TURONIAN MICROFOSSIL ASSEMBLAGE OF THE EAGLE FORD FORMATION FROM THE LA BOLITA LOCALITY, COAHUILA, NORTHWEST MEXICO

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ABSTRACT – Late Cretaceous carbonate rocks of the Eagle Ford Formation are widely distributed in north-western Mexico (Nuevo León, Coahuila, Chihuahua) and southern USA (Texas). Around the La Bolita locality, Castaños town (Coahuila State), this unit consists of approximately 31 m of marine deposits, characterized by thin-bedded, slightly clayey limestones. Within the scope of a microfacial analysis, 20 hand samples were collected from selected limestone levels. Identified microfossil remains are mostly represented by planktonic foraminifers, among which: *Planoheterohelix moremani*, *P. reussi*, *P. globulosa*, *Globigerinelloides bollii*, *Globigerinelloides* spp., *Muricohedbergella delrioensis*, *M. planispira*, *Muricohedbergella* spp., *Whiteinella archaocretacea*, *W. aprica*, *W. baltica*, *W. brittonensis*, *W. inornata*, *W. paradubia*, *Whiteinella* spp., *Clavohedbergella moremani*, *C. simplex*, *Marginotruncana renzi*, *M. sigali*, *M. schneegansi*, *M. pseudolinneana*, *Marginotruncana* spp., *Praeglobotruncana algeriana*, and *Dicarinella canaliculata*. There are also abundant calcispheres, such as *Risserella rablingae*, *Pithonella ovalis*, and *Calcisphaerula innominata*; as well as roveacrinoid ossicles (genus *Roveacrinus*), and unidentified radiolarians. Based on the stratigraphic range of both the genus *Marginotruncana* and the species *Praeglobotruncana algeriana*, an early–middle Turonian age is assigned to the studied section. The pelagic microfossil assemblage and the lithological features all suggest deposition of the studied sediments in an open marine platform, with poorly oxygenated, nutrient-rich waters.

Keywords: planktonic foraminifers, Cretaceous, Turonian, Eagle Ford Formation, Coahuila, Mexico.

RESUMO – Rochas carbonáticas do Cretáceo Superior da Formação Eagle Ford são amplamente distribuídas no noroeste do México (Nuevo León, Coahuila, Chihuahua) e sul dos EUA (Texas). Em torno da localidade de La Bolita, cidade de Castaños (Estado de Coahuila), esta unidade consiste em aproximadamente 31 m de depósitos marinhos, caracterizados por calcários de camada fina e levemente argilosos. No âmbito de uma análise microfaciológica, foram coletadas 20 amostras de mãos de níveis selecionados de calcário. Os restos microfósseis identificados são representados principalmente por foraminíferos planctônicos, dentre os quais: *Planoheterohelix moremani*, *P. reussi*, *P. globulosa*, *Globigerinelloides bollii*, *Globigerinelloides* spp., *Muricohedbergella delrioensis*, *M. planispira*, *Muricohedbergella* spp., *Whiteinella archaeocretacea*, *W. aprica*, *W. baltica*, *W. brittonensis*, *W. inornata*, *W. paradubia*, *Whiteinella* spp., *Clavihedbergella moremani*, *C. simplex*, *Marginotruncana renzi*, *M. sigali*, *M. schneegansi*, *M. pseudolinneiana*, *Marginotruncana* spp., *Praeglobotruncana algeriana*, e *Dicarinella canaliculata*. Também existem calcisferas abundantes, como *Risserella rablingae*, *Pithonella ovalis* e *Calcisphaerula innominata*; bem como ossículos roveacrinoides (gênero *Roveacrinus*) e radiolários não identificados. Com base na amplitude estratigráfica do gênero *Marginotruncana* e da espécie *Praeglobotruncana algeriana*, é atribuída uma idade eo/mesoturoniana para a seção estudada. O conjunto de microfósseis pelágicos e as características litológicas sugerem a deposição dos sedimentos estudados em uma plataforma marinha aberta, com águas pouco oxigenadas e ricas em nutrientes.

Palavras-chave: foraminíferos planctônicos, Cretáceo, Turoniano, Formação Eagle Ford, Coahuila, México.

INTRODUCTION

The Eagle Ford Formation has been studied for more than 100 years. Roemer (1852) described it first in the Texas area, as black shales with fish remains. Later, Hill (1887, in GEOLEX, 2018) proposed the name of Eagle Ford for a succession of blue clay shales at the top and at the base and yellow ones in the middle, exposed at Eagle Ford, Dallas county, northeastern Texas. Finally, Albritton (1941, in GEOLEX, 2018), instead of the descriptive term, gave it the range of “unit”, naming it the Eagle Ford Formation.

