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New Eocene bivalves from Bateque Formation, Baja California Sur, Mexico

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Abstract

A total of 11 new mollusc bivalves are reported (*Lithophaga* sp., *Anadara*? sp., *Gryphaeostrea sanjuanicus* sp. nov., *Ostrea* sp., cf. *O. contracta amichel*, *Argopecten*? sp., *Chlamys* sp. a, *Chlamys* sp. b, *Pecten*? sp., *Tellina* sp., *Macrocallista* sp. and *Pitar* sp.), in the Bateque Formation, which includes one of the most complete fossil records for the Eocene Epoch, in Baja California Sur, Mexico. Prior to this work, existing faunal lists were reviewed, resulting in 155 macroinvertebrate species reported for the Bateque Formation. The faunal assemblage indicates an age range of early Eocene ("Capay Stage") to the late middle Eocene ("Tejon Stage"), and also it is characteristic of shallow marine water (inner shelf to outer) and tropical to subtropical climates. The abundance and diversity of macroinvertebrates previously reported and new records of molluscs contribute to the understanding of the origin of the different taxonomic groups in Baja California Sur and the Pacific Coast of North America. Most species are indicative of warm waters from the Tethys circum-global current, which created the conditions for a wide biotic exchange between marine organisms of the Atlantic, Gulf of Mexico-Caribbean, and Pacific.

Keywords: Bivalves, Bateque Formation, Eocene, Baja California Sur, Mexico.

Resumen

Se reportan 11 nuevos moluscos: bivalvos (Lithophaga sp., Anadara? sp., Gryphaeostrea sanjuanicus sp. nov., Ostrea sp., cf. O. contracta amichel, Argopecten? sp., Chlamys sp. a, Chlamys sp. b, Pecten? sp., Tellina sp., Macrocallista sp. y Pitar sp.), de la Formación Bateque, la cual representa uno de los registros fosilíferos más completos de la época del Eoceno, en Baja California Sur, México. Antes de este trabajo, se revisaron los listados faunísticos ya existentes, dando como resultado 155 especies reportadas de macroinvertebrados para la Formación Bateque. Esta fauna es indicativa de aguas poco profundas (plataforma interna a externa) y de climas tropicales a subtropicales. El conjunto faunístico indica un intervalo de edad del Eoceno temprano ("Piso Capay") al Eoceno medio superior ("Piso Tejon"). La abundancia y diversidad de los macroinvertebrados previamente reportados, así como los nuevos registros de moluscos, contribuyen en el entendimiento del origen de los diferentes grupos taxonómicos en Baja California Sur y en la costa del Pacífico de Norteamérica. La mayoría de las especies, son indicativas de aguas cálidas relacionadas con la corriente circum-tropical del Tethys, la cual creó las condiciones para un amplio intercambio biótico entre los organismos marinos del Atlántico, el Golfo de México-Caribe y el Pacífico.

Palabras clave: Bivalvos, Formación Bateque, Eoceno, Baja California Sur, México.

1. Introduction

Macroinvertebrates found in Bateque Formation represent one of the most complete fossil records of the Eocene Epoch (56 to 33.9 Ma) in Mexico. This formation is exposed on the Pacific Ocean side of the Baja California peninsula on the eastern and western shores of Laguna San Ignacio to Arroyo El Mezquital (between San Juanico and La Purisima) (Figure 1) (Squires and Demetrion, 1992, 1994a, González-Barba, 2003).

Previous listings of macroinvertebrate fauna reported 155 species for the Bateque Formation (Table I). However, in 2011, new sites were visited and 11 new records of bivalve molluscs were found: *Lithophaga* sp., *Anadara* sp., the new species *Gryphaeostrea sanjuanicus*, *Ostrea* sp., cf. *O. contracta amichel*, *Argopecten*? sp., *Chlamys* sp. a, *Chlamys* sp. b, *Pecten*? sp., *Tellina* sp., *Macrocallista* sp. and *Pitar* sp.

The phylum Mollusca is the most diverse and abundant group in the area, and is found in various formations along the Pacific Coast of North America. Most species of molluscs are attributed to an early Eocene age ("Capay Stage"), an age that is determined by the presence of *Spondylus batequensis* Squires and Demetrion, 1990, which is a diagnostic species of this stage (Squires and Demetrion, 1994a). However, several species exhibit a wider age range that extends to the late middle Eocene ("Tejon Stage"). A special case is the genus *Argopecten*?, which records show has the wider age range from Oligocene to Recent according Paleobiology Database (2013), but our specimens could extend the age range of the genus, *i.e.* from late middle Eocene ("Tejon Stage") to Recent.

The abundance and diversity of macroinvertebrates previously reported and the new records of molluscs contribute to understanding the origins of the different invertebrate groups in the state. Most species indicate a warm-water biota (tropical to subtropical) related to the

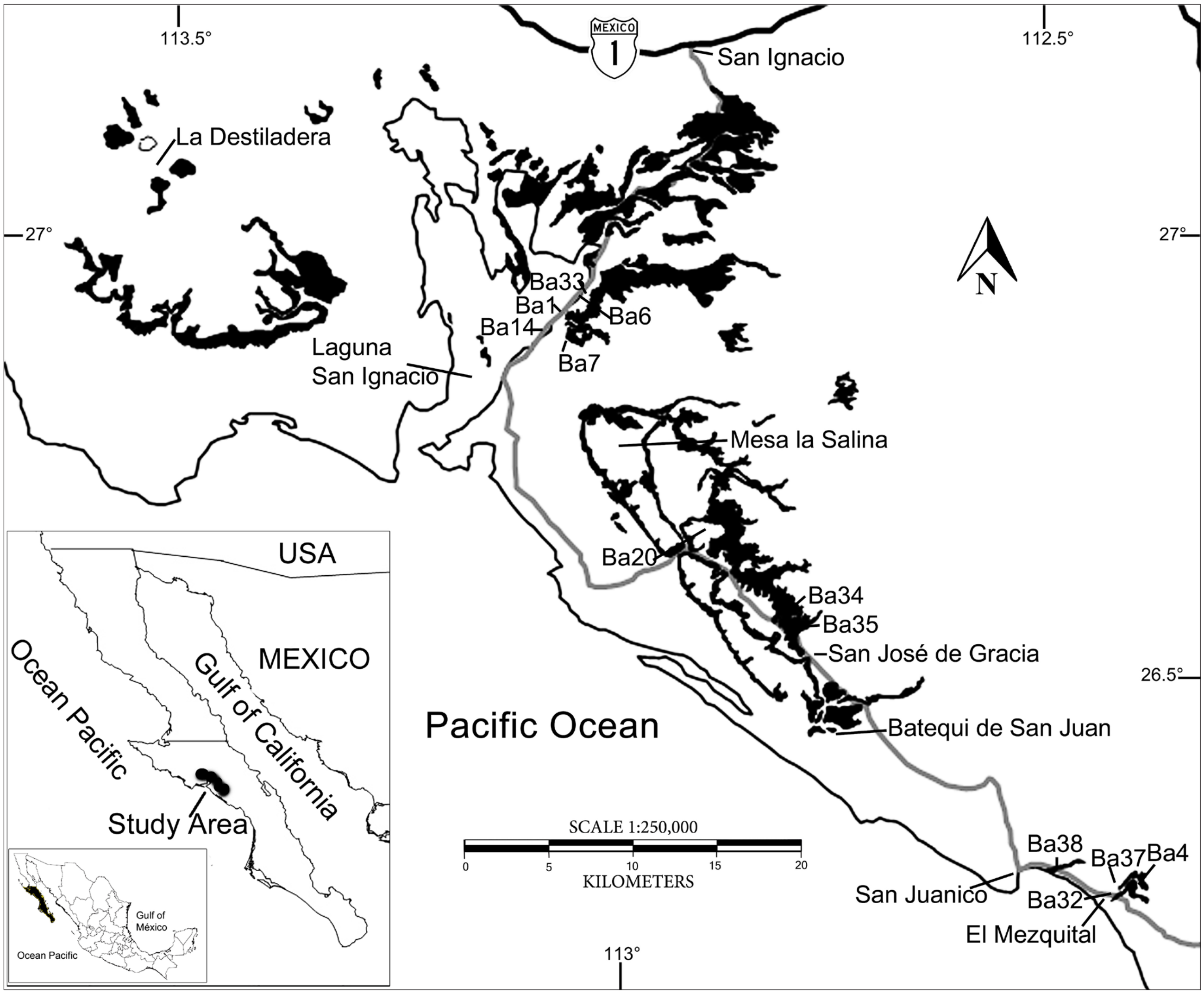

Figure 1. Index map showing the outcrops of the Bateque Formation, Baja California Sur, Mexico (Geological-Mining Letter, Baja California Sur, 2008), localities (Ba), and geographic place names. Country road continuous gray line.

Table 1. Age range of the marine invertebrates from Bateque Formation; from upper Paleocene to late middle Eocene, represented by Molluscan Stage Range of the Pacific Coast of North America; wherein: Mr = "Martinez Stage" and Me = "Meganos Stage", correspond to the upper Paleocene; Ca = "Capay Stage", Do = "Domengine Stage", Tr = "Transition Stage" and Te = "Tejon Stage", correspond to Eocene. The symbols represent: "--" = presence of the genus and/or species on the Pacific Coast of North America (from Chiapas, Mexico to Washington, United States of America). "●"=presence of the species in the formation. "?"=probably with this age range.

	Mr	Me	Ca	Do	Tr	Te	Range Reference
Protista							
Lepidocyclina sp.			●	--	--	--	Vaughan, 1933 (Lepidocyclina)
Operculina sp., aff. *O. cookie* Cushman, 1921a				●	●	●	Squires and Demetrion, 1992
Actinocyclina sp., aff. *A. aster* Woodring, 1930			●	--	--	--	Vaughan, 1933 (Actinocyclina); Squires and Demetrion, 1992
Pseudophragmina clarki (Cushman, 1920)			●	●			Squires and Demetrion, 1992
Pseudophragmina advena (Vaughan, 1929)			●	●	●	●	Squires and Demetrion, 1992
Porifera							
Elasmostoma bajaensis Squires and Demetrion, 1989			●				Squires and Demetrion, 1992; Morales-Ortega, 2010
Clionaidae?, indet.			●	●?			Squires and Demetrion, 1992
Cnidaria							
Spongiomorphidae?, indet.			●				Squires and Demetrion, 1992
Heliopora ? sp.			●	--			Frost and Langenheim, 1974; Squires and Demetrion, 1992
Parisis batequensis Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Astrocoenia dilloni Durham, 1942			●	●?			Squires and Demetrion, 1992
Stylophora chaneyi Durham, 1942			●	●?			Squires and Demetrion, 1992
Heterocoenia ? sp.			●				Squires and Demetrion, 1992
Stylosmilia ameliae Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Actinacis ? sp.			●	●?			Frost and Langenheim, 1974; Squires and Demetrion, 1992
Balanophyllia sp.			●	--			Frost and Langenheim, 1974; Morales-Ortega, 2012b
Goniopora sp., cf. *G. vaughani* Nomland, 1916			●	●?			Frost and Langenheim, 1974; Squires and Demetrion, 1992
Porites ? sp.			●				Morales-Ortega, 2012b
Colpophyllia nicholasi Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Montastrea laurae Squires and Demetrion, 1992			●	--			Frost and Langenheim, 1974; Squires and Demetrion, 1992
Antillia batequensis Squires and Demetrion, 1992			●	●			Squires and Demetrion, 1992; Squires, 2001
Stephanocyathus ? sp.			●				Squires and Demetrion, 1992
Turbinolia dickersoni Nomland, 1916	--	--	●	●			Squires and Demetrion, 1992
Placotrochus ? sp.			●				Squires and Demetrion, 1992
Bryozoa							
Stomatopora sp.			●				Squires and Demetrion, 1992 (age range: K-Rec)
Conopeum ? sp.			●			--	Morales-Ortega, 2012b; upper Eocene of Russia and United States of America (age range K-Rec)
Cellaria sp.			●				Squires and Demetrion, 1992
Annelida							
Serpula batequensis Squires and Demetrion, 1992			●				Squires y Demetrion, 1992
Rotularia sp.	--	--	●	--	--		Squires and Goedert, 1994; Morales-Ortega, 2012b
Brachiopoda							
Terebratellidae?, indet. King, 1850						●	Morales-Ortega, 2012b
Terebratulinae, indet. Gray, 1840						●	Morales-Ortega, 2012b
Terebratulina sp., cf. *Terebratulina louisianae* Stenzel,1940			-- ?	--		●	Sandy *et al* ., 1995; Squires, 2001; Morales-Ortega, 2010
Terebratalia batequia Sandy, Squires and Demetrion, 1995				--		●	Sandy *et al*., 1995; Squires, 2001
Mollusca: Scaphopoda							
Detalium stentor Anderson and Hanna, 1925				●	●	●	Squires and Demetrion, 1992
Diodora batequensis Squires and Demetrion, 1994			●				Squires and Demetrion, 1994a
Arene mcleani Squires, 1988b			●				Squires and Demetrion, 1992
Velates perversus (Gmelin, 1791)		--	●	●?			Squires, 1999
Velates batequensis Squires and Demetrion, 1990			●				Squires and Demetrion, 1992
Turritella andersoni s.s. Dickerson, 1916		-- ?	●				Squires and Demetrion, 1992; Squires, 1984; 2008
Turritella andersoni lawsoni Dickerson, 1916				●			Squires and Demetrion, 1992; Squires, 1984

Table 1 (Continuation).

	Mr	Me	Ca	Do	Tr	Te	Range Reference
Turritella sp., cf. *T merriami* ? Dickerson, 1913			●				Squires and Demetrion, 1992
Turritella buwaldana Dickerson, 1916	--	●?	●	●	●	●	Squires, 2008
Turritella uvasana subsp.			●	●		-- ?	Squires, 1984; Morales-Ortega, 2012b
Vermetidae, indet.						●?	Morales-Ortega, 2012b
Tenagodus bajaensis Squires, 1990a			●				Squires and Demetrion, 1992
Acrilla ? sp. Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Epitonium sp.			●				Squires and Demetrion, 1992
Cirsotrema eocenica Squires and Demetrion, 1994				●			Squires and Demetrion, 1994a
Xenophora stocki Dickerson, 1916			●	●	●	●	Squires and Demetrion, 1992
Lobatus sp., aff., *Lobatus peruvianus* (Swainson, 1823)			●				Morales-Ortega, 2012b
Platyoptera pacífica Squires and Demetrion, 1990			●	--			Squires and Demetrion, 1992; Squires, 2001
Ectinochilus (*Macilentos*) *macilentus* (White, 1889)			●	●			Squires, 2008
Ectinochilus (*Cowlitzia*) sp., aff. *E.* (*C.*) *canalifera* (Gabb, 1864)			●				Squires and Demetrion, 1992
Paraseraphs erracticus (Cooper, 1894)			●	●	●		Squires and Demetrion, 1992
Bernaya (*Protocypraea*) *grovesi* Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Megalocypraea clarki Ingram, 1940			●				Squires and Demetrion, 1994a
Eocypraea ? sp.			●				Squires and Demetrion, 1992
Cypraedia sp.			●				Squires and Demetrion, 1992
Amauropsis sp.			●				Squires and Demetrion, 1992; Squires, 2008
Gyrodes ? sp.			●				Squires and Demetrion, 1992
Crommium sp., cf. *C. andersoni* Dickerson 1914			●				Morales-Ortega, 2012b
Eocernina hannibali Dickerson, 1914			●	●	--		Squires and Demetrion, 1992; Squires, 2008
Pachycrommium clarki (Stewart, 1927)		--	●	●	●	●	Morales-Ortega, 2010; Squires, 2008
Galeodea sp.			●	--	-- ?		Squires and Demetrion, 1992; Squires, 2008
Galeodea (*Caliagaleodea*) *californica* Clark 1942			●	--			Squires and Demetrion, 1994a
Phalium (*Semicassis*) *louella* Squires and Advocate, 1986			●				Squires and Demetrion, 1994a
Olequahia domenginica (Vokes, 1939)			●	--			Squires, 1988b; Squires and Demetrion, 1992
Campanile sp.			●				Squires and Demetrion, 1992
Dirocerithium sp.				●			Squires and Demetrion, 1994a
Clavilithes tabulatus (Dickerson, 1913)			●	●			Squires and Demetrion, 1992
Olivella mathewsonii ? Gabb, 1864	--	--	●	--	--	--	Squires and Demetrion, 1992; Squires, 2008
Lyria andersoni Waring, 1917			●	●			Squires and Demetrion, 1992
Lyrischapa lajollaensis (Hanna, 1927)			●	●			Squires and Demetrion, 1992
Eocithara mutica californiensis (Vokes, 1937)			●	--			Squires, 1984; Morales-Ortega, 2012b
Conus caleocius Vokes, 1939			●	●			Squires and Demetrion, 1992
Conus sp., aff. *C.* (*Lithoconus*) sp.						●	Morales-Ortega, 2010, 2012b
Terebra californica Gabb, 1869			--	--	--	●	Squires, 1984; Morales-Ortega, 2012b
Architectonica (*Stellaxis*) *cognata* Gabb, 1864			●	●			Squires, 1984; Squires and Demetrion, 1992
Architectonica (*Architectonica*) *llajasensis* Sutherland, 1966				●			Squires and Demetrion, 1994a
Retusa (*Cylichnina*) sp. = *Cylichnina tantilla*			●	●	●	●	Squires and Demetrion, 1992
Scaphander ? sp.			●				Squires and Demetrion, 1992
Megistostoma gabbianum (Stoliczka, 1868)				●	●	●	Squires and Demetrion, 1992
Mollusca: Bivalvia							
Barbatia (*Barbatia* ?) sp.			●				Squires and Demetrion, 1992
Barbatia (*Acar* ?) sp.			●				Squires and Demetrion, 1992
Anadara ? sp.						●	**Ba37**
Glycymeris (*Glycymerita*) *sagittata* (Gabb, 1864)			●	●	●	●	Squires and Demetrion, 1992
Lima kennedyi Squires and Demetrion, 1992			●				Squires and Demetrion, 1992
Lithophaga sp.							**Ba14**
Pinna llajasensis Squires, 1983			●	●			Squires and Demetrion, 1992
Nayadina (*Exputens*) *batequensis* Squires, 1990a			●				Squires, 1990a; Squires and Demetrion, 1992

Table 1 (Continuation).

	Mr	Me	Ca	Do	Tr	Te	Range Reference
Argopecten? sp.						●	**Ba1**
Batequeus mezquitalensis Squires and Demetrion, 1990						●	Squires and Demetrion, 1990b, 1992
Chlamys sp. a						●	**Ba32**
Chlamys sp. b						●	**Ba32**
Pecten? sp.						●	**Ba32**
Plicatula surensis Squires and Saul, 1997			●				Squires and Saul, 1997
Plicatula? sp. b Squires and Saul, 1997			●	●	●	●	Squires and Saul, 1997
Spondylus batequensis Squires and Demetrion, 1990b			●				Squires and Demetrion, 1990b
Anomia? sp.			●	--			Squires, 1984; Squires and Demetrion, 1992
Pycnodonte (*Phygraea*) *pacifica* Squires and Demetrion, 1990b			●	●	●	●	Squires and Demetrion, 1990b; Squires, 2001
Pycnodonte (*Phygraea*) *cuarentaensis* Squires and Demetrion, 1994			●				Squires and Demetrion, 1994a
Pycnodonte (*Pegma*) *bajaensis* Squires and Demetrion, 1990b			●	●	●	●	Squires and Demetrion, 1990b
Gryphaeostrea sanjuanicus sp. nov.			●			●	**Ba35 and 38**
Cubitostrea mezquitalensis Squires and Demetrion, 1990						●	Squires and Demetrion, 1990b
Ostrea sp., cf. *O. contracta amichel* Gardner, 1945							**Ba38**
Glyptoactis (*Claibornicardia*) *domenginica* (Vokes, 1939)			●	●	●		Squires and Demetrion, 1992
Crassatella sp.			●				Squires and Demetrion, 1992
Acanthocardia (*Agnocardia*) sp., aff. *A.* (*A.*) *sorrentoensis* (Hanna, 1927)			●	●			Squires and Demetrion, 1992; Squires, 2001
Nemocardium liteum (Conrad, 1855)		●	●	●	●	●	Squires and Demetrion, 1992; Squires, 1999
Dosinia sp.					--	●?	Squires, 2008
Fimbria pacifica Squires, 1990c			●				Squires and Demetrion, 1992
Solena (*Eosolen*) *novacularis* (Anderson and Hanna, 1928)			●	●	●	●	Squires and Demetrion, 1992
Tellina sp.			●	●	●?	●	**Ba4, 6, 14, 32 and 33**
Macrocallista sp.		--	--	--	--	●	**Ba37**
Pitar (*Lamelliconcha*) *joaquinensis* Vokes, 1939			●	●			Squires and Demetrion, 1992; Squires, 2008
Pitar sp.			●			●?	**Ba1, 6 and 7**
Pholadomya sp., cf. *P.* (*Bucardiomya*) *givensi* Zinsmeister, 1978			●	●	●	●	Squires and Demetrion, 1992
Teredinidae, indet.			●				Squires, 2008
Mollusca: Cephalopoda							
Hercoglossa? sp.			●				Squires and Demetrion, 1992
Aturia myrlae Hanna, 1927			●	●			Squires and Demetrion, 1992
Arthropoda							
Callianassidae *sensu lato* species 1 *in* Schweitzer *et al*., 2005				●		●	Schweitzer *et al*., 2005
Callianassidae *sensu lato* species 2 *in* Schweitzer *et al*., 2005			--	●		●	Schweitzer *et al*., 2005
Callianassidae *sensu lato* species 3 *in* Schweitzer *et al*., 2005				●		●	Schweitzer *et al*., 2005
Callianassidae *sensu lato* species 4 *in* Schweitzer *et al*., 2005				●		●	Schweitzer *et al*., 2005
Callianassidae *sensu lato* species 5 *in* Schweitzer *et al*., 2005			--	●		●	Schweitzer *et al*., 2005
Paguroidea species 1 *in* Schweitzer *et al*., 2005				●		●	Schweitzer *et al*., 2005
Paguroidea species 2 *in* Schweitzer *et al*., 2005				●		●	Schweitzer *et al*., 2005
Paguroidea species 3 *in* Schweitzer *et al*., 2005			--	●		●	Schweitzer *et al*., 2005
Paguristes mexicanus (Vega *et al*., 2001)			--	●		●	Schweitzer *et al*., 2005
Galatheinae genus and species indet. *herein*				●		●	Schweitzer *et al*., 2006
Holoma bajaensis Schweitzer *et al*., 2006				●		●	Schweitzer *et al*., 2006
Lophoranina bishopi Squires and Demetrion, 1992			●	●?		●?	Squires and Demetrion, 1992; Schweitzer *et al*., 2002
Ranina berglundi Squires and Demetrion, 1992			●	●?		●?	Squires and Demetrion, 1992; Schweitzer *et al*., 2006
Raninoides acanthocolus Schweitzer *et al*., 2006				●		●	Schweitzer *et al*., 2006
Raninoides proracanthus Schweitzer *et al.*, 2006				●		●	Schweitzer *et al*., 2006
Cyclodorippoidea: family, genus and species indet. *herein*				●		●	Schweitzer *et al*., 2006
Calappilia hondoensis Rathbun, 1930b			--	●		●	Schweitzer *et al*., 2006
Prehepatus mexicanus Schweitzer *et al*., 2006				●		●	Schweitzer *et al*., 2006
Daldorfia salina Schweitzer *et al*., 2006				●		●	Schweitzer *et al*., 2006
Anatolikos undecimspinosus Schweitzer *et al*., 2006				●		●	Schweitzer *et al*., 2006
Lobonotus mexicanus Rathbun, 1930b			--	●		●	Schweitzer *et al*., 2002; Schweitzer *et al*., 2005

Table 1 (Continuation).

	Mr	Me	Ca	Do	Tr	Te	Range Reference
Archaeotetra inornata Schweitzer, 2005				●		●	Schweitzer, 2005
Montezumella tubulata Rathbun 1930b				●		●	Schweitzer *et al*., 2006
Xanthoidea: family, genus and species indet. *herein*				●		●	Schweitzer *et al*., 2006
Paracorallicarcinus tricarinatus Schweitzer *et al* ., 2006				●		●	Schweitzer *et al*., 2006
Carcininae genus and species indet. *Herein*				●		●	Schweitzer *et al*., 2006
Echinodermata							
Cidaroida, indet. spine A			●				Squires and Demetrion, 1992
Cidaroida, indet. spine B						●	Squires and Demetrion, 1992
Cidaroida, indet. spine C						●	Squires and Demetrion, 1992
Cidaroida?, indet. spine D			●				Morales-Ortega *et al*., 2015
Cassidulus ellipticus Kew, 1920			●				Squires and Demetrion, 1995
Calilampas californiensis Squires and Demetrion, 1995			●				Squires and Demetrion, 1995
Haimea bajasurensis Squires and Demetrion, 1994			●				Squires and Demetrion, 1994b
Schizaster (*Paraster*) sp., aff. *S. lecontei* Merriam, 1899		--	●	--	--	--	Squires and Demetrion, 1992
Eupatagus batequensis Squires and Demetrion, 1992			●				Squires and Demetrion, 1992

current tropical Tethys Sea, although their centres of origin are in different parts of the world (Squires and Demetrion, 1992; Morales-Ortega, 2010, 2012a).

2. Previous works

The first authors to work with descriptions of marine invertebrates were Squires and Demetrion (1989, 1990a, 1990b, 1991, 1992, 1994a, 1994b, 1995). They described new species of gastropods and bivalves, and also echinoderms and a new form of sponge; in addition they made comparisons between the faunas of Bateque and Tepetate formations. In 1992, they were the first to make a list of marine macrofossils found in the Bateque Formation, reporting 95 species, including 63 molluscs (one scaphopod, 37 gastropods, 23 bivalves and two nautiloids).

Squires (1990a, 1990b, 1990c) made comparisons between different molluscs found in the Pacific coast of North America, *i.e.* from California (United States of America) to Baja California Sur (Mexico). Sandy *et al.* (1995) described two species of brachiopods of Middle Eocene from the uppermost part of the Bateque Formation; both species are also present in the middle part of the Tepetate Formation. Subsequently, Squires and Saul (1997) described and compared new species of genus *Plicatula*, found in Cretaceous and Cenozoic strata of California and Baja California Sur. In recent years, Schweitzer (2005) and Schweitzer *et al*. (2005, 2006) described new species of decapod (Infraorders: Thalassinidean, Anomura: Paguroidea and Brachyura) from the Bateque and Tepetate formations.

It is important to point out that the marine invertebrate fauna of the Bateque Formation indicates an age from "Capay Stage" (Early Eocene) to "Tejon Stage" (late Middle Eocene); this age range is based on the Molluscan Stages Range of the Pacific Coast of North America, informally proposed by Clark and Vokes (1936). However, the stages have been recently designate by various authors and based on the fauna of gastropods found in different formations in Washington, Oregon, California (United States of America) and Baja California Sur (Mexico). Below are listed stages in ascending order of the Paleocene and Eocene Epochs: “Martinez Stage” –Squires (1997); “Meganos Stage” –Squires (1990b); “Capay Stage” –Squires and Goedert (1994), Squires (2000); “Domengine Stage” –Squires (1984, 2000, 2001); “Transition Stage” –Squires (1999a); “Tejon Stage” –Clark and Anderson (1938), Givens and Kennedy (1979), Nesbitt (1995). It is important to mention that these stages have not yet been properly defined. Future multidisciplinary studies of palaeomagnetism and stable isotopes will be needed, as well as a review of studies of molluscan taxonomy and biostratigraphy and other fossil groups (*i.e.* foraminifera, brachiopods, or vertebrates) (Squires, 2003).

3. Depositional environments

Bateque Formation represents an age range from the middle Paleocene to Eocene (Mina-Uhink, 1956, 1957; Sorensen, 1982). Its base is not exposed and has disconformity with volcanic and sedimentary rocks, with age ranges from Upper Eocene to Holocene (Squires and Demetrion, 1992). Also, Sandy *et al*. (1995) mention that in the southern outcrops of the Bateque Formation (between San Juanico and La Purisima) it shows a discordant stratigraphic relation with Isidro Formation (Miocene).

Moreover, the fossil records are characteristic of deep marine deposits and shelf environments during the Early Eocene, and also deep environments the Middle Eocene, this generated by transgressive seas and the global circulation of the warm current of Tethys (Squires and Demetrion, 1992; González-Barba *et al*., 2002).

4. Stratigraphic and faunal correlation

Cenozoic history of Baja California Sur begins with the deposition of marine rocks of the Tepetate and Bateque formations, which are important in the geological record, especially in the North American Pacific region, as they may represent one of the most complete fossil and palaeoceanographic records of the Paleogene period (66 to 23.03 Ma) (Morales-Ortega, 2012a).

Tepetate Formation has been originally described as a package of sandstone 1000 meters thick and suggests the existence of deep environments at least from the Maastrichtian (Upper Cretaceous) to late early Eocene in some localities, while in platform environments the formation only records the Early Eocene to the Middle Eocene (Heim, 1922; Schwennicke *et al*., 2004; Miranda-Martínez and Carreño, 2008). New data supports the idea of a "concordant" sequence, *i.e*. that older deposits are found at the bottom and the newest at the top, with regressive-transgressive marine sequences interspersed throughout the formation (Morales-Ortega, 2012b).

In the Bateque Formation deep marine and shelf environments during the Early Eocene, and also deep environments in the Middle Eocene have been reported (Squires and Demetrion, 1992). All this was generated by transgressive seas in the continental masses and the circulation of Tethys (Squires and Demetrion, 1992; González-Barba, 2003). This formation has an inclination of 3 degrees northwest, where the oldest deposits are found in the northwest and the youngest deposits in the southeast. The combining this regional slope favoured the wash, which prevents observation of the oldest outcrops in the southern part of the formation, between Batequi San Juan and San Juanico (Squires and Demetrion, 1992).

Previous studies, based on invertebrate faunal associations in both formations, suggest that they possess a similar age range. The fossils of the Tepetate Formation indicate an age range equivalent to the Molluscan Stage Range of the Pacific Coast of North America, from "Martinez Stage" (Selandian and Thanetian) to the "Tejon Stage" (Lutetian, Bartonian, and lower part of the Priabonian?) (Morales-Ortega, 2010). The invertebrates found in the Bateque Formation show an age range of "Capay Stage" (Ypresian) to "Tejon Stage" (Lutetian and Bartonian) (Squires and Demetrion, 1992).

The litho- and biostratigraphic data are consistent when both formations are compared, *i.e*. the fossils found in the middle part of the Tepetate Formation coincide with those present in the middle of the Bateque Formation, which proves that both formations are equivalent in time, corresponding to the "Capay Stage" (Ypresian). The depositional environments found in most localities of both formations are of the inner to outer shelf. In addition, the type of materials in of both formations is a yellow sandstone, which helps preserve the fossils, although they are mostly internal moulds or mineralized shells (Squires, 1992; Squires and Demetrion, 1992; González-Barba *et al*., 2002; Schwennicke *et al*., 2004; Morales-Ortega, 2010, 2012b).

The abundance and diversity of marine invertebrate species is due primarily to the circum-tropical Tethys current, which created the conditions for a wide biotic exchange between the Atlantic, Gulf of Mexico, Caribbean and Pacific. All this coincides with a rise in the sea level which was recorded globally, possibly associated with greenhouse gases without forming polar ice during most of the Eocene. Actually, this fauna correlates with the faunal records of Europe (France, United Kingdom, and Italy), the Middle East, Caribbean (Cuba and Jamaica) and the North Pacific from Washington, United States to Chiapas, Mexico. The abundance and diversity of species is due primarily to circum-tropical currents of Tethys, which caused a wide biotic exchange between the Atlantic, Gulf of Mexico, Caribbean and Pacific Oceans (Squires, 1992; Schweitzer *et al*., 2002; Morales-Ortega-2010, 2012a).

5. Localities

All localities are in the Bateque Formation. They are indicated in the Mexican government topographic quadrangle map (Instituto Nacional de Estadística, Geografía e Informática (INEGI), scale 1:50000) (Figure 1). The stratigraphic section of the locality Mesas San Ramón is shown in Figure 2. Below are listed the localities visited during this work.

- MHN-UABCS Ba1. Mesa San Ramón (La Rinconada), at Lat. N. 26°58.6’, Long. W 113°01.6’, Mexican government topographic quadrangle map (1:50000) of Laguna San Ignacio (G12A53-INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba4. Rancho Malbar (southern Arroyo Mezquital), at Lat. N. 26°13.1, Long. W 112°18.2’, Mexican government topographic quadrangle map (1:50000) of San Isidro (G12A86-INEGI, 2004), Baja California Sur, Mexico.
- MHN-UABCS Ba6. Hill A North, at Lat. N. 26°56.1’, Long. W 113°04.7’, Mexican government topographic quadrangle map (1:50000) of Laguna San Ignacio (G12A53 INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba7. Mesa La Salina, at Lat. N. 26°45.8’, Long. W 113°01.1’, Mexican government topographic quadrangle map (1:50000) of Laguna San Ignacio (G12A53 INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba14. Locality 1219, Squires and Demetrion (1992), at Lat. N. 26°55.9’ Long. W 113°04.8’, Mexican government topographic quadrangle map (1:50000) of Laguna San Ignacio (G12A53-INEGI, 2003), Baja California Sur, Mexico.

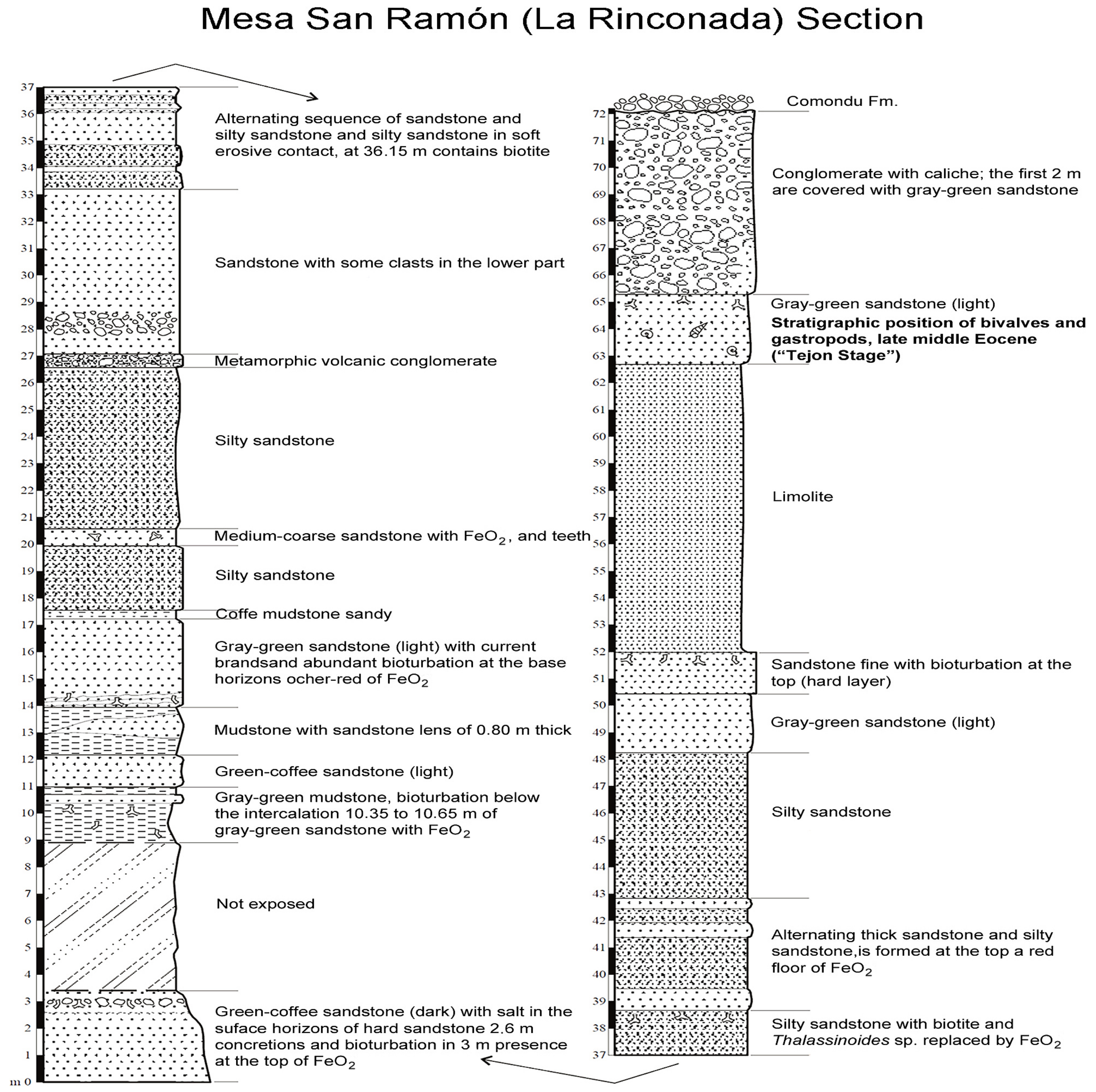

Figure 2. Composite section of the Mesa San Ramon locality showing stratigraphic position of some macrofossil localities (late Middle Eocene, "Tejon Stage") (modified section of González-Barba, 2003).

- MHN-UABCS Ba20: Arroyo Cantil Blanco (southeast of Mesa La Ladera to El Bule), at Lat. N. 26°40.1', Long. W 112°52.4', Mexican government topographic quadrangle map (1:50000) of San José de Gracia (G12A64-INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba32. Mesa El Mezquital, at Lat. N. 26°14.7', Long. W 112°21.7', Mexican government topographic quadrangle map (1:50000) of Punta Pequeña (G12A85-INEGI, 2004), Baja California Sur, Mexico.
- MHN-UABCS Ba33. Near the locality 1219, Squires and Demetrion (1992), at Lat. N. 26°58.8', Long. W 113°01.3', Mexican government topographic quadrangle map (1:50000) of Laguna San Ignacio (G12A53-INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba34. San Juan Basin-Mesa Azufrera, at Lat. N. 26°33.6', Long. W 112°46.4', Mexican government topographic quadrangle map (1:50000) of San José de Gracia (G12A64-INEGI, 2003), Baja California Sur, Mexico.

