 2, 3, 7; Villain, 1977, p. 155; Castro and Martínez-Gallego, 1980, p. 319, pl. 1, figs. 2, 7; Ornelas, 1984, p. 362, pl. 2, fig. 9, pl. 3, fig. 5; Dali-Ressot, 1989, p. 193, pl. 1, figs. 7 d; Martínez-Pardo *et al.*, 1994, p. 186, pl. 1, figs. 13, 15; Dias-Brito, 2000, p. 341, pl. 19, figs. b, c, e; Reháková, 2000, p. 240, pl. 6, fig. 9; Dias-Brito, 2002, p. 2, fig. 1c; Bucur and Baltres, 2002, p.90, pl.1, fig. 5.

**Type species.** *Bonetocardiella conoidea* (Bonet, 1956).

**Description.** *Bonetocardiella conoidea* is a species with a characteristic heart shape which shows an apical aperture situated in a depression, with a lamellar wall formed by calcite crystals oriented in linear rows on the wall which is replaced by

cryptocrystalline calcite like the matrix of the surrounding rock.

**Dimensions.** The measurements of this species in the analyzed material are height 84  $\mu\text{m}$ , width 70  $\mu\text{m}$  and aperture diameter is 35  $\mu\text{m}$ .

**Remarks.** Dufour (1968) proposed the nom *Bonetocardiella* for the *Stomiosphaera conoidea* described by Bonet (1956) for the first time from the Sierra de la Gloria, Monclova, Coahuila, Mexico.

**Discussion.** *Bonetocardiella conoidea* (Bonet, 1956) is similar to *Bonetocardiella betica* Azéma (1966) but differs by having a small aperture and a round periphery rather than an acute border. Andri (1972) indicated that there is a close relationship between the two species because transitional forms prevail.

**Occurrence.** Samples C-10, C-14.

Genus *Pithonella* Lorenz, 1902

***Pithonella ovalis* (Kaufmann, 1865)**

(Figures 10 b, c, d)

*Lagena ovalis* Kaufmann (*in* Heer, 1865), p. 96, figs. 104, 107.

*Pithonella ovalis* (Kaufmann, 1865) Lorenz, 1902, p. 46, pl. 9, fig. 2.

*Fissurina ovalis* (Kaufmann, 1865) Colom, Castany, Durand Delga, 1953, p. 529–531, fig. 10.

*Pithonella ovalis* (Kaufmann, 1865) Colom, 1955, p. 121, fig. 4, pl. 3, fig. 31, pl. 5 figs. 2–8, 10; Bonet, 1956, p. 456, pl. 22, fig. 1, pl. 23, fig 1–2, pl. 26; Bonet and Trejo, 1958, p. 46, pl. 1, figs. 8–10, pl. 2, figs. 3–6; Ayala-Castañares, 1959, p. 33, pl. 2, figs. 5–6; Bignot and Lezaud, 1964, p. 141–143, pl. 1, figs 1, 8–11, pl. 2, figs. 2–9, pl. 3, figs. 1–2; Adams *et al.*, 1967, p. 64, pl. 1, fig. 3a; Vezzani, 1968, p. 249, fig. 20, p. 250, figs. 21, 22, p. 254, fig. 27; Andri, 1972, text-fig. 8, pl. 2, fig.1 (c), pl. 3 fig. 1; Banner, 1972, p. 280, pl. 1, fig.1; Castro and Martínez-Gallego, 1980, p. 319, pl. 1, fig. 1 b; Dali-Ressot, 1989, p. 193, pl. 1, figs. 7 c; Vašiček *et al.*, 1994, p. 119, pl. 5, fig.5; Dias-Brito, 2000, p. 340, pl. 18, figs. a, b, c, d; Dias-Brito, 2002, p.