This unit is widely distributed in northeastern Mexico (PEMEX, 1988; González-Ramos *et al.*, 1997; Santiago-Carrasco *et al.*, 1998) and from northeastern Texas (USA) to Nuevo León, Coahuila (Santamaría *et al.*, 1991), and Chihuahua (Franco-Rubio, 2007).

Most previous works on the Eagle Ford Formation focused on its paleogeography, structural geology, stratigraphy, and paleontology. Its fossil record is represented by plants, marine reptiles, pterosaurs (Vega-Vera *et al.*, 2007), fishes (Blanco-Piñón & Alvarado-Ortega, 2005; Alvarado-Ortega *et al.*, 2006), ammonites, inoceramids, and decapods (Stinnesbeck *et al.*, 2005; Ifrim *et al.*, 2007; Vega-Vera *et al.*, 2007).

Moreover, this formation contains an abundant microfauna including foraminifers (*Heterohelix globulosa*, *H. moremani*, *Globigerinelloides* sp., *Clavihedbergella amabilis*, *Clavihedbergella simplex*, *Thalmaninella appenninica*, *Ticinella roberti*, *Rotalipora* sp., *Archaeoglobigerina bosquensis*, *A. blowi*, *A. cretacea*, *Radotruncana calcarata*, *Globotruncanella stuarti*, *Globotruncanella petaloidea*, *Helvetoglobotruncana helvetica*, *Marginotruncana renzi*, *Dicarinella carinata*, *D. indica*, *Whiteinella archaeocretacea*, *Planulina austiniana*, *Schackoina cenomana*), and calcispheres (genera *Pithonella* and *Stomiosphaera*) (Silva-Martínez, 2014).

According to the aforementioned studies, the lack of thorough biostratigraphic studies on the Eagle Ford Formation is evident. The purpose of this work is to document the microfossil content occurring in this unit exposed at La Bolita, southeastern Coahuila State; to refine its age assignment as much as possible and finally to reconstruct its paleoenvironmental conditions.

STUDY AREA AND GEOLOGICAL SETTING

The study area is located in the Castaños municipality, Coahuila State, northeastern Mexico. The outcrop is exposed 6 km to the southeast of La Bolita common public land, in the surroundings of Lomas Los Piloncillos, geographic coordinates 26°28'29"N/101°19'42"W (Figure 1).

Regionally, the studied area is located between the limits of the geological provinces Coahuila Platform and the Mio-geoclinal of the Gulf of Mexico (Ortega-Gutiérrez *et al.*, 1992). The whole studied section belongs to the Eagle Ford Formation, located within the Sabinas Oil Basin (PEMEX, 2010), which corresponds to a rift-type extension pit, associated with the opening of the Gulf of Mexico during the Middle Jurassic (Salvador, 1987). This pit is limited by the Coahuila block to the southwest and by the Tamaulipas block to the northeast, joining the Chihuahua Basin to the northwest and the Paleo-Gulf of Mexico to the southeast (Eguiluz de Antuñano, 2001).

MATERIAL AND METHODS

The material analyzed comes from a unique stratigraphic section measured and sampled at La Bolita locality, Coahuila. The samples were collected during the bed-by-bed descriptive observation of the lithological and paleontological features of the exposed sequence. The size of the collected samples was approximately 10–15 cm by 10–15 cm to warrant a sound sample nucleus and to avoid weathered areas when later processing thin sections.

Thin sections were processed in the facility of the Mexican Geological Survey (SGM by its Spanish initials) at the Centro Experimental Oaxaca, as a couple of large-sized ones, one parallel, the other perpendicular to the bedding plane. For microfacial purpose, thin sections were analyzed under transmitted light microscope. The material herein described (thin sections) is housed in the Paleontological Collection of the SGM, under the abbreviation **LB** (for La Bolita) and catalogue numbers from LB-01 to LB-22.

In this study, we follow the criteria of Loeblich & Tappan (1988), Huber & Leckie (2011), and Haynes *et al.* (2015) for the study of planktonic foraminifers. Concerning the

Figure 1. Location of the study area at La Bolita, Castaños municipality, southeastern Coahuila (modified from Romo-Ramírez & Muñoz-Jarillo, 2017).

identification of calcispheres (as pithonellids and others) we refer to Bonet (1956), Trejo (1983), Elbrächter *et al.* (2008), and Wendler *et al.* (2013); while biozonation assignment refers to Caron (1985), Sliter (1989), and Premoli-Silva & Verga (2004).