- MHN-UABCS Ba35. Southern Mesa Copalar, at Lat. N. 26°33.4', Long. W 112°45.8', Mexican government topographic quadrangle map (1:50000) of San José de Gracia (G12A64-INEGI, 2003), Baja California Sur, Mexico.
- MHN-UABCS Ba37. Arroyo El Mezquital, at Lat. N. 26°13.2', Long. W 112°21.3', Mexican government topographic quadrangle map (1:50000) of San José de Gracia (1:50000) of San Juanico (G12A75-INEGI, 2004), Baja California Sur, Mexico.
- MHN-UABCS Ba38. Punta Ostra, at Lat. N. 26°16.8', Long. W 112°24.6', Mexican government topographic quadrangle map (1:50000) of San José de Gracia (1:50000) of San Juanico (G12A75-INEGI, 2004), Baja California Sur, Mexico.

6. Systematic palaeontology

We follow the classification system for bivalves that was proposed by Coan and Valentich-Scott (2012) to the genus level, except for the case of the extinct genus *Gryphaeostrea*, in which Stenzel (1971) was used. The specimens studied have been deposited in the Colección de Referencia Paleontológica de Invertebrados, Museo de Historia Natural de la Universidad Autónoma de Baja California Sur (MHN- UABCS).

Class Bivalvia Linnaeus, 1758
Subclass Protobranchia Pelseneer, 1889
Order Mytilida Férussac, 1822
Superfamily Mytiloidea Rafinesque, 1815
Family Mytilidae Rafinesque, 1815
Subfamily Lithophaginae Adams and Adams, 1857

Genus *Lithophaga* Röding, 1798

Type species. *Lithophaga mytiloides* Röding, 1798, p. 156 (=*Mytilus lithophagus* Linnaeus, 1758); designation by monotype. Recent, Mediterranean.

Diagnosis. Shell elongate and cylindrical. Sculpture absent or of weak oblique striae; posterior slope frequently with ridges or radial riblet. Umbones anterior; ligament external, elongate usually sunken into groove and attached to resilial ridge.

Lithophaga sp.
(Figure 3.1)

Description. The specimen has a thin cylindrical shell that tapers towards the rear. Sculpture is weak, with oblique striae. Umbones anterior.

Material. One specimen, MHN-UABCS Ba14/33/32; 30 mm in length by 13,5 mm in height.

Occurrence. Locality 1219, Squires and Demetrion (1992).

Age. Early Eocene ("Capay Stage").

Discussion. The specimen was embedded in a sandstone rock, apparently *in situ*, because these bivalves drilled rocks, coral heads and even other shells, in order to create a burrow.

Lithophaga is a genus with wide age range and a cosmopolitan distribution. However, this is the first report in the state of Baja California Sur, which would further extend its known distribution range.

Order Arcida Gray, 1854
Superfamily Arcoidea Lamarck, 1809
Family Arcidae Lamarck, 1809
Subfamily Anadarinae Reinhart, 1935

Genus *Anadara* Gray, 1847

Type species. *Arca antiquata* Linnaeus, 1758; original designation. Recent, Indian Ocean.

Diagnosis. Shell inequivalve of subquadrate oval or trapezoidal shape and generally longer than high. Umbo is prominent, usually ahead of the midline but symmetric in the cardinal area. Outer surface has numerous radial ribs and with radial striated interspaces. Elongated flap more or less straight to slightly curved with numerous transverse teeth.

Anadara? sp.
(Figure 3.2)

Description. One internal mould with poor preservation and incomplete. The shell shape is slightly longer than tall. The mould only retains a very prominent umbo. Radial ribs on the surface observed, although not completely checked. The shape of the flap is flat or slightly arched.

Material. One specimen, MHN-UABCS Ba37/44/388; with a height of 26 mm, with a length of 33 mm.

Occurrence. Arroyo El Mezquital.

Age. Late Middle Eocene ("Tejon Stage").

Discussion. The specimen was classified within the family Arcidae mainly by the shape of the hinge, as it is straight and this is one of the main characteristics of the family. The form of the shell is the main criterion to assign to the genus *Anadara* (Poutiers, 1995; Coan *et al*., 2000), because several species of this genus have a similar form to the specimen found.

Order Ostreida Férussac, 1822
Superfamily Ostreoidea Rafinesque 1815
Family Gryphaeidae Vyalov, 1936
Subfamily Exogyrinae Vyalov, 1936

Genus *Gryphaeostrea* Conrad, 1865

Type species. *Gryphaea eversa* Melleville, 1843, p. 87. Eocene, France.

Diagnosis. Valve left convex, with a well-developed

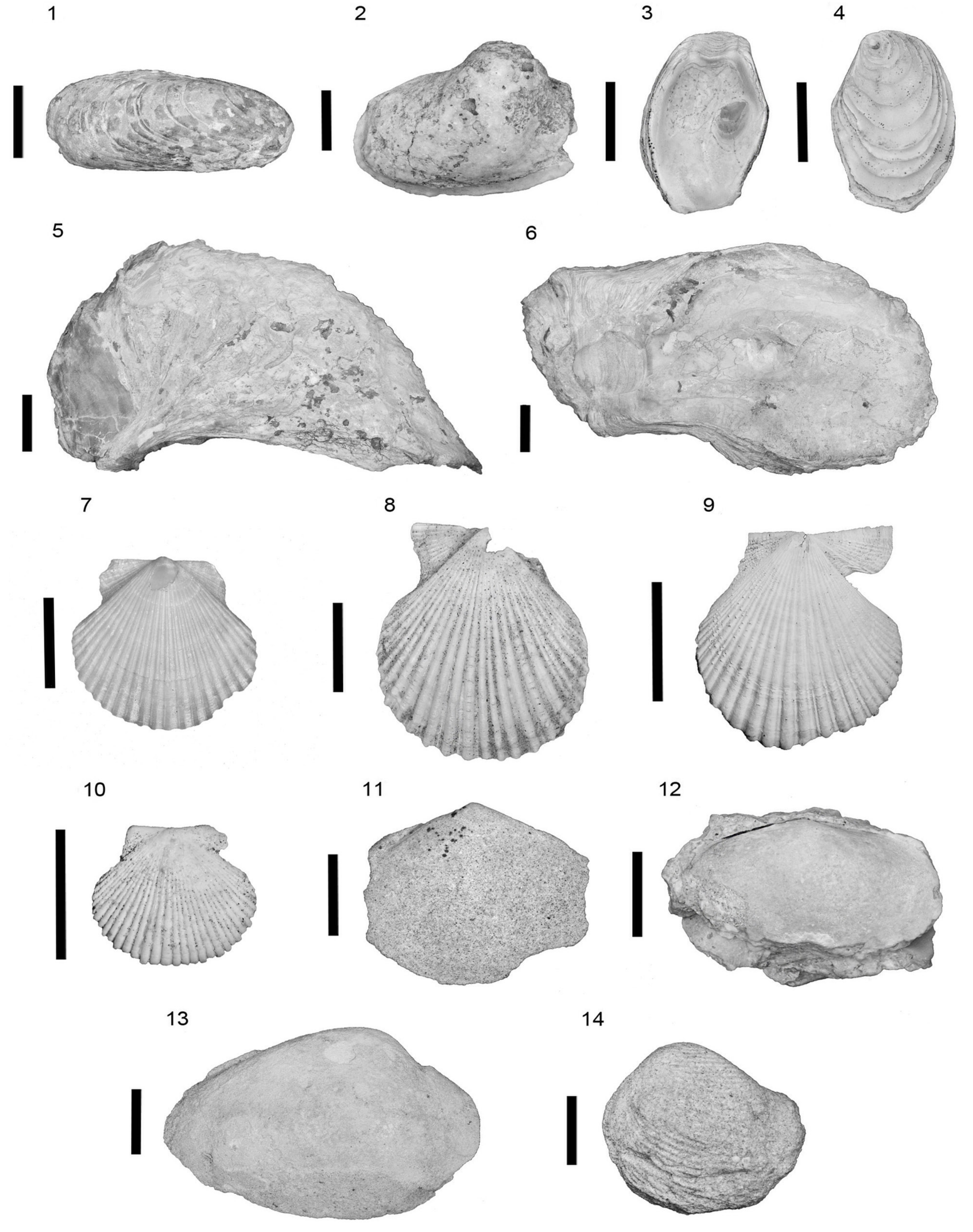

Figure 3. 1, *Lithophaga* sp., MHN-UABCS Ba14/33/32, right valve; 2, *Anadara*? sp., MHN-UABCS Ba37/44/388, right valve; 3–4, *Gryphaeostrea sanjuanicus* sp. nov., MHN-UABCS Ba38/45/80, right valve (holotype); 5–6, *Ostrea* sp., cf. *O. contracta amichel*, MHN-UABCS Ba38/45/39, right valve (5, external lateral view and 6, interior view); 7, *Argopecten*? sp., MHN-UABCS Ba1/9/52, right valve; 8, *Chlamys* sp. a, MHN-UABCS Ba32/36/76, left valve; 9, *Chlamys* sp. b, MHN-UABCS Ba32/36/82, right valve; 10. *Pecten*? sp., MHN-UABCS Ba32/36/84, right valve; 11–12, *Tellina* sp., MHN-UABCS Ba32/36/98, left valve (11), and MHN-UABCS Ba33/39/123, right valve (12); 13. *Macrocallista* sp., MHN-UABCS Ba37/44/969, right valve; 14. *Pitar* sp., MHN-UABCS Ba6/23/33, right valve. Scales to 10 mm, except *Ostrea* sp., cf. *O. contracta amichel* to 20 mm.

area without commissural chomata deep umbonal cavity dominated by the hinge area; fixing large area in many species, but small in others, this position posterior or posterodorsal margin of the valve, as they may be inclined roughly between 45° to 90° in an anteroposterior direction. Right valve flat oval to triangular and lacking chomata, is considerably smaller than the left valve, leaving a bare margin of up to seven millimetres in the left valve. Both valves are deep, narrow and spiral growth displaying a ligamental area that expands and straightens sharply near the end of the shell growth. External sculpture of both valves with numerous concentric growth lines and regularly spaced, strongly folded and elevated.

Gryphaeostrea sanjuanicus sp. nov.
(Figures 3.3–4, and Figure 4)

Etymology. The nearest town to the locality where the specimens were collected is San Juanico.

Description. Original shells in a good state of preservation, 12 right valves and eight fragments with poor preservation. Shell small, slightly flat with an oval or quadrate contour, with a deep umbonal cavity, the valve surface with numerous concentric growth lines and regularly spaced, tightly folded and raised over the entire surface of the shell; the adductor scar have a sub-circular to oval shaped, near to the posterior margin and approximately half the height of the valve. Ligamental area has a deep fossa, with two lateral areas thickening. Hinge lacking teeth.

Type. Holotype, MHN-UABCS Ba38/45/80; and eight paratypes, MHN-UABCS Ba38/45/66-73.

Material. 20 specimens, MHN-UABCS Ba35/42/31 and MHN-UABCS Ba38/45/66-84. 12 right valves and eight fragments.

Measurement. At different stages of growth, maximum height 39 mm, while minimum height 12 mm.

Type locality. Punta Ostra, near the town of San Juanico, Baja California Sur, Mexico.

Occurrence. Ba35, south of Mesa Copalar; and Ba38, Punta Ostra.

Age. Early Eocene (“Capay Stage”) and late Middle Eocene (“Tejon Stage”).

Discussion. The specimens found in Bateque Formation are considered a new species on the Pacific Coast of North America, since to date these are the only original shells described. Previously, Moore (1987) mentioned *G. aviculiformis* Anderson (1905, p 194-195, pl. 13, figs. 3-5) from the Domengine Formation, California, in his comments indicate that the right valve have a similar form to a operculum, as *G. sanjuanicus*, however, the description is limited and is based on shell fragment. The original description by Anderson is a similar to *G. sanjuanicus*, but the holotype is broke, and the comparison is difficult.

Several authors have reported the genus *Gryphaeostrea* in different parts of the world since the age range is from the Cretaceous to the Miocene. The Eocene species reported are *G. vomer* Morton, 1834, New Jersey and North Carolina, United States of America and parts of Europe; *G. trachyoptera* White, 1887, Brazil; *G. eversa* (Melleville, 1843) of the Paris Basin; *G. plicatella* (Morton, 1834) United States of America; *G. aviculiformis* (Anderson, 1905) of Domengine Formation, California. *G. callophyla* (Ihering, 1903) for the Danian Stage, Paleocene in Argentina (Moore, 1987; Casadío, 1998).

Despite the wide age range and its wide distribution, especially in the Atlantic Coast, the new species *Gryphaeostrea sanjuanicus* provides new data for understanding the paleobiogeography and the evolutionary history of the genus on the Pacific Coast of North America.

Family Ostreidae Rafinesque, 1815
Subfamily Ostreinae Rafinesque, 1815

Genus *Ostrea* Linnaeus, 1758

Type species. *Ostrea edulis* Linnaeus, 1758; by subsequent designation. Recent, England.

Ostrea sp., cf. *O. contracta amichel* Gardner, 1945
(Figures 3.5–6)

Description. Specimens were abundant, but only found in one locality. In this site, valves were found, both right and left, but no articulated specimen. The original shell is large, thick, oval, elongated, and inequivalve. The left valve is slightly convex, while the right is almost flat. Surface sculpture has numerous concentric sheets and growth lines. The ventral margin is rounded, while the lateral margins are almost straight, with numerous longitudinal strips. The ligament area is large with concentric grooves. Imprint of the adductor muscle is relatively small and oval.

Material. 17 specimens, MHN-UABCS Ba38/45/39-55.

Measurement(s). 200 mm maximum height found, common between 140 to 180 mm, 150 mm maximum length, common between 70 to 130 mm.

Occurrence. Punta Ostra.

Age. Late Middle Eocene (“Tejon Stage”).

Discussion. *Ostrea* is one of the most abundant fossil records around the world, as it is a cosmopolitan genus. Despite this, identification of species is difficult since in some cases it is difficult to differentiate between left and right valves. This is because these oysters have an extensive and irregular shell, which makes the observation of certain characters difficult (Poutiers, 1995).

Taking into account the characteristics of the specimens found in the Bateque Formation, the specific determination of the genus *Ostrea* is somewhat complicated. So far, there is only one species described from the middle Eocene in Mier Basin, Tamaulipas, which matches the characteristics of *Ostrea* sp., this species is *O. contracta amichel* Gardner (1945). However, this species is similar to *O. contracta*, but this has a long and narrow shell (Perrilliat, 1963).

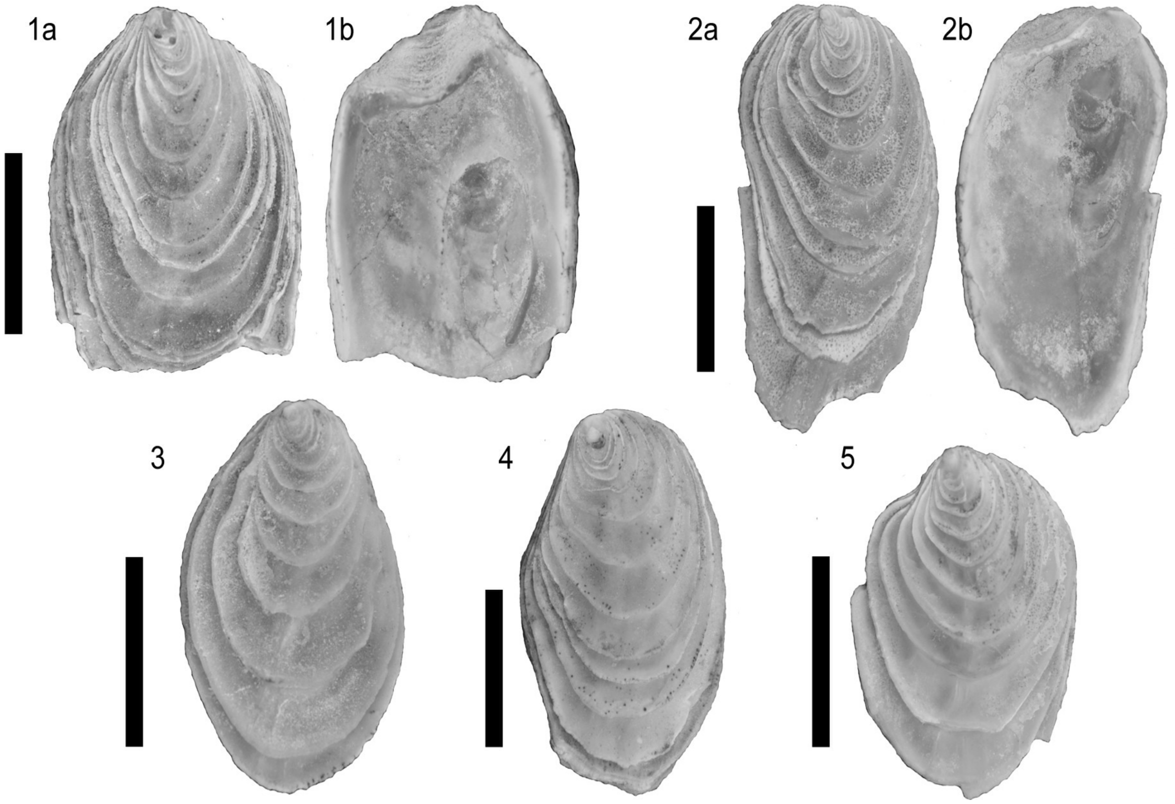

Figure 4. *Gryphaeostrea sanjuanicus* sp. nov., right valves paratypes. 1, MHN-UABCS Ba38/45/66 (1a, external view, and 1b, interior view); 2, MHN-UABCS Ba38/45/67 (2a, external view, and 2b, interior view); 3–5, MHN-UABCS Ba38/45/68-70 (external view). Scales to 10 mm.

O. contracta is probably a descendant of the subspecies *amichel*, although for many years it was known with the name of *O. alabamiensis* Lea (1833). All the specimens there have been reported in the eastern or the western Mexico Gulf (Gardner, 1945).

The specimens from Mier Basin in Tamaulipas and those found in Bateque Formation, Baja California Sur, are the only records we have of this genus and/or species in Mexico. The affinity between the specimens is remarkable and for this reason, the specific determination should be respected.

Order Pectinida (Gray, 1854)
Superfamily Pectinoidea Rafinesque, 1815
Family Pectinidae Rafinesque, 1815
Subfamily Chlamydinae Teppner, 1922

Genus *Argopecten* Monterosato, 1889

Type species. *Pecten solidulus* Reeve, 1853 (=*Pecten ventricosus* G. B. Sowerby, 1842), by subsequent designation (Monterosato, 1889, p 193). Holocene, from southern California to Peru.

Diagnosis. Shell convex, thin, usually subcircular. Both valves with numerous imbricated, strong and broad radial ribs, interspaces overlain by fine commarginal lamellae. Anterior and posterior ears, long and uneven.

Argopecten? sp.
(Figure 3.7)

Description. Only three original shells with good preservation, including two complete, one right and one left. All valves are of small size; despite this, the shell is thicker and sub-circular in shape, moderately convex. External carving has 24 square radial ribs separated by and flat bottom interspaces slightly narrower than the ribs. On the surface, concentric growth lines are also observed. The anterior and posterior ears of both valves (left and right), presented six radial ribs crossed by growth lines. The hinge only contains faint marginal reliefs (toothless).

Material. Complete original shells; MHN-UABCS Ba1/9/52 20 mm in height by 19 mm in length; MHN-UABCS Ba1/9/53, 11 mm in height by 10,5 mm in length.

Occurrence. Mesa San Ramón (La Rinconada).

Age. Late Middle Eocene (“Tejon Stage”).

Geological range. The age range reported for the genus ranges from the Oligocene to Recent.

Discussion. Up until now, the genus *Argopecten* had not been reported in the Eocene Epoch, so this would be the first record for this period and for the Pacific Coast of North America. However, the specific determination can raise questions about the material found in the Bateque

Formation, as this is very similar to *A. cristobalensis*, differing only in the size and number of ribs in the auricles of the left valve (with eight or nine ribs and a slight indentation in the anterior ear). *A. cristobalensis*' geological range is Pliocene, being reported in the Almejas Formation with a geographical distribution from Cedros Island to Turtle Bay in Baja California.

Due to its characteristics, the material found can generate some doubt, as the Almejas and Bateque formations are closely together, but specimens were obtained from a locality named Mesa San Ramón (La Rinconada) which have been attributed to late Middle Eocene age (González-Barba, 2003). The idea of extending the age range of *Argopecten* cannot be conclusive because the fossils could have been transported in some way, or it could just be a new species. However, we need to find new specimens in other localities of the Bateque Formation, which could confirm this hypothesis, but the information presented herein should be considered.

Genus *Chlamys* Röding, 1798

Type species. "*Pecten islandicus* Linnaeus" (=*Ostrea islandica* Gmelin, *Pecten islandicus* Müller); by subsequent designation (Herrmannsen, 1847–49, p. 231). Recent, North Atlantic from Norway to Iceland, Greenland, and south to Cape Cod.

Diagnosis. Shell small subcircular in form, generally higher than long and often oblique. Radial shape with numerous primary and secondary ribs. Presents a concentric figure consisting of small flakes which gives the ribs a rough texture (rough or uneven). Unequal atria, *i.e.* longer than the anterior posterior. The anterior ear feature byssal notch, and usually with a ctenolium with four to six teeth.

Discussion. Both generic and specific determination are complicated, since the specimens found have quite poor preservation and most are incomplete. The genus *Chlamys*, despite having a wide age range (from the Permian to Recent), is virtually unknown in the Pacific Coast of North America with Eocene age. The specific determination can be argued; however, as reported here, it should be considered for future ecological and biogeographic interpretations of the genus.

Chlamys sp. a
(Figure 3.8)

Description. Original shells with good preservation, although no complete shell. Two left valves were found, while the rest are indistinguishable. Shell of medium size, compressed and thin, more height than length. The anterior and posterior margins are straight. Both valves show almost the same convexity. The outer surface has between 22 to 24 radial ribs, rounded. The ribs show protuberances in the form of small spines and small scales, particularly well developed in the ventral and lateral margin ribs, and numerous concentric grooves. The density and size of the scales and spines vary considerably between individuals. The anterior and posterior auricles of the left valve between seven and ten have perfectly smooth ribs; no spines or flakes are observed on these.

Material. Six specimens, MHN-UABCS Ba32/36/76-81. Specimen with key MHN UABCS Ba32/36/76, height of 27 mm by 22 mm in length; remaining are incomplete specimens.

Occurrence. Mesa El Mezquital.

Age. Late Middle Eocene ("Tejon Stage").

Discussion. There are several species of the genus *Chlamys* reported in the Eocene Epoch in different parts of the world. The only record of this genus in the Pacific Coast of North America is reported by Nilsen in 1987, where it is mentioned that Nilsen and Addicott (1971) collected fragments *Chlamys*? sp. in San Emigdio, Kern County, California, United States of America, with an age range of "Tejon Stage"; however, there is no description of the material.

The specimens found in Bateque Formation, have some affinities with *Chlamys varia* (=*Mimachlamys varia*), but this species has an age range from Miocene to Recent, and has only been reported in different European localities.

So far, *Chlamys* sp. a represents the first species reported from the Pacific Coast of North America with an Upper Eocene age; however, more and better-preserved specimens are needed to better determine the species. Furthermore, this record should be taken into account for future paleobiogeographic interpretations.

Chlamys sp. b
(Figure 3.9)

Description. Original thin and fragile shells but with good preservation. Of the six valves, three are right, one is left, and two are incomplete fragments. The shell is of small size, and slightly equilateral convex, is higher than long. The anterior and posterior margins are straight. Rights valves have bifurcated radial ribs, which appear towards the middle, between two ribs, a thinner rib, a total of between 38 to 42 ribs, the interspaces are narrow and smooth. The above atrium six to eight shows radial ribs and concentric lamellae, which pass above and through the ribs, while the atrium is smaller after six radial ribs. Straight hinge line with a byssal notch and ctenolium.

Material. Six valves (MHN- UABCS Ba32/36/82-87), of which only three right valves rights are complete. MHN-UABCS Ba32/36/82, height 19,5 mm, length 16,5 mm, hinge length 11,5 mm; MHN- UABCS Ba32/36/83, height 24 mm, length 21,5 mm, hinge length 14 mm; MHN-UABCS Ba32/36/84, height 15 mm, length 13,5 mm, hinge length 9 mm.

Occurrence. Mesa El Mezquital.

Age. Late Middle Eocene ("Tejon Stage").

Discussion. *Chlamys* sp. b confirms the presence of the genus in Bateque Formation; however, the specific determination remains controversial. This species has some affinity with *C. opuntia*; both species are very similar, the only differences being the "size" and the number of ribs in the ear (12 ribs), plus the age range, Pliocene to Pleistocene for this species (Quiroz-Barroso and Perrilliat, 1989; Powell and Stevens, 2000).

So far there is no complete shell, *i.e.* right and left, making it even more difficult to describe the species. Nevertheless, similar to *Chlamys* sp. a, this record should be taken into account for further works.

Subfamily Pectininae Wilkes, 1810

Genus *Pecten* Müller, 1776

Type species. *Ostrea maxima* Linnaeus, 1758, p. 824; by subsequent designation (Schmidt, 1818). Recent, Atlantic Ocean.

Diagnosis. Shell subcircular with well-developed radial ribs, usually with grooves or slots on the ribs. Concavity present in many shells on the umbonal area of the right valve.

Pecten? sp.
(Figure 3.10)

Description. Only two original valves, with good preservation were found, and they are small and fragile. The shape of the shell is subcircular. Both valves are right and the ornamentation consists of 32–34 rounded radial ribs, separated by narrow slightly rounded interspaces and concentric growth lines are also observed. Poor preservation of the ears does not allow the observation of the ribs but lighter grooves are observed. The hinge lacks teeth, and contains only faint marginal relief.

Material. Only two specimens; MHN- UABCS Ba32/36/74, 11,5 mm high by 12 mm long and hinge length, 8 mm; MHN- UABCS Ba32/36/75, 10 mm high by 10 mm long and hinge length, 4,5 mm.

Occurrence. Mesa El Mezquital.

Age. Late Middle Eocene (“Tejon Stage”).

Discussion. *Pecten*? sp. exhibits some affinity with *Pecten* (*Plagioctenium*) *evermanni* Jordan and Hertlein, 1926 (synonyms: *P.* (*Aequipecten*) *evermanni* in Grant and Gale, 1931 and *Argopecten evermanni* in Moore, 1984) reported on the Almejas Formation, Baja California, Mexico, with the Pliocene species. However, the right valve of *P.* (*Pl.*) *evermanni* has 30–31 radial ribs, and the anterior ear have four radial ribs including a very thick on the base, while the posterior ear is similar but without the thick rib (Jordan and Hertlein, 1926; Puffett, 1974; Moore, 1984; CAS, 2012).

The genus *Pecten* is known in the Eocene Epoch and in the Pacific Coast of North America, but these specimens represent the first record in the Bateque Formation.

Superorder Heterochonchia Gray, 1854
Order Venerida Gray, 1854
Superfamily Tellinoidea Blainville, 1814
Family Tellinidae Blainville, 1814

Genus *Tellina* Linnaeus, 1758

Type species. *Tellina radiata* Linnaeus, 1758; by subsequent designation (Children, 1823). Recent, Caribbean.

Diagnosis. Shell elongated and compressed. Hinge with two cardinal teeth in each valve, and a lateral tooth in one or both valves. The division of the genus *Tellina* in subgenus is inconsistent until now and there are most likely numerous morphological convergences.

Tellina sp.
(Figures 3.11–12)

Description. All specimens found are internal moulds or impressions of shells, some with good preservation, and others incomplete. Various forms, but most elongated-oval and with compressed shell. A deep mantle is observed in some specimens. The outer surface of all specimens is extremely smooth.

Material. 11 specimens, MHN-UABCS Ba4/47/11, MHN-UABCS Ba6/23/42-45, MHN-UABCS Ba14/33/39, MHN-UABCS Ba32/36/98 and MHN-UABCS Ba33/39/123-126. Moulds with different stages of growth, maximum height 30 mm, minimum 13 mm; 47 mm maximum length, minimum 23 mm.

Occurrence. Ba4 Rancho Malbar (south of Arroyo Mezquital); Ba6, Hill A Norte; Ba14 locality 1219, Squires and Demetrion (1992); Ba32, Mesa El Mezquital and Ba33, near locality 1219, Squires and Demetrion (1992).

Age. Early Eocene (“Capay Stage”) and late Middle Eocene (“Tejon Stage”).

Discussion. The evolutionary history of the family Tellinidae reveals diversification in different ocean basins, which seems to have resulted in many parallel forms. A clear example is the genus *Tellina*, which features a large number of subgenera and species that have generated a lot of contradictions when identifying and classifying (Moore, 1969a).

The specimens found in the Bateque Formation certainly belong to the genus *Tellina*; however, they have different contours, which means that they may belong to different subgenera. For example, it is possible that the specimens of the Locality 1219, Squires and Demetrion (1992) (Ba14 and Ba33) have affinity to *T.* (*Tellina*) (Moore, 1969b, p. N614, figs 11a, b) (Figure 3.12, MHN-UABCS Ba33/39/123) since the shape is more elongated, however the poor preservation of specimens makes a subgeneric and specific determination difficult.

Superfamily Veneroidea Rafinesque, 1815
Family Veneridae Rafinesque, 1815

Genus *Macrocallista* Meek, 1876

Type species. *Venus gigantea* Gmelin, 1791, p. 3282 (=*Venus nimbosa* Lightfoot, 1786, p. 175); designated by monotype. Recent, Caribbean.

Macrocallista sp.
(Figure 3.13)

Description. Only one complete internal mould was found, the remaining specimens are incomplete and are poorly preserved. Shape oval-elongated, slightly flattened and completely smooth shell. It has a moderately deep pallial sinus.

Material. Complete internal mould, MHN-UABCS Ba37/44/469, 40 mm tall and 60 mm in length; and other specimens with key MHN-UABCS Ba37/44/470-472.

Occurrence. Arroyo El Mezquital.

Age. Late Middle Eocene ("Tejon Stage").

Discussion. Three species of the genus *Macrocallista* are reported in the Pacific Coast of North America: *M.*? *packi* Dickerson (1914), *M. horni* (Gabb) Stewart (1930), and *M. meganosensis* Clark and Woodford (1927), all of the Eocene Epoch, found in strata of California, United States of America (Dickerson, 1914; Moore, 1968).

The poor preservation of specimens makes comparison with previously reported species difficult, since the descriptions are made with original shells and not with internal moulds. *Macrocallista* sp. of the Bateque Formation represents the first record of the genus in Baja California Sur, Mexico, therefore the geographical distribution should be extended.

Genus *Pitar* Römer, 1857

Type species. *Venus tumens* Gmelin, 1791, selected by a recent monotype. West Africa.

Diagnosis. Oval shell, orbicular, or subtriangular, usually with prominent umbones, located in the midline of valve or in front of the axis. Lunule usually present. External sculpture with numerous concentric ribs and/or a radial component.

Pitar sp.
(Figure 3.14)

Description. Internal moulds with poor preservation. Shell has sloping posterior margin, a concave anterior ventral margin, and an oval contour. Slightly elongated oval shell with prominent features which are umbones, prosogyrates, and anteriorly incurved. Sculpture with high external concentric ribs, each with different thickness, covering the entire shell. No internal structure is observed.

Material. Three specimens MHN- UABCS Ba1/38/38, MHN-UABCS Ba6/23/33, and MHN-UABCS Ba7/24/72. Average height 22 mm, average length 28 mm.

Occurrence. Ba1, Mesa San Ramón (La Rinconada); Ba6, Hill A Norte; and Ba7, Mesa La Salina.

Age. Early Eocene ("Capay Stage").

Discussion. *Pitar* is a very common genus in the Eocene Epoch, however it has many synonyms or simply several species of the genus have been reassigned to other genus of the family Veneridae, hence allocation of this genus is truly complicated and even more so when there are no complete specimens.

The specimens found are very similar to the specimens reported by Weaver and Van Winkle-Palmer (1922) in his "Fauna from the Eocene of Washington", where they describe two new species of the genus *Pitaria*. The first is *P. eocenica*, while the second is *P. stocki*, both very similar, and very similar to the internal moulds found, although only certain external characters are comparable.

Both species are very similar, *i.e.*, the shape of the shell is almost equal showing differences in the shape of the anterior and posterior margin, while the position of the umbo is perhaps one of the biggest differences between them. The umbo of *P. stocki* is positioned at an angle of 35° of the anterior margin, while the umbo of *P. eocenica* is one third of the distance from the anterior margin. Similarly, both species have an outer surface having numerous concentric ribs; however, the interspaces are wider in *P. eocenica* than *P. stocki* (Weaver and Van Winkle-Palmer, 1922).

Because of the resemblance, it is truly difficult to distinguish the species, and, in addition, currently the genus *Pitaria* is obsolete and their species have mainly been allocated to the genus *Pitar*.

On the other hand, there are several species of genus *Pitar* reported in the Pacific Coast of North America, in the Eocene Epoch, which are: *P.* (*Calpitaria*) *uvasanus* (Conrad, 1855); *P.* (*Lamelliconcha*) *joaquinensisk* Vokes, 1939; and *P. uvasana coquillensis* Turner, 1938, but none of these species were found in the Bateque Formation (Squires and Demetrion, 1992; Squires, 1984, 1999, 2001).

Although the generic and specific designation is still a question for specimens found in Bateque Formation, it is highly likely that the genus *Pitar* had a wide distribution and extends in to part of Baja California Sur, during the Eocene.

7. Conclusions

Marine invertebrates found in the Bateque Formation indicate a warm-water biota related to the tropical Tethys Sea current, which created the conditions for a wide biotic exchange between marine organisms of the Atlantic, Gulf of Mexico-Caribbean, and Pacific.

The fossil fauna indicates an age range of the "Capay Stage" (Early Eocene: Ypresian) to the "Tejon Stage" (late Middle Eocene: Bartonian). The problem lies in the limits of "Tejon Stage", because this stage includes part of the Middle Eocene (upper part Lutetian and the whole

Bartonian), and a small portion of the Upper Eocene (lower part of Priabonian). Thus, studies of magnetic stratigraphy, biostratigraphy, and stable isotopes are needed in order to obtain a more precise age-calibration.

The age previously suggested by Mina-Uhink (1956, 1957) and Sorensen (1982) for the Bateque Formation is the middle Paleocene, based on small foraminifera faunal; however, this cannot be corroborated by the results of this study, since no invertebrate or locality indicated this age.

The litho- and biostratigraphic data are consistent when the comparison between both formations is carried out, *i.e.* the fossils found in the middle part of the Tepetate Formation coincide with those present in the middle of the Bateque Formation, which proves that both formations are partially contemporaneous and correspond to the "Capay Stage" (early Eocene: Ypresian). Depositional environments that prevail during the Eocene correspond to inner to outer shelf, according to the faunal associations found in the majority of the localities.

Finally, this study represents the acquisition of new data, whose interpretations provide foundation knowledge for palaeontologic, stratigraphic correlation and evolutionary history of species in the Pacific region of North America

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Occurrence of *Retrocypoda almelai* Via Boada, 1959 (Decapoda: Retroplumidae) in the Eocene of Central Iran

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Abstract

The decapod crustacean *Retrocypoda almelai* Via Boada, 1959 is reported from Bartonian (middle Eocene) strata of Soh (North of Isfahan, Iran) and represents the most oriental record for the species, hitherto considered endemic and restricted to the western margin of Tethys. This finding is important to understand the paleobiogeographic distribution of retroplumid crabs, which were abundant during Late Cretaceous in America and Africa, but today their representatives are restricted to the Indopacific region.

Keywords: Crustacea, Decapoda, Retroplumidae, Eocene, Isfahan, central Iran.

Resumen

El crustáceo decápodo Retrocypoda almelai *Via Boada, 1959 es reportado en estratos del Bartoniano (Eoceno medio) de la región de Soh (Norte de Isfahán, Irán), y representa el registro más oriental de la especie, considerada previamente como endémica y restringida al margen occidental del Tethys. Este hallazgo es importante para comprender la distribución paleobiogeográfica de los cangrejos retroplúmidos, que fueron abundantes durante el Cretácico Tardío en América y Africa, pero actualmente sus representantes están restringidos a la región Indopacífica.*

Palabras clave: Crustacea, Decapoda, Retroplumidae, Eoceno, Isfahan, central Irán.

1. Introduction

The discovery of one specimen of *Retrocypoda almelai* Via Boada, 1959 on Bartonian (middle Eocene) strata of Soh (North of Isfahan, Iran) (Fig. 4.1), represents the most oriental record for the species, hitherto considered endemic and restricted to the western margin of Tethys. The genus *Retrocypoda* was erected by Via Boada (1959) to accommodate the sole species *R. almelai* Via Boada, 1959, based upon samples recovered in the Bartonian (middle Eocene) outcrops of Central Catalonia (NE Iberian Peninsula), but he also reported and figured the presence of *R. almelai* in Lutetian (middle Eocene) outcrops of other localities of Central Catalonia (see also Via, 1969, p. 330–331). Beschin *et al.* (1996, 2012) reported the presence of specimens of *R. almelai* in the Lutetian outcrops of the Vicenza area (northern Italy). In addition, *R. almelai* is also recorded in the Lutetian outcrops of Alicante Province (south-eastern Spain) (AO pers. obs.), and also in the Priabonian (middle Eocene) outcrops of the Central Pyrenees in Huesca Province (northern Spain), where the species migrated westward during the Bartonian transgression (Ossó *et al*., 2014). Likewise, the genus is recorded lately also in Ilerdian (early Ypresian) outcrops of Aude (south-eastern France) (AO pers. obs.). Therefore, we can observe that until now the genus *Retrocypoda* seemed confined to the Mediterranean margin of the western Tethys during the early to late Eocene. The new Iranian specimen demonstrates that *Retrocypoda* also inhabited the oriental part of the Tethys during Eocene times.

The systematic position of *Retrocypoda almelai* has been the object of different placements and proposals of phylogenies through time. Originally, it was placed by Via (1969, 1988) and Via Boada (1959, 1980, 1982) as Retroplumidae Gill, 1894, within Ocypodoidea Rafinesque, 1815 with possible relationship with the Macrophthalminae Dana, 1851. Glaessner (1969) placed it within Palicidae Bouvier, 1898, albeit with a query. It was not until 1989 that de Saint Laurent clarified the systematics of *Retrocypoda*, and included it within the Retroplumoidea Gill, 1894, pointing out its possible relationship with *Costacopluma* Collins and Morris, 1975.