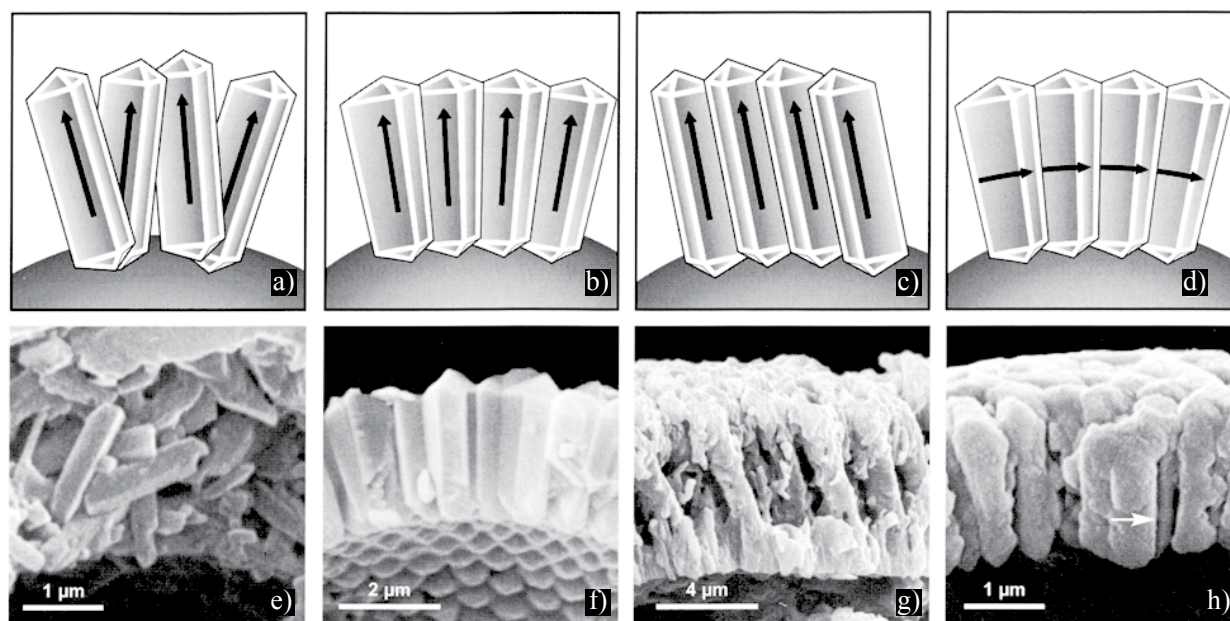


Figure 8. Cyst wall ultrastructure (illustrated from Kohring *et al.*, 2005). a–d–Schematic diagrams of wall ultrastructures and orientations of c-axes of wall crystals. a) Oblique wall type; b) Radial wall type; c) Pithonellid wall type; d) Tangential wall type. e–h Wall structure images from selected calcareous dinoflagellate. e) Oblique wall type (*Pirumella multistriata* forma *patriciagreleyae*); f) Radial wall type (*Orthopithonella congruens*); g) Pithonellid wall type (*Pithonella* sp.); h) Tangential wall type (*Futterella-tesserula*).