RESULTS AND DISCUSSION

Lithostratigraphy

The studied sequence consists of 31 m of limestones and clayey limestones interbedded with shaley limestones. Some limestone levels are partially recrystallized with disseminated pyrite. There are also parallel lamination and calcite-filled veins. At the base of this sequence are concentrated many impressions of ammonites, while the rest of the measured section contains some of ammonites, belemnites, and inoceramids.

In general, the limestone and clayey-limestone beds are thin-to-medium, 8 to 30 cm-thick. At the base, the calcareous shale is disposed in thin, 20 to 70 cm-thick, layers, whereas while we observed thick-packed (up to 3.70 m) sediments towards the middle-upper part (Figures 2A–D). Based on its megascopic characteristics, we recognized three lithological sets (Figure 3).

Lithological set A (samples LB-01 to LB-02)

This lithological set consists of 1.11 m of thin-bedded (14 to 17 cm-thick), slightly clayey limestones, with a dark grey fracture and light brown weathered hue, parallel lamination, veins filled with calcite, and compact structure. It is observed

partially recrystallized with scarce disseminated pyrite and noorganic remains. The limestone is interbedded with grey calcareous shale.

Lithological set B (samples LB-04 to LB-16)

The lithological set B is composed by 24.83 m of thin-bedded (6 to 30 cm) limestones, occasionally slightly clayey, with a dark grey-to-black fracture and some greenish and brown hue that turns to light brown-to-reddish when weathered. Its structure is homogeneous and massive, slightly brittle, with scattered metallic minerals (mainly pyrite); parallel lamination and partial recrystallization are observed too, as well as calcite-filled veins and some iron oxides. The limestone is interbedded with dark grey calcareous shale, all thin-bedded in sedimentary sets of up to 3.70 m thickness. At the base of this sedimentary bundle, there is a level with abundant ammonite casts, while the middle part shows some bivalve remains.

Lithological set C (samples LB-17 to LB-22)

It consists of an alternance of limestone and shale beds, about 5.78 m-thick. The limestone with a dark grey-to-black fracture and a light brown weathered hue is set into thin-to-medium beds (13 to 28 cm). This deposit bundle is slightly clayey, partially recrystallized with some calcite-filled veins, and some parallel-laminated layers. Ammonite remains are observed in the middle of this bundle set, whereas its upper part displays fragments of inoceramids (*Inoceramus* sp.). The shale is dark grey, thin-bedded, and forming medium-to-thick bundle sets (70 to 125 cm).

Figure 2. A–B, basal part of the sequence showing the calcareous shale levels; C, detailed view of a clayey limestone; D, upper part of the sequence showing thick limestone beds.

Planktonic microfossil assemblage and age

The microfossil association is mostly represented by planktonic foraminifers such as hedbergellids (*Clavihedbergella*, *Muricohedbergella*, *Praeglobotruncana*, *Whiteinella*), globotruncanids (*Marginotruncana*, *Dicarinella*), heterohelicids (*Planoheterohelix*), as well as scarce globigerinelloids (*Globigerinelloides*).

Planktonic foraminifers consist of: *Planoheterohelix moremani* (Cushman, 1938), *P. reussi* (Cushman, 1938), *P. globulosa* (Ehrenberg, 1840), *Globigerinelloides bollii* (Pessagno, 1967), *Globigerinelloides* sp., *Muricohedbergella delrioensis* (Carsey, 1926), *Muricohedbergella* sp. (Figure 4), *M. planispira* (Tapan, 1940), *Whiteinella archaeoetacea* (Pessagno, 1967), *W. aprica* (Loeblich & Tappan, 1961), *W. baltica* Douglas & Rankin, 1969, *W. brittonensis* (Loeblich & Tappan, 1961), *W. inornata* (Bolli, 1957), *W. paradubia* (Sigal, 1952) (Figure 5), *Clavihedbergella moremani* (Cushman, 1931), *C. simplex* (Morrow, 1934), *Marginotruncana renzi* (Gandolfi, 1942), *M. sigali* (Reichel, 1950), *M. schneegansi* (Sigal, 1952), *M. pseudolinneiana* Pessagno, 1967, *Marginotruncana* spp., *Praeglobotruncana algeriana* (Caron, 1966), and *Dicarinella canaliculata* (Reuss, 1854) (Figure 6).