The Iranian specimen of *Retrocypoda almelai* expands eastward the distribution of this species during the Eocene and by extension the paleobiogeographical distribution of the family Retroplumoidea. The paleobiogeography of this family has been discussed formerly by many authors (for instance: Via and Cals, 1979; Via, 1980; Vega and Feldmann, 1992; McLay, 2006; Fraaije *et al*., 2006; Hyžný and Müller, 2010; Feldmann *et al*., 2014), who also hypothesized about the origins of the group and its apparent subsequent expansion eastward from both sides of the Atlantic, whether from Central America or from the west coast of Africa, where it is assumed that the group arose during the Late Cretaceous (Hyžný *et al*., 2016).

2. Geological setting

Outcrops in the Soh area include the widely distributed Paleozoic (Zahedi, 1973; Adhamian, 2003; Wendt *et al*., 2005; Ghobadipour *et al*., 2013; Bahrami *et al*., 2015) and Mesozoic deposits (Mannani and Yazdi, 2009; Yazdi *et al*., 2010), as well as the Paleocene to Oligo-Miocene deposits, the youngest marine sequences, which start with terrigenous red to white sequence of Paleocene conglomerate and sandstone, continued by Eocene fossiliferous carbonates and marls. The Sabkha deposits at the top of the Oligo-Miocene Qom Formation terminates the depositional cycle of the marine sequence.

A thick Eocene succession is widely exposed in the studied region (Sadri, 2011; Janssen *et al*., 2013). The studied section is located near the village of Soh (70 km northwest of Isfahan) (Fig. 1) and is accessible by a 35 km unpaved road off the Isfahan – Tehran highway. The section is situated on the right side of a seasonal river valley that is observable from a distance in the plain. Coordinates for the fossil locality are: N 33º28´36″, E 51º27´6″. Structurally, the locality belongs to the Central Iran microplate, which is restricted by the NW-SE Sanandaj- Sirjan metamorphic belt to the West, and by the Great Kavir fault to the East. The studied profile (Figs. 2, 3) is about 354 meters thick. Based on field observation, sedimentological features and fossil contents, 11 lithological packages are discriminated. The details of each package are given from the top to the base:

- Alternation of light brown to grey sandstone and conglomerate with reworked clasts including *Heterastridium* spp. of late Triassic due to movements of Alpine orogeny, 33 m (package 11).
- Alternation of thin bedded sandstone with green to white marly subminors including two igneous levels (trachy-andesite and basalt), 20 m (package 10).
- Alternation of white to light brown limestone, sandy limestone, thin layers of marly limestone with abundant silicified bivalves and gastropods (*Pinna* sp., *Glycymeris* sp., *Velates* sp., *Conus* sp., *Oliva* sp., *Natica* sp.), solitary corals, condensed ostreoid layers and the *Retrocypoda almelai* specimen here reported, 68 m (package 9).
- Pink to brown trachy-andesite, 10 m (package 8).
- White to yellow green marl with sandy limestone including foraminifers, echinoids, bivalves and gastropods, 35 m (package 7).
- Alternation of dark brown to grey siliceous conglomerate and sandstone, 35 m (package 6).
- Yellow to grey medium to thick bedded sandy limestone including micro and macrofauna (*Ostrea* sp., *Natica* sp., *Velates* sp., *Cardium* sp., bivalve coquina and bryozoan remains), 30 m (package 5).
- Alternation of sandstone and marl, two green to grey tuffaceous silty horizons, and purple fossiliferous marl with abundant bivalves, 60 m (package 4).
- Green to gray loose marl including, pteropods (marine pelagic gastropods), *Helioconoides* sp. crinoids, ostracods, tiny layers of siliceous sandy limestone with foraminifera (*Nodosaria catesbi*, *Nodosaria scalaris*, *Elphidium* sp., *Marginulina* sp., *Nummulites globulus*, *Coskinolina* sp., *Spirolina cylindracea*, *Textularia* sp.), and bivalves (*Ostrea* sp., *Pinna* sp.), 30 m (package 3).
- Brown fine-grained cross-bedded marly sandstone, 15 m (package 2).
- Grey marls with thin layer of brown to yellow limestone including abundant *Rotularia* sp. (polychaete worm), charophye algae, ostracods, oysters and foraminifera (*Nodosaria catesbi*, *N. scalaris*, *Elphidium* sp., *Marginulina* sp., *Nummulites globulus*, *Coskinolina* sp.), fine sandy carbonate bed rich in crustacean remains, mainly Callianassidae at the base of the package, 18 m (package 1 – Eocene).
- Disconformity (Paleocene-Eocene boundary).
- Alternation of red to dark brown conglomerate, sandstone and siltstones including siliceous *Orbitolina* and mollusk debris, reworked from the Cretaceous due to the post Laramidian orogenetic movements, 60 m, (Paleocene).

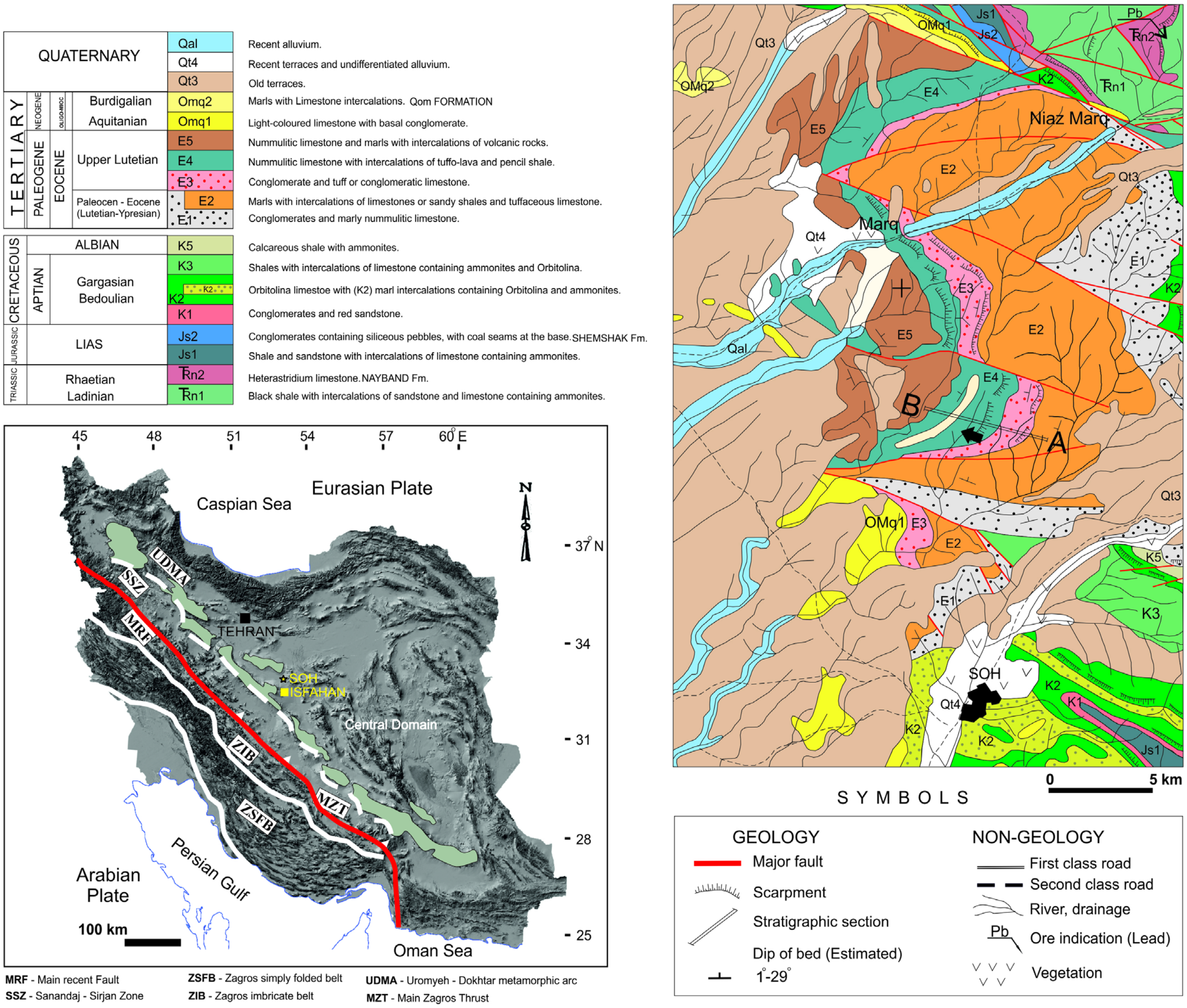

Figure 1. Location and geologic maps of study area with position of fossil locality (arrow), north of Isfahan, Iran.

3. Repository

Department of Geology, Faculty of Science, University of Isfahan, Iran: EUIC. Museo del Desierto, Saltillo, Coahuila, Mexico: MUDE. Museu de Geologia de Barcelona (Barcelona, Catalonia): MGB. Museo Civico "G. Zannato" di MontecchioMaggiore (Vicenza, Italy): MCZ.

4. Systematic Paleontology

Order Decapoda Latreille, 1802
Infraorder Brachyura Latreille, 1802
Section Eubrachyura de Saint Laurent, 1980
Subsection Heterotremata Guinot, 1977
Superfamily Retroplumoidea Gill, 1894
Family Retroplumidae Gill, 1894

Genus *Retrocypoda* Vía Boada, 1959
Type species. Retrocypoda almelai Vía Boada, 1959

Retrocypoda almelai Vía Boada, 1959
(Fig. 4)

1943 Fragmentos de crustáceos; Ríos *et al*., p. 360
1949 "especie completamente inédita"; Via, p. 171
1950 *Macrophthalmus almelae* n. sp.; Bataller, p. 224 (*nomen nudum*).
1952 *Ocypodidae* n. sp.; Via, p. 86.
1959 *Retrocypoda almelae* Vía Boada, 1959; p. 394, f. 20.
1961 *Retrocypoda almelae* Via Boada, 1959; Farrés, p. 21
1969 *Retrocypoda almelai* Via Boada, 1959; Glaessner in Moore, p. 532, f. 339.1.
1969 *Retrocypoda almelai* Vía Boada, 1959; Via, p.

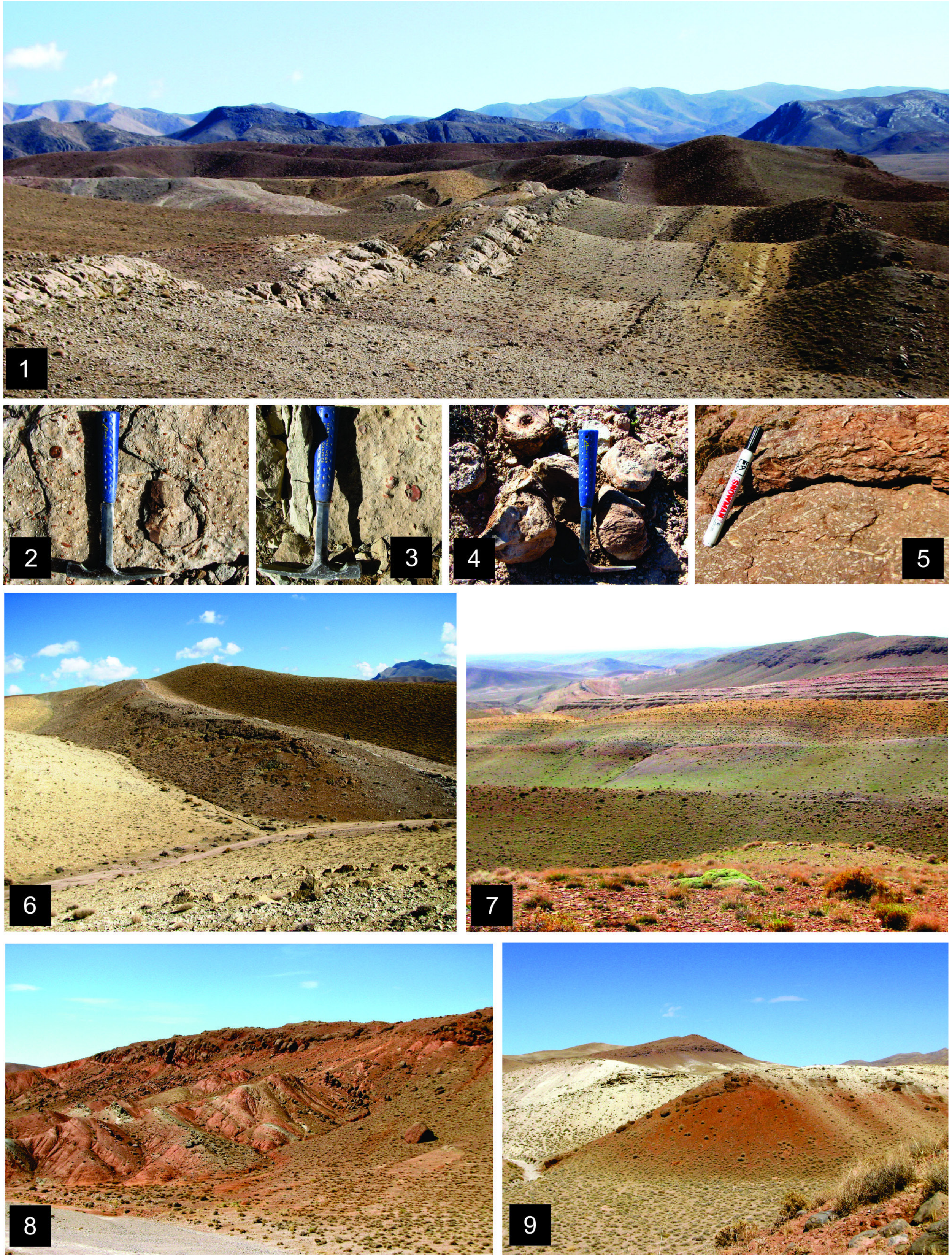

Figure 2.1, General view of the Sarakeh syncline with indication of the crustacean horizon in studied carbonate level. 2, 3, Silicified echinoids, bivalves and foraminifers found below and within the studied carbonate horizon. 4, Oyster rich level at the top of the carbonate horizon. 5, Silicified foraminifera horizon 2 m above the Oyster rich level.6, Igneous (trachy-andesite) below the carbonate level. 7, General view of the Srakeh syncline with indication of conglomerate levels at the base and top of the carbonate horizon. 7, Paleocene red clastic and continental deposits at base of studied profile. 9, Paleocene-Eocene boundary (red to white) transitional level.

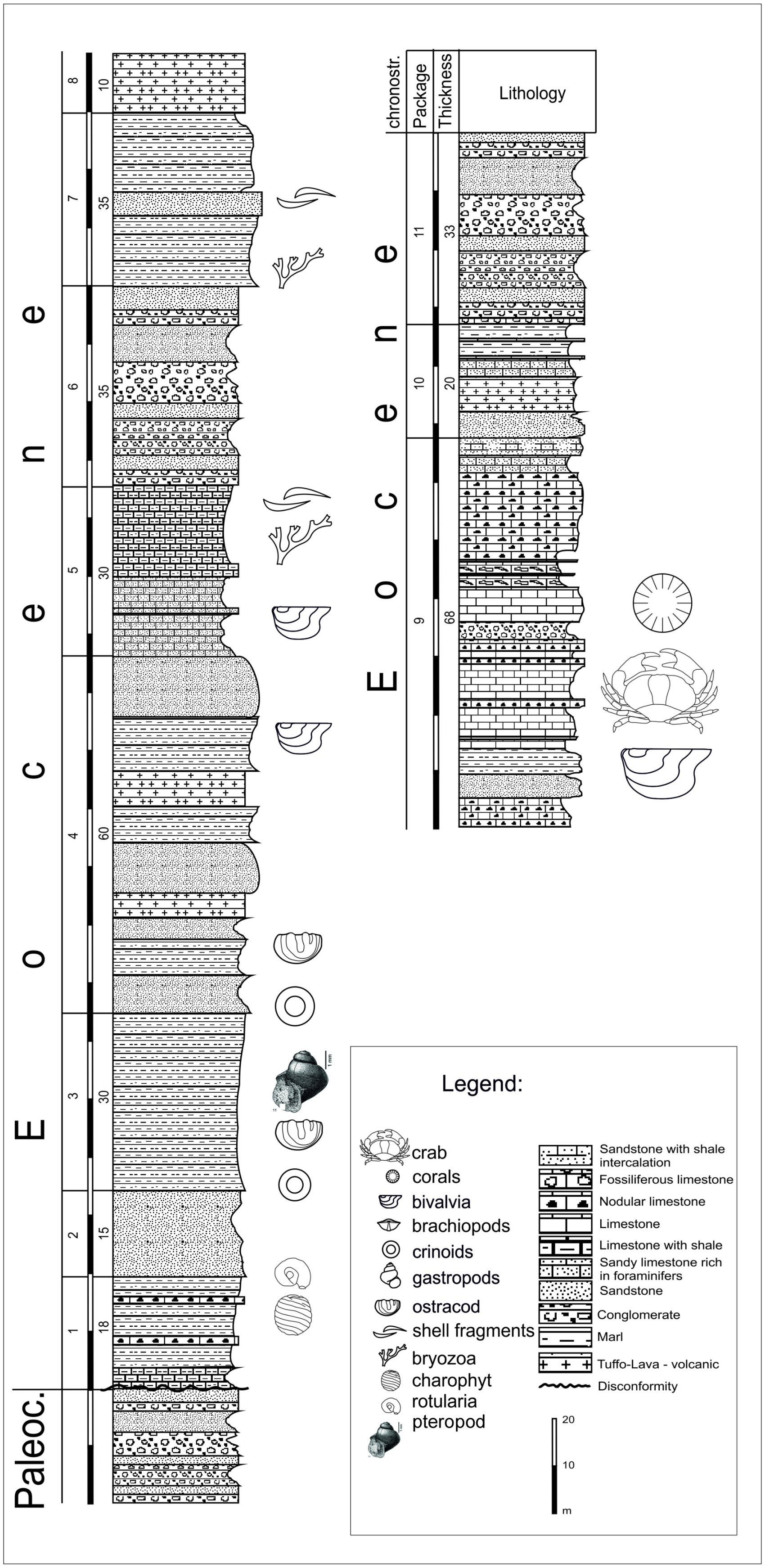

Figure 3. Stratigraphic profile of study section.

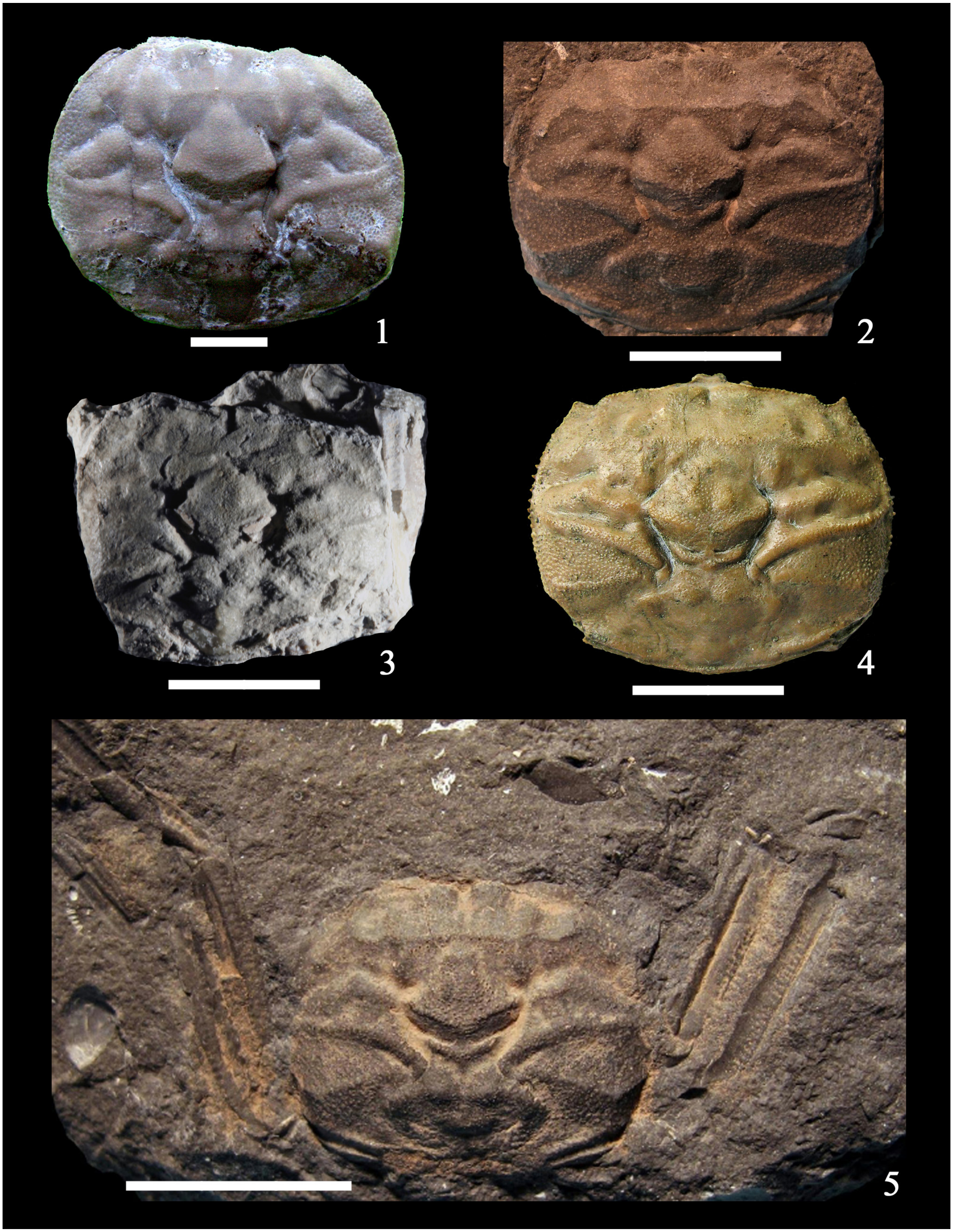

Figure 4. *Retrocypoda almelai* Via Boada, 1959.1: EUIC 2238, Bartonian (middle Eocene) of Soh (Isfahan, Iran). 2: MGB 70438, Priabonian (late Eocene) of Yebra de Basa (Huesca, Spain). 3: CPC-1840, Bartonian (middle Eocene) of La Pobla de Claramunt (Anoia, Catalonia).4: MCZ 2727, Lutetian of Grola, (Vicenza, Italy). 5: AO C-023/6, Priabonian (late Eocene) of Yebra de Basa (Huesca, Spain). Scale bar equal to 10 mm.

330, fig. 41, t. 38, f. 4, t. 39, ff. 1–5.
1980 *Retrocypoda almelai* Vía Boada, 1959; Via Boada, p. 58, t. 1, f. 5.
1982 *Retrocypoda almelai* Via Boada, 1959; Via Boada, p. 18, f. 1.
1985 *Retrocypoda almelai* Via Boada, 1959; Vela, p. 22.
1988 *Retrocypoda almelai* Via Boada, 1959; Via, p. 351, f. 343.G.
1989 *Retrocypoda almelai* Vía Boada, 1959; Solé and Vía, p. 31.
1989 *Retrocypoda almelai* Vía Boada, 1959; de Saint Laurent, p. 143-150, t. 6, ff. A-E, t. 7, ff. A-G.
1996 *Retrocypoda almelai* Vía Boada, 1959; Beschin *et al*., p. 96, fig. 5, t. 2, f. 1.
2001 *Retrocypoda almelai* Vía Boada, 1959; De Angeli and Beschin, p. 28, f. 21.3.
2006 *Retrocypoda almelai* Vía Boada, 1959; De Angeli and Garassino, p. 52.
2007 *Retrocypoda almelae*Via Boada, 1959; Feldmann and Portell, p. 91.
2010 *Retrocypoda almelai* Vía Boada, 1959; Schweitzer *et al*., p. 100.
2011 *Retrocypoda almelai* Via Boada, 1959; De Angeli *et al*., p. 41, T1.
2013 *Retrocypoda* Via Boada, 1959; Guinot *et al*., p. 140, 216.
2015 *Retrocypoda almelai* Via Boada, 1959: Jagt *et al*., p. 887, 880, f. 71–15.6, B-C.

Description. Carapace medium sized; subrectangular, wider than long (ratio 0,80), maximum width at midlength of carapace; sculptured, finely granulated; crossed by four more or less marked transverse ridges. Frontal margin long; front very narrow, not present; supraorbital margin long, sinuous; strong outer orbital tooth broken. Lateral margins convex; laterally stepped, inward directed anteriorly, finely spiny; anterolateral margins gently arched toward the anterior corner, posterolateral margins convex, posteriorly convergent; posterior margin long, slightly convex, rimmed. Anterior first ridge straight medially, and downward oblique laterally crossing the protogastric and hepatic regions; second ridge sinuous, with rounded edge, acute in mesogastric lobe, crossing mesogastric and epibranchial regions; third ridge acute, downward oblique, short, traverses from epi- and mesobranchial regions to branchicardiac groove; posterior fourth ridge upward oblique, short, crossing mesobranchial and cardiac regions, interrupted by branchiocardiac groove. Epigastric lobes slightly inflated; protogastric lobes slightly swollen; mesogastric lobe well marked, bounded and separated from narrow metagastric lobes by deep cervical groove; urogastric region depressed; cardiac lobe rhomboidal, slightly swollen; intestinal region depressed. Gastric pits present between meso- and metagastric lobes.

Material. One specimen, EUIC 2238.

Measurements (in mm). Length = 39.9 Width = 51.6, Fronto-orbital width = 32.3. Ratio L/W = 0.77; ratio FOW/W = 0.62.

Discussion. The Iranian specimen of *Retrocypoda almelai*, dorsally well preserved (Fig. 4.1), fits perfectly with the Iberian and Italian specimens of this species (Fig. 4.2 – 4.5), being noteworthy in its unusual larger size (51 mm width). This discovery expands the paleobiogeographic range of this species, so far considered endemic of the Western Tethys. It was recovered in a sandy limestone level attributed to the Bartonian. Accompanying fauna such as bivalves, gastropods and oyster layers, indicates a nearshore environment (Janssen *et al*., 2013).

The apparent confinement of *Retrocypoda* to the Mediterranean margin of Western Tethys might not be such, in light of this new discovery in Iran, and to attribute this apparent confinement to the lack of fossil record in other Tethyan areas. However, the fossil record shows that Europe and especially the area of the western end of Tethys (comprised between northern and eastern of Iberian Peninsula and northern Italy), comprises the highest stock of retroplumids genera during the Eocene, higher than any other geological epochs, including the present time, namely: *Gaudipluma* Artal, Van Bakel *et al*., 2013, *Loerenthopluma* Beschin *et al*., 1996, *Loerenthoplumopsa* Schweitzer *et al*., 2011 (see *Loerentheya* Beurlen in Lőrenthey and Beurlen, 1929), *Retrocypoda* Via Boada, 1959, *Retropluma* Gill, 1894 (2 species) and *Serrablopluma* Artal *et al*., 2013, which have their first occurrences mainly in the mentioned area since the early Eocene. This fact might support in part, the hypothesis of Hyžný *et al*. (2016) according to which, ancestors of these Tethyan retroplumids, would have to be found among the African lineage of *Costacopluma* Collins and Morris, 1975, for instance *C. senegalensis* (Rémy in Gorodiski and Rémy, 1959) from the Paleocene of Senegal, which is geographically and temporally closest to the aforementioned area of the Western Tethys (Hyžný *et al*., 2016, p. 153). We concur, at least regarding *Retrocypoda* which is *Costacopluma*'s closest genus, differing from it in their spiny lateral margins medially convex, carapace sculpture and by its supplementary fourth transverse ridge, instead of the three in *Costacopluma*.

Since de Saint Laurent (1989) clarified the retroplumid condition of *Retrocypoda almelai*, subsequent authors, with some exceptions, accepted this systematic placement (*e.g*. Beschin *et al*., 1996; De Angeli and Beschin, 2001; De Angeli and Garassino, 2006; Feldmann *et al*., 2006; McLay, 2006; Feldmann and Portell, 2007; Hyžný and Müller, 2010; Schweitzer *et al*., 2010; De Angeli *et al*., 2011 and Hyžný *et al*., 2016). We can add in support of the retroplumid condition of *Retrocypoda*, that besides the contrasted presence of modified and reduced sternite 8 and reduced coxa of P5 (Via, 1969, p. 335; de Saint Laurent, 1989, T7, fig. A-B), some samples preserved in matrix of *Retrocypoda almelai* from outcrops of Central Catalonia, preserved remains of the reduced subcylindrical P5 (See appendix). However, *Retrocypoda* possesses stronger and more developed chelipeds, markedly heterochelic, mainly in males, characterised by long palms with acute upper margin, with short and stout dactily, unlike most of other retroplumid genera whose chelipeds are usually slender and thin with elongate and sharp tipped dactily (Via, 1969, p. 329; de Saint Laurent, 1989, p.113-114, f.7; McLay, 2006, p. 389). These cheliped features can be observed also in some samples of *Costacopluma nordestina* Feldmann and Martins-Neto, 1995 (cfr. Távora and Miranda, 2004, fig. 5), thus arguing in favor of the close relationship of *Retrocypoda* with *Costacopluma*.

Extant and Miocene-Pleistocene retroplumids prefer deep water with muddy or muddy sand bottoms, in contrast to the Paleogene fossil record (de Saint Laurent, 1989; Collins *et al*., 2003; De Angeli *et al.*, 2011; Baldanza *et al*., 2013; Găsparič and Hyžný, 2014). *Retrocypoda* dwelt in muddy sandy or sandy bottoms, in shallower waters from inner to outer continental platform. Occurrences of *Retrocypoda* during Ypresian to Bartonian indicates a nearshore environment, whereas the Priabonian ocurrences are on muddy soft bottom of an offshore environment (see Abad, 2001; Beschin *et al*., 2012; Ossó *et al*., 2014 and herein).

5. Discussion and conclusions

Extant members of Retroplumidae, *Retropluma* and *Bathypluma* are reported only in Indo-West Pacific waters. The Iranian *Retrocypoda almelai* documents the presence of the family in the Middle East during the Eocene (Fig. 5), as does *Costacopluma* cf. *concava* Collins and Morris, 1975, recorded in the uppermost Maastrichtian of northern India (Gaetani *et al*., 1983) and *Retropluma laurentae* Collins *et al*., 2003 in the Miocene of Indonesia. Therefore, albeit being represented by very scarce taxa, Retroplumidae is documented in the Middle and Eastern Tethys during the Late Cretaceous and Cenozoic. This means either that Retroplumidae inhabited simultaneously from the Atlantic coast of America to the coast of Africa and the eastern Tethys, though the fossil record is scarce in those eastern areas, or rather, that the eastward migratory trend, widely discussed by the majority of works above mentioned, was real (Fig. 6). Given the abundant retroplumid stock of Atlantic, represented by *Costacopluma* in the Late Cretaceous and the varied Cenozoic retroplumid stock of the West Tethys, the second hypothesis seems more plausible for the time being. It is noteworthy that unlike other retroplumid genera, which generated different species through time, *Retrocypoda* remains monotypic during the whole Eocene.

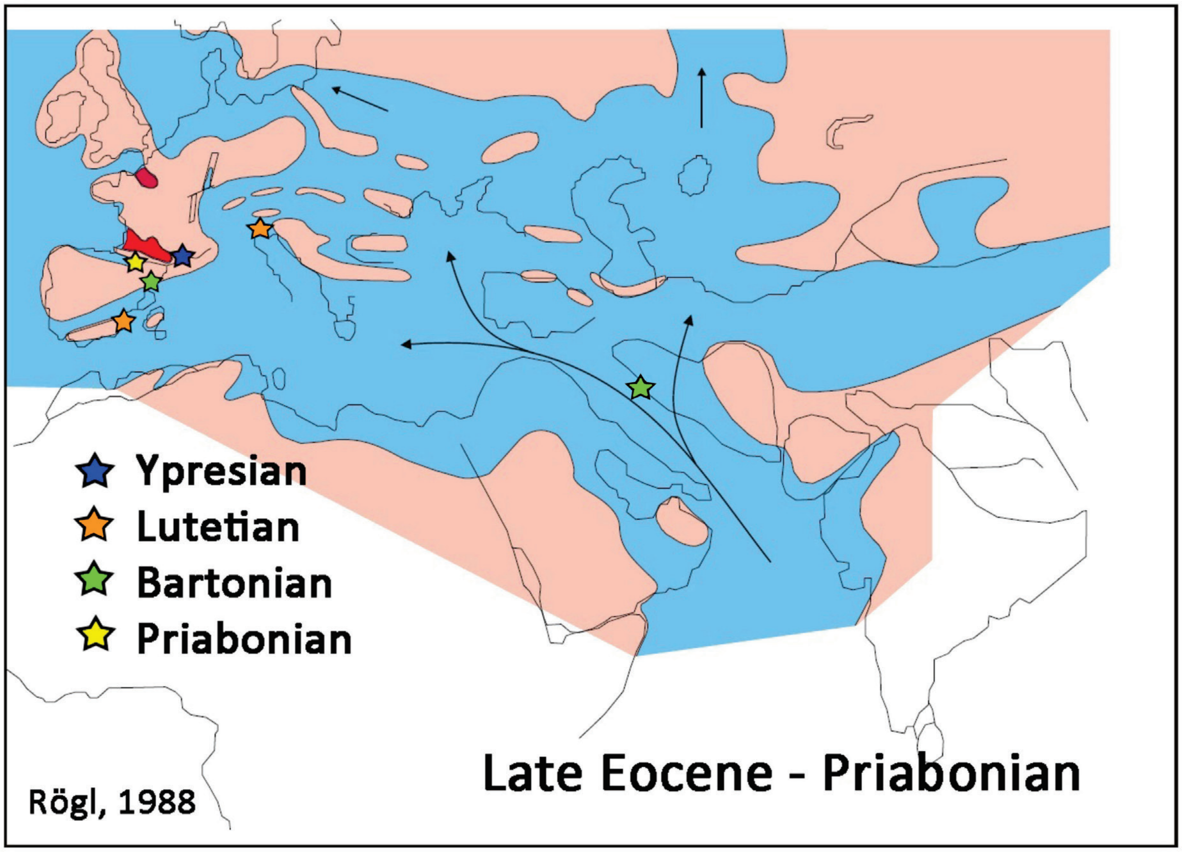

Figure 5. Approximate distribution of *Retrocypoda* during the Eocene (modified from Rögl, 1998).

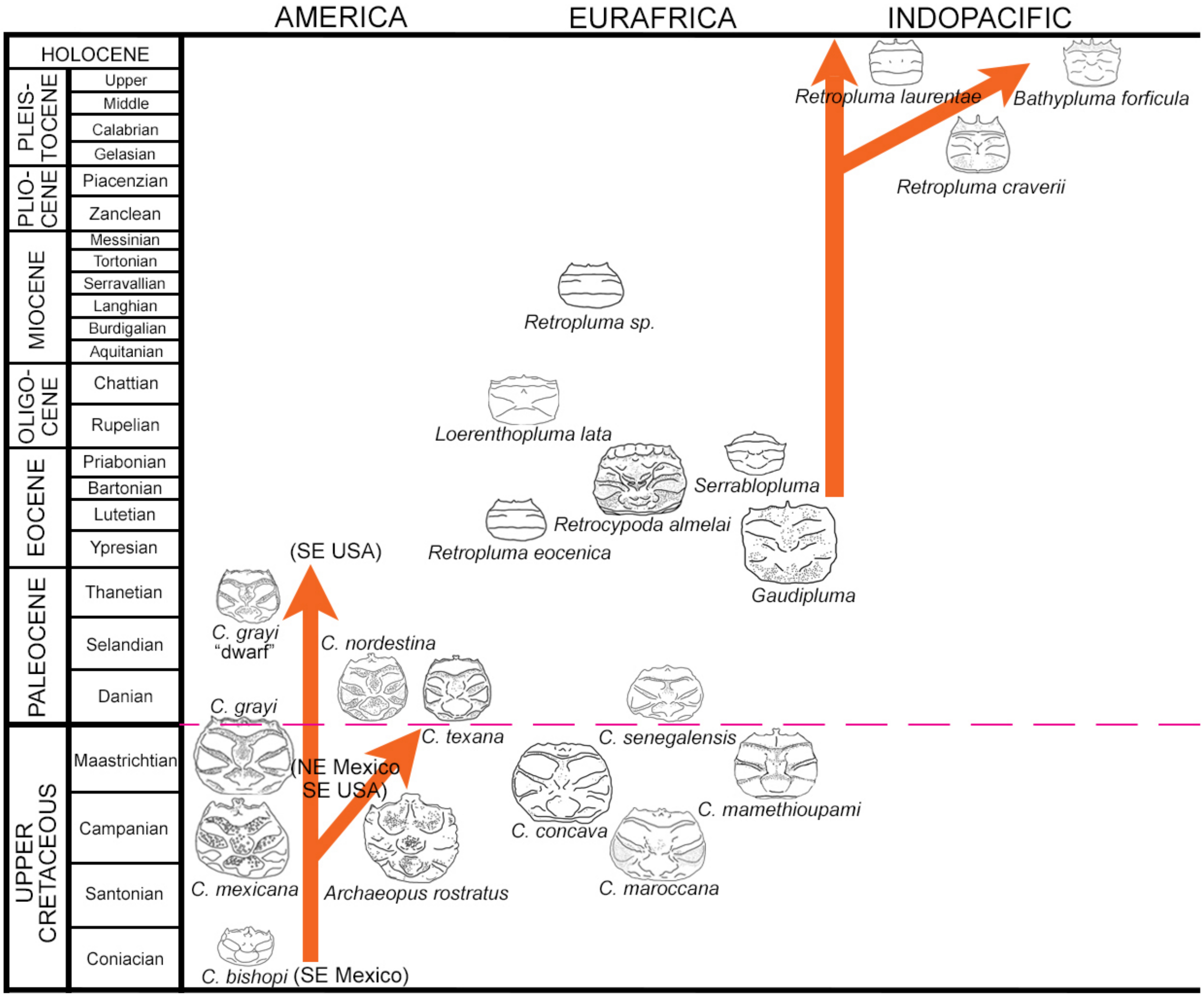

Figure 6. Paleobiogeographic distribution of Retroplumidae since Late Cretaceous (modified from Via, 1969).