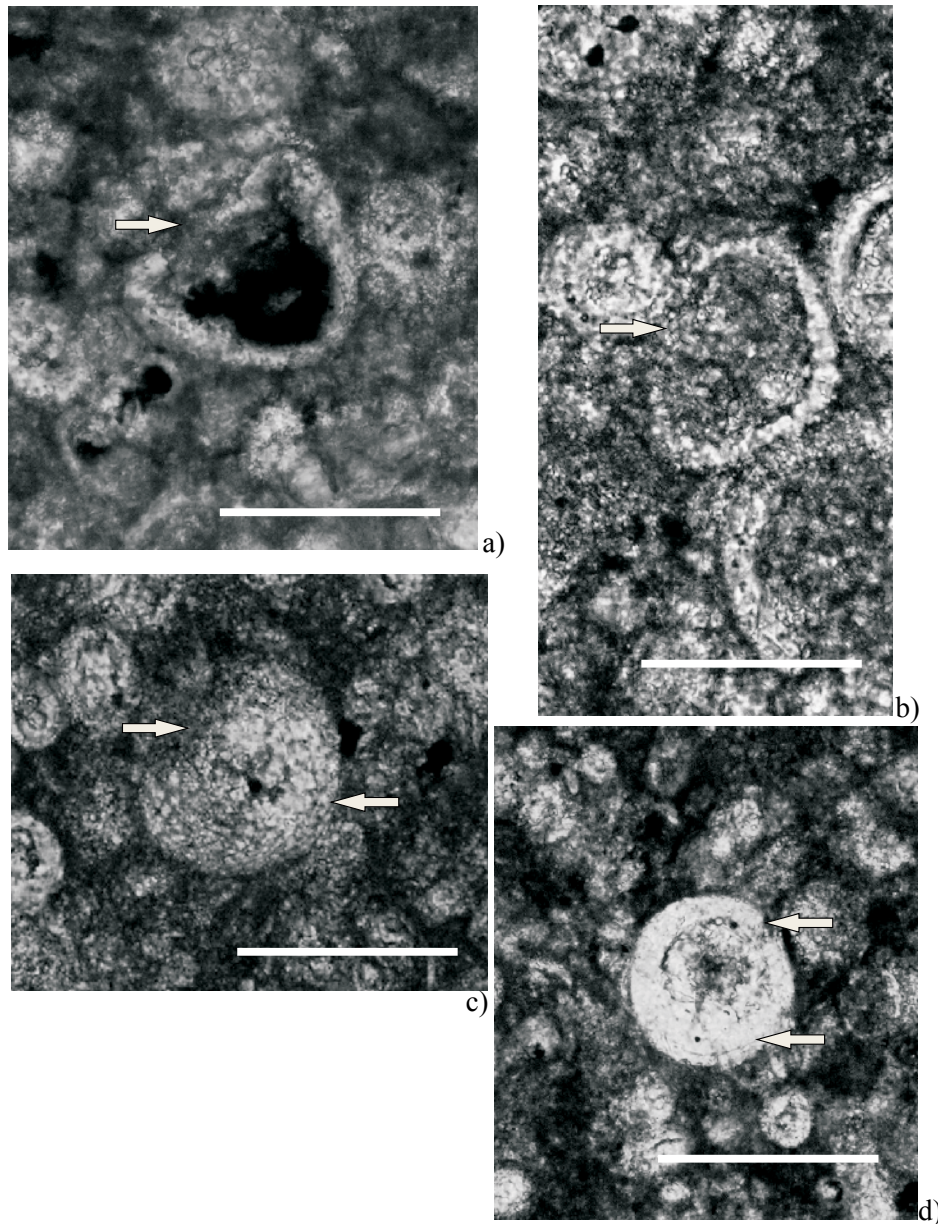


Figure 9. Calcisphere-rich packstone-wackestone (Soyatal Formation). Scale bar 100  $\mu\text{m}$ . a) Axial section of *Bonetocardiella conoidea* with a heart shaped form showing the aperture (Sample C-10-1); b) Subaxial section of *Bonetocardiella conoidea* showing the pithonellid wall (Sample C-10-1); c) External view of *Bonetocardiella conoidea* showing the concentric arrangement of the crystals (Sample C-10-4); d) Axial section of *Pithonella sphaerica* showing the aperture and the thick wall (Sample C-10-1).

2, fig. 1c; Bucur and Baltres, 2002, p. 90, pl. 1, fig. 1-4; Niebuhr, 2005, p. 33, fig. 2c

**Type species.** *Pithonella ovalis* (Kaufmann, 1865).

**Description.** *Pithonella ovalis* (Kaufmann, 1865) has an elliptical-shaped form with small aperture at one end. In thin section, we observed a thick wall that measured 10-15  $\mu\text{m}$ . The irregular internal part of the wall is difficult to see, but frequently an irregular fracture along the ellipse is distinguished. This species measured height 70  $\mu\text{m}$ , width 35  $\mu\text{m}$ , apertural diameter 7  $\mu\text{m}$ .