These planktonic foraminifers are associated with abundant calcitic dinoflagellate cysts (so-called calcispheres: *Risserella rablingae* Trejo, 1983, *Pithonella ovalis* (Kaufmann, 1865), *Calcisphaerula innominata* (Bonet, 1956) and roveacrinid remains (some of them assignable to *Roveacrinus* Douglas, 1908 (Figure 7), and recrystallized radiolarians.

The microfaunal association shows little variation all through the stratigraphic column (Figure 8). The most prominent change is observed in the middle part (samples LB-13 to LB-16), where the content of hedbergellids, and globotruncanids diminishes considerably. *Whiteinella* and *Marginotruncana* recovered in the highest part (last 7 m, samples LB-17 to LB-22), while the scarce hedbergellids are represented by a single species (*Muricohedbergella planispira*). Noteworthy is the restricted occurrence of *Calcisphaerula innominata* at the base of the sequence.

Due to the controversy over the stratigraphic range of the respective reported species, we focused on the main species, with ranges agreed by most researchers, namely Caron (1985), Sliter (1989), Premoli-Silva & Verga (2004), and the Mikrotax database (see Huber & Petrizzo, 2016).

Based on the co-occurrence *Marginotruncana schneegansi* and *Praeglobotruncana algeriana*, we suggest a Turonian

Figure 3. Stratigraphic column of the Eagle Ford Formation in La Bolita outcrop. Keys LB-1 to LB-22 represent the sampled levels; A–C, represent differentiated lithological sets.

age for the whole studied sediments (La Bolita outcrop) corresponding to the Eagle Ford Formation.

In particular, the presence of *M. schneegansi* (sample LB-09) in the middle part of the sequence indicates the base of the middle Turonian. This age is consistent with the rest of the sequence (samples LB-10 to LB-22) due to the last occurrence of *Praeglobotruncana algeriana*, also corresponding to the middle Turonian (Caron, 1985; Sliter, 1989; Premoli-Silva & Verga, 2004).

The microfaunal assemblages and the inferred age all are congruent with an assignment to the *Helvetoglobotruncana helvetica* Total Range Zone as recognized for Mexico by Aguilera-Franco (2002) and Omaña-Pulido (2012). This biozone is also characterized by the first appearance and diversification of the genus *Marginotruncana*, and the reappearance of large and robust planktonic foraminifers: *M. coronata*, *M. marianosi*, *M. pseudolinneiana*, *M. schneegansi*, and *M. sigali* (Premoli-Silva & Verga, 2004; Premoli-Silva & Sliter, 1981; Sliter, 1989; Robaszynski & Caron, 1979).

In the Guerrero-Morelos Basin particularly, the *Helvetoglobotruncana helvetica* Zone (early-middle Turonian) is characterized by the first occurrence of the eponymous index species, the presence of dicarinellids, praeglobotruncanids, whiteinellids, hedbergellids, scarce radiolarians and calcispheres, and an increase of keeled planktonic foraminifers (Aguilera-Franco, 2003). However, the index species has not been evidenced so far, hampering to recognize this biozonal range in La Bolita.

Sedimentary paleoenvironment

The most used fossil group in environmental interpretations is undoubtedly the foraminifera (Lipps, 1979a). In particular, planktonic foraminifers have been used in biostratigraphic correlations and paleoceanographic reconstructions, while its paleoecologic value has been neglected, mainly to infer paleotemperatures and paleobathymetry (Lipps, 1979b). The analysis of planktonic foraminifers, considering the biological, biogeochemical, ecological, and sedimentological processes related to them; provide powerful tools to reconstruct ancient marine systems and climatic conditions (Schiebel & Hemleben, 2005). To do that, information about their habitat including their horizontal and vertical distribution in the water column is needed (Kretschmer *et al.*, 2018).

Because planktonic foraminifers are very sensitive to physical and chemical variations, both down vertically in the water column and latitudinally, they are considered excellent environmental indicators (Cita & Premoli-Silva, 1978; Keller *et al.*, 2001; Flügel, 2010). Their evolution, diversification, and extinction are generally associated with water column stratification, vertical changes in the trophic structure, temperature, density gradient, and the differentiation of respective ecological niches (Price & Hart, 2002; Keller, 2003; Keller & Pardo, 2004).

Planktonic foraminifers live under relatively restricted conditions of temperature, salinity, and water depth (Cita & Premoli-Silva, 1978; Arellano-Torres, 2003; Molina, 2004) since they are adapted to different oceanic

Figure 4. Microphotographs of planktonic foraminifers. A, D, *Planoheterohelix globulosa*, equatorial and axial sections respectively. B–C, *Planoheterohelix reussi*, equatorial and axial sections respectively. E–F, *Planoheterohelix moremani*, axial section. G–H, *Globigerinelloides bollii*, axial section. I–J, *Muricohedbergella delrioensis*, axial section. K, *Muricohedbergella* sp., axial section.