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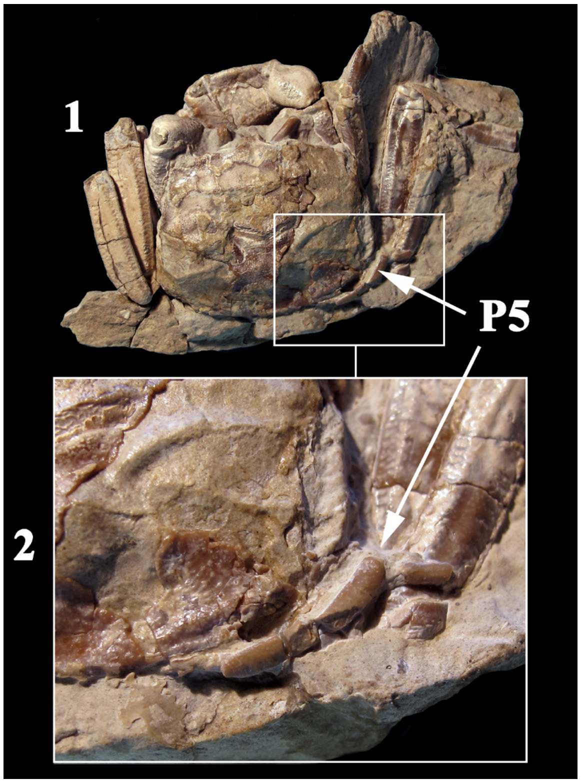

Appendix. *Retrocypoda almelai* Via Boada, 1959. AO C-023/4., Bartonian (middle Eocene) of La Pobla de Claramunt (Anoia, Catalonia). 1: Dorsal view; 2: close-up showing the reduced P5. Abreviations: P5 = fifth pereiopod. Scale bar equal to 10 mm.

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Icnofósiles del Cámbrico Inferior de San José de Gracia, Sonora

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Resumen

Se describen los icnofósiles *Skolithos* isp., *Arenicolites* isp., *Palaeophycus* isp., *Asteriacites* isp. y *Asterosoma* isp. procedentes de capas de arenisca con bioturbación del Cámbrico Inferior, en el miembro B del cerro Chihuarruita, ubicado en la región de San José de Gracia, centro–este del estado de Sonora. La asociación de organismos que produjo las icnitas demuestra que se desarrolló en ambientes marinos bentónicos, someros, con abundantes nutrientes que propiciaron una gran diversidad de los diferentes taxones en el Cámbrico Temprano de la región central de Sonora. La distribución de la biota cámbrica de San José de Gracia, entre ella los icnofósiles, denota que existió una amplia provincia faunística que comprende varias localidades en México (Caborca, Ures), en los Estados Unidos de América (Idaho, Utah, California), en Europa (Italia), Asia (India, Pakistán) y Tasmania que formaban parte del Océano Pantalásico.

Palabras clave: icnofósiles, Cámbrico Inferior, Sonora, México.

Abstract

This work describes the ichnofossils Skolithos *isp.,* Arenicolites *isp.,* Palaeophycus *isp.,* Asteriacites *isp. and* Asterosoma *isp. found in bioturbated sandstone layers from the Lower Cambrian in Chihuarruita hill, located in the region of San José de Gracia, Sonora. The organism association that produced the ichnites was developed in benthic, shallow marine environments with abundant nutrients that led to a high diversity of different taxa in the Early Cambrian in central Sonora. The distribution of the Cambrian biota of San José de Gracia, including those trace fossils, indicates that there was a wide faunal province comprising several locations in Mexico (Caborca, Ures), in the United States of America (Idaho, Utah, California), in Europe (Italy), Asia (India, Pakistan), and Tasmania, that belonged to the Panthalassic Ocean.*

Keywords: ichnofossils, Lower Cambrian, Sonora, Mexico.

1. Introducción

Los icnofósiles se consideran como evidencias indirectas de la existencia de los organismos, tanto invertebrados como vertebrados. Su estudio es importante porque proporciona información sobre organismos no preservados que complementan el conocimiento sobre la vida del pasado geológico y su evolución. Estas evidencias indirectas, en muchos casos, se utilizan como índices estratigráficos cuando sus alcances son reducidos en el tiempo geológico y tienen una amplia distribución geográfica (Knaust y Bromley, 2012). También el conocimiento que aportan los icnofósiles se aplica en el estudio de las icnofacies, pues proporciona información sobre la batimetría, salinidad, cantidad de oxígeno presente y características del sustrato, como la polaridad de las capas, por lo tanto tal información es valiosa en los estudios de la sedimentología (Seilacher, 1967; Frey y Seilacher, 1981). Una de las aplicaciones del conocimiento de los icnofósiles es en el análisis de estructuras biogénicas en las rocas sedimentarias que da información sobre las propiedades petrofísicas o calidad de un yacimiento como porosidad y permeabilidad. Con relación a la diferente distribución que presentaban los continentes y mares en tiempos geológicos pasados, los icnofósiles indican que no hubo desplazamiento secundario, pues se encuentran en el mismo lugar donde fueron generados por los diversos organismos que habitaron determinados lugares (Laporte, 1974). La integración de evidencias icnológicas con datos sedimentológicos y estratigráficos permite caracterizar sucesiones sedimentarias para detectar tendencias transgresivas y regresivas (Frey y Seilacher, 1981; Seilacher, 2007; Knaust y Bromley, 2012).

2. Estudios previos

Sobre la región fosilífera del Paleozoico Inferior de San José de Gracia, existen algunos trabajos entre ellos Stewart *et al*. (2002) en el que se establece la correlación estratigráfica entre varias regiones del suroeste de Estados Unidos de Norteamérica y Sonora; Cuen *et al*. (2009) publicaron sobre los invertebrados marinos del Cámbrico Temprano y Medio en la parte central del estado de Sonora; Nardin *et al*. (2009) reportaron la presencia de placas aisladas de la columna y teca de equinodermos blastoideos, particularmente de la especie *Gogia granulosa*; Buitrón *et al*. (2011) dieron a conocer la existencia de hiólitidos de las especies *Hyolithes sonora* y *Haplophrentis reesei*; Cuen *et al*. (2013) estudiaron las esponjas de los géneros *Chancelloriia* y *Reticulosa* del Cámbrico Medio. Cuen (2012 y 2013) se refirieron al estudio de la estratigrafía y contenido biótico de afloramientos del Cerro Chihuarruita en donde se encontraron esponjas, braquiópodos y trilobites. Particularmente sobre el estudio sistemático de los icnofósiles de San José de Gracia, existen únicamente menciones de su presencia en estas rocas en los trabajos antes referidos.

3. Localización geográfica

Los afloramientos del Cámbrico Inferior de la región central del estado de Sonora son escasos. Formando parte del municipio de Ures, se localiza el cerro Chihuarruita en la proximidad del rancho San José de Gracia que encuentra a 40 km al noreste de la ciudad de Hermosillo (Figura 1). La secuencia estratigráfica cubre un área que rodea al cerro Chihuarruita con coordenadas 29º17'05" N, 110º35'03" W a 310 msnm.

4. Marco geológico

Rocas del Neoproterozoico Superior y Paleozoico Inferior afloran extensamente en todo el territorio de Sonora.

Figura 1. Localización del área de estudio en la parte central de Sonora.

Sin embargo, escasas localidades ubicadas en la parte central del estado, entre ellas San José de Gracia, muestran rocas problemáticas respecto a la edad y su contenido fósil sigue siendo poco conocido. En el área de estudio, siguiendo la propuesta de Almazán en Nardin *et al*. (2009) se han reconocido seis unidades litológicas diferentes (Figura 2).

Con base en las observaciones en campo se determinó que la secuencia del Cámbrico Temprano-Medio presenta 232 m de espesor que se dividieron en siete diferentes miembros, los cuales corresponden a litofacies con contenido biótico (figuras 3, 4 y 5).

4.1. Miembro A

Este miembro tiene 12 m de espesor y consiste en cuarcitas de color marrón oscuro y está posiblemente incompleta debido a que su base está cubierta por una falla inversa. Las rocas clásticas están constituidas por granos milimétricos de cuarzo subredondeados, con una tendencia al engrosamiento. Los estratos del miembro superan con frecuencia un metro de espesor (figuras 3 y 5).

4.2. Miembro B

Este miembro presenta 5 m de espesor y se considera como una facies clástica. Las rocas consisten en areniscas con bioturbación, ricas en cuarzo de color marrón amarillento, la fuerte bioturbación eliminó las estructuras sedimentarias. Esta unidad está cubierta por sedimentos aluviales. En este miembro fueron recolectados los icnofósiles como *Skolithos* isp., *Arenicolites* isp., *Palaeophycus* isp., *Asteriacites* isp. y *Asterosoma* isp.

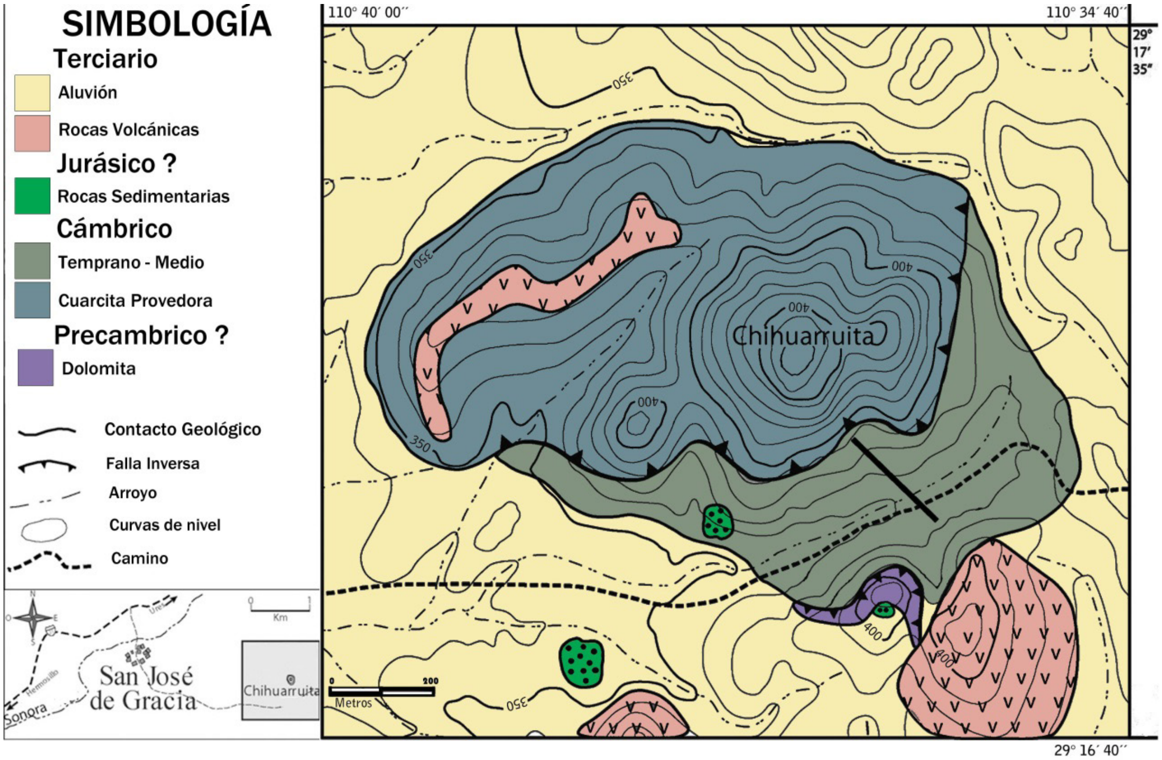

Figura 2. Esquema geológico del área de estudio en San José de Gracia (Nardin *et al*., 2009).

Figura 3. Afloramiento en donde se observan los miembros A, B y C, de cuyo estrato B se recolectaron los icnofósiles (Cuen, 2013).

4.3. Miembro C

Se encuentran concordantemente 10 m de cuarcitas oscuras color marrón sobre el miembro anterior. Los elementos epiclásticos subangulares, que presenta tienen dimensiones menores de un milímetro de diámetro. Las condiciones hidrodinámicas de la sedimentación dieron origen a una clara gradación del tamaño de grano, desde granos gruesos a medios. La roca está piritizada y es posible observar las concentraciones de acumulaciones dispersas de cristales euhedrales de pirita hasta de un milímetro de longitud, parcialmente oxidada (Figuras 3, 4 y 5).

4.4. Miembro D

Este miembro denota un claro cambio litológico a horizontes clásticos y carbonatados. El miembro tiene un espesor total de 40 m, donde predomina arenisca rojiza y amarillenta. La parte inferior del miembro se compone de capas de arenisca, con lentes de pedernal, que varían en longitud lateral de 5 a 15 m. La mayoría de las capas se identifican topográficamente debido a su moderada silicificación, induciendo una mayor resistencia a la erosión. En la parte media hay calizas con bioturbación que tienen un espesor de 20 m, con estructuras oncoidales de algas con dimensiones entre 0.5 a 4 cm de diámetro.

Las capas medias contienen abundantes moluscos Hyolíthidos de las especies *Hyolithes sonora* (Lochman) y *Haplophrentis reesei* Bobcock (Buitrón *et al*., 2011) y placas de la teca y columna de pelmatozoarios-eocrinoideos que se identificaron con la especie *Gogia granulosa* Robison (Nardin *et al*., 2009). Es probable que el depósito de estas rocas se produjera durante el lapso de aproximadamente 517 a 510 Ma.

La parte superior del miembro está formada por lutitas grises con estructura masiva. Está intensamente fracturada y erosionada en láminas finas (0.5 a 3 cm). Estas lutitas localmente evolucionan a limolita con tonos verdosos y horizontes delgados de calizas color gris, con frecuencia contienen conchas de Hyolíthidos asociados con varios fragmentos de trilobites.

4.5. Miembro E

El miembro E se encuentra concordantemente sobre el miembro C y está constituido por 15 m de caliza gris oscura, sus estratos varían de 60 cm a 5 m de espesor. Contiene ooides con un diámetro menor a un milímetro. Además, la caliza presenta microfracturas rellenas de calcita y algunos nódulos de hematita y pirita.

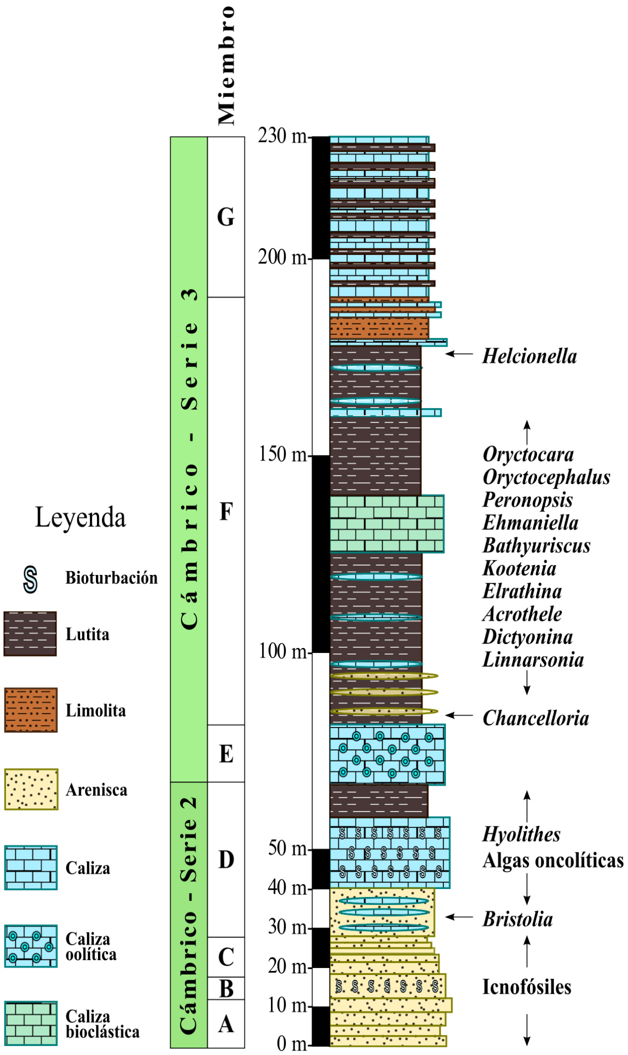

Figura 4. Columna estratigráfica de la secuencia Cámbrico Temprano y Medio de la zona de estudio en San José de Gracia, Sonora, según la propuesta de Almazán publicada en Nardin *et al*. (2009).

4.6. Miembro F

El miembro F constituye una de las litofacies más expuestas de la secuencia, ya que está formada por una gruesa columna estratigráfica de 110 m constituida por lutita alternando con horizontes calcáreos delgados a medianos. Este miembro se compone principalmente de estratos arcillosos de color rojizo claro, con estratificación masiva, parcialmente cementadas por carbonatos.

La intensa fracturación tiene como resultado la separación de la roca en láminas pequeñas de menos de 2 cm de longitud. Existen cambios litológicos en los niveles calcáreos y arcillosos a limolitas. Las capas de caliza están intercaladas con capas clásticas delgadas. La parte superior de las calizas muestra irregularidades más fuertes, probablemente como resultado de una intensa bioturbación. Numerosos horizontes calcáreos en forma de lente, presentan erosión en las superficies superior e inferior, y su grosor está comprendido entre 3 a 15 m. En la base del miembro varias capas de caliza contienen abundantes espículas de esponjas Hexáctinelidas de la especie *Chancelloria eros* Walcott (Cuen *et al*., 2013).

En la parte superior de algunas capas de caliza, se encuentra frecuentemente un alto porcentaje (60 % y 80 %) de fragmentos de trilobites de los géneros *Elrathina*, *Peronopsis* y *Ogygopsis*. También se encuentran en las rocas una abundante, diversa y bien conservada fauna de braquiópodos inarticulados y articulados (Cuen *et al*., 2009).

4.7. Miembro G

La parte superior de la columna está formada predominantemente por 40 m de capas de calizas que varían de 2 a 20 cm de espesor con intercalaciones delgadas de arcilla calcárea de 3 a 35 cm de espesor. El miembro G está tectónicamente cubierto por rocas dolomíticas precámbricas? y riolíticas del Terciario (Figura 2 y 4).

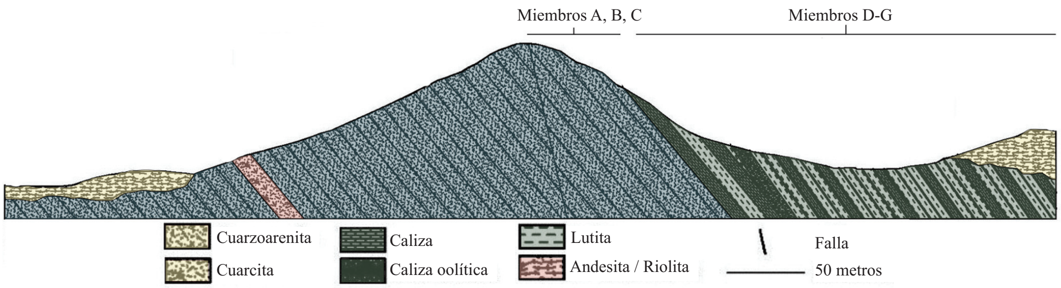

Figura 5. Sección estratigráfica del Cerro Chihuarruita (Cuen, 2013).

5. Icnología sistemática

El estudio de los icnofósiles del Cámbrico de San José de Gracia reveló una abundancia de ejemplares, pero escasa diversidad. El material parcialmente obtenido en el campo, del miembro B, se encuentra depositado en la Colección Paleontológica del Departamento de Geología de la Universidad de Sonora con los números de Catálogo USON-DG-231 - USON-DG-234. También se encuentran depositadas las fotografías de las muestras que no pudieron obtenerse en el campo por sus grandes dimensiones.

Para la identificación de los icnotaxones se sigue la propuesta de Buatois y Mángano (2011) y Knaust y Bromley (2012) sobre paleoicnología sistemática.

Icnogénero *Arenicolites* Salter, 1857

Arenicolites isp.
(figuras 6 y 7)

Descripción. Las madrigueras son simples, perpendiculares al plano de estratificación, con forma de "U" abierta, la pared es delgada y sin escultura. Las madrigueras presentan orificios de entrada y salida de forma circular.

Alcance estratigráfico. Cámbrico (Estado 2) al Reciente en ambiente marino y del Carbonífero al Reciente en ambiente continental (Eagar *et al*., 1985; Buatois y Mángano, 2011).

Distribución geográfica. Europa, Norteamérica (Häntzschel, 1962) y África (Seilacher, 1990).

Discusión. Los diferentes tipos de *Arenicolites* se pueden diferenciar con base en la amplitud de la forma de la "U". La interpretación que se da a esta estructura es la de una madriguera de vivienda, posiblemente hecha por un verme poliqueto (Seilacher, 1990). La perturbación es de tipo *spreiten* que significa que es el producto del desplazamiento lateral o vertical de un túnel, especialmente en forma de "U". Pemberton *et al*. (1992) consideran que estos icnofósiles forman parte de la icnofacies *Skolithos*.

Icnogénero *Palaeophycus* Hall, 1847

Palaeophycus isp.
(Figura 8)

Descripción. Las madrigueras son simples, no presentan ramificación, tienen forma cilíndrica o subcilíndrica, alineadas, predominantemente horizontales y rectas, con paredes lisas y comúnmente sin estructura, de diámetro variable entre 1 y 2 mm.

Alcance estratigráfico. Paleozoico (Cámbrico temprano)-Mesozoico (Jensen *et al*., 2006).

Distribución geográfica. Europa, Norteamérica (Häntzschel, 1962).

Discusión. Este icnofósil se considera como el resultado de excavaciones hechas por diversas especies de invertebrados, tanto marinos como continentales (Seilacher, 2007). Según varios autores existe confusión

Figura 6. *Arenicolites* isp.

Figura 7.- Orificios de entrada y salida de *Arenicolites* (Ejemplar USON-DG-231).

Figura 8. *Paleophycus* isp.

en la determinación morfológica entre *Planolites* y *Palaeophycus*, pues son semejantes en la forma y dirección de las madrigueras. Se hace énfasis en que *Palaeophycus* se encuentra generalmente en hiporelieve. El ambiente en el que vivieron puede ser marino o continental incluyendo aluvial, lacustre y eólico (Seilacher, 2007).

Icnogénero *Skolithos* Haldeman, 1840

Skolithos isp.
(Figura 9)

Descripción. Las madrigueras presentan forma de tubos rectos orientados verticalmente, nunca ramosos que tienen una longitud mucho mayor en comparación con la anchura, con diámetros de 0.2 a 1 cm, raramente anillados (Alpert, 1974).

Alcance estratigráfico. Cámbrico Inferior-Ordovícico (Brasier, 1994).

Distribución geográfica. Europa, América, Groenlandia, Tasmania (Häntzschel, 1962).

Discusión. Se encuentran generalmente en arenisca. Se interpretan como galerías de vivienda hechas por invertebrados, como gusanos o phoronidios (Seilacher, 1967; Knaust y Bromley, 2012). Pemberton *et al.* (1992) consideran que estos icnofósiles son los que determinan a la icnofacies *Skolithos*, debido a que son los más típicos.

Icnogénero *Asterosoma* Von Otto, 1854

Asterosoma isp.
(Figura 10)

Descripción. Estructuras con diámetro amplio y aberturas con capas concéntricas redondas, alrededor de un eje cilíndrico central; con dimensiones de 1 a 5 mm de diámetro y surcos de 4 a 13 mm.

Alcance estratigráfico. Cámbrico-Cretácico Superior (Häntzschel, 1962).

Distribución geográfica. Europa y Norteamérica (Häntzschel, 1962).

Discusión. El icnogénero *Asterosoma* Von Otto, 1854 corresponde a una estructura que pudo ser producto de la actividad de un organismo vermiforme en busca de alimento (Chamberlain, 1971). Seilacher (2007) interpreta como un patrón causado por la actividad de organismos estacionarios en sedimentos marinos del Cámbrico (Hofmann *et al.*, 2012). Según Pemberton *et al.* (1992) consideran que estos icnofósiles forman parte de la icnofacies *Cruziana*.

Icnogénero *Asteriacites* Schlotheim, 1820

Asteriacites isp.
(Figura 11)

Descripción. La impresión del icnofósil tiene forma

Figura 9. *Skolithos* isp. (Ejemplar USON-DG-233).

Figura 10. *Asterosoma* isp (Ejemplar USON-DG-234).

Figura 11. Forma estelar de *Asteriacites* y *Arenicolites* en forma de "U".

estelar con cinco brazos separados con ángulos de 90° y 45°, con longitud promedio de 6 mm y anchura variable. El ejemplar se observa en bajo relieve.

Alcance estratigráfico. Cámbrico-Reciente.

Distribución geográfica. Europa y Norteamérica (Häntzschel, 1962).

Discusión. Estas impresiones estelares se interpretan como huellas de descanso cuyos posibles productores son equinodermos asteroideos (estrellas de mar). Son de ambiente totalmente marino. Buatois y Mángano (2011) considera que forman parte de la icnofacies Cruziana.

6. Discusión

Los icnofósiles estudiados del cerro El Chihuarruita, en la región de San José de Gracia corresponden a los icnogéneros *Skolithos*, *Arenicolites*, *Palaeophycus*, *Asteriacites* y *Asterosoma* que proceden del estrato de arenisca con bioturbación del miembro B con una edad del Cámbrico Inferior, pues en estratos suprayacentes, particularmente los del miembro D, está presente el género de trilobites *Bristolia* que es índice de esta edad (Resser, 1928; Lieberman, 1999).

Es posible que en la localidad existiera una biocenosis del Cámbrico, conformada por organismos del tipo de los vermes, artrópodos crustáceos de los que únicamente se conservaron los fósiles traza. Siguiendo la interpretación propuesta por Mount (1980) y Briggs y Mount (1982) se intuye que la asociación biótica de San José de Gracia vivió en condiciones paleoambientales correspondientes a mares tropicales, someros, bien oxigenados.

La asociación faunística de la localidad permitió establecer relaciones paleogeográficas con faunas del norte de Utah y con el sureste de Idaho. La evidencia geológica y paleomagnética que se tiene indica que en el Precámbrico se tenía un Supercontinente. Reconstrucciones paleogeográficas de Norte América (Stewart *et al*., 2002) sugieren que el margen occidental se encontraba localizado en los trópicos, orientado este-oeste durante el Cámbrico Temprano. Como consecuencia de esta posición, la fauna de esta zona es muy particular y única, pues son escasas las localidades con icnofósiles estudiados hasta ahora; particularmente sobre el Cámbrico de Sonora, se citan los trabajos de McMenamin (1996) y Sour *et al*. (2007).

7. Conclusiones

Se describen por primera vez para la región de San José de Gracia los icnofósiles *Skolithos*, *Arenicolites*, *Asterosoma* y *Palaeophycus*, que pueden ser interpretados como túneles o madrigueras de invertebrados hechas por vermes, artrópodos-crustáceos y equinodermos-asteroideos.

La edad de los icnofósiles se determinó fundamentalmente por la posición estratigráfica en la columna y con relación a las rocas que los suprayacen, con especímenes del trilobites índice *Bristolia* ampliamente registrado en rocas del Cámbrico Inferior del mundo.

La distribución de la biota cámbrica de San José de Gracia, entre ella los icnofósiles denota que existió una amplia provincia faunística que comprende varias localidades en México (Caborca, Ures) y en los Estados Unidos de Norteamérica (Idaho, Utah, California), en Europa (Italia), Asia (India, Pakistán) y Tasmania que formaban parte del Océano Pantalásico.

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The Cretaceous corals from the Bisbee Group (Sonora, Mexico; Late Barremian - Early Albian): suborder Heterocoeniina

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Abstract

The current work constitutes the fourth part of the systematic revision of the corals from the Bisbee Group in Sonora, northwest Mexico (Late Barremian to Early Albian) and deals with the suborder Heterocoeniina. Twelve species from three families are reported: Carolastraeidae (genera *Heteropistophyllum*, *Latusastrea*, *Pleurocoenia* and *Pleurodendron*), Heterocoeniidae (genus *Heterosmilia*), and Paronastraeidae (genus *Tiarasmilia*) are described and illustrated. The family taxon Carolastraeidae is applied instead of the problematic family taxon Elasmocoeniidae which was temporarily applied to Heterocoeniina with a bilateral septal symmetry. With the exception of the genus *Pleurocoenia*, the genera are rare in the Cretaceous and do not show distinct palaeobiogeographic relationships.

Keywords: Corals, Scleractinia, Early Cretaceous, Bisbee Group.

Resumen

El presente trabajo constituye la cuarta parte de la revisión sistemática de los corales del Grupo Bisbee (Barremiano temprano al Aptiano tardío) que trata sobre el suborden Heterocoeniina. Se reportan doce especies de tres familias: Carolastraeidae (géneros Heteropistophyllum, Latusastrea, Pleurocoenia y Pleurodendron), Heterocoeniidae (género Heterosmilia), y Paronastraeidae (género Tiarasmilia). La familia Carolastraeidae se utiliza en lugar de la familia Elasmocoeniidae que se ha usado temporalmente para el suborden Heterocoeniina que posee una simetría septal bilateral. Con la excepción del género Pleurocoenia, los géneros son escasos para el Cretácico y no presentan muchas relaciones paleobiogeográficas con otras áreas.

Palabras clave: Corales, Scleractinia, Cretácico temprano, Grupo Bisbee.

1. Introduction

Building off the first part of the series (Löser, 2011), which introduced the Early Cretaceous (Late Barremian to Albian) coral fauna from the Bisbee Basin, this fourth part deals with material of the suborder Heterocoeniina. The suborder occurs from the Late Jurassic to the Late Cretaceous and encompasses five families. Members of three of these families could be found in the Early Cretaceous of Sonora, encompassing twelve species in six genera. Two of these genera were reported in previous studies (Baron-Szabo and González-León, 1999; 2003), but newly collected material allows for an increase in the number of genera and species. Details on the study area, lithology, stratigraphy, and outcrops are reported in Löser (2011). Details on the sample locations cited in the studied section referenced to in the systematic description are given in Löser (2011: tab. 1).

2. Material

The material varies in its state of preservation. Samples from marly layers are slightly better preserved than samples from carbonates. For the latter, it was more difficult to obtain good thin sections for the purpose of exact measurements and illustrations. Colony surfaces are rarely well preserved. Only thin sections were used for the determination. All specimens described here are kept at the collection of the Universidad Nacional Autónoma de México, Instituto de Geología, Estación Regional del Noroeste (ERNO) in Hermosillo, Sonora, Mexico. The material described by Baron-Szabo and González-León (1999, 2003) was available for study and, for many specimens, further thin sections were prepared to specify the morphology and taxonomy of species described by the two authors.

3. Methods

3.1. Sample preparation

Thin sections were prepared from well-preserved samples in both transversally and longitudinally-oriented directions where possible. The thin sections were scanned using a flatbed scanner with an optical resolution of 6400dpi. The images were saved as 8-bit grey scale JPG files without compression. To increase the quality of the images contrast stretching was applied. The images were used to prepare illustrations and to systematically record calicular dimensions.

3.2. Species separation

The material consists of cerioid (*Latusastrea*, *Pleurocoenia*), phaceloid (*Heteropistophyllum*, *Heterosmilia*, *Pleurodendron*), and solitary (*Tiarasmilia*) forms. Species separation in these forms is based on the smaller and larger calicular diameter (in phaceloid forms the inner and outer diameter was measured) and septal counts. The number of septa within one specimen is fairly constant. The differentiation of species was relatively easy in the present material because the number of species of each genus is low.

3.3. Distribution data

The distribution data (as reflected in the synonymy lists) are entirely based on well-examined material. Material only mentioned in the literature as well as material not available for study has not been taken into account. To obtain better insight into the distribution patterns of the corals from Sonora, additional unpublished material – indicated by a collection acronym and sample number in parenthesis – was included.

4. Systematic Description

Abbreviations

Collection abbreviations are as follows:

- ANSP, Academy of Natural Sciences, Philadelphia, USA;
- BSPG, Bayerische Staatssammlung für Paläontologie und Geologie, München, Germany;
- ERNO, Universidad Nacional Autónoma de México, Instituto de Geología, Estación Regional de Noroeste, Hermosillo, Mexico;
- GPSL, Geologische und Paläontologische Sammlung der Universität Leipzig, Germany;
- IGM, Instituto de Geología, Mexico City, Mexico;
- MB, Museum für Naturkunde der Humboldt-Universität, Berlin, Germany;
- MNHN, Muséum National d'Histoire Naturelle, Paris, France;
- UP, Université de Provence, Marseille, France.

The following abbreviations are used describing the dimensions of the corals:

- c, calicular diameter;
- c max, larger outer calicular diameter;
- c min, smaller outer calicular diameter;
- cl, calicular diameter (calicular pit);
- cl max, large lumen;
- cl min, small lumen;
- s, number of radial elements in adult calices.

The following abbreviations are used describing the statistical data:

- n, number of measurements;
- min-max, absolute range (mm);
- μ, arithmetic mean (mm);
- s, standard deviation (mm);
- cv, coefficient of variation (%);
- μ±s, first interval (mm).

Statistical data for less than ten values are not given because of the low confidence. The abbreviations used in the synonymy lists follow Matthews (1973): *: earliest valid publication of the species name; p: the described material belongs only in part to the species concerned; v: the specimen was observed by the author.

Order Scleractinia Bourne, 1900
Suborder Heterocoeniina Beauvais, 1974

Remarks. The constitution of the suborder was just recently discussed (Löser *et al*., 2013; Löser, 2014). Five families are distinguished mainly based on the septal symmetry and septal ornamentation.

Family Carolastraeidae Eliášová, 1976

Remarks. The family taxon Elasmocoeniidae Duncan, 1884 cannot be applied as proposed by Löser *et al*. (2013, p. 17) because Duncan (1884) introduced the name as an Alliance. In the nomenclatory rules this term is not mentioned as a level of the family group, and because Duncan has arranged it below the Tribus, an Alliance denominates a generic group. This family taxon cannot be used for genera formerly assigned to the informal *Latusastrea* group (Löser, 2013b). Here, it is therefore proposed to apply the name Carolastraeidae. *Carolastraea* Eliášová, 1976 is a phaceloid coral with a bilateral septal symmetry and ornamented septa. Formerly the family was assigned to the suborder Amphiastraeina (*e.g.* Kolodziej, 2012). But a strong ornamentation of the septal lateral faces, as shown by *Carolastraea*, is not typical for this suborder. The use of the family is preliminary since the thin sections obtained from the type of the type species of the name giving genus *Carolastraea* are not accessible at the collections of the Czech Geological Survey (Prague).

Heteropistophyllum Löser *et al.*, 2013

Type species. *Pseudopistophyllum quinqueseptatum* Turnšek and Buser, 1976.

Heteropistophyllum carchensis Löser *et al.*, 2015

Figs. 1A–C

*v 2015 *Heteropistophyllum carchensis* Löser *et al.*, p. 52, figs. 6a-f.

Description. Phaceloid colony. Calicular outline elliptical. Septa compact. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Septa alternating in length and thickness. Septa rarely connected to each other in the calicular centre. Septal distal margin unknown, lateral face with thorns, inner margin T-shaped in places. Pali, costae, synapticulae, and columella absent. Endotheca consists of numerous thin tabulae. Wall compact, constitution unknown. Coenosteum absent. Budding intracalicinal, marginal.

Material examined. ERNO L-4266, L-4282; 2 thin sections.

Dimensions

(L-4266)	n	min-max	μ	s	cv	μ±s
cl min	15	2.09-3.50	2.53	0.4	16.1	2.12-2.94
cl max	15	2.94-4.97	3.98	0.59	15	3.38-4.58
c min	15	2.99-5.39	3.97	0.62	15.6	3.35-4.59
c max	15	4.34-7.19	5.84	0.97	16.7	4.86-6.82
s	5					

Occurrence in Sonora. Early Albian of Municipio Arizpe, Arizpe, Cerro La Ceja, Municipio Cucurpe, Cucurpe, La Mesa.

Occurrence elsewhere. Early Late Aptian of Spain (Murcia) Jumilla, Sierra del Carche.

Heteropistophyllum quinqueseptatum (Turnšek and Buser, 1976)

Figs. 1D–F

*v 1976 *Pseudopistophyllum quinqueseptatum* Turnšek and Buser, p. 17, 41, pl. 7, figs. 1-3, pl. 8, figs. 1, 2, pl. 9, figs. 1, 2.

v 2003 *Pseudopistophyllum quinqueseptatum* Turnsek, 1976 - Baron-Szabo and González León, p. 205, figs. 6E, G.

v 2013 *Heteropistophyllum quinqueseptatum* (Turnšek and Buser 1976) - Löser *et al.*, p. 19, pl. 4, figs. 5-7.

Description. Phaceloid colony. Calicular outline elliptical, elongated. Septa compact. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Septa alternating in length and thickness. Septa rarely connected to each other in the calicular centre. Septal distal margin unknown, lateral face with thorns, inner margin T-shaped in places. Pali, costae, synapticulae, and columella absent. Endotheca consists of numerous thin tabulae. Wall compact, constitution unknown. Coenosteum absent. Budding intracalicinal, marginal.

Material examined. ERNO 3065, L-4242, L-4277, L-4399; 3 thin sections.

Dimensions

(L-4242)	n	min-max	μ	s	cv	μ±s
cl min	30	1.39-2.83	2.04	0.4	19.7	1.64-2.45
cl max	30	2.79-4.99	3.82	0.56	14.6	3.26-4.39
c min	30	2.23-3.92	3.05	0.47	15.4	2.58-3.53
c max	30	3.84-6.47	5.23	0.62	11.9	4.61-5.86
s	15	5-7	5.66	0.72	12.7	5-6

Occurrence in Sonora. Early Albian of Municipio Cucurpe, Cucurpe, La Mesa; Municipio Naco, Naco, Sierra San Jose; Municipio Opodepe, Tuape, Cerro de la Espina; Municipio Ures, Cerro de Oro.

Occurrence elsewhere. Cretaceous of Slovenia (West Slovenia) Banjska planota, Kanalski Lom, southeast. Early Late Albian (*Mortoniceras inflatum* Zone) of Spain (Valencia, Alicante) Sierra de Llorençá.