**Remarks.** *Pithonella ovalis* was described by Kaufmann (in Heer, 1865) from the type locality of the Cenomanian to Coniacian Seewerkalk in Central Switzerland.

**Occurrence.** Samples C-10; C-14.

***Pithonella sphaerica* (Kaufmann, 1865)**

(Figure 9 d, 10 a)

*Lagena sphaerica* Kaufmann, (in Heer, 1865); de Lapparent, 1918, p. 18, pl. 2, figs. 1-2; de Lapparent, 1923, p. 274, pl. 14, fig. 1, pl. 22, figs 2-3.

*Stomiosphaera sphaerica* (Kaufmann, 1865) Bonet, 1956, p. 64-66, pl. 23, figs. 1-2; Adams *et al.*, 1967, p.64, pl. 1, figs. 6a; Vezzani, 1968, p. 249, fig. 20, p. 250, fig. 21, p. 254, fig. 27; Andri, 1972, p. 26, fig. 11, pl. 2, figs. 10-12; Castro and Martínez-Gallego, 1980, p. 319, pl. 1, figs. 3, 4, 8; Vašiček *et al.*, 1994, p. 119, pl. 5, fig.5.

*Pithonella sphaerica* (Kaufmann, 1865) Dali-Ressot, 1989, p. 193, pl. 1, figs. 7a, b; Dias-Brito, 2000, p. 340, pl. 18, figs. a b, c, d, pl. 19,