Figure 5. Microphotographs of planktonic foraminifers. All axial sections. A–B, *Muricohedbergella planispira*. C, *Whiteinella archaeocretacea*. D, *Whiteinella aprica*. E–F, *Whiteinella baltica*. G–H, *Whiteinella brittonensis*. I, *Whiteinella inornata*. J–K, *Whiteinella paradubia*.

Figure 6. Microphotographs of planktonic foraminifers. A–B, *Clavihedbergella simplex*, axial and equatorial sections respectively. C–D, *Clavihedbergella moremani*, equatorial and axial sections respectively. E–F, *Marginotruncana sigali*, axial section. G, *Marginotruncana pseudolinneiana*, axial section. H–I, *Marginotruncana schneegansi*, axial section. J, *Marginotruncana renzi*, axial section. K, *Marginotruncana* sp., axial section. L–M, *Praeglobotruncana algeriana*, axial section. N, *Dicarinella canaliculata*, axial section.

Figure 7. Microphotographs of calcispheres and roveacrinid ossicles. **A**, *Calcisphaerula innominata*. **B**, *Pithonella ovalis*, axial and transverse sections. **C**, *Risserella rablingae*, axial and transverse sections. **D**, *Roveacrinus* sp., probable tangential/transverse section of a theca (Tg/TS-?Theca), 10x, **E**, *Roveacrinus* sp., squashed oblique section of atheca (OblS-Theca), 10x, **F**, Roveacrinidae indet., tangential section of radial ornament (TgS-Rad), 10x, **G**, Roveacrinidae indet., tangential section of the first primibrach (TgS-IBr1), 10x.

layers with particular temperature and densities (Flügel, 2010). According to Flügel (2010), most planktonic foraminifers are restricted to marine salinities from 30 to 40‰, and the temperature-controlled species exhibit particular morphological characteristics (shape, size, and whorl direction). Specifically, it has been suggested that foraminifera modify their shape and size, and any frictional drag acting upon them, in direct response to changes in water density and viscosity (Caromel *et al.*, 2014).

The vertical distribution of planktonic foraminifers is related to their respective morphology: the non-keeled forms inhabit shallower waters (less than 50 m), the incipient-keeled occupy intermediate waters (between 50 and 100 m); whilst keeled forms dwell deeper waters (more than 100 m) (Bé, 1977 in Hart & Bailey, 1979; Aguilera-Franco, 1995; Keller *et al.*, 2001; Molina, 2004; Flügel, 2010).

Planktonic foraminifers in La Bolita are mostly morphotypes devoid of any keel (whiteinellids, hedbergellids, and

Figure 8. Stratigraphic distribution of taxa in the La Bolita section.

heterohellicids), whereas keeled forms (helvetoglobotruncanids, dicarinellids, and marginotruncanids) occur subordinately. Microfossil assemblage and lithological features all suggest that the deposition of the Eagle Ford Formation in the La Bolita outcrop took place in an outer platform environment, between 50 and 100 m water depths, deepening upwards the sequence where diversity and abundance of globular forms dwindle and keeled forms overcome. This is also consistent with the presence of roveacrinids (order Roveacrinida) as small, pelagic, and opportunistic crinoids thriving during sea level rises and subsequent nutrient-flux events (Ferré *et al.*, 2005; Buitrón-Sánchez & Omaña-Pulido, 2015) in open-marine environments (Ferré *et al.*, 2016).

CONCLUSIONS

The planktonic foraminifer assemblage identified in the Eagle Ford Formation at La Bolita consists of: *Planoheterohelix moremani*, *P. reussi*, *P. globulosa*, *Globigerinelloides bollii*, *Globigerinelloides* spp., *Muricohedbergella delrioensis*, *M. planispira*, *Muricohedbergella* spp., *Whiteinella archaeocretacea*, *W. aprica*, *W. baltica*, *W. brittonensis*, *W. inornata*, *W. paradubia*, *Whiteinella* spp., *Clavihedbergella moremani*, *C. simplex*, *Marginotruncana renzi*, *M. sigali*, *M. schneegansi*, *M. pseudolinneiana*, *Marginotruncana* spp., *Praeglobotruncana algeriana*, and *Dicarinella canaliculata*. This microfauna indicates an early to middle Turonian age and suggests an outer platform setting.

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