Latusastrea Orbigny, 1849

Type species. *Explanaria alveolaris* Goldfuss, 1829

Latusastrea rubrolineata Löser *et al.*, 2009

Figs. 1G–I

v 2003 *Latusastrea* sp. - Kolodziej, p. 207, figs. 20a-c.

v 2003 *Confusaforma weyeri* Löser, 1987 - Baron-Szabo and González León, p. 207, fig. 7B.

*v 2009 *Latusastraeopsis rubrolineata* Löser *et al.*, p. 338, figs. 4, 5.1-5.4.

Description. Cerioid colony. Calicular outline elliptical, pit depressed. Septa compact. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Cycles of septa irregular, but size orders can be distinguished. Septal generations differ in length and thickness. Septa not connected to each other. A group of about five main

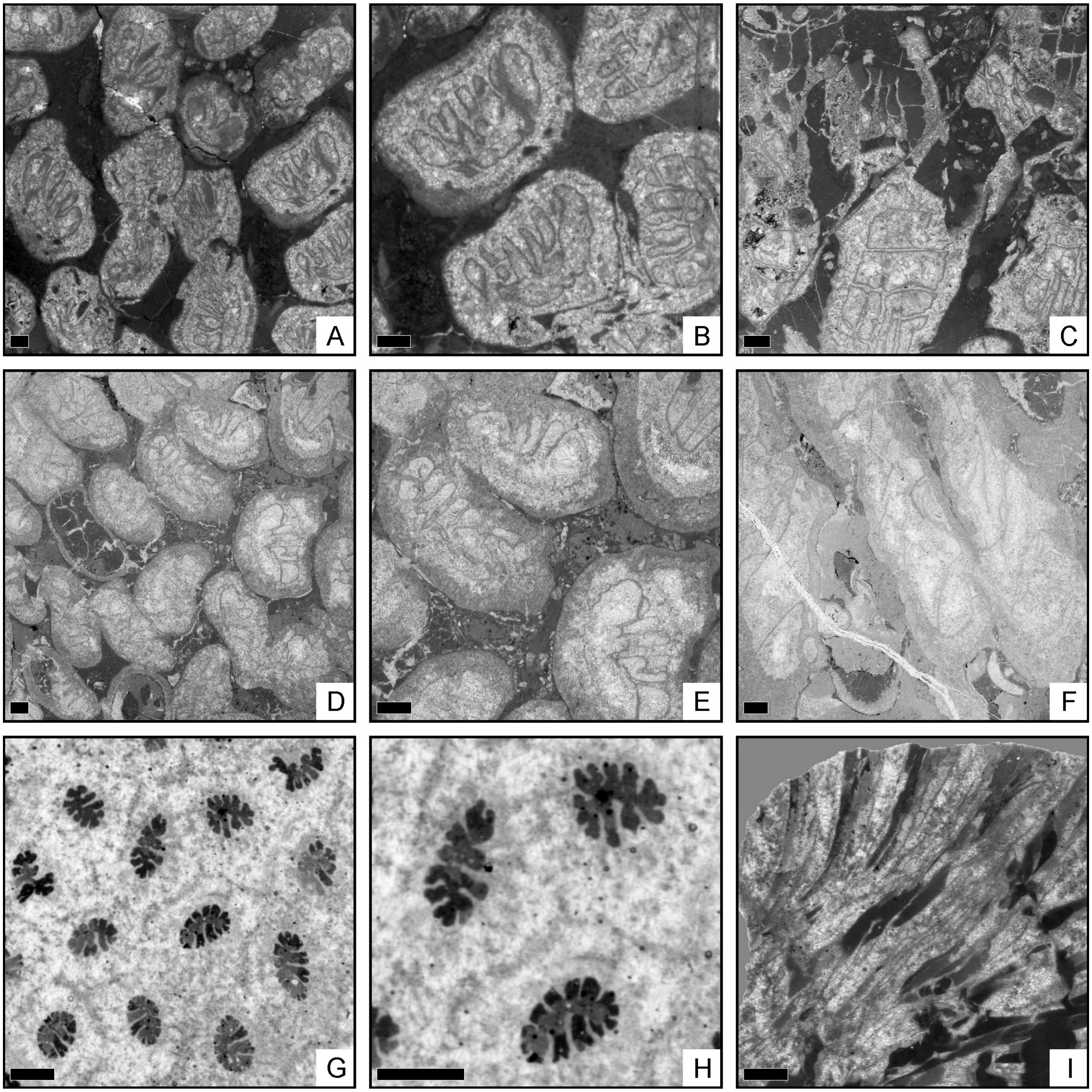

Figure 1. A–C, *Heteropistophyllum carchensis* Löser *et al*., 2015, ERNO L-4266. A, transversal thin section. B, transversal thin section, detail. C, longitudinal thin section. D–F, *Heteropistophyllum quinqueseptatum* (Turnšek and Buser, 1976), ERNO L-4242. D, transversal thin section. E, transversal thin section, detail. F, longitudinal thin section. G–I, *Latusastrea rubrolineata* Löser *et al*., 2009, ERNO L-4309. G, transversal thin section. H, transversal thin section, detail. I, longitudinal thin section. Scale bar 1mm.

septa exist. One main septum slightly longer and thicker than the others. Septal distal margin unknown, lateral face with few thorns, inner margin swollen in places. Pali or paliform lobes absent. Costae absent. Synapticulae absent. Columella absent. Endotheca consists of regular tabulae and occasional dissepiments. Wall compact, structure unknown. Coenosteum absent. Budding extracalicinal.

Material examined. ERNO 3198, L-4284, L-4285, L-4287, L-4309, L-4820, L-4821, L-4822, L-4825, L-4827, L-4908; 11 thin sections.

Dimensions

(L-4309)	n	min-max	µ	s	cv	µ±s
cl min	60	0.58-1.23	0.87	0.15	17.7	0.71-1.02
cl max	60	0.81-1.79	1.29	0.22	17.4	1.07-1.52
s	20	12-19	14.55	2.25	15.5	12-17

Remarks. The material differs from the type species by its more cerioid organisation form. The type of *L. rubrolineata* shows a very reduced coenosteum, but because the present material differs from the type material only by the absence of the coenosteum, it does not seem useful to create a new species or even genus.

Occurrence in Sonora. Early Albian of Municipio Agua Prieta, east San Bernardino Valley, Cordon Caloso; Municipio Cucurpe, Cucurpe, La Mesa; Municipio Opodepe, Tuape, Cerro de la Espina; Municipio Ures, Cerro de Oro.

Occurrence elsewhere. Tithonian to Early Berriasian of Poland (Malopolskie, Wadowice) Wadowice, Wozniki. Hauterivian of Jamaica (Saint Catharine) Benbow Inlier, Copper. Early Albian of Mexico (Baja California) Santo Tomás, Arroyo de la Cueva (ERNO L-1347062).

Pleurocoenia Orbigny, 1849

Type species. *Pleurocoenia provincialis* Orbigny, 1849

Pleurocoenia irregularis Toula, 1884
Figs. 2A–C

*v 1884 *Pleurocoenia irregularis* Toula, p. 1318, pl. 6, fig. 6.
v 1909 *Heliopora decipiens* - Prever, p. 65, pl. 1, figs. 18, 18 a, 23, pl. 2, figs. 1, 1 a, 2.
vp 1948 *Heliopora japonica* n.sp. - Eguchi, p. 363, pl. 60, figs. 1, 2, 5, 7.
v 1971 *Heterocoenia minima* n.sp. - Morycowa, p. 66, text-fig. 19, pl. 12, figs. 1, 2.
v 1981 *Latusastraea decipiens* (Prever) 1909 - Turnšek and Mihajlovic, p. 19, pl. 13, figs. 7, 8.
v 1984 ? *Polytremacis* cf. *urgoniensis* Koby, 1897 - Scholz, p. 475.
1985 *Latusastraea exiguis* (Fromentel, 1862) - Sikharulidze, p. 23, text-fig. 2, pl. 8, fig. 1, pl. 9, fig. 1.
1993 *Latusastraea provincialis* (d'Orbigny 1850) - Baron-Szabo, p. 157, text-fig. 4, pl. 2, fig. 3.
v 1997 *Latusastrea provincialis* (d'Orbigny, 1849) - Baron-Szabo, p. 46, pl. 2, figs. 5, 6.
v 1999 *Latusastrea provincialis* d'Orbigny, 1849 - Baron-Szabo and González León, p. 482, fig. 4d.
v 2006 *Latusastrea irregularis* (Toula, 1884) - Löser and Ferry, p. 480, fig. 4.3.
v 2008 *Latusastrea irregularis* (Toula, 1884) - Löser, p. 44, pl. 2, fig. 5.

Description. Plocoid colony in form of a swallow‘s nest. Calicular outline elliptical to semi-circular, pit depressed. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Septa not connected to each other. Main septum present, other septa reduced to spines. Septal distal margin unknown, lateral face occasionally with thorns, inner margin smooth. Pali or paliform lobes absent. Costae present but short. Synapticulae and columella absent. Endotheca consists of regular tabulae. Wall compact, constitution unknown. Coenosteum medium broad, consists of costae. Budding extracalicinal.

Material examined. ERNO 2175, 2200, L-4220, L-4221, L-4430, L-4449, L-4450; 8 thin sections.

Dimensions

(L-4220)	n	min-max	μ	s	cv	μ±s
cl min	25	0.49-0.82	0.66	0.08	13.1	0.57-0.75
cl max	25	0.66-1.14	0.9	0.11	13	0.78-1.01

Occurrence in Sonora. Early Albian of Municipio Opodepe, Tuape, Cerro de la Espina; Municipio Opodepe, Tuape, Cerro de la Espina; Municipio Ures, Cerro de Oro.

Occurrence elsewhere. Hauterivian of Georgia (Imereti) Kvemo-Chalovani. Barremian of Mexico (Puebla) Tehuacán, San Antonio Texcala (GPSL FLX 1606). Early Barremian of France (Drôme) Vercors Mts, section NW Archiane. Barremian to Early Aptian of Romania (Suceava) Pojorîta area, Cîmpulung-Moldovenesc. Late Barremian of France (Ardèche) St.Remèze, Belvedere du Gaud. Late Barremian to Early Aptian (*Gerhardtia sartousiana* to *Deshayesites forbesi* zones) of Germany (Bayern) Allgäuer Helvetikum. Aptian of Mexico (Puebla) San Juan Raya (IGM 9228). Early Aptian (*Deshayesites oglanlensis* to *Deshayesites forbesi* zones) of France (Vaucluse) Sault. Early Aptian of Greece (Viotía) Arachova (BSPG 2003 XX 5515); Levadia, Perachorion (BSPG 2003 XX 5784). Italy (Abruzzi, L'Aquila) Monti d'Ocre (ERNO L-5402). Serbia (East Serbia) Pirot, Bela Palanka; Rajcinica; Zljebine. Early Aptian (*Deshayesites forbesi* to *Dufrenoyia furcata* zones) of Tanzania (Tanganyika, Mtwara) Nambawala plateau, Kikomolela, Likwaja (MB K1366). Early Late Aptian of Algeria (Tebessa) Commune Ouenza, Ouenza Mt (UP M 5133). Late Aptian of Spain (País Vasco, Vizcaya) Gamecho, Playa de Laga. Latest Aptian of Japan (Iwate-ken) Shimohei-gun, Iwaizumi-cho, Moshi, Matsushima. Early Albian of Mexico (Baja California) El Progreso, Los Torotes section (ERNO L-4390); Eréndira, Playa Blanca (ERNO L-134906). Early Cenomanian of UK (Wiltshire) Norton Bavant 2 miles S Warminster (ANSP 72289).

Pleurocoenia provincialis Orbigny, 1849
Figs. 2D–F

*v 1849 *Pleurocoenia provincialis* Orbigny, p. 7.
v 1891 *Latusastraea provincialis* - Felix, p. 158, pl. 25, fig. 16.
v 1909 *Heliopora aprutina* - Prever, p. 65, pl. 27, fig. 1.
v 1964 *Latusastraea exiguis* (Fromentel, 1862) - Morycowa, p. 69, pl. 22, fig. 3.
v 1964 *Latusastraea provincialis* (d'Orbigny, 1850) - Morycowa, p. 70, pl. 19, fig. 3, pl. 20, fig. 4.
v 1971 *Heterocoenia* sp. - Morycowa, p. 68, pl. 13, fig. 3.
v 1981 *Latusastraea decipiens* (Prever) 1909 - Turnšek and Mihajlovic, p. 19, pl. 13, fig. 7, 8.

1993 *Latusastraea decipiens* Prever 1909 - Baron-Szabo, p. 157, pl. 2, fig. 4.
v 1994 *Latusastrea xigazeensis* (sp. nov.) - Liao and Xia, p. 67, 221, pl. 5, fig. 5, 6.
1995 *Latusastraea exiguis* (Fromentel, 1862) - Morycowa *et al*., p. 18, fig. 1, 2, 3 a-f.
v 1996 *Latusastrea provencialis* (d'Orbigny, 1850) - Baron-Szabo and Steuber, p. 18, pl. 7, fig. 6.
v 1997 *Latusastrea provincialis* (d'Orbigny, 1849) - Baron-Szabo, p. 46, pl. 2, fig. 5, 6.
v 2006 *Latusastrea* cf. *provincialis* (d'Orbigny, 1849) - Löser and Ferry, p. 480, fig. 4.6, 4.7.

Description. Plocoid colony in form of a swallows nest. Calicular outline circular, elliptical or irregular, pit depressed. Septa in cross section thicker close to the wall, becoming thinner toward the centre. Symmetry of septa bilateral. Septa not connected to each other. Main septum present, other septa reduced to spines. Septal distal margin unknown, lateral face occasionally with thorns, inner margin swollen in places. Pali or paliform lobes absent. Costae present but short. Synapticulae and columella absent. Endotheca consists of regular tabulae. Wall compact, constitution unknown. Coenosteum narrow, consists of costae and trabeculae. Budding extracalicinal.

Material examined. ERNO L-4219, L-4230, L-4459; 4 thin sections.

Dimensions

(L-4459)	n	min-max	μ	s	cv	μ±s
cl min	37	0.57-1.28	0.84	0.12	14.8	0.71-0.96
cl max	22	0.75-1.41	1.1	0.15	13.9	0.95-1.26

Occurrence in Sonora. Early Albian of Municipio Opodepe, Tuape, Cerro de la Espina.

Occurrence elsewhere. Barremian of Mexico (Puebla) Tehuacán, San Antonio Texcala. Late Barremian of France (Ardèche) St.Remèze, Belvédère du Serre-de-Tourre. Late Barremian to Early Aptian of Switzerland (Bern) Rawil pass. Poland (Malopolskie) without precise locality (UJ 4P10#2). Late Barremian to Early Aptian (*Gerhardtia sartousiana* to *Deshayesites forbesi* zones) of Germany (Bayern) Allgäuer Helvetikum, Brandalpe. Aptian of Mexico (Puebla) San Juan Raya (IGM 9224). Early Aptian of Greece (Viotía) Arachova; Perachorion (BSPG 2003 XX 5775); Italy (Abruzzi, L'Aquila) Monti d'Ocre, Fossa Mezza Spada; Poland (Malopolskie, Wadowice) Lanckorona, Jastrzebia (ERNO L-5427); Serbia (East Serbia) Zljebine. Early Aptian (*Palorbitolina lenticularis* Zone) of Romania (Suceava) Pojorîta area, Cîmpulung-Moldovenesc, Valea Izvorul Alb.

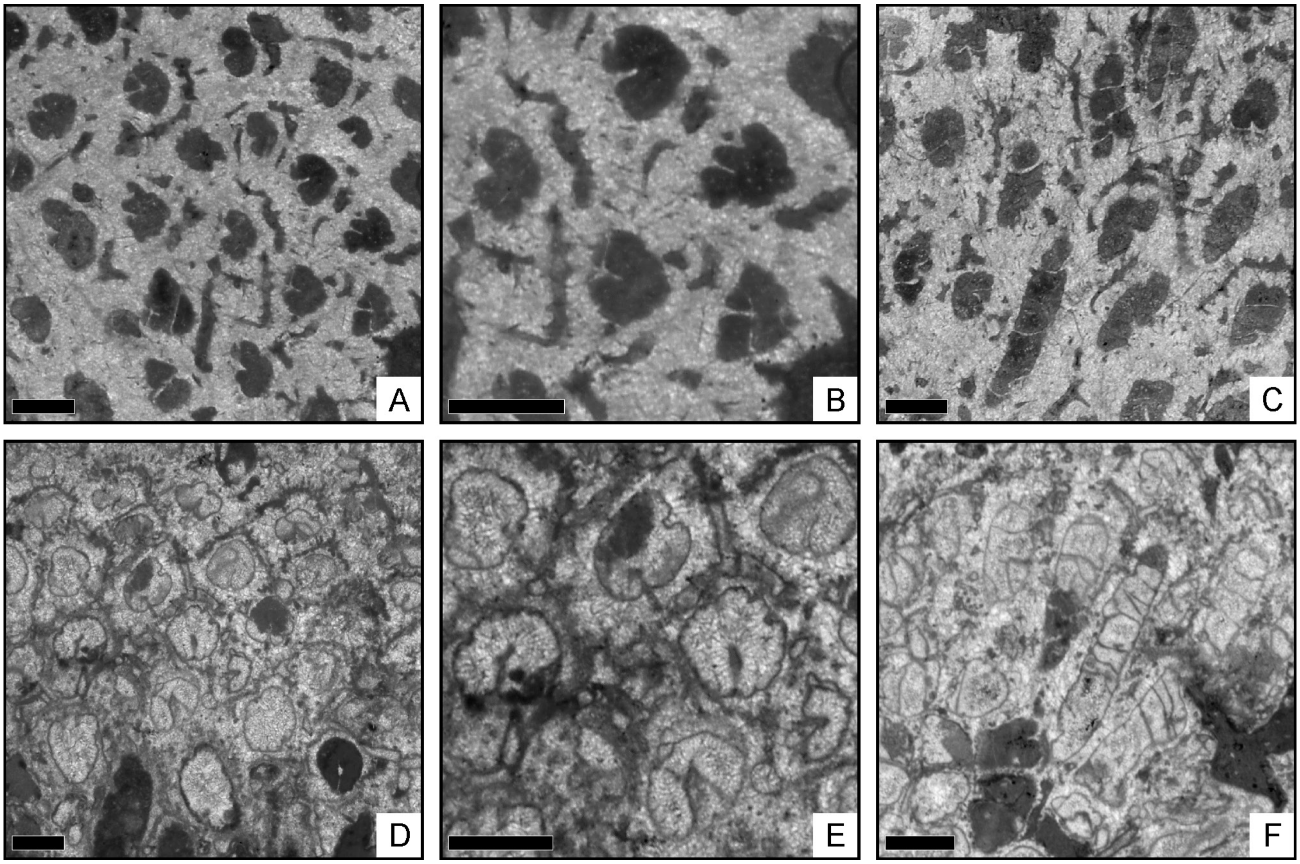

Figure 2. A–C, *Pleurocoenia decipiens* (Prever, 1909), ERNO L-4220. A, transversal thin section. B, transversal thin section, detail. C, longitudinal thin section. D–F, *Pleurocoenia provincialis* d'Orbigny, 1849, ERNO L-4459. F, transversal thin section. E, transversal thin section, detail. F, longitudinal thin section. Scale bar 1mm.

Late Aptian of Spain (País Vasco, Vizcaya) Gamecho, Playa de Laga. Early Cenomanian of China (Xizang [= Tibet] Autonomous Region) Xigaze county, Donggar district, suburb of Dongga. Late Turonian of France (Vaucluse) Orange, Uchaux.

Pleurocoenia sp.
Figs. 3A–B

v 1905 *Heterocoenia verrucosa* - Angelis d'Ossat, p. 23, pl. 1, fig. 15, 16.
v 1964 *Latusastraea decipiens* (Prever, 1909) - Morycowa, p. 71, pl. 20, fig. 1, 2.
v 1974 *Latusastrea decipiens* (Prever) - Turnšek and Buser, p. 16, 34, pl. 6, fig. 3.
v 2003 *Latusastrea provencialis* (d'Orbigny, 1849) - Baron-Szabo and González León, p. 206, fig. 7G.
v 2013a *Pleurocoenia* cf. *irregularis* - Löser, p. 101, fig. 5.1-5.3.

Description. Plocoid colony in form of a swallows nest. Calicular outline circular, elliptical or irregular, pit depressed. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Septa not connected to each other. Main septum present, other septa reduced to spines. Septal distal margin unknown, lateral face rarely with thorns, inner margin smooth. Pali or paliform lobes absent. Costae unknown. Synapticulae and columella absent. Endotheca unknown. Wall compact, constitution unknown. Coenosteum narrow. Budding extracalicinal.

Material examined. ERNO 3141; 1 thin section.

Dimensions

(3141)	n	min-max	µ	s	cv	µ±s
cl min	30	0.37-0.71	0.57	0.08	15.1	0.48-0.66
cl max	30	0.58-0.90	0.72	0.07	9.9	0.64-0.79

Remarks. The specimen is comparable to *P. provencialis* but differs by larger calicular dimensions. It belongs probably to a new, yet undescribed species.

Occurrence in Sonora. Early Albian of Municipio Ures, Cerro de Oro.

Occurrence elsewhere. Barremian of Italy (Campania, Napoli) Isle of Capri, Venassino. Late Barremian of Poland (Malopolskie, Tarnów) Tarnów, Trzemesna. Early Aptian of Italy (Abruzzi, L'Aquila) Monti d'Ocre, Fossa Mezza Spada (BSPG 2003 XX 5331); Poland (Malopolskie, Wadowice) Lanckorona, Jastrzebia; Slovenia (West Slovenia) Banskja Planota, Osojnica. Late Aptian of Greece (Viotía) Aliartos, Chiarmena.

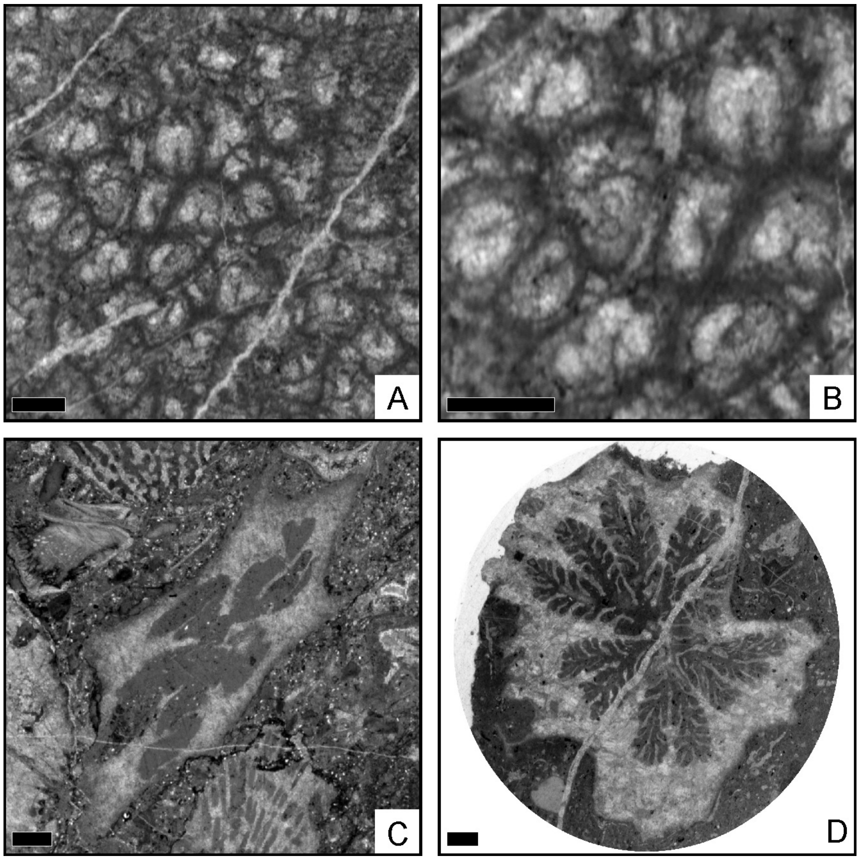

Figure 3. A–B, *Pleurocoenia* sp., ERNO 3141. A, transversal thin section. B, transversal thin section, detail. C, *Heterosmilia* sp., ERNO 3025, transversal thin section. D, *Tiarasmilia* sp., ERNO L-4276, transversal thin section. Scale bar 1mm.

Pleurodendron Löser *et al*., 2013

Type species. *Pleurodendron prebeticum* Löser *et al*., 2013

Pleurodendron microsa (Baron-Szabo and González León, 2003)
Figs. 4A–C

*v 2003 *Pleurophyllia microsa* Baron-Szabo and González León, p. 205, fig. 6C, D, 7C.

Description. Phaceloid colony, branches connected by apophyses. Calicular outline elliptical. Septa compact. Septa in cross section slightly thicker close to the wall, becoming slightly thinner toward the centre. Symmetry of septa bilateral. Cycles of septa subregular. Septal generations differ in length and thickness. Septa not connected to each other. Main septum present, septum thicker and longer than other septa. Septal distal margin unknown, lateral face with rare thorns, inner margin slightly swollen in places. Pali or paliform lobes, costae, synapticulae, and columella absent. Endotheca consists of tabulae. Wall compact, structure unknown. Coenosteum absent. Budding intracalicinal.

Material examined. ERNO 3069; 4 thin sections.

Dimensions

(3069)	n	min-max	μ	s	cv	μ±s
cl min	15	0.58-1.34	0.92	0.24	26.9	0.67-1.16
cl max	15	1.03-1.80	1.29	0.22	17	1.07-1.51
c min	17	1.38-2.35	1.84	0.29	16.2	1.54-2.14
c max	17	2.10-3.03	2.54	0.3	11.9	2.23-2.84
s	5					

Remarks. The assignation of the species to this genus is questionable. It does not show apophysal connections between the calices, and no channels, as in *Pleurodendron*. The species cannot be assigned to *Pleurophyllia*. This genus shows much larger calices, and smooth septa.

Occurrence in Sonora. Early Albian of Municipio Opodepe, Tuape, Cerro de la Espina.

Family Heterocoeniidae Oppenheim, 1930
Heterosmilia Kolodziej *et al*., 2012

Type species. *Heterosmilia spinosa* Kolodziej *et al*., 2012

Heterosmilia sp.
Figs. 3C

Material examined. ERNO 3025; one thin section.

Description. Phaceloid colony. Calicular outline polygonal. Septa compact. Septa in cross section thick close to the wall, thinner toward the centre. Symmetry of septa radial and regularly hexameral. Cycles of septa regular. Septal cycles differ in length and thickness. Septa not connected to each other. Septal distal margin unknown, lateral face with few apophysal septa, inner margin branching. Pali or paliform lobes absent. Costae present. Synapticulae, and columella absent. Endotheca unknown. Wall compact, structure unknown. Coenosteum absent. Budding unknown.

Dimensions

(3025)	
c	4
cl	2.5
s	6+6

Remarks. The only specimen is an oblique portion in thin section. It differs from *Heterosmilia* by its polygonal calicular outline.

Occurrence in Sonora. Late Barremian to Early Aptian (*Palorbitolina lenticularis* zone) of Municipio Ures, Cerro de Oro.

Occurrence elsewhere. Aptian of Mexico (Puebla) Tehuacán, Barranco San Lucas, N Plan de Fierro (ERNO L-100103).

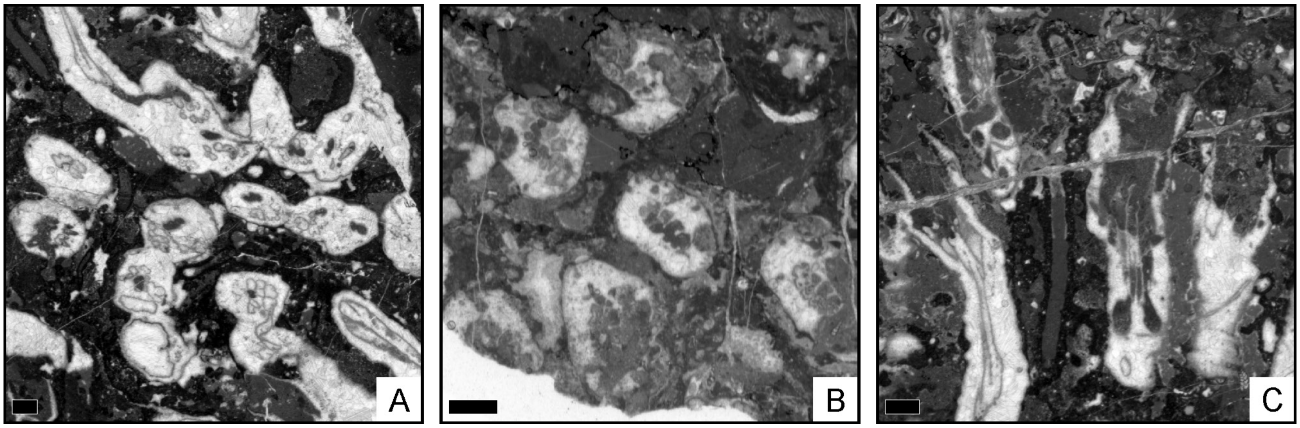

Figure 4. A–C, *Pleurodendron microsa* (Baron-Szabo and González León, 2003), holotype, ERNO 3069. A, transversal thin section. B, transversal thin section, detail. C, longitudinal thin section. Scale bar 1mm.

Family Paronastraeidae Beauvais, 1974
Tiarasmilia Wells, 1932

Type species. *Tiarasmilia casteri* Wells, 1932

Tiarasmilia sp.
Figs. 3D

1997 *Trochoidomeandra* cf. *problematica* Morycowa 1971 - Baron-Szabo and Fernández Mendiola, p. 48, fig. 5 e.
v 2010 *Tiarasmilia* sp. 1 - Löser, p. 162, figs. 2.9, 3.1, 3.2.
v 2013b *Tiarasmilia* sp. - Löser, p. 18, fig. 6l.

Description. Solitary turbinate coral. Calicular outline irregularly circular. Septa compact. Septa in cross section thick close to the wall, thinner toward the centre. Symmetry of septa radial and regularly hexameral. Cycles of septa regular. Septal cycles differ in length and thickness. Septa not connected to each other. Main septum present, but barely distinguishable from the other septa of the first cycle. Septal distal margin smooth, lateral face with long apophysal septa, inner margin slightly swollen in places. Pali and paliform lobes absent. Costae present but short. Synapticulae and columella absent. Endotheca unknown. Wall compact, structure unknown.

Material examined. ERNO L-4276; 1 thin section.

Dimensions

	(L-4276)
c	10-11
cl	8-9
s	6+6

Remarks. The genus was just recently revised (Löser, 2010). The present material differs from all other species by its low number of septa. The present material does not allow to establish a new species because there exists only one specimen.

Occurrence in Sonora. Early Albian of Municipio Cucurpe, Cucurpe, La Mesa (ERNO L-4276).

Occurrence elsewhere. Late Barremian of Mexico (Puebla) Tehuacán, La Compañía (IGM 9263). Aptian to Albian of Greece (Fokída) Kiona massif, Panourgias [= Dremisa] (BSPG 2003 XX 5901). Early Albian of Spain (Cantabria, Santander) Cabo de Ajo. Late Early Albian (*Douvilleiceras mammillatum* Zone) of France (Aude) Padern, SE Le Crès, 1.45 km WWS Padern. Early Cenomanian of Greece (Kozani) Kozani, Nea Nikopolis (BSPG 2003 XX 5921). Middle Cenomanian (*Mantelliceras mantelli* to *Acanthoceras rhotomagense* zones) of Belgium (Hainaut) Tournai-Chercq (MNHN M00283).

5. Discussion

The Sonoran species of the suborder Heterocoeniina belong to a rather rare genera, with the exception of *Pleurocoenia*, which is globally distributed, ranging from the Hauterivian to the Santonian. *Heteropistophyllum* has a wide geographic distribution, but is much rarer, and it is restricted to the Aptian and Albian. Distribution data of the just recently established *Heterosmilia* are poor; the genus is known from the Late Barremian to Middle Albian. *Latusastrea* reaches from the Late Jurassic to the Middle Albian. *Tiarasmilia* has a wide geographic distribution, but it is relatively rare. The genus ranges from the Barremian to the Early Cenomanian. Because of the rarity of most genera studied here, few distribution data are available (Fig. 5). Most of the reported species here occur from the Barremian to the Aptian, although there are a few appearances occurring as far back as the Late Jurassic, and some can be found ranging into the Turonian. As most genera have their last occurrence in the Albian (*Heteropistophyllum*, *Heterosmilia*, *Latusastrea*, *Pleurodendron*), they became extinct before OAE (Ocean Anoxic Event) 2. A possible explanation may be OAE 1c and 1d. Geographically, the Sonoran species of the suborder Heterocoeniina show only some relationship to Western and Central Tethyan faunas, but also to other regions on the American continent (Fig. 6).

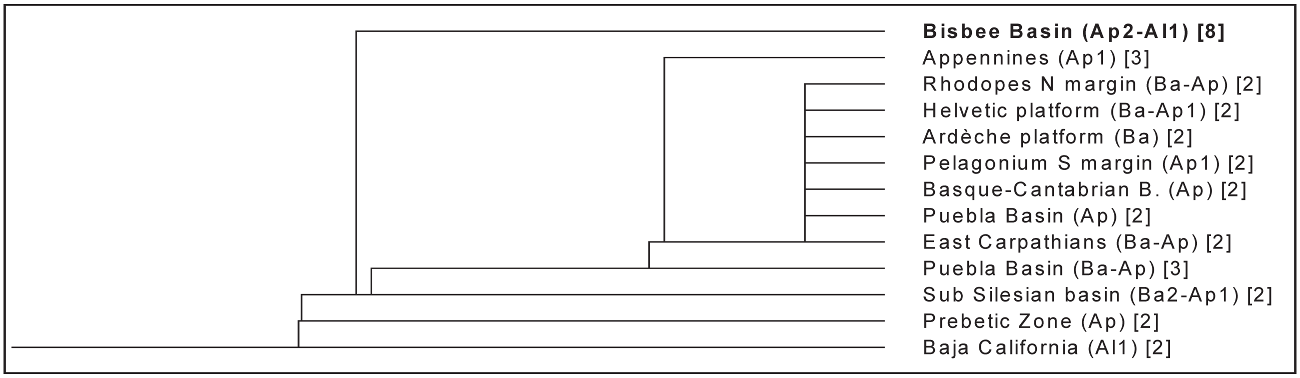

Figure 5. Correlation of provinces with joint species in the study area. Provinces with less than two joint species are suppressed. The Correlation Ratio coefficient was applied, the graph is logarithmic. For details of calculation see Löser and Minor (2007).

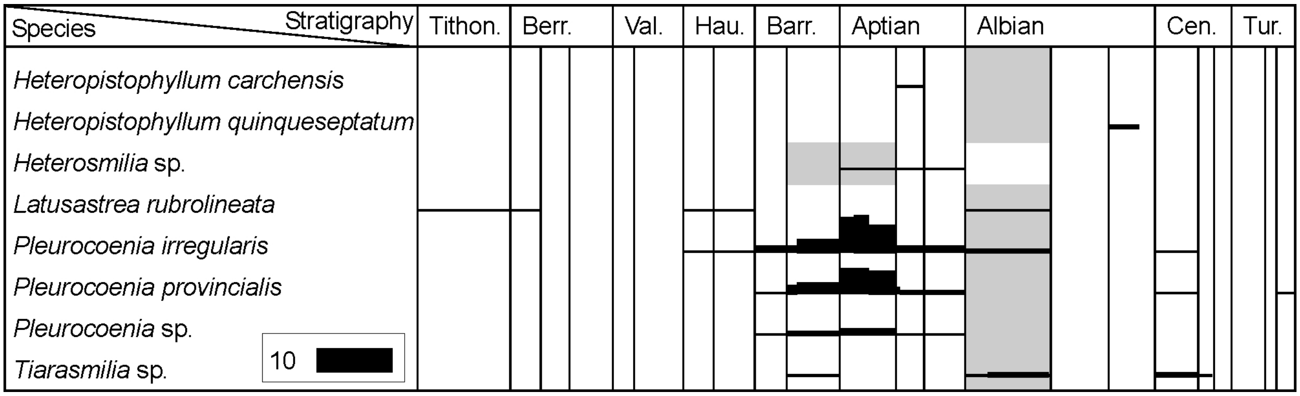

Figure 6. Stratigraphic distribution and commonness of species. The thickness of the bars indicates the number of localities (multiples localities within the same lithostratigraphic unit are counted as one) in which the concerned species was found. Grey bar indicates the study area.

The correlation is generally low because of the rarity of the genera, with the exception of *Pleurocoenia*.

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Cenomanian algae and microencrusters from the El Abra Formation, W Valles–San Luis Potosí, Mexico

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Abstract

This work deals with calcareous algae and microencrusters (*incertae sedis*) from the upper part of the El Abra Formation, which crops out at the W Valles–San Luis Potosí Platform. Two assemblages of calcareous algae are recognized: one composed of rivulariacean-type cyanobacteria such as *Cayeuxia kurdistanensis* Elliott and *Garwoodia* sp. as well as the dasycladalean species *Clypeina* sp., *Neomeris cretacea* Steinmann, *Salpingoporella hasi* Conrad, Radoičić and Rey, *Trinocladus* cf. *T. divnae* Radoičić; the bryopsidales *Boueina pygmaea* Pia, *Halimeda* cf. *H. elliotti* Conard and Rioult, and the microencrusters *Lithocodium aggregatum* Elliot and *Thaumatoporella parvovesiculifera* (Raineri), and the other assemblage consisting of the gymnocodacean algae *Permocalculus irenae* Elliott and *P. budaensis* Johnson. The first assemblage is associated with the benthic foraminifera *Pseudolituonella reicheli* Marie, *Hemicyclammina sigali* Maync, *Daxia cenomana* Cuvillier and Szakall, *Merlingina cretacea* Hamoui and Saint Marc, is dated as mid-late Cenomanian on the basis of the stratigraphic distribution of the foraminifera, and suggests an oligotropic environment within the euphotic zone on the open marine platform. Over this is documented a succession consisting of a community with abundant gymnocodacean algae and a decrease in the benthic foraminifera which could be related to increased nutrient availability in mesotrophic conditions. The shallow-water association composed of the studied microfossils is typical of the Tethys Realm.