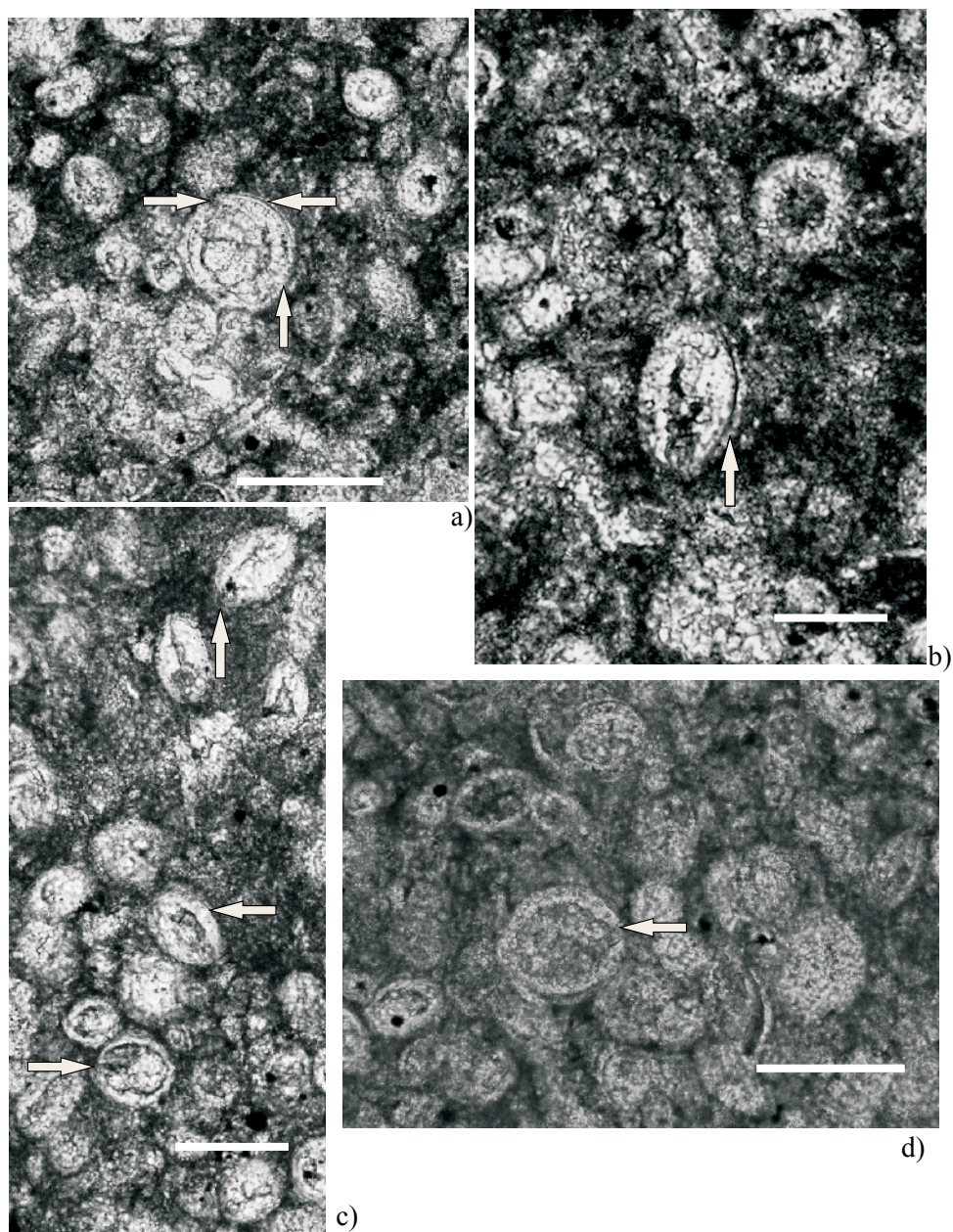


Figure 10. Calcispheres rich packstone-wackestone (Soyatal Formation). Scale bar 100  $\mu\text{m}$ . a–b Axial section of *Pithonella sphaerica* showing the double layer of the wall and the aperture; b, c, d *Pithonella ovalis* showing the thick wall and the aperture (Sample C-10-1).

figs. a–e; Dias-Brito, 2002, p. 2, fig. 1c; Niebuhr, 2005, p. 33, fig. 2c.  
**Description.** The species is a spherical form. The apertural diameter is variable depending of the orientation of the cut of the specimen. The wall that measured 25  $\mu\text{m}$  is formed by two concentric layers divided by dark lines. The diameter ranged from 70 to 100  $\mu\text{m}$  for the analyzed specimens.

**Occurrence.** Samples C-10; C-14.

## CONCLUSIONS

The pithonellid bloom is the result of special environmental conditions related to an early phase of the transgression that flooded the

Valles–San Luis Potosí platform in the latest Cenomanian. The pelagic sediment contains abundant calcispheres, which are interpreted to be opportunistic organisms that inhabit eutrophic, unstable environments together with other opportunist forms such as r or r-k strategists planktic foraminifera and roveacrinids.

The acme of the pithonellids is related to oceanographic changes such as the early transgression that occurred in the latest Cenomanian at a global level.

The pithonellids from the Cerritos section (western Valles–San Luis Potosí platform) are of relatively low diversity, consisting of two genera and three species (*Bonetocardiella conoidea* (Bonet, 1956), *Pithonella ovalis* (Kaufmann, 1865) and *P. sphaerica* (Kaufmann, 1865) but they are very abundant and make up the whole rock.

These microfossils are associated with planktic foraminifera such as the opportunistic foraminifera r-strategists *Muricohedbergella delrioensis*, *M. planispira*, *Heterohelix moremani*, *H. reussi*, or r-k intermediate strategists such as *Whiteinella archaeocretacea*, *W. paradubia*, *W. brittonensis*, which is assigned *Whiteinella archaeocretacea* Partial Range zone in the Cenomanian-Turonian boundary interval.

The association composed by the pithonellids, and planktic foraminifera analyzed in this study are forms characteristics of the Tethyan realm.

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