Keywords: Algae, microencrusters, El Abra Formation, Cenomanian, Valles–San Luis Potosí Platform, Mexico.

Resumen

Este trabajo trata sobre las algas calcáreas y microencrustantes (incertae sedis) de la parte superior de la Formación El Abra que aflora en la parte occidental de la Plataforma Valles-San Luis Potosí. Se reconocen dos conjuntos de algas calcáreas, uno compuesto por cianobacterias tales como Cayeuxia kurdistanensis Elliott, Garwoodia sp. así como dasycladaleans: Clypeina sp., Neomeris cretacea Steinmann, Salpingoporella hasi Conrad, Radoičić y Rey Trinocladus cf. T. divnae Radoičić, bryopsidales: Boueina pygmaea Pia, Halimeda cf. H. elliotti Conard y Rioult y los microincrustantes Lithocodium aggregatum Elliott Thaumatoporella parvovesiculifera (Raineri). La otra asociación consiste de algas gymnocodaceas como: Permocalculus budaensis Johnson y P. irenae Elliott. El primer grupo se asocia con los foraminíferos bentónicos Pseudolituonella reicheli Marie, Hemicyclammina sigali Maync, Daxia cenomana Cuvillier y Szakall, Merlingina cretacea Hamoui y Saint Marc, lo cual es datado como Cenomaniano medio-tardío sobre la base de la distribución estratigráfica de los foraminíferos. Este conjunto sugiere un ambiente oligotrópico dentro de la zona eufótica en la plataforma marina abierta. Sobre esta sucesión se documenta una comunidad con algas gymnocodaceas abundantes y una disminución en los foraminíferos bentónicos, lo cual podría estar relacionado con un aumento de la disponibilidad de nutrientes en condiciones mesotróficas. La asociación de aguas someras compuesta de los microfósiles estudiados es típica del dominio Tethysiano.

Palabras clave: Algas, microencrustantes, Formación El Abra, Cenomaniano, Plataforma Valles-San Luis de Potosí, México.

1. Introduction

The Valles-San Luis Potosí Platform (VSLPP) is part of a large carbonate platform system that rimmed the ancestral Gulf of Mexico during the Mid-Upper Cretaceous (Scott, 1990). The shallow-water deposit is represented by the El Abra Formation, which holds a rich assemblage of benthic foraminifers. Together with benthic foraminifers the calcareous algae are an important element in the Cretaceous shallow-water deposits. The term "El Abra Limestone" was first used by Garfias (1915) for the shallow-water carbonates of the Sierra de El Abra. This unit is characterized by a great variety of invertebrate fossils, mostly Albian rudists, which have been analysed and published by authors including Coogan (1973), Alencaster (1987, 1998), and Alencaster and García Barrera (2008).

The benthic foraminifers from the El Abra Formation were reported by Bonet (1956); Tavitas and Solano (1984); Omaña and Torres Hernández (2000); Ornelas *et al.* (2006). In Mexico, few studies of fossil algae have been carried out; *Neomeris cretacea* was described for the first time by Steinmann (1899) from the Cenomanian of the Cerro Escamela in the state of Veracruz. Barattolo (1983) described *Triploporella steinmanni* (probably of mid-Albian age) of the Cretaceous of Orizaba from the same locality of Steinmann (1899); later, Barattolo (1990) made a careful revision of *Neomeris cretacea*.

Other reports on Cretaceous algae have been published by Buitrón *et al.* (1995) about the Albian–Cenomanian algae from the El Abra Limestone. Hernández-Romano *et al.* (1998); Aguilera Franco *et al.* (2001) recorded algae in the Cenomanian from the Guerrero–Morelos Platform. In the Chiapas region, Michaud (1987) and Deloffre *et al.* (1985) registered the occurrence of Late Cretaceous algae. Filkorn and Scott (2011) found a late Albian algal assemblage from the Mal Paso Formation in the state of Guerrero.

The purpose of this study is to document the occurrence of rivulariacean-type cyanobacteria, calcareous algae (dasycladales, bryopsidales) and microencrusters from the upper part of the El Abra Formation in material from the west part of the Valles–San Luis Potosi Platform, and to describe and illustrate the species identified.

2. Geological Setting

The study area is located east of the city of San Luis Potosí (Figure 1). This area is situated on the western part of the Valles–San Luis Potosí Platform (VSLPP). The Early Cretaceous was a time of remarkable tectonic stability in the Gulf of Mexico Basin, characterized by decreased terrigenous influx and 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. Along the western flank of the basin in east-central Mexico, carbonate platforms were restricted to more local developments such as the VSLPP, which remained active until the earliest Late Cretaceous (Cenomanian) (Salvador, 1991).

3. Material and Methods

The material studied comes from the upper part of the El Abra Limestone. It was collected from four localities situated at the western part of the VSLPP: Llano del Carmen (LLC), Guadalcázar (G), Cerritos (C), and El Temazcal (ET). The limestone was examined in thin sections and algae and microencrusters were studied. The micropaleontological preservation is good, permitting identification. Most of the specimens are identified and illustrated from cross-sections.

The biostratigraphical framework is based on the benthic foraminiferal stratigraphic ranges. In addition, a microfacies study was carried out to infer the paleoenvironment.

4. Results

4.1. Lithology and microfacies

The samples with algae were collected east of the city of San Luis Potosí and proceed from the El Abra Formation. This unit presents two facies: the Taninul and El Abra, which are stratigraphically correlated (Aguayo, 1998). In this study from the upper part of the El Abra Formation (Taninul Facies), two main microfacies were distinguished.

Microfacies 1 is a peloidal bioclastic packstone and well sorted grainstone (Figure 2a-b).

This microfacies includes an algal assemblage composed of *Clypeina* sp., *Neomeris cretacea* Steimann, *Salpingoporella hasi* Conrad, Radoičić and Rey, *Trinocladus* cf. *T. divnae* Radoičić, *Boueina pygmaea* Pia, and *Halimeda* cf. *H. elliotti* Conard and Rioult, *Cayeuxia kurdistanensis* Elliott, *Garwoodia* sp. and the microencrusters *Lithocodium aggregatum* Elliott and *Thaumatoporella parvovesiculifera* (Raineri). In this interval we identified the following benthic foraminifera: *Pseudolituonella reicheli*, *Hemicyclammina sigali*, *Daxia cenomana*, *Merlingina cretacea*, *Cuneolina conica*, *Cuneolina parva*, *Pseudocyclammina* sp., *Nezzazata simplex*, *Peneroplis parvus*, *Dicyclina schlumbergeri*, *Minouxia inflata*, *Nezzatinella picardi*, *Spiroloculina cretacea*.

Other fossil components of this microfacies include fragments of rudists, gastropods, corals, echinoderms, and calcareous worm tubes. This microfacies was recorded at all four localities (LLC, G, C, and ET). The abundant and diversified fauna and flora and the packstone texture of the rock which characterizes microfacies 1 suggest a depositional environment within the euphotic zone on the shallow open marine platform (zone 7 Flügel, 2004; Wilson, 1975). The environmental interpretation is also supported by

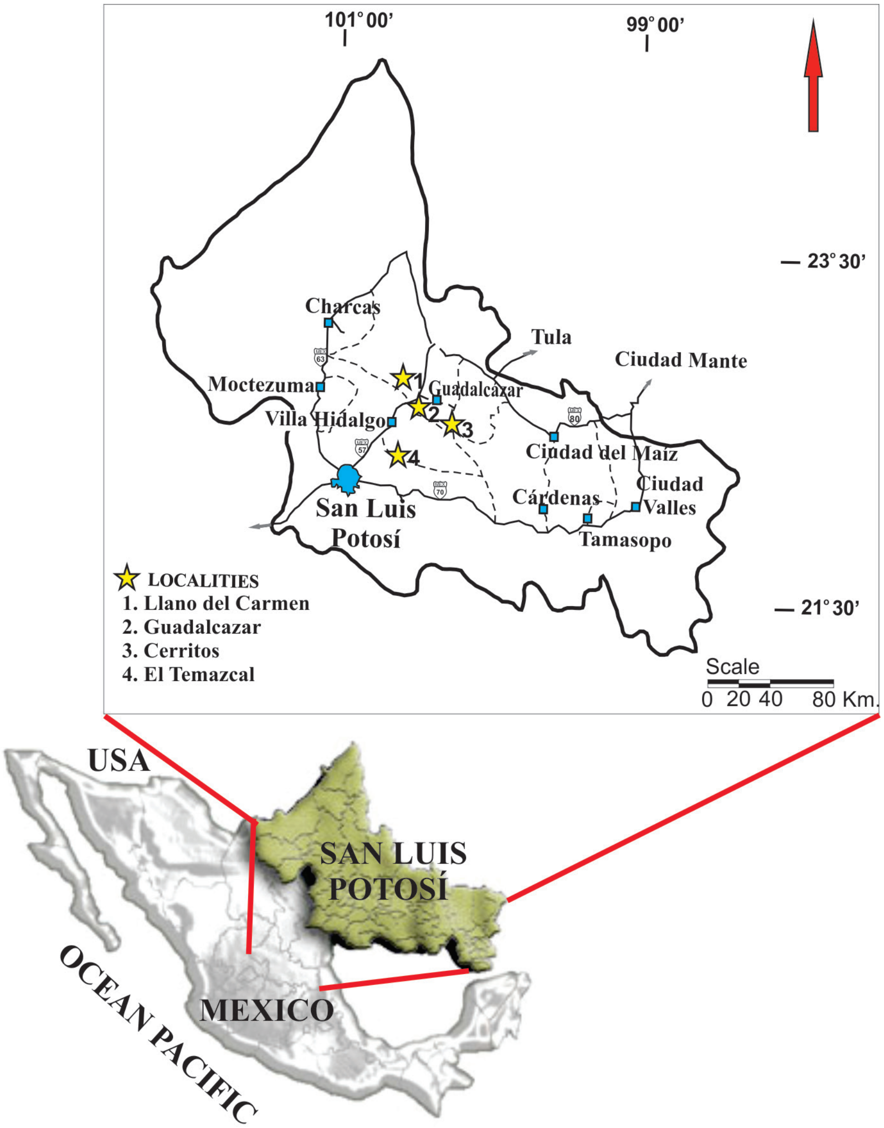

Figure 1. Geographic map with the location of the studied area.

the presence of calcareous algae and benthic foraminifera.

Microfacies 2 is an algal-foraminiferal wackestone-packstone characterized by fragments of *Permocalculus* (*Permocalculus irenae* Elliott, *P. budaensis* Johnson), and scarce benthic foraminifera such as *Nezzazatinella picardi*, miliolids, rotalids, textularids, gastropods, and echinoderms. This microfacies was identified in the Cerritos section (Figure 2c-d). The abundant occurrence of gymnocodaceans, as well as less diverse benthic foraminifera, indicates a marine deposit associated with an increase in the flux of nutrients (mesotrophic stage) before platform flooding.

4.2. Age

The benthic foraminiferal association is used for defining the age in the succession studied. On the basis of the stratigraphic distribution of *Pseudolituonella reicheli*, *Daxia cenomana*, *Merlingina cretacea* and *Hemicyclammina sigali*, the interval that contains the algae and microencrusters was dated as mid-late Cenomanian age. This dating is reinforced by the occurrence of the *Whiteinella cretacea* Zone (latest Cenomanian–earliest Turonian) that overlies the upper part of the El Abra Formation (Omaña *et al*., 2013).

4.3. Systematic Paleontology

The thin sections that contain the algae are housed in the Paleontology Collection of the Instituto de Geología (Universidad Nacional Autónoma de México).

PHYLUM CYANOPHYTA Sachs, 1874
Order Nostocales Geitler, 1925
Family Rivulariaceae Robenhorst, 1865

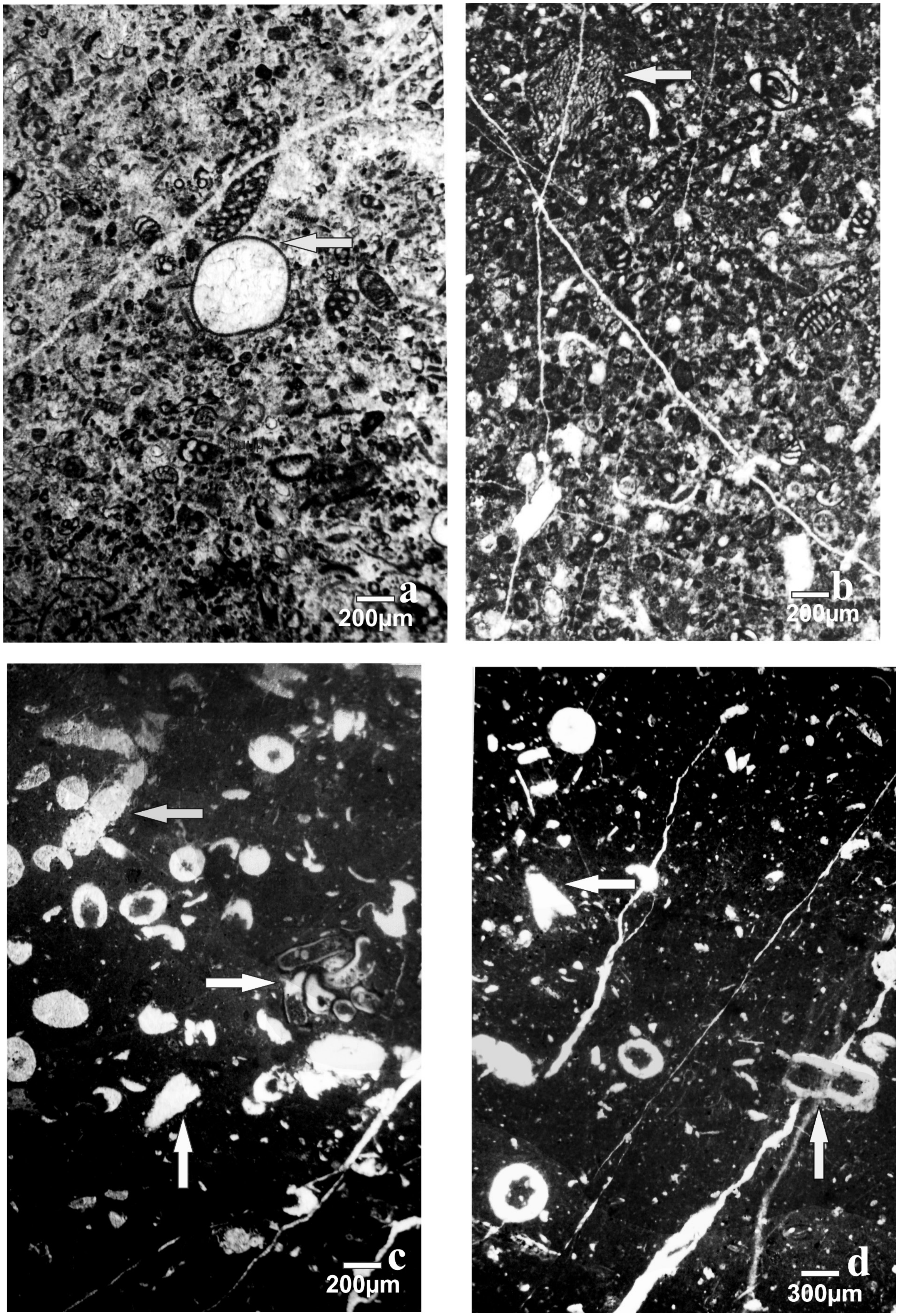

Figure 2. Microfacies with algae, foraminifers and encrusting associations. a) Foraminiferal packstone with *Thaumatoporella vesicularis* (Sample C-4). b) Peloidal bioclastic packstone with algae and foraminifers (Sample). c) Gymnocodacean algal packstone-wackestone with serpulids (Sample C-8). d) Gymnocodacean algal wackestone (Sample C-8).

The Cyanobacteria are an especially difficult group to classify. They are possibly one of the most ancient groups of organisms on earth, with some fossil representatives having very similar morphologies to present-day species (Schopf, 1974; Knoll, 2008).

Genus *Cayeuxia*

Frollo (1938) proposed the genus *Cayeuxia* with two new species, *C. piae* and *C. moldavica*, regarded as Codiaceae from the Tithonian, in East Carpathians. Dragastan (1985) transferred the genus to the cyanophyceans as a synonym of the genus *Rivularia*.

Dragastan (2008) noted that Luchinina and Shuysky in Chiuvashov *et al*. (1987) introduced other classification Phylum Cyanophyta, Family Garwoodiaceae including *Ortonella*, *Garwoodia*, *Hedstroemia*, *Cayeuxia*.

Type species. *Cayeuxia piae* Frollo, 1938.

Cayeuxia kurdistanensis Elliott, 1957
Figure 3 a, b, c

1957 *Cayeuxia kurdistanensis* Elliott, p. 790–791, pl. 25, figs. 8–10; Johnson, 1969, 37–38, pl. 26, fig. 1; Buitrón *et al*., 1995, p. 150, pl. 3, fig. 1; Filkorn and Scott, 2010, p. 182, fig. 3, 3; *Rivularia kurdistanensis* (Elliott), Dragastan, 1985, pl. 4, figs. 8–14; Mancinelli and Ferrandes, 2001, p. 538, figs. 3.4, 4.6.

Description. Fan-like thallus formed by radiating tubular filaments that diverge toward the distal margin and bifurcate from preceding tubes with an angle of divergence of about 45º, which is characteristic of *Cayeuxia*; the tubes filled with spar calcite as Filkorn and Scott (2011) have already observed.

Stratigraphic distribution. *Cayeuxia kurdistanensis* was described for the first time by Elliott (1957) from the Aptian of Iraq. This species has a wide distribution in the Jurassic and Cretaceous strata in Europe (Italy and France) as well as in the Americas (USA, Mexico, and Argentina).

Measurements.
Height 1mm

Occurrence. *Cayeuxia kurdistanensis* identified from the Llanos del Carmen (Sample LLC-1).

Garwoodia sp. Figure 3 d

Description. Thallus with tubes dichotomically branched laterally at an angle of about 90 degrees; the sheaths arranged in an irregular form; their walls are separated and the space is filled with calcite.

Remarks. The coarser tubes of *Garwoodia* have been used as an argument for assigning it to the udotacean green algae (Flügel, 2004).

Measurements.
Length 1000 µm.
Width 700 µm.

PHYLUM CHLOROPHYTA Pascher, 1914, p. 147
Class Dasycladophyceae Hoek *et al*., 1995
Order Dasycladales Pascher, 1931
Family Polyphysaceae Kützing, 1841

Genus *Clypeina* Michelin, 1845

According to Granier *et al*. (2014) the type species of *Clypeina* is *Clypeina marginiporella* (Michelin, 1845) which was originally described as an organism similar to a coral by Michelin (1840–1847; p. 177–178). The genus name derives from the Latin word "*clypeus*" for the reason that the first specimens collected by Michelin had the appearance of "perfect rings" and "half rings." In the second half of the nineteenth century, there was no consensus on the taxonomic position of these isolated "whorls" which were placed into the foraminifers by various authors as Parker and Jones (1860, p. 473–474); Carpenter (1862, p. 130–131), and Gümbel (1872, p. 262), but they were appropriately recognized as algae by Munier-Chalmas (1877) who regarded them as "*Siphonées verticillées*". Morellet and Morellet (1913) put them in the "*Acétabulariées*". In 1918, these authors proposed a new species: *Clypeina helvetica*, in addition to the two species previously identified from the Cenozoic, *C. marginiporella* (Michelin, 1845) and *C. digitata* (Parker and Jones, 1860). However, there was no record of Mesozoic forms up to the description of *Clypeina jurassica* from the Purbeckian strata (Favre and Richard, 1927).

Clypeina sp.
Figure 4 a,b,c,d, e, f, g

Description. Tallus cylindrical, euspondyl composed of one fertile whorl that consists of seven to 13 elongated primary laterals irregularly arranged containing one ovoid sporangial structure. The laterals are connected to the stem by small pores. The outer thallus diameter (D) was varying from 1000 to 625 µm; inner thallus diameter (d) 450–250 µm; pore diameter (p) 250–50 µm.

Class Dasycladophyceae Hoek *et al*., 1995
Order Dasycladales Pascher, 1931
Family Dasycladaceae Kützing, 1841
Tribe Dasycladeae Pia, 1920

Genus *Neomeris* Lamouroux, 1816

According to Granier *et al*. (2012a) "The main feature of the *Neomeris* genus is a main stalk bearing regularly spaced

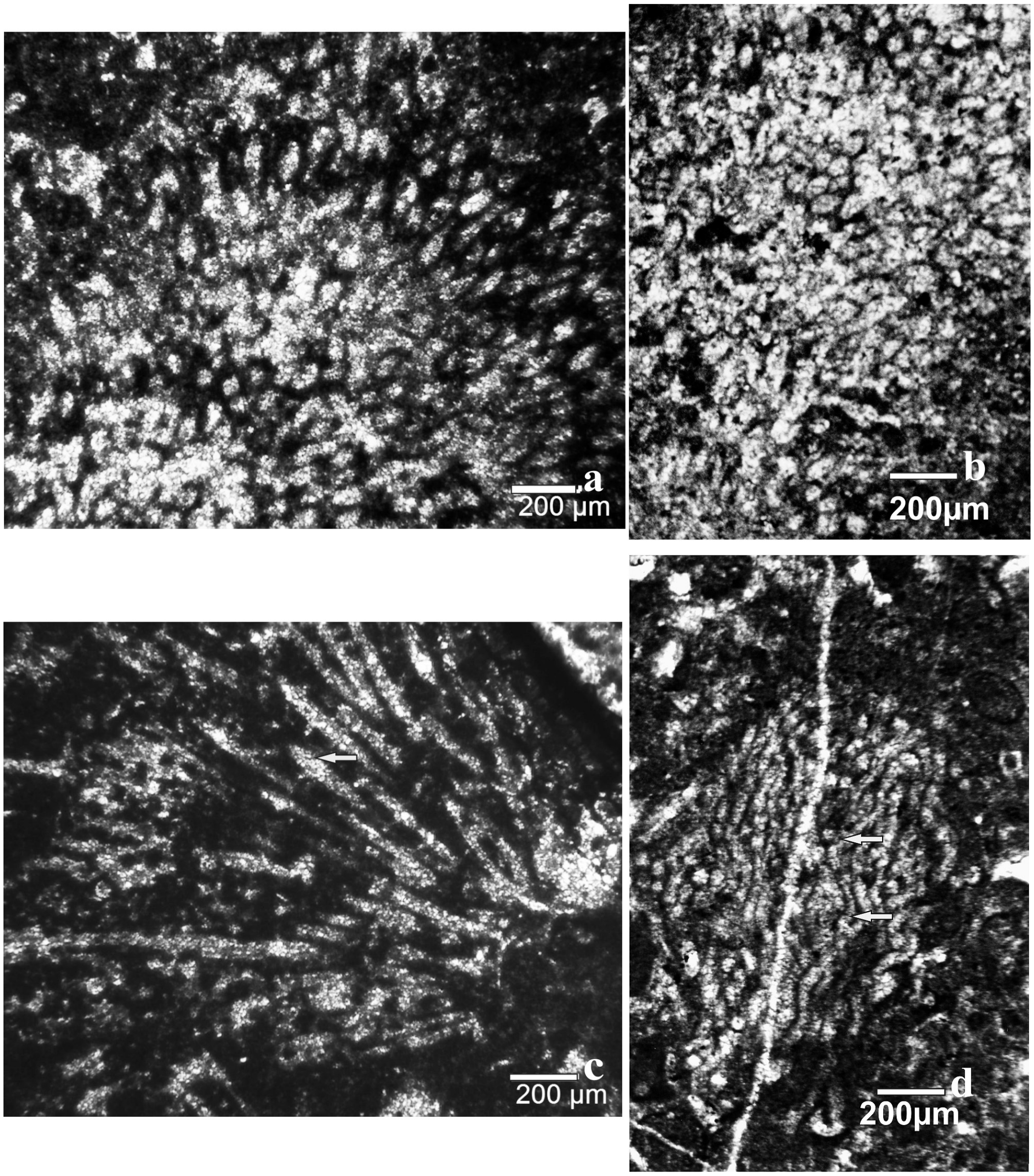

Figure 3. Cenomanian rivulariacean-type cyanobacteria from the El Abra Formation. a) Longitudinal section of *Cayeuxia kurdistanensis* (Sample LLC-1). b–c) Tangential section of *Cayeuxia kurdistanensis* (Sample LLC-1). d) Longitudinal section of *Garwoodia* sp. (Sample LLC-2).

verticils of laterals with two (exceptionally three, *e.g.*, in the living *N. stipitata* Howe, 1909) secondary sterile segments and, where they are fertile, one gametophore in terminal position (choristosporate type) per primary segment”.

Neomeris cretacea Steinmann, 1899
Figure 5 a,b

Neomeris (*Herouvalina*) *cretacea* Steinmann, 1899, p. 149–154, figs. 14–20; Raineri 1922, p. 74–75, figs. 5, 6; Basson and Edgell, 1971, p. 422, pI. 5, figs. 4, 5; Kuss, 1986 b, p. 228-230, fig. 5d; Kuss and Conrad, 1991, p. 872, fig. 2.17.

Description. Cylindrical, elongated thallus with a central hollow which have two types of ramifications: primary branches each bearing two sterile secondary branches which are situate on both sides of the fertile ovoid to ellipsoidal ampulla.

Measurements.
Outer thallus diameter (D) 650 µm.
Inner thallus diameter (d) 350 µm.
Sporangia diameter (p) 50 µm.

Remarks. *Neomeris cretacea* was first described by Steimann (1899) from the Cenomanian of Cerro Escamela in Mexico.

Stratigraphic distribution. The earliest representative of *Neomeris* should have been ‘‘born’’ at the transition between the Jurassic and the Cretaceous, considering the

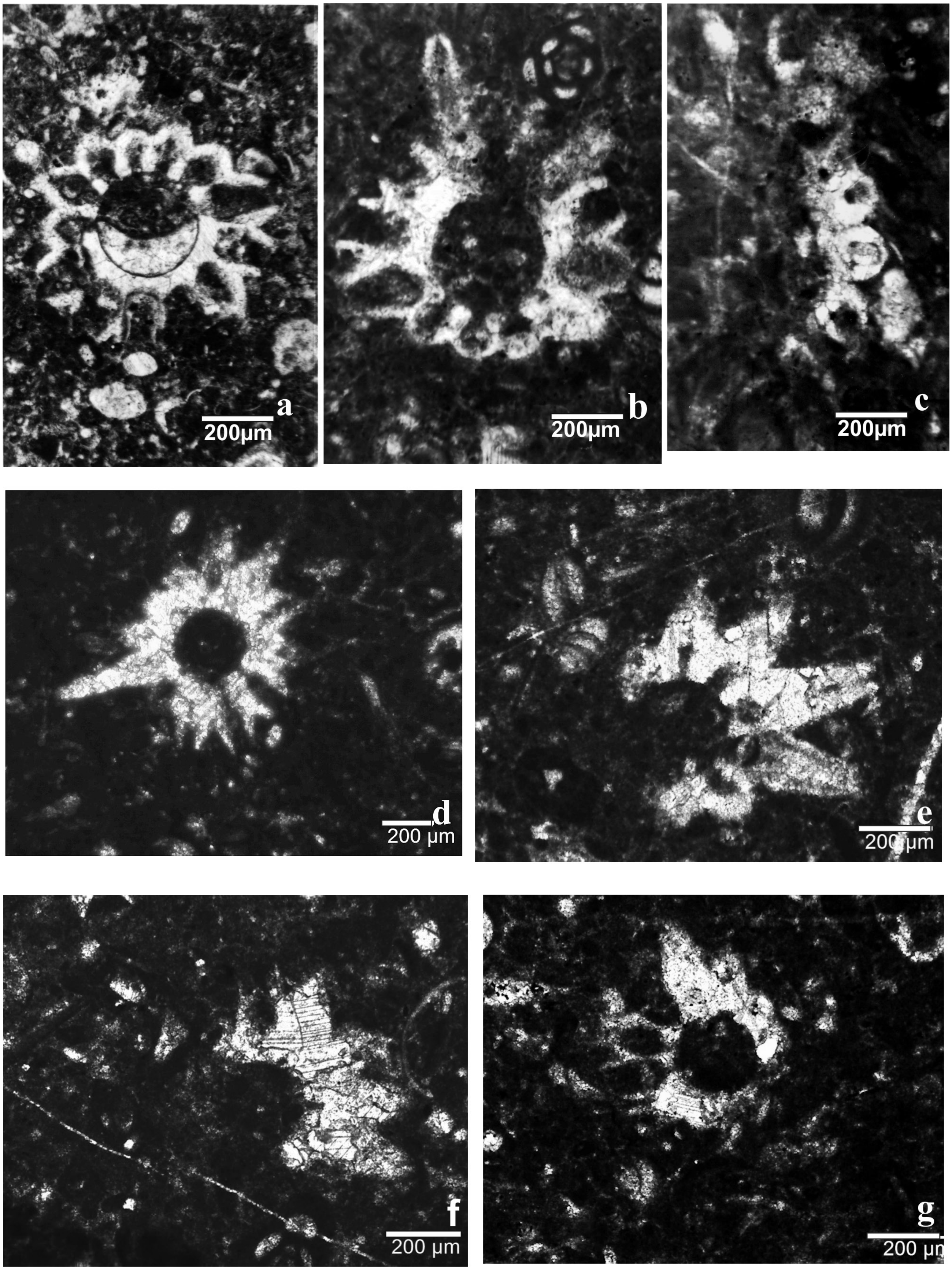

Figure 4. Cenomanian Dasycladacean algae from the El Abra Formation. a) Cross section of *Clypeina* sp. (Sample G-5). b, d, g) Cross section of *Clypeina* sp. (Sample G-5). c) Tangential section of a verticil of *Clypeina* sp. (Sample G-5). e–f) Cross section of *Clypeina* sp. (Sample G-5).

choristosporate model of reproduction, which is the main trait of the family Dasycladaceae, as emended by Granier and Bucur (Granier *et al*., 2012b).

Other reports are from the Late Cretaceous (Cenomanian-Turonian) of Iraq. In Lebanon it spans from late Aptian to Cenomanian, but the most typical specimens recorded are from Cenomanian (Basson and Edgell, 1971).

Occurrence. In our material we found this species only in the Temazcal (Sample ET-4) associated with *Daxia cenomana*, *Cuneolina pavonia*, *Cuneolina parva* and *Dicyclina schlumbergeri*.

Family Triploporellaceae Pia, 1920
Tribe Salpingoporelleae Bassoullet *et al*., 1979
Sub-tribe Salpingoporellinae Bassoullet *et al*., 1979

Genus *Salpingoporella* Pia, 1918 in Trauth, emend Carras *et al*., 2006

Type-species. *Salpingoporella muehlbergii* (Lorenz, 1902) Pia, in Trauth, 1918 emend. Carras *et al*., 2006.

Salpingoporella hasi Conrad, Radoičić and Rey, 1977
Figure 5 c

Salpingoporella hasi Conrad, Radoičić and Rey, 1977, pl. 1, fig. 5–6; Cherchi and Schroeder, 1980, pl. 1, 474; Kuss and Conrad, 1991, fig. 4.17; Radoičić, 1994, pl. 1, fig. 1; Sokač, 1996, pl. 2, fig. 1–5; pl. 8; Masse and Arnaud-Vanneau, 1999, pl. 1, fig. 11–12; Masse and Isintek, 2000, pl. 2, fig. 3–5; Radoičić, 2006, p.85, pl. 7, fig. 1

Original description. “Cylindrical thallus whose verticils are made up of a small number of branches, transversally flattened, and whose tubular proximal part is well developed. At their distal end, the branches widen out quickly and become rectangular. The nearby branches belonging to the same verticil may touch each other or not, depending on the space available, which in turn depends on their length and on the diameter of the siphon. The calcareous envelope is made up of a simple mosaic of hyaline crystals” (Carras *et al*., 2006).

Measurements.

Outer thallus diameter (D) 450 μm.

Inner thallus diameter (d) 250 μm.

Stratigraphic distribution. *Salpingoporella hasi* was described as an Albian-Cenomanian species of different localities of the Mediterranean region (Conrad *et al*., 1977). This species has been recorded in the Albian from the Karaburun Peninsula in Turkey (Masse and Isintek, 2000) and the Guyot Resolution in W Pacific (Masse and Arnaud-Vannaeu, 1999).

Occurrence. *Salpingoporella hasi* identified in the Guadalcazar site (Samples G-5).

Family Triploporellaceae (Pia, 1920) emend. Berger and Kaever, 1992
Subtribe Triploporellinae (Pia, 1920) emend. Bassoullet *et al*., 1979

Genus *Trinocladus* Raineri, 1922

Elliott (1972, p. 619) indicated that *Trinocladus* is composed of “successive verticils of radial branches, each branch showing outwardly widening primaries giving rise to several secondaries, and these in turn to bunches of tertiaries. Branches of the lower verticils may not show the full detail. Branches usually not alternate in position from verticil to verticil.”

Trinocladus cf. *T. divnae* Radoičic, 2006
Figure 5 e

Description. Fragment of longitudinal section with typical *Trinocladus* organization of the laterals with inflated parts of the secondaries that are well preserved and the occurrence of small tertiaries.

Measurements.

Length of segment 1250 μm.

Occurrence. *Trinocladus* cf. *T. divnae* identified in the Guadalcazar site (Samples G-5).

Bryopsidales
Udoteaceae

The Udotaceae in the Cretaceous are represented by assemblages of dissociated segments which have been referred to three genera, *Boueina*, *Arabicodium*, and Halimedaceae *Halimeda* (Bassoullet *et al*., 1983). Although the segments are different in size and shape and internal structure, they all coincide in possessing a longitudinal medullary zone and a cortical zone which is similar to that in living *Halimeda* and closely related to it.

Steinmann (1901) stated that *Boueina* can also be differentiated from *Halimeda* based on its external character. He claimed “that *Boueina* is a cylindrical, unbranching plant, then we may emphasize that this feature is not common for the genus *Halimeda*, in spite of the similarities concerning the internal structure. All *Halimeda* species are branched and articulated.”

Elliott (1965, p. 199) stated that *Boueina* “in thin-section shows a medullar zone of coarse tangled threads, and a cortex of approximately radial finer branching threads, whereas in *Halimeda* the central coarse threads are mostly longitudinally directed and the cortical threads show constrictions and swellings.” This last characteristic underlined by Steinmann (1901), Elliott (1965), and Bucur (1994) has been omitted by some subsequent authors who studied algae from the *Boueina-Arabicodium-Halimeda* group.

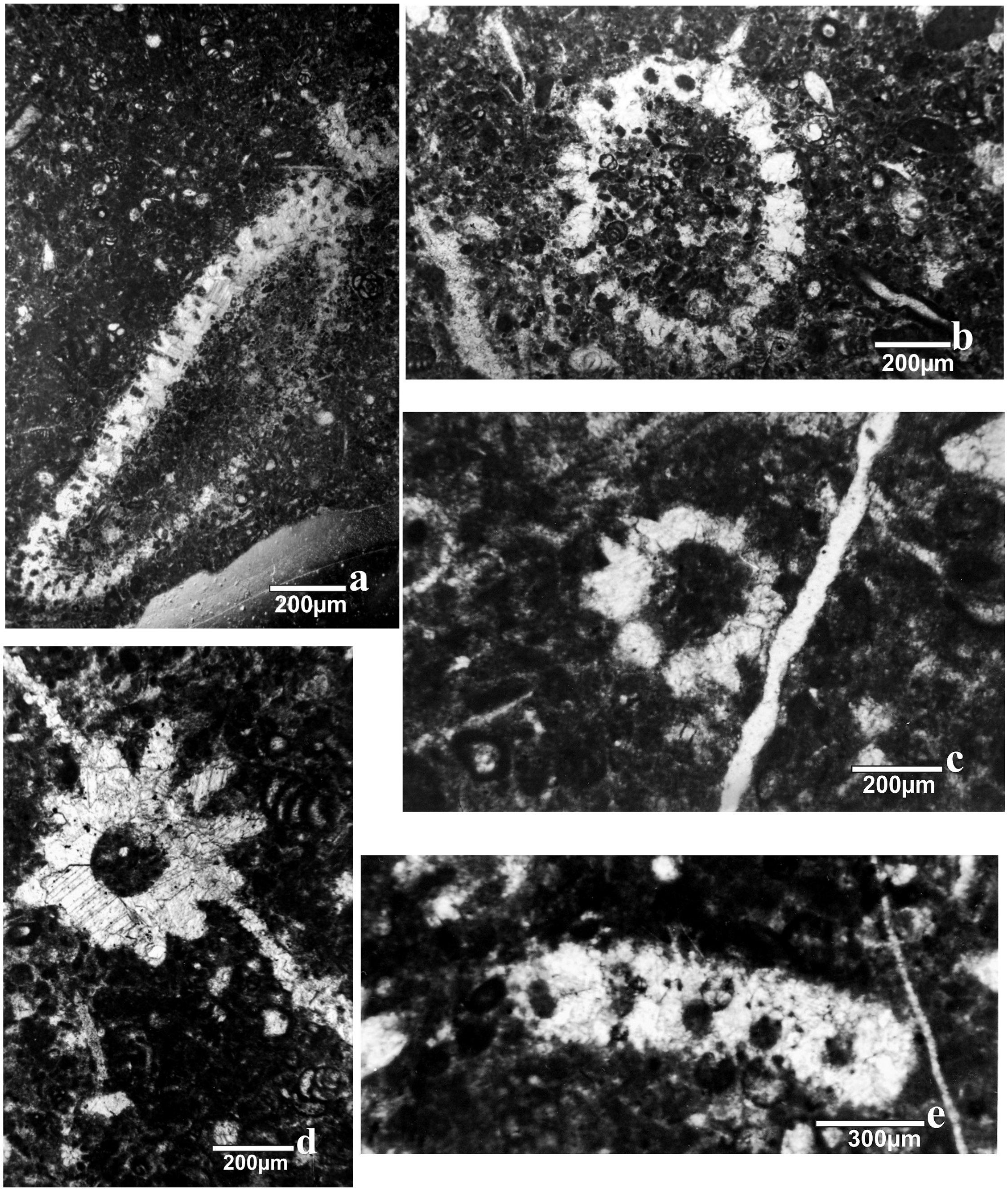

Figure 5- Cenomanian Dasycladacean algae from the El Abra Formation. a) Tangential section of *Neomeris cretacea* (Sample ET-4). b) Cross section of *Neomeris cretacea* (Sample ET-4). c) Cross section of *Salpingoporella hasi* (Sample G-5). d) Cross section of *Salpingoporella* sp. (Sample G-5). e) Longitudinal section of *Trinocladus* cf. *T. divnae* (Sample G-5).

Dragastan and Herbig (2007) indicated that "the classification of fossil-calcified-green siphonaceous algae is based on skeleton morphology. In general, internal morphology shows siphons, arranged in a central medulla and external cortex. Descriptive terms have been used with different meanings, such as tubes or filaments." Littler and Littler (1990, 1992) point out that the filament term, used by previous workers, is generally defined as a chain of cells and is incorrectly applied to siphonaceous algae such as *Udotea*, *Halimeda*, and *Penicillus*. They proposed the siphon terms for the medulla and utricle for the cortex.

Class Bryopsidophyceae Round, 1963
Order Bryopsidales Schaffner, 1922
Suborder Halimedineae Hillis-Colinvaux, 1984
Family Udoteaceae (Endlicher) Agardh, 1887–1888

Genus *Boueina* Toula, 1884

Type-species. *B. hochstetteri* Toula, 1884

Boueina pygmaea Pia, 1936
Figure 6 a

Boueina pygmaea Pia, 1936, p. 12–13, pl. 5, figs. 1–9; Elliot, 1965, p. 204, pl. 24, figs. 2, 6; Kuss, 1986, p. 231, fig. 5f-i; Kuss, 1994, p. 313, fig.9; Bauer *et al*., 2002, p. 17, pl. 4, fig. 3.

Description. Cylindrical thalli showing a strong calcification of the medullary and cortical zones. The interwoven siphons of the narrow medullary zone diverge to the cortical zone; toward the periphery where they then ramify into smaller utricules curving and diverging in all directions.

Measurements.

Height of thalli (h) 1250 µm.

Width of thalli 750 µm.

Medular zone 300 µm; cortical zone 450 µm.

Stratigraphic distribution. Pia (1936) described *Boueina pygmaea* from the Cenomanian-Turonian of Lybia. It has been recorded from the Cenomanian of France and Spain (Pfender, 1940; Ramírez del Pozo and López, 1988); Kuss (1994) found the species from the Cenomanian limestone of Gebel El Mushera in northern Sinai. Elliot (1965) reported *Boueina* cf. *B. pygmaea* from the Cenomanian of Bou-Saâda, Algeria.

Occurrence. We found *Boueina pygmaea* in the Llanos del Carmen site (Sample LLC-1).

Suborder Halimedineae Hillis-Colinvaux, 1984
Family Halimedaceae Link, 1832
Genus *Halimeda* Lamouroux, 1812

Halimeda cf. *H. ellioti* Conard and Rioult, 1977
Figure 6 b

Description. Cylindrical thalli, with elongated segments; large and thicker medullary zone crossed by tubular siphons that are extend as bifurcated cortical utricules which are inflated and constrained in their bases (Bucur *et al*., 2010).

Remarks. *Halimeda* cf. *H. ellioti* identified in our material is identical to Figure 9 (plate 6) illustrated by Radoičić (2006).

Measurements.

Length of segment 1950 µm.

Diameter of the medullary zone 400 µm.

Diameter of the cortical zone 200 µm.

Stratigraphic distribution. *H. elliotti* was described by Conard and Rioult (1977) from the Upper Cretaceous (Turonian) of southern France. Some Cenomanian-Turonian series in the Pastrik Mountain area (Kukes Cretaceous Unit) in Albania are characterized by the presence of the little-known udoteacean species *Halimeda elliotti* Conard and Rioult. "The inferences based on the data presented are that the range of *Halimeda elliotti* is from the middle Cenomanian into the middle Turonian and its maximum development is in the uppermost Cenomanian and lower Turonian" (Radoičić, 2005).

Occurrence. *Halimeda* cf. *H. elliotti* identified in the Llanos del Carmen locality (Sample LLC-1).

Family Gymnocodiacea Elliot, 1955
Genus *Permocalculus* Elliot, 1955

Type-species. *Permocalculus irenae* Elliot, 1955

Permocalculus budaensis Johnson, 1968
Figure 6 c, e

Permocalculus budaensis Johnson, 1968, p. 8, 9, pl. 1, figs. 2–5; Hernández Romano *et al*., 1998, p. 50, fig. 5d.

Description. Segmented thallus with cortical crenulations, with the sporangia in cortical or subcortical position. The weak calcification is responsible for the darker appearance of *P. budaensis* in comparison with other species of *Permocalculus* (Kuss and Conrad, 1991).

Measurements.

Height of thalli (h) 1350 µm.

Diameter of thalli 600 µm.

Stratigraphic distribution. *Permocalculus budaensis* was described and illustrated from the Buda Limestone of Cenomanian age (Johnson, 1968). Kuss and Conrad (1991) recorded the occurrence of the species in the Cenomanian of Jordan and within the Turonian of the Sinai.

Occurrence. This species was recorded from the Cerritos locality (Sample C-8).

Permocalculus irenae Elliot, 1955
Figure 6 d

Permocalculus irenae Elliot, 1955, p. 258–259, pl. 47, fig. 2, p1. 48, figs. 2–6; Johnson, 1965, p. 719, pl. 89, fig. 4; Basson and Edgell, 1971, p. 429, pl. 6, fig. 8; Kuss and Schlaginweit, 1988, p. 92, pl. 19, fig. 1; Shirazi, 2008, p. 803, pl. III, figs. 1–9.

Description. Slightly segmented thallus, segments long, ovoid or subcylindrical, irregular finger-like or pinched and swollen units with fine pores at outer zone, internal sporangia are not visible. Calcification varies from thin to thick layers to total calcification. Broken thalli fragments are often accumulated, creating the typical "algal-debris-facies" of Elliott (1958).

Measurements.

Height of thalli (h) 450 µm.

Diameter of thalli 300 µm.

Stratigraphic distribution. Elliott (1958) described *Permocalculus irenae* from the Cenomanian of northern Iraq; Cenomanian of Iran and Albian-Cenomanian of Lebanon reported by Basson and Edgell (1971). Kuss and Conrad (1991) recorded the species in the Albian from the Sinai and the Cenomanian from Jordan and northeastern Egypt.

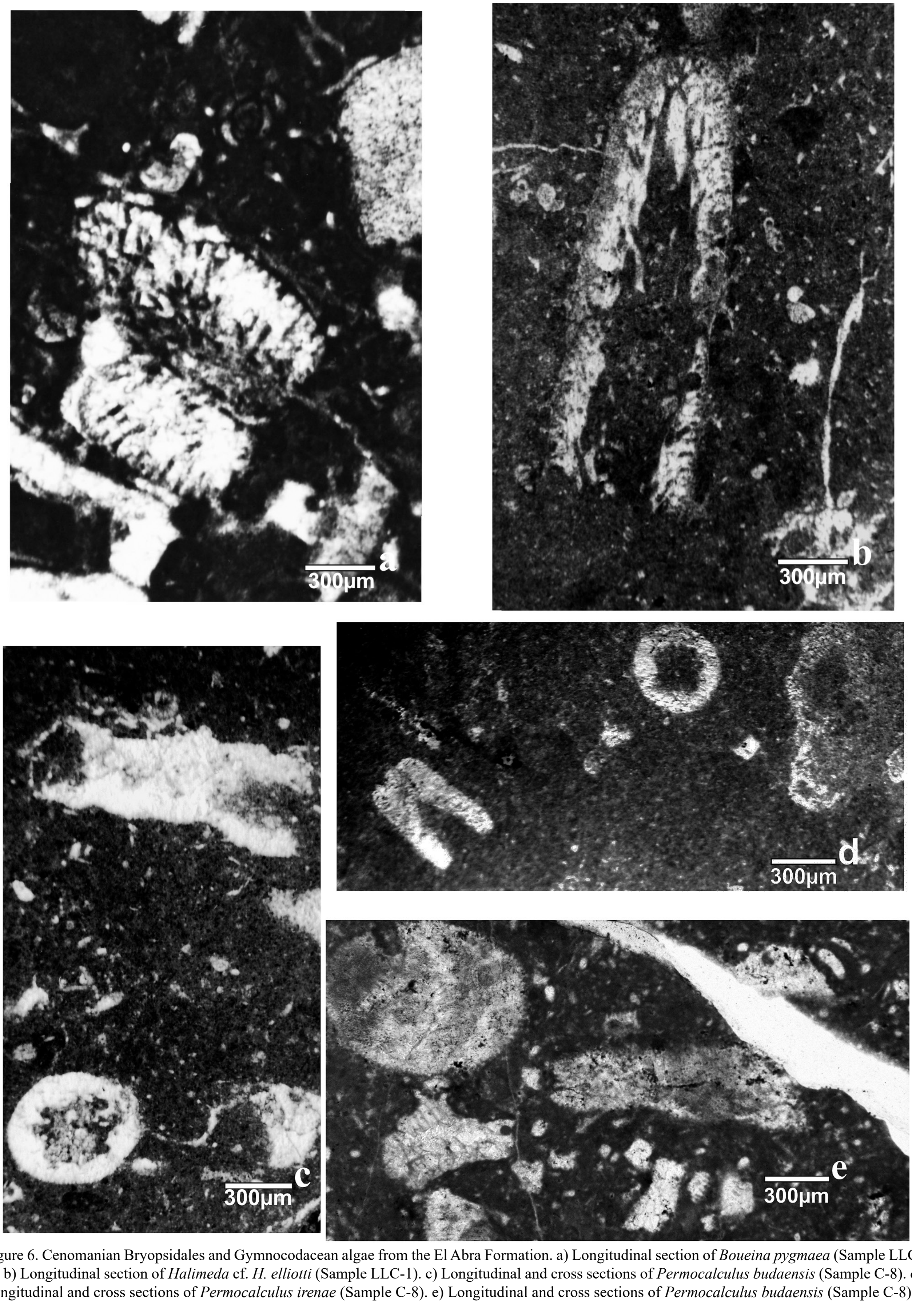

Figure 6. Cenomanian Bryopsidales and Gymnocodacean algae from the El Abra Formation. a) Longitudinal section of *Boueina pygmaea* (Sample LLC-4). b) Longitudinal section of *Halimeda* cf. *H. elliotti* (Sample LLC-1). c) Longitudinal and cross sections of *Permocalculus budaensis* (Sample C-8). d) Longitudinal and cross sections of *Permocalculus irenae* (Sample C-8). e) Longitudinal and cross sections of *Permocalculus budaensis* (Sample C-8)..

Occurrence. This species was recorded in Cerritos locality (Sample C-8).

Incertae sedis (Microencrusters)
Genus *Lithocodium* Elliot, 1956

Lithocodium aggregatum Elliot, 1956
Figure 7a, b

1956 *Lithocodium aggregatum* Elliot, p. 331, pl. 1, figs. 2, 4–5; Banner *et al*., 1990, p. 24, pl. 1, fig. 2, p. 31, pl. 4 fig. 1; Radoičić, 2005, pl. 5, figs. 1–6; pl. 6, figs. 1, 2; Schlagintweit and Bover-Arnal, 2011, p. 4, figs. 2e, g.

Description. The *Lithocodium* crusts consist of an irregular network and the periphery presents a thin alveolar system forming bifurcated filaments perpendicular to the surface.

Remarks. *Lithocodium aggregatum* was described by Elliott (1956) from Iraq. The taxonomic position of this encrusting microorganism has been controversial during recent decades. *Lithocodium aggregatum* was originally described as a siphonal (=non-septate filaments) codiacean alga by Elliot (1956) and interpreted also as a codiacean green algae by Banner *et al*. (1990). Its codiacean nature was accepted by many subsequent authors (Praturlon, 1964; Johnson, 1964; Poignat, 1968; Radoičić, 2005). Besides the assumed green algal nature, other authors such as Koch *et al*. (2002) indicated that *Lithocodium aggregatum* is more similar to sponges.

Schlagintweit (2010) and Schlagintweit *et al*. (2010) considered *Lithocodium* to be a filamentous-septate heterotrichale ulvophycean alga (order Ulotrichales?) exhibiting a heteromorphic life cycle consisting of two phases: an epilithic gametophytic stage and an euendolithic sporophytic (*Gomontia*) stage.

The taxonomic interpretation of *Lithocodium aggregatum* as sessile green algae (Schlagintweit *et al*., 2010) is accepted by Huck *et al*. (2012).

The taxon has been regarded as a foraminifer as well (Schmid and Leinfelder, 1995, 1996), which was discussed and rejected by Cherchi and Schroeder (2006) and Schlagintweit (2008); however, some authors, such as Dupraz and Strasser (2002), agree with the interpretation of Schmid and Leinfelder (1995, 1996) regarding the foraminiferal character of *Lithocodium aggregatum*. It has also been regarded as calcimicrobial colonies (Camoin, 1983). Cherchi and Schroeder (2006) showed that *Lithocodium aggregatum* is a colony of calcified cyanobacteria. This interpretation is confirmed by Conrad and Clavel (2008) who found that the *Lithocodium* crusts have a high organic content. Cherchi and Schroeder (2010, 2011, 2013) stated that *Lithocodium aggregatum* is a sponge (Entobia)-calcimicrobe consortium. They agree with the interpretation that these crusts are colonies of calcified microbes, probably cyanobacteria, which were transformed into dense, homogeneous micrite. Numerous occasionally broken needle-shaped sponge spicules and minute sedimentary particles were introduced by currents, trapped by calcimicrobial mucilage, and incorporated into the crusts.

Stratigraphic distribution. *Lithocodium aggregatum* ranging to the Late Triassic–Middle Cretaceous carbonate platforms of the Tethyan realm (Elliott, 1963; Flügel, 2004)

Occurrence. Identified from the Llanos del Carmen (Sample LLC-1).

Genus *Thaumatoporella* Pia, 1927

Thaumatoporella parvovesiculifera (Raineri 1922)
Figure 7 d–e

1922 *Gyroporella parvovesiculifera* n. sp. Raineri, p. 83, pl. 13, fig. 17–18.

Thaumatoporella parvovesiculifera (Raineri,1922): Pia, 1927, p. 69; Sartoni and Crescenti, 1962, p. 270, pl. 16; pl. 46, figs. 2–3, 5; De Castro, 2002, text-fig. 2, pl. 1, fig. 1–11; Flügel, 2004, p. 566, pl. 99, fig. 2; Senowbari-Daryan *et al*., 2011, p. 512, fig. 11–M; Schlagintweit, 2013, p. 8, figs. 8 d–e.

Description. *Thaumatoporella parvovesiculifera* (Rainieri, 1922) consists of an outer thin-walled structure with cells forming an irregular, lobed, ovoid to globular and cylindrical structure, with an internal cavity preserved as sparry calcite (Flügel, 2004).

Thaumatoporellaceans can be free-living, attached to hard substrates, or dwell as cryptoendoliths inside hollow bioclasts (Schlagintweit *et al*., 2013).

Remarks. Rainieri (1922) described *Gyroporella parvovesiculifera* from the Upper Cretaceous of southern Italy and placed it in the Dasycladacean algae. Later, Pia (1927) proposed the genus *Thaumatoporella* taking into account the differences between *Gyroporella* Raineri's genus, accepting its place within the Dasycladacean algae.

Pia (1938) observed that "the thalli were not growing in an upright position like that of the Dasycladacean but were creeping on the sea floor". This author noted the peculiarity of this genus which has no internal structure and emphasized the high variability in morphology and dimension including the width of the thallus, pore diameter, and wall thickness.

This problematic genus has been interpreted as red algae (Ramalho, 1971; Flügel, 1979), chlorophycean algae (Barattolo, 1991) and as a different group of green algae (De Castro, 1990). *Thaumatoporella parvovesiculifera* can be free-living or attached to hard substrates, as has been already observed by Schlagintweit and Velić (2012).

Stratigraphic distribution. *Thaumatoporella parvovesiculifera* successfully inhabited different shallow-water environments over a long period of more than 150 million years from the Middle Triassic (Landian) (de Castro, 1990; Flügel, 2004; Schlagintweit, 2012) to the lower Eocene (Ilerdian) in the Limalok Guyot (Central

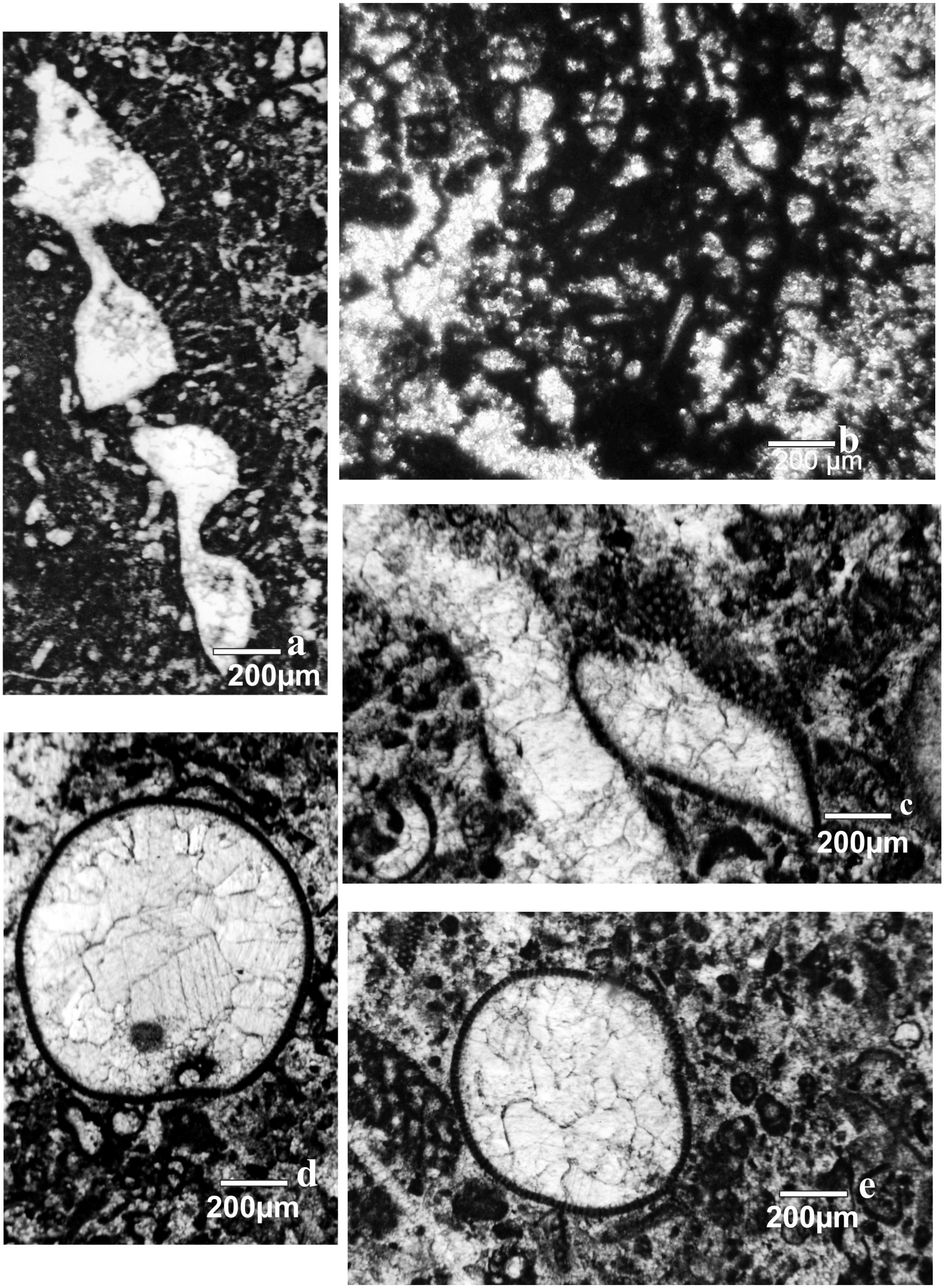

Figure 7. Cenomanian incertae sedis (microencrusters) from the El Abra Formation. a–b) *Lithocodium aggregatum* (Sample LLC-1). c–e) *Thaumatoporella parvovesiculifera* (Samples C-5, 6).

Pacific). At this site it was observed in younger sediments of middle Eocene (Lutetian) (Nicora *et al*., 1995). Later, Vecchio and Barattolo (2006) and Vecchio and Hottinger (2007) recorded thaumatoporellacean algae in southern Italy in the same interval; from these published data the occurrence of this fossil ranged to the Eocene (uppermost Ypresian–lowermost Lutetian).

Measurements.

Diameter 600–800 µm

Occurrence. *Thaumatoporella parvovesiculifera* was living free or on a hard substrate, as was already observed by Schlagintweit and Velić (2012). In our material it is very common in the Cerritos locality (Samples C-5, C-6).

5. Conclusions

The deposit of the upper part of the El Abra Limestone (Taninul Facies) contains a diverse algal and benthic foraminiferal assemblage. It is dated as mid-late Cenomanian based on the occurrence of *Pseudolituonella reicheli*, *Daxia cenomana* and *Merlingina cretacea*.

The textural features and the microfossil association allow for two different depositional environments to be inferred. The first is characteristic of a warm shallow-water carbonate platform with open circulation and medium-high hydrodynamic energy with a great diversity of benthic and algal species in an oligotrophic stage, and the other represents a reduction of the benthic foraminiferal assemblages associated with the gymnocodacean algae such as *Permocalculus irenae* and *P. budaensis*, which could be related to increasing nutrient availability in mesotrophic conditions.

The algal association is typical Tethysian, similar to Mediterranean localities.

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New records and redescriptions of brazilian Scleractinia corals (Itamaracá, Maria Farinha and Pirabas Formations)

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Abstract

This work deals with the systematic study of the corals from Itamaracá, Maria Farinha and Pirabas formations (Lower Maastrichtian, Paleocene-Eocene and Lower Miocene, respectively) at Pernambuco and Pará states. Herein are presented the first records of the species *Actinastrea dickersoni* (Wells, 1941), *A. jukesbrownei* (Wells, 1945), *Caulastraea dendroidea* (Coryell and Ohlsen, 1929), *C. portoricensis* (Coryell and Ohlsen, 1929), *Ceratotrochus* (*C.*) sp., *Enallhelia* aff. *E. occidentalis* Wells, 1944, *Hydnophora latefundata* Gregory, 1895, *Stephanocoenia marylandica* (Conrad, 1841), *Trochocyathus* (*T.*) *collignoni* (Alloiteau, 1958) and *T.* (*Platycyathus*) sp. as well as redescriptions of *Cladocora* sp., *Stephanocoenia pernambucensis* Fernandes, 1978, *Stylophora silicensis* Weisbord, 1973 and *Paracyathus rugosus* Vaughan, 1900.

Keywords: Brazil, corals, Scleractinia, Maastrichtian, Tertiary.

Resumen

Especies de corales colectadas en estratos del Maastrichtiano Inferior, Paleoceno- Eoceno y Mioceno Inferior, correspondientes a las formaciones Itamaracá, Maria Farinha y Pirabas en Pernambuco y Pará provincias son identificadas y descritas. Esta fauna está representada por Actinastrea dickersoni (Wells, 1941), A. jukesbrownei (Wells, 1945), Caulastraea dendroidea (Coryell and Ohlsen, 1929), C. portoricensis (Coryell and Ohlsen, 1929), Ceratotrochus (C.) sp., Enallhelia aff. E. occidentalis Wells, 1944, Hydnophora latefundata Gregory, 1895, Stephanocoenia marylandica (Conrad, 1841), Trochocyathus (T.) collignoni (Alloiteau, 1958) y T. (Platycyathus) sp. También se presentan redescripciones de Cladocora sp., Stephanocoenia pernambucensis Fernandes, 1978, Stylophora silicensis Weisbord, 1973 y Paracyathus rugosus Vaughan, 1900.

Palabras clave: Brasil, corales, Scleractinia, Maastrichtiano, Terciario.

1. Introduction

One of the biggest gaps of Brazilian paleontological research is the systematic characterization of corals, especially the marine Post Paleozoic in sedimentary basins of the continental margin. Although coralinofauna is rare in the majority of litostratigraphic units, its definition expands the body of knowledge about the Cretaceous and Tertiary corals, helping to define detailed biogeographic patterns in the Caribbean and South America regions.

This paper deals with the systematic study of 35 specimens of Itamaracá, Maria Farinha and Pirabas formations, deposited in the collections of Departamento de Geologia, Centro de Tecnologia e Geociências da Universidade Federal de Pernambuco (DGEO-CTG-UFPE), Museu Nacional/Universidade Federal Rio de Janeiro (MN/UFRJ), and Museu de Geociências-Universidade Federal do Pará (MG/UFPa).

The records of corals of the Itamaracá Formation were only cited before by Oliveira (1957) and Moura (2007). Regarding the Maria Farinha Formation, its corals were initially mentioned by Rathbun (1875), Oliveira (1953), Kegel (1955) and Beurlen (1959), but these authors only cited their occurrences. The systematic characterization of these invertebrates was introduced by Fernandes (1978, 1984), which proposed the new species *Stephanocoenia pernambucensis* and *Madracis whitei* and recognized *Paracyathus rugosus* Vaughan and *Caryophyllidae* gen. et sp. indet. At Pirabas Formation Maury (1925), Fernandes (1979, 1981), Távora *et al*. (2002, 2015) and Lalor and Távora (2006), have described a total of 15 to date.

In Pernambuco state (Figure 1) the specimens come from the Fosforita quarry, Olinda city (8º 0' 34" S, 34º 51' 19" W), Poty quarry, Paulista city (7º 56' 24" S, 34º 52' 20" W) and Zumbi mill, Igarassu city (7º 50' 4" S, 34º 54' 23" W). Atalaia and Maçarico beaches, Salinopolis city (0º 36' 5" S, 47º 18' 48" W), Fortaleza Island, São João de Pirabas city (0º 41' 43" S, 47º 10' 23" W), and Caieira locality, Capanema city (1º 12' 19" S, 47º 9' 25" W), are the localities where specimens were collected at Pará state (Figure 2). The majority of these corals were reef-building species, lived in symbiotic relationship with zooxanthellae algae and limited their ecologic distribution to substrates in shallow, well-lit, warm marine waters.

2. Location and Stratigraphy

The Paraíba Basin in northeastern Brazil occupies a continental area of about 7600 km^2 and oceanic area about 31400 km^2, extending along a continental shelf more than 3000 m deep, where a complete carbonate sequence of Cretaceous-Paleogene rocks are present. The depositional history of these rocks started with the Beberibe Formation, followed by the Itamaracá, Gramame and Maria Farinha formations, deposited on a steep distal carbonate ramp (Nascimento-Silva *et al*., 2011).

The Itamaracá Formation is a transitional unit formed during continental to marine stage, represented by an estuarine, coastal lagoon and tidal plain deposits, with marine and brackish fossils. This formation is mainly composed by siliciclastic sediments, mixed and bioelementary facies including phosphatic calciferous sandstones, shales and limestones with fossiliferous siliciclastic deposits, as well as phosphorites on the upper portion. They appear in its uppermost stratum, characterizing a maximum flood surface that separates a transgressive tract system from a high stand tract. Its fossiliferous content includes corals, bivalves, gastropods, cephalopods, polychaets, echinoids, fishes, reptiles, foraminifera, coprolites and plants that suggest Lower Maastrichtian age (Nascimento-Silva *et al*., 2011; Moura, 2007; Silva, 2014).

The Maria Farinha Formation is composed of limestones, marly limestones and thick levels of marls in its lower

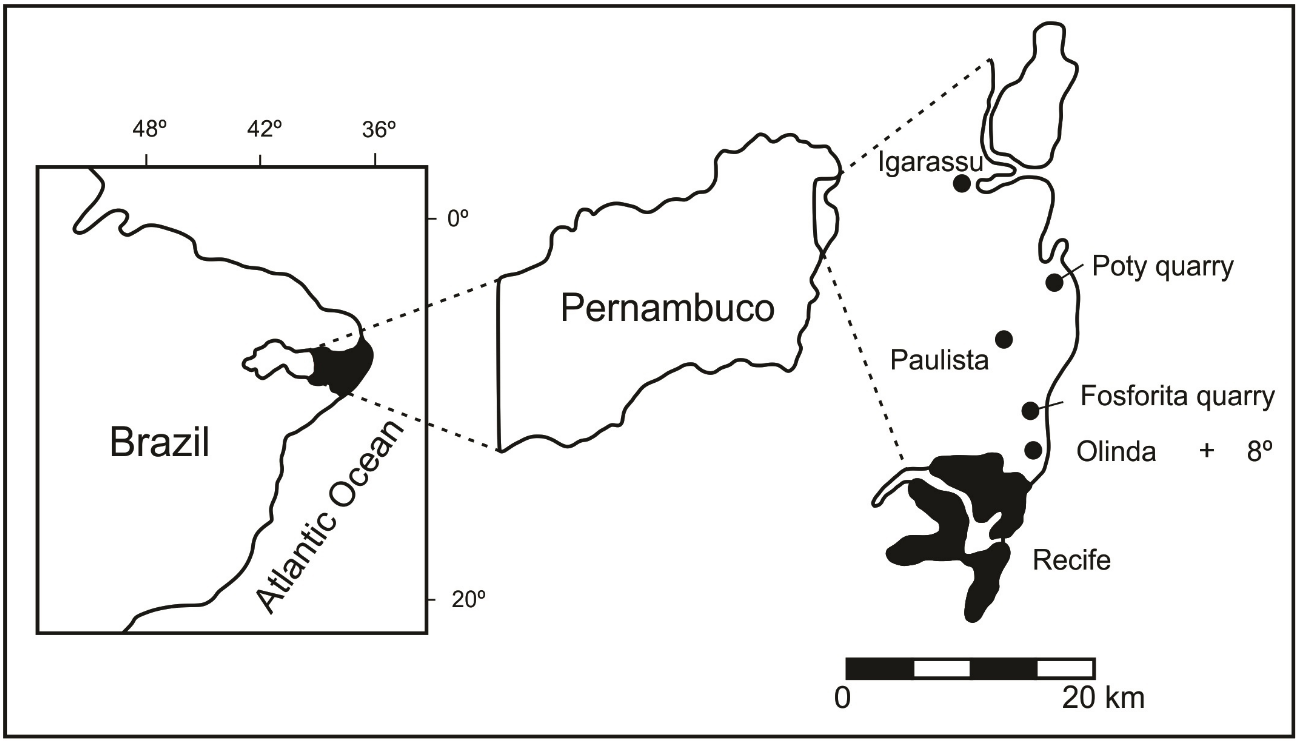

Figure 1. Map showing the study area in Pernambuco state, pointing the localities and cities where the fossil corals were collected (Távora and Miranda, 2004).

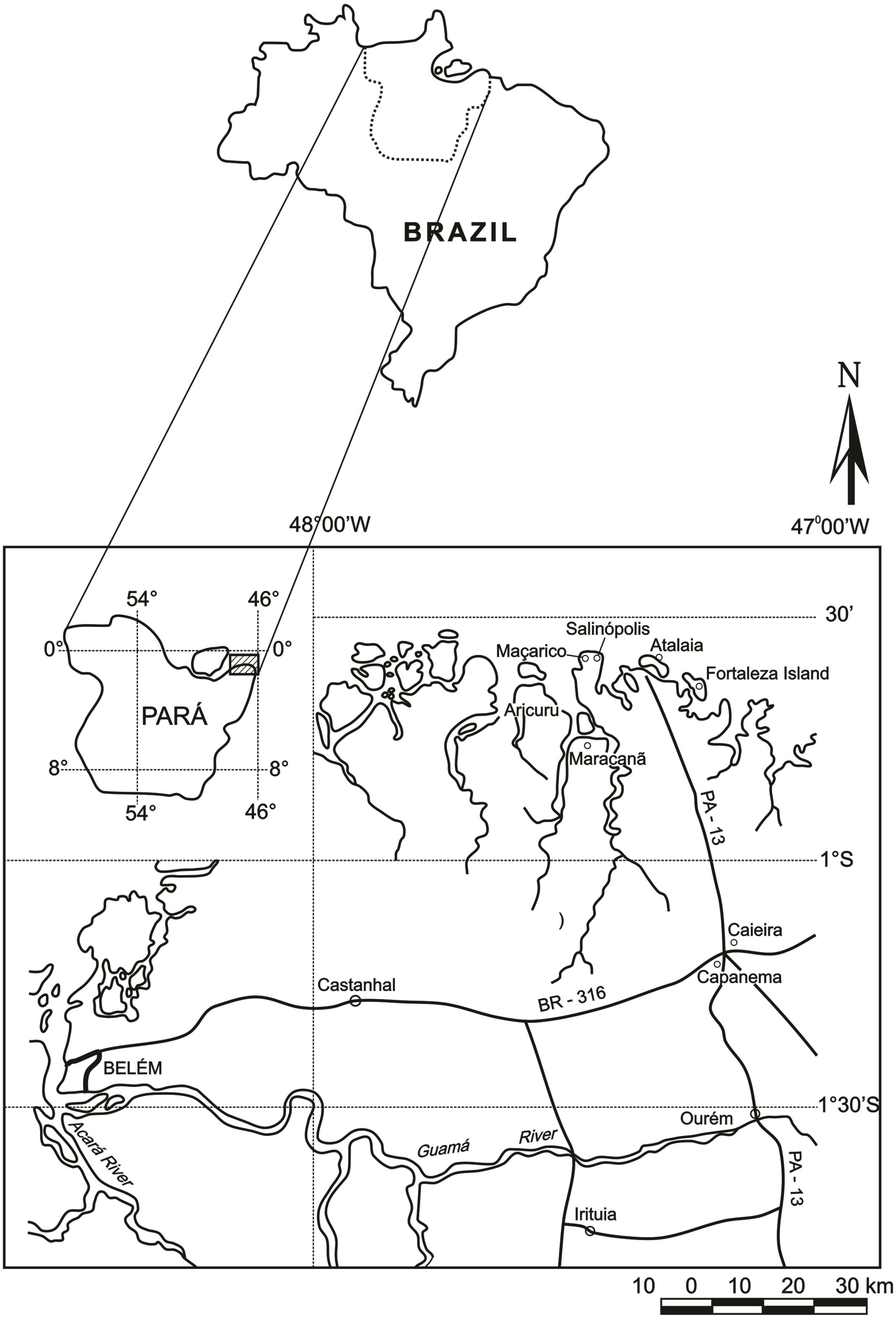

Figure 2. Map showing the study area in Pará state, pointing the localities and cities where the fossil corals were collected.

portion, while dolomitic limestones, containing fossil reefs and lagoonal reefs, characterize its upper portion. This formation exhibits the regressive profile typical of high- to low-energy oscillations. At the contact between the Gramame and Maria Farinha formations, there is an erosional unconformity characterized by a carbonate sequence with intraclasts, which displays a conglomeratic look typically associated to the Cretaceous-Paleogene transition (Nascimento-Silva *et al*., 2011). The paleontological content of this litostratigraphic unit consists of calcareous algae, foraminifera, corals, bryozoans, bivalves, gastropods, cephalopods, decapods crustaceans, echinoderms, fishes, reptiles and plants of Paleocene-Eocene age (Távora and Miranda, 2004).

The sedimentary evolution in western Amazonia region during the Miocene was mostly influenced by NW-SE normal faults dipping northeasterly and also sets of NE-SW strike-slip and transfer faults. This geometry is a manifestation of the final extensional deformation phase of the Gondwana breakup responsible for the split of the South American and African continents (Costa *et al*., 1993; Rossetti and Góes, 2004).

The Pirabas Formation (Maury, 1925), with broad outcrops along the northeastern region of the Pará, Maranhão, and Piauí states, provides some of the best marine Cenozoic paleontological occurrences in Brazil. The Pirabas Formation type location is in the Pirabas River estuary, in the Bragantina platform east of Salinas County near Salinópolis city, northeastern Pará state (Rossetti and Góes, 2004). The Pirabas Formation consists of richly fossiliferous limestones that point out to a warm, shallow marine depositional environment where foraminifera, ostracods, porifera, corals, bryozoans, bivalves, gastropods, cephalopods, decapoda and cirripedia crustaceans, echinoderms, fishes, reptiles and mammals of Lower Miocene age thrived (Fernandes, 1981; Ramalho *et al*., 2015; Távora *et al*., 2010; Zagorsek *et al*., 2014).

3. Material and Methods

The samples analyzed comprise 34 specimens, all of them isolated corals, with colonial corals as dominant. The cnidaria are represented by external and internal moulds, some filled or replaced with finely crystallized calcite, displaying surface structures and fine ornamentation of partially well-preserved septal borders. The inner structures are not so well preserved due their more delicate nature. The analysis of these corals was carried out by using a Leika S6E binocular microscope, with the aid of a precision caliper for obtaining measurements. The photographs were obtained with a Sony DSC-HX1 digital camera.

The corals at the Itamaracá and Maria Farinha formations are very rare and the specimens illustrated are the best preserved. Detailed descriptions depend on the quality of the material, in cases where most diagnostic morphological structures are preserved. These structures, namely septa, pali and columella, were directly visualized with the aid of a stereomicroscope, making polished or thin sections unnecesary. In the Pirabas Formation this taxa ranges from little common to rare, excepting *Flabellum wailesi* Conrad, 1855, an abundant species.

4. Systematic Descriptions

The systematic classification and essential terminology used in this paper is mainly based on Wells (1956). The descriptions and nomenclature follow the proposal of Baron-Szabo (2006, 2008, 2014), Budd (1987), Budd and Johnson (1999), Cairns (1995), Cairns and Wells (1987), Filkorn *et al*. (2005), Roniewicz and Stolarski (1999) and Wells (1933, 1941a, 1941b, 1944, 1945, 1946). In addition, other complementary works such as Bosellini (1999), Budd *et al*. (1992), Fernandes (1978, 1979), Geyer (1954), Gregory (1895), Löser (2006), Löser *et al*. (2013) and Vaughan (1900, 1919) were considered.

The following abbreviations are used to indicate the dimensions of the corals: h: height; l: length; w: width; cd: calicular diameter; s: septa; cdp: calice's depth; c: costae's thickness and pd: pedicel's diameter. In the case of *Caulastraea dendroidea*, *C. portoricensis* and *Cladocora* sp. the size the corallites (dbc) it is also included, and *Stylophora silicensi*s and *Enallhelia* aff. *E. occidentalis* include the branch's diameter (bd) and branch's length (bl) measurements. The wt (walls' thickness) is also used to describe the cerioid and plocoid scleractinian taxa.

Order Scleractinia Bourne, 1900
Suborder Archaeocoeniina Alloiteau, 1952
Family Actinastraeidae Alloiteau, 1952

Genus *Actinastrea* d'Orbigny, 1849

Type species. *Actinastrea goldfussi* d'Orbigny, 1850

Diagnosis. Corallum colonial, massive, ramose or encrusting, cerioid to subcerioid or subplocoid. Corallites small, prismatic, directly united by septothecal walls, smooth or porous. Septa compact, radials, non-confluent and granulated laterally. Columella styliform well developed. Paliform lobes and endothecal dissepiments sparse and thin. Synapticulae situated laterally (Wells, 1956; Baron-Szabo, 2014).

Distribution. Jurassic–Recent (Geyer, 1954; Wells, 1956; Baron-Szabo, 2014).

Actinastrea dickersoni (Wells, 1941a)
Figure 3A

1941a *Astrocoenia dickersoni* Wells. Bull. Amer. Paleontology, v. 26, p. 5-6, pl. 2, fig. 4.

1984 *Madracis whitei* Fernandes. An. XXXIII Cong. Bras. Geol., v. 1, p. 312- 313, figs.1-3.

Description. Corallum colonial massive, encrusting, subplocoid to cerioid and irregularly spherical. Corallites small and numerous, cylindrical to subcylindrical, separated by thick, smooth and elevated septothecal walls. Calices monocentric and polygonal, hexagonal or pentagonal in outline, arched and moderately deep. Septa straight, equal to subequal, laminar, granulated laterally and hexamerally arranged in three incomplete to complete cycles, ranging from 16 to 24 units. Septal margins elevated, crenulated and ornamented by granules. The septa from the first cycle are thick and continuous with denticulate upper edges, and its terminations extend to the columella. The septa from the second cycle are smaller, also extending to the columella. The third cycle's septa are short, less than a half of the size of the first two cycles and do not merge to the columella. Columella well developed, small and styliform. Holotheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Cuba: Perseverancia Formation, Upper Cretaceous (Wells, 1941a); Brazil: Maria Farinha Formation, Paleocene-Eocene (Fernandes, 1984); Itamaracá Formation, Lower Maastrichtian (present study).

Material. four colony fragments (DGEO-CTG-UFPE-1537-A-C; DGEO-CTG-UFPE-2707) from the Fosforita quarry locality, Olinda city, Pernambuco state, Brazil.

Dimensions. (DGEO-CTG-UFPE-1537-A) h: 11 mm; l: 18 mm; cd: 2–2.7 mm; s: 18- 24; wt: 0.2- 0.6 mm; cdp: 0.3- 0.6 mm. (DGEO-CTG-UFPE-1537-B) h: 12 mm; l: 19 mm; cd: 1.7–2.5 mm; s: 16- 24; wt: 0.4–0.7 mm; cdp: 0.2–0.4 mm. (DGEO-CTG-UFPE-1537-C) h: 10 mm; l: 18 mm; cd: 1.8–2 mm.

Discussion. The taxonomic relationships between *Actinastrea* d'Orbigny, 1849 and *Astrocoenia* Milne Edwards and Haime, 1848 has been discussed in the past 60 years. Initially, Milne Edwards and Haime (1848) individualized the genus *Astrocoenia*, and d'Orbigny (1849) proposed *Actinastrea* based on morphologically identical copies, characterized by their small-calicular diameter colonial cerioids. Alloiteau (1954) corroborated the existence of two genus, based on the differences on the calicular extremities, septal walls, endothecal dissepiments and columella. Ever since, the characterization of the species assigned to the *Astrocoenia*-*Actinastrea* clade was confusing and insufficiently enlightening (Baron-Szabo, 2014).

Geyer (1954) considered *Astrocoenia* restricted to the Triassic, and positioned all of these clade's records from the Jurassic in *Actinastrea*. Löser (2012, 2013) proposed that Jurassic to Early Cretaceous corals assigned to *Actinastrea* belonged to the genus *Stelidioseris*. In the present research the authors follow Baron-Szabo (*op. cit.*). Thus, all species of Central and South America considered as *Astrocoenia* must be attributed in *Actinastrea*.

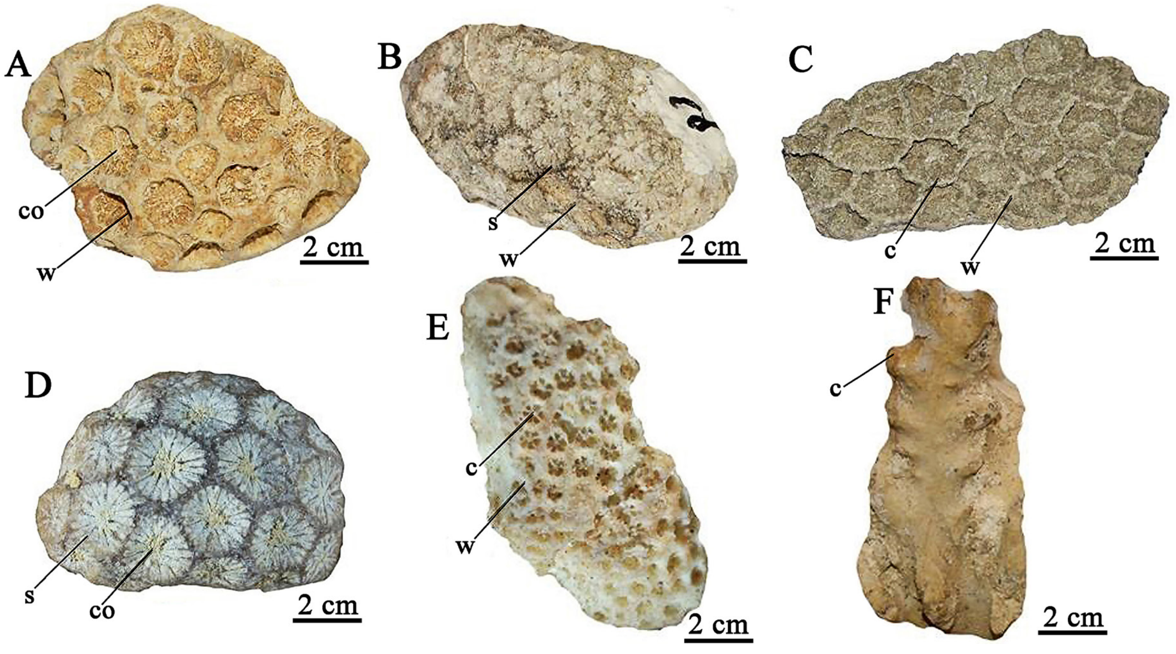

Figure 3. A) *Actinastrea dickersoni* (Wells, 1941) (DGEO-CTG-UFPE-1537-A): upper surface view of corallum subplocoid to cerioid, laminated septa, styliform columella and polygonal calices, separated by elevated walls; B) *A. jukesbrownei* (Wells, 1945) (DGEO-CTG-UFPE-2408): corallum cerioid to subcerioid and small and subcircular corallites, closely separated; C) *Stephanocoenia marylandica* (Conrad, 1841) (DGEO-CTG-UFPE-7667-A): upper surface view of corallum cerioid to subplocoid and polygonal and large calices; D) *S. pernambucensis* Ferreira, 1978 (MN-5415-I): upper surface view of corallum cerioid to subcerioid, styliform columella and polygonal calices, separated by septothecal walls; E) *Stylophora silicensis* Weisbord, 1973 (MN-5364-I): corallum plocoid to subplocoid and small and circular calices, separated by thick walls; F) *Enallhelia* aff. *E. occidentalis* Wells, 1944 (DGEO-CTG-UFPE-1540-A): upper surface view of subcylindrical branches and small and cylindrical corallites organized in one plane; (c: calice; co: columella; s: septa; w: walls).

The identifiable morphological features in *Actinastrea* sp. of the Upper Cretaceous of Mexico by Filkorn *et al*., (2005), resemble *A. dickersoni* but this species has the largest calices recorded and more numerous septa. There are also similarities in the shape of corallum, columella, calices and corallites of the *A. peruviana* (Wells, 1941b) and *A. kellumi* (Wells, 1946) recorded in the Lower Cretaceous of Peru and Upper Jurassic of Mexico, respectively. The specimens studied have more rounded and less numerous (18–24) calices and a distinct hexameral arrangement of septa. This is the first occurrence of this species on South America's Cretaceous, being previously restricted to the Cretaceous of Cuba.

The morphological review of *Madracis whitei* suggests that their diagnostic features are sufficient to consider it synonymous with *Actinastrea dickersoni*.

Actinastrea jukesbrownei (Wells, 1945)
Figure 3B

1945 *Astrocoenia jukesbrownei* Wells. Geol. Soc. America Bull., p. 3–4, figs. 4–5.

Description. Corallum colonial massive, encrusting, cerioid to subcerioid. Corallites small and prismatic, separated by porous and dentate septothecal walls. Calices monocentric, moderately deep, subcircular to polygonal, with three to six sides. Septa straight, equal to subequal, laminar, laterally smooth and octamerally arranged in two incomplete to complete cycles, ranging from 14 to 18 units. Septal margins elevated, subcrenulated and ornamented by granules. The septa from the first cycle are thicker, equal and continuous and its terminations extend to the columella, while in the second cycle are smaller, laminated and discontinuous, less than a half of the size of the first ones and doesn't merge to the columella. Columella well developed, styliform and suboval. Holotheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Jamaica: Troy Formation, Middle Eocene; Barbados: Scotland Formation, Middle Eocene; Panama: Gatuncillo Formation, Upper Eocene (Wells, 1945; Budd *et al*., 1992; Stemann, 2004); Brazil: Maria Farinha Formation, Paleocene-Eocene (present study).

Material. a colony fragment (DGEO-CTG-UFPE-2408) from the Engenho Zumbi locality, Igarassu city, Pernambuco state, Brazil.

Dimensions. h: 21.5 mm; l: 19.5 mm; w: 17 mm; cd: 1–1.5 mm; s: 14–18; wt: 0.1–0.2 mm; cdp: 0.3–0.5 mm.

Discussion. This taxon is very close to *A. incrustans* (Duncan, 1873) and *A. decaturensis* (Vaughan, 1919) in the skeletal elements, but these species show bigger-diameter corallites divided by thicker separation walls.

Suborder Astrocoeniina Vaughan and Wells, 1943
Family Astrocoeniidae Koby, 1890
Subfamily Astrocoeniinae Koby, 1890

Genus *Stephanocoenia* Milne Edwards and Haime, 1848

Type species. *Astrea intersepta* Lamarck, 1816.

Diagnosis. Corallum colonial massive, plocoid to subcerioid. Corallites small to medium size, separated by septothecal to parathecal walls. Septa disposed in three cycles with denticulate outlines and composed by a 12-paliform lobes system in the first and second cycles. Columella styliform. Endothecal and exothecal dissepiments, evenly spaced (Wells, 1956; Budd, 1987).

Distribution. Cretaceous–Recent (Wells, 1956; Budd, 1987).

Stephanocoenia marylandica (Conrad, 1841)
Figure 3C

1841 *Astrea marylandica* Conrad. Proceed. Acad. Nat. Sci. Philadelphia, v. 1, p. 28–33.

1904 *Septastraea marylandica* (Conrad). Vaughan, Maryland Geol. Sur., Miocene, Syst. Paleont., p. 444-447, pl. 126, figs. 1a, 1b; pl. 127, figs. 1–3; pl. 128, figs. 1–2; pl. 129.

1942 *Astrangia marylandica* (Conrad). Richards and Harbison, Acad. Nat. Sci. Priladelphia Proc., v. 94, p. 178, 224.

1971 *Septastraea marylandica* (Conrad). Weisbord, St. Florida, Dept. Nat. Res. Bureau Geol., Geol. Bull., n. 53, p. 47–52, pl. 12, figs. 1–7 (see complete synonymy in Weisbord, 1971).

Description. Corallum colonial massive, encrusting, cerioid to subplocoid. Corallites larger and prismatic, separated by dentate and delicate septothecal walls. Calices monocentric, polygonal, hexagonal, pentagonal and quadrangular in outline, broad and moderately deep. Septa straight, equal to subequal, thick, equidistant, laterally granulated and hexamerally arranged in three incomplete cycles, averaging from 12 to 18 units. Septal margins elevated, dentated and ornamented by granules. The septa from the first and second cycles are thicker, equal, and continuous, merged internally in a ring-shaped system of six pali around the columella. The third cycle's septa are short and laminated, less than a quarter of the size of the first two cycles and do not merge to the paliform system. Columella well developed, thick and styliform to papillose. Holotheca, trabecular structures and endothecal and exothecal dissepiments absent.

Occurrence. United States of America: Jackson Bluff Formation, Upper Miocene; Mary Formation, Miocene-Pliocene; Yorktown Formation, Miocene-Pliocene (Conrad, 1841; Richard and Harbison, 1942; Weisbord, 1971); Brazil: Maria Farinha Formation, Paleocene-Eocene (present study).

Material. two colony fragments (DGEO-CTG-UFPE-7667-A and DGEO-CTG-UFPE-7667-B) from the Poty quarry locality, Paulista city, Pernambuco state, Brazil.

Dimensions. (DGEO-CTG-UFPE-7667-A) h: 5 mm; l: 32.5 mm; w: 17 mm; cd: 3.5–5.5 mm; s: 12–18; wt: 0.3- 0.6 mm; cdp: 0.3–0.5 mm. (DGEO-CTG-UFPE-7667-I-B) h: 6.5 mm; l: 26.5 mm; w: 13 mm; cd: 3.5–4.5 mm; s: 12–18; wt: 0.2–0.4 mm; cdp: 0.2–0.3 mm.

Discussion. *Stephanocoenia marylandica* (Conrad, 1841) is similar to *S. pernambucensis* Fernandes, 1978, also recorded at the Maria Farinha Formation. The distinction between them is in the shape and arrangement of corallites and septa as well as separation walls and diameter of calices. In addition, the species herein described include affinities with *S. storrsi* Wells, 1941b recognized from the Eocene of Peru. However, the characters related to the corallites (diameter and separation walls), calice, septa, columella and paliform structures are different between these taxa.

Stephanocoenia pernambucensis Fernandes, 1978
Figure 3D

1978 *Stephanocoenia pernambucensis* Fernandes. An. XXX Cong. Bras. Geol., v. 2, p. 961, pl. I, figs.1–4.

Description. Corallum colonial massive, encrusting, cerioid to subcerioid and irregularly spherical. Corallites prismatic to subcylindrical, separated by smooth septothecal walls. Calices broad, shallow and monocentric, subcircular to polygonal (hexagonal and pentagonal) in outline. Septa straight, equal to subequal, thick, equidistant, laterally smooth and hexamerally arranged in three complete cycles with 24 units. The septa from the first cycle are thicker, equal and continuous, merged internally in a ring-shaped system of six pali around the columella. The septa from the second cycle are laminated and do not merge to the paliform system. The third cycle's septa are smaller and discontinuous, less than a quarter of the size of the first two cycles and do not merge to the paliform system. Columella well developed, central, thick and styliform. Holotheca, trabecular structures and endothecal and exothecal dissepiments absent.

Occcurrence. Brazil: Maria Farinha Formation, Paleocene-Eocene (Fernandes, 1978).

Material. Five colony fragments (MN-5415-I; MN-5416-I; MN-5417-I; MN-5418-I and MN-5419-I) from the Maria Farinha river, Maria Farinha district, Paulista city, Pernambuco state, Brazil, deposited on the paleoinvertebrates collection at the Museu Nacional/UFRJ.

Dimensions. (MN-5415-I, holotype) h: 6 mm; l: 11 mm; w: 8 mm; cd: 2–3 mm; s: 24; wt: 0.1–0.4 mm; cdp: 0.2–0.3 mm.

Discussion. This taxon is similar to *S. intersepta* (Esper, 1795) and *S. marylandica* (Conrad, 1841) in the corallum, coralites, calice and columella (Fernandes, 1978) but it is different in the size and arrangement of secondary septa, separation walls and paliform system.

Family Pocilloporidae Gray, 1842

Genus *Stylophora* Schweigger, 1819

Type species. *Madrepora pistillata* Esper, 1797 emend. Milne Edwards and Haime, 1850.

Diagnosis. Corallum plocoid, ramose to submassive in shape, separated by compact walls. Corallites tending to spiral irregularly around branches. Septa compact with the first cycle attached to styliform columella. Endothecal dissepiments delicate and vesicular (Wells, 1956; Baron-Szabo, 2006).

Distribution. Eocene-Recent (Wells, 1956).

Stylophora silicensis Weisbord, 1973
Figure 3E

1973 *Stylophora silicensis* Weisbord. Bull. State Florida Dept. Nat. Res. Div. Int., Res. Bureau Geol., v. 53, p. 20–22, pl. 2, figs. 1–4.

1979 *Stylophora* cf. *S. silicensis* Weisbord. Fernandes, Bol. Mus. Par. Emílio Goeldi, n. ser. Geol., 22, p. 16–19, est. I, figs. 1–4.

Description. Corallum colonial massive to branching, plocoid to subplocoid, with subcircular branches in cross section. Corallites cylindrical, small and numerous, disposed obliquely in longitudinal section and separated by thick and smooth walls. Calices circular to subcircular disposed irregularly or regularly in transverse rows, monocentric, moderately deep and elevated in their superior edges. Septa straight, equal to subequal, laminar, equidistant and hexamerally arranged in three incomplete to complete cycles, averaging from 20 to 24 units. Septal margins slightly concave and smooth. The septa from the first cycle are thicker, equal and continuous, merged internally to the columella. The septa from the second and third cycles are smaller, discontinuous, rudimentary and do not merge to the columella. Columella well developed, circular, central and styliform. Holotheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. United States of America: Tampa Formation, Lower Miocene (Weisbord, 1973); Brazil: Pirabas Formation, Lower Miocene (Fernandes 1979).

Material: Three colony fragments (MN- 5364-I; MN-5365-I and MN-5366-I) from Atalaia beach locality, Salinopolis city, Pará state, Brazil, reposited on the paleoinvertebrates collection at the Museu Nacional/UFRJ.

Dimensions. (MN- 5364-I) h: 20 mm; l: 40 mm; cd: 1–1.2 mm; bd: 0.6–9 mm; wt: 0.2–0.6 mm; cdp: 0.2–0.3 mm. (MN- 5365-I) l: 45 mm; cd: 1–1.2 mm; wt: 0.4–0.7 mm.

Discussion. Fernandes (1979) recognized similarities in branches, corallites, calice and septa with the species of the Lower Miocene of Florida, *S. minutissima* Vaughan, 1900 and *S. imperatoris* Vaughan, 1919 (Weisbord, 1971; 1973). Moreover, they are similar with *S. affinis* Duncan, 1863 (Pleistocene of Sudan) in corallum, corallites and columella, but very different in diameter of calices and number of septa (Hamed, 2015).

Suborder Stylinina Alloiteau, 1952
Family Stylinidae d'Orbigny, 1851
Subfamily Euheliinae de Fromentel, 1861

Genus *Enallhelia* Milne Edwards and Haime, 1849

Type species. *Lithodendron compressum* Goldfuss, 1829 emend. Milne Edwards and Haime, 1851.

Diagnosis. Corallum colonial branching to dendroid. Corallites and calice may anastomose, lying in one plane. Costae thin, recovered by stereome. Columella styliform well developed (Wells, 1956).

Distribution. Middle Jurassic-Lower Cretaceous (Wells, 1956).

Enallhelia aff. *E. occidentalis* Wells, 1944
Figure 3F

1944 *Enallhelia occidentalis* Wells. Journ. Paleont., v. 18, n. 5, p. 437, pl. 70, figs. 4–6.

Description. Corallum colonial branching to dendroid with anastomosed and subcylindrical branches. Corallites small and cylindrical, organized in one plane, separated by smooth and compact parathecal walls. Calices circular to elliptical, monocentric and shallow. Septa equidistant and laminar, averaging from 10 to 12 units. Columella poorly preserved, small and styliform. Trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Venezuela: Barranquin Formation, Lower Cretaceous (Wells, 1944); Brazil: Itamaracá Formation, Lower Maastrichtian (present study).

Material. eight colony fragments (DGEO-CTG-UFPE-1540-A-H) from the Fosforita quarry locality, Olinda city, Pernambuco state, Brazil.

Dimensions. (DGEO-CTG-UFPE-1540-A) h: 15 mm; l: 30 mm; cd: 1.3–1.5 mm; bd: 3.5–4.5 mm; bl: 10–13mm; s: 10. (DGEO-CTG-UFPE-1540-B) h: 19 mm; l: 38 mm; cd: 1.2–1.3 mm; bd: 3.5–5.5 mm; bl: 10–16 mm; s: 12. (DGEO-CTG-UFPE-1540-C) h: 25 mm; l: 40 mm; bd: 5–5.5 mm; bl: 18 mm. (DGEO-CTG-UFPE-1540-D) h: 20 mm; l: 40 mm; bd: 5 mm. (DGEO-CTG-UFPE-1540-E) h: 29 mm; l: 21 mm; bd: 5 mm. (DGEO-CTG-UFPE-1540-F) h: 16 mm; l: 28 mm. (DGEO-CTG-UFPE-1540-G) h: 14 mm; l: 20 mm. (DGEO-CTG-UFPE-1540-H) h: 19 mm; l: 22 mm.

Discussion. The Stylinidae family is rare in the Occidental Atlantic (Löser *et al.*, 2013) probably due to environmental or taphonomic peculiarities. The genus *Enallhelia* Milne Edwards and Haime, 1849 and Oculina Lamarck, 1816 are very similar in the shape of corallum and calice but distinct in the size of corallum and calice, arrangement of corallites and septa (Wells, 1956). Furthermore the Lamarck genus is cenozoic and *Enallhelia* is restricted to the Cretaceous. *Enallhelia occidentalis* Wells, 1944 was proposed and recognized only in the Lower Cretaceous of Venezuela. The specimens studied herein show similarities but their skeletal elements calice and septa are obliterated due the preservation setting, preventing the undoubted systematic characterization of the species of the Barranquin Formation. Likewise there are resemblance with *E. anomalos* (Felix, 1891) and *E. somaensis* Eguchi, 1942, both found in the Cretaceous of Mexico (Löser, 2006; Löser *et al.*, 2013) in the corallum, columela, corallites and separation walls, but the calice, septa and arrangement of branches are dissimilar.

Suborder Faviina Vaughan and Wells, 1943
Superfamily Faviicae Gregory, 1900
Family Faviidae Gregory, 1900
Subfamily Faviinae Gregory, 1900

Genus *Caulastraea* Dana, 1846

Type species. *Caulastraea furcata* Dana, 1846.

Diagnosis. Corallum colonial phaceloid with intracalicular budding. Corallites circular to elliptical, with up to three distinct centers. Costae well developed. Columella trabecular to spongy, without paliform lobes. Endotheca vesicular and epitheca absent (Wells, 1956; Budd and Johnson, 1999).

Distribution. Eocene–Recent (Wells, 1956; Budd and Johnson, 1999).

Remarks. The species from genus *Caulastraea* herein studied were considered originally by Coryell and Ohlsen (1929) as belonging to the genus *Calamophyllia* Blainville, 1830.

Caulastraea dendroidea (Coryell and Ohlsen, 1929)
Figures 4A, 4B

1929 *Calamophyllia dendroidea* Coryel and Ohlsen. Scient. Sur. Porto Rico Virgin Island, v. 3, n. 3, pl. XXX, figs. 2–3.

1999 *Caulastraea dendroidea* (Coryell and Ohlsen, 1929). Bull. Amer. Paleont., v. 356, p. 39.

Description. Corallum colonial, dendroid, phaceloid and constituted by recurved and random arrangement branches, whose bifurcation angles are unequal and averaging from 25º to 30º between the three corallites. Epitheca thick, smooth, incomplete and rudimentary. Corallites monocentric and subcylindrical, with mid-lower segments united by a basal extremity. Calices subelliptical, shallow and laterally compressed. Septa arranged in five incomplete cycles (61 to 65 units), equal to subequal, recurved, continuous, laterally granulated, moderately thick, spaced on smaller cycles, compressed on the bigger ones and merged to the columella on the first three cycles. Costae well developed and straight, uninterrupted in the primary and secondary septa. Columella sublamellar and elongated. Exothecal dissepiments delicate and locally preserved on the lower third of the samples. Trabecular structures, paliform lobes and endothecal dissepiments absent.

Occurrence. Puerto Rico: Ponce Formation, Middle Miocene (Coryell and Ohlsen, 1929); Brazil: Pirabas Formation, Lower Miocene (present study).

Material. A colony fragment (MG-7151-I) from the Ponta do Castelo locality, Fortaleza island, São João de Pirabas city, Pará state, Brazil.

Dimensions. h: 56 mm; l: 43 mm; cd: 27–29 mm; dbc: 4 mm; s: 61–65; c: 1–1.5 mm.

Discussion. *Caulastraea dendroidea* (Coryell and Ohlsen, 1929) resembles *Retiophyllia dawsoni* (Clapp and Shimer, 1911) in some features of the corallum, corallites, calices and septa. However, *R. dawsoni* has thin epitheca, smaller number of septa, more reduced calicular diameter and common endothecal dissepiments. Also the species *C. dendroidea* is very similar to the *C. portoricensis* (Coryell and Ohlsen, 1929) in corallum, calice, septa and columella, but are distinct the epitheca thickness, size and bifurcation angle of corallites as well as the origin of branch points.

Caulastraea portoricensis (Coryell and Ohlsen, 1929)
Figures 4C, 4D

1929 *Calamophyllia portoricensis* Coryel and Ohlsen. Scient. Survey Porto Rico Virgin Island, v. 3, n. 3, p. 199–200, pl. 30, fig. 4.

1999 *Caulastraea portoricensis* (Coryell and Ohlsen, 1929). Budd and Johnson, Bull. Amer. Paleont., v. 356, p. 38–39, pl. 2, figs. 1-10, text-figures 4, 6, 21, 22.

Description. Corallum colonial, dendroid, phaceloid, branching and recurved. Branches multidirectional and characterized by unequal bifurcations varying from 35º to 45º between the five corallites. Epitheca delicate, smooth, incomplete and rudimentary. Corallites monocentric, subcylindrical and spaced, with lower segments united by a basal extremity. Calices shallow and laterally compressed, elliptical to subeliptical. Septa disposed in five incomplete cycles (48 to 52 units), equal to subequal, recurved, continuous, laterally granulated, moderately thick, spaced on smaller cycles, compressed on the bigger ones and merged to the columella on the first three cycles. Costae well developed and recurved, continuing from the primary and secondary septa. Columella sublamellar and elongated to styliform. Trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Puerto Rico: Lares de Calcário, Lower Miocene; Los Puertos and Ponce Formations, Middle Miocene; Mona Island, Upper Miocene; Dominican Republic: Mao Formation, Lower Pliocene; Bahamas: Upper Pliocene; Jamaica: Manchioneal and Hope Gate Formation, Plio-Pleistocene; Costa Rica: Moín Formation, Plio-Pleistocene (Coryell and Ohlsen, 1929; Budd and Johnson, 1999); Brazil: Pirabas Formation, Lower Miocene (present study).

Material. A colony fragment (MG-7152-I) from the Ponta do Castelo locality, Fortaleza island, São João de Pirabas city, Pará state, Brazil.

Dimensions. h: 46 mm; l: 62 mm; cd: 19–25 mm; dbc: 6 mm; s: 48–52; c: 1–1.5 mm.

Discussion. *Caulastraea portoricensis* (Coryell and Ohlsen, 1929) is like *Dermosmilia cretacica* Turnsek 1974 in corallum, calices, arrangement and thickness of septa, columella and costae. But *D. cretacica* is different in calices' shape and bifurcation angles, as well as having distinct biogeographic and biocronologic patterns. With *C. dendroidea* the differences are in the thickness of the epiteca, corallum's size, number of septa, bifurcation angles and branching points of corallites.

Subfamily Montastreinae Vaughan and Wells, 1943

Genus *Cladocora* Ehrenberg, 1834

Type species. *Madrepora flexuosa* Pallas, 1766.

Diagnosis. Corallum phaceloid-dendroid to subflabelloid. Wall septothecal and septoparathecal. Costosepta compact, finely granulated laterally and dentated marginally. Paliform lobes opposite all but last cycle of septa. Pseudo-columella formed by trabecular extensions of axial septal ends, irregularly parietal, spongy to papillose, sublamellar deeper in corallum. Endothecal dissepiments delicate (Wells, 1956; Baron-Szabo, 2006).

Distribution. Upper Cretaceous-Recent (Wells, 1956).

Remarks. According to Wells (1956), based on fossil and recent occurrence, the genus *Cladocora* is divided in *C.* (*Cladocora*) Ehrenberg, 1834 fossil and *C.* (*Dendrocora*) Duncan, 1876 recent subgenus, proposal not cited nor adopted in subsequent studies, (Eguchi, 1974; Baron-Szabo, 2006; Baron-Szabo *et al*., 2006) including this work.

Cladocora sp.
Figure 4E

Description. Corallum colonial phaceloid to dendroid, occupying a hollow cavity. Corallites branching, cylindrical and subparallel, without lateral connections. Calices circular to subcircular, monocentric and shallow. Septa subequal, continuous and thick, hexamerally arranged with 16 to 20 units. The septa from first cycle are thicker and merged internally to the center. Septal margins gently elevated, forming costae upwards the calicular margins. Columella apparently papillose, developed from the union of septa. Epitheca, paliform lobes, trabecular structures, endothecal and exothecal dissepiments absent.

Occurrence. Brazil: Pirabas Formation, Lower Miocene (Fernandes, 1979).

Material. One colony fragment (MN- 5363-I) from the Caieira locality, Capanema city, Pará state, Brazil, deposited on the paleoinvertebrates collection at the Museu Nacional/ UFRJ.

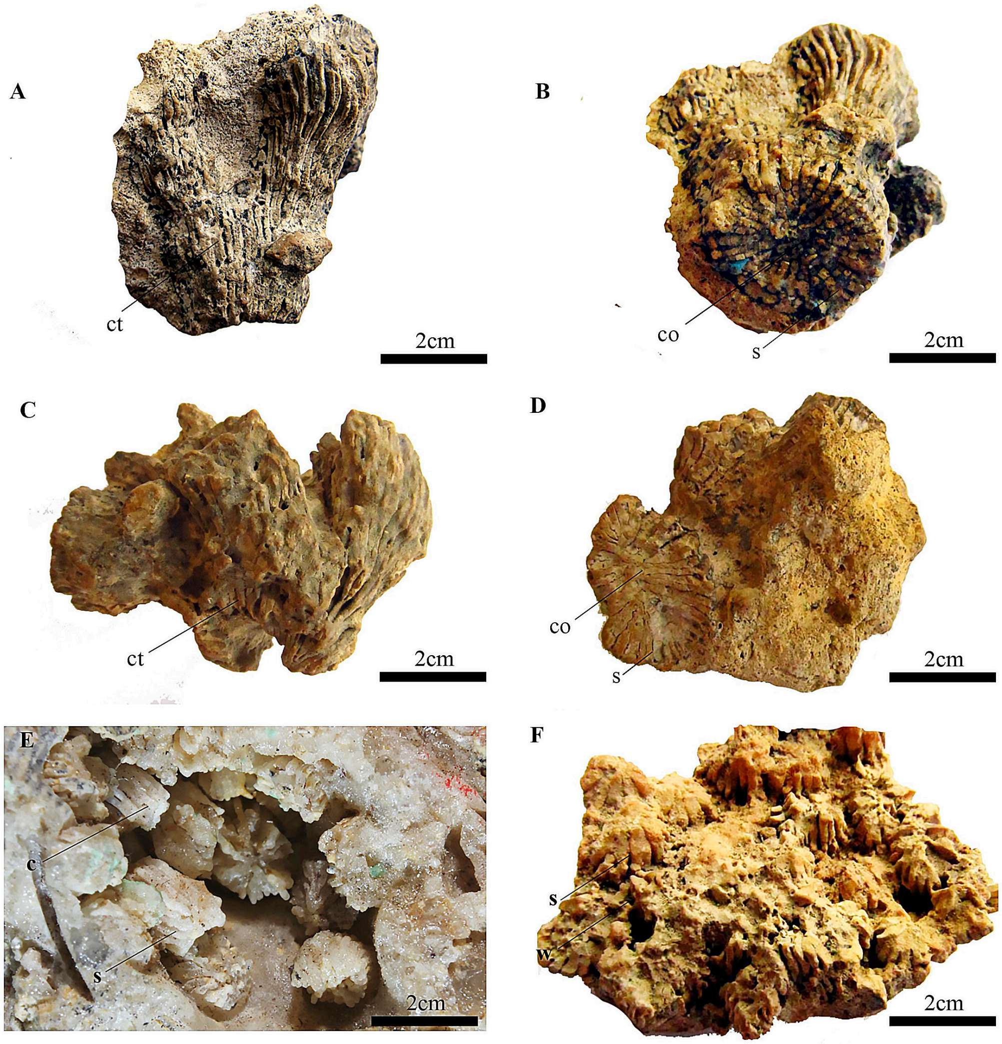

Figure 4. A) *Caulastraea dendroidea* (Coryell and Ohlsen, 1929) (MG-7151-I): lateral view of corallum phaceloid, subcylindrical corallites and a well-developed costae; B) *Caulastraea dendroidea* (Coryell and Ohlsen, 1929) (MG-7151-I): upper surface view of subelliptical calice, thick septa and sublamellar columella; C) *C. portoricensis* (Coryell and Ohlsen, 1929) (MG-7152-I): lateral view of corallum phaceloid, recurved, spaced corallites and a well-developed costae; D) *C. portoricensis* (Coryell and Ohlsen, 1929) (MG-7152-I): upper surface view of elliptical calice, thick septa and an elongated columella; E) *Cladocora* sp. (MN-5363-I): upper surface view of branching and cylindrical corallites and circular calices; F) *Hydnophora latefundata* Gregory, 1895 (MG-7153-I): upper surface view of conical and flat monticules, elevated calices and a discontinuous and lamellar columella; (c: calice; co: columella; ct: costae; s: septa; w: walls).

Dimensions. h: 10 mm; l: 40 mm; cd: 1–3 mm; dbc: 2–3 mm; s: 16–20; c: 0.1 mm.

Discussion. The morphology of corallum, corallites, costae and septa are diagnostic of the genus *Cladocora* (Wells, 1956; Baron-Szabo, 2006). The specimen is similar to *C. arbuscula* Lesueur, 1821 from the Plesistocene of Panamá and *C. johnsoni* Gane, 1895 from the Pliocene of United States of America in corallum, calice and columella, but is distinct in the septa, corallites and branches arrangement. The species definition is not possible to be stablished due to a lack of recognition of diagnostic morphological details from the calice and septa (Weisbord, 1974).

Family Merulinidae Verrill, 1866

Genus *Hydnophora* Fischer, 1807

Type species. *Hydnophora demidovii* Fischer, 1807.

Diagnosis. Corallum colonial massive, encrusting and hydnophoroid. Monticules conical to cylindrical, short and discontinuous, separated by septoparathecal walls. Septa compact, finely granulated laterally. Columella irregularly trabecular to lamellar, discontinuous. Endothecal dissepiments delicated and vesicular (Wells, 1956; Baron-Szabo, 2006).

Distribution. Cretaceous–Recent (Wells, 1956).

Hydnophora latefundata Gregory, 1895
Figure 4F

1895 *Hydnophora latefundata* Gregory. Quart. Journ. Geol. Soc. London, 51, p. 267–268. Pl. 11, fig. 1.

1901 *Hydnophora latefundata* Gregory. Vaughan, Samml. Geolog. Reichs-Museums in Leiden, v. 2, n. 1. p. 7.

1999 *Hydnophora latefundata* Gregory. Bosellini, Paläontologische Zeitschrift, v. 73, n. 3/4, p. 235–236.

Description. Corallum colonial, massive, encrusting, subplocoid to plocoid, The lateral fusion of corallites walls constitute special structures named monticules, that are numerous, with a shape varying between conical, flat, elongated, straight or slightly sinuous. Calices elevated, monocentric, irregularly distributed and subcircular to elliptical in outline. Septa straight, equal to subequal, thick, equidistant, laterally smooth and hexamerally arranged in three incomplete cycles, averaging from 18 to 23 units. The septa from the first cycle are thicker, equal and continuous, limited to the upper section of the monticules. The second and third cycle's septa are subequal and laminated, limited to the lower section of the monticules, near to the columella. Septal margins elevated, dentated and smooth. Columella lamellar and discontinuous. Holotheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Barbados: Miocene; Saint Croix: Miocene; Trinidad: Miocene (Gregory, 1895); Brazil, Pirabas Formation, Lower Miocene (present study).

Material. A colony fragment (MG-7153-I) from the Maçarico beach locality, Salinópolis city, Pará state, Brazil.

Dimensions. h: 13 mm; l: 49 mm; w: 44mm; cd: 5–8 mm; s: 18–23; wt: 0.8–1.4 mm.

Discussion. The genus *Hydnophora* is very similar to *Polyphylloseris* Fromentel 1857 in the corallum, septa and calices features (Wells, 1956) and has a distinct morphology between corallites and columella. *H. latefundata* Gregory, 1895 seems similar to *Agaricia agaricites* Linnaeus, 1758, in the septa and interseptal furrows (Vaughan, 1901). Also, the corallum and septa arrangement resembles *H. variabilis* (Duncan, 1873) from the Eocene of Saint Bartholomew and *H. reussi* (Duncan, 1868) from the Oligocene of Antigua. Meanwhile in *H. variabilis* the shape of calices and number of septa are different, and *H. reussi* possesses thicker separation walls of corallites and septotecate. Until now *H. latefundata* Gregory, 1895 is the only occurrence of this genus in the Miocene of the Caribbean region (Bosellini, 1999) and this research recognized it in the brazilian Miocene.

Suborder Caryophylliina Vaughan and Wells, 1943
Superfamily Caryophylliicae Gray, 1847
Family Caryophyllidae Gray, 1847
Subfamily Caryophylliinae Gray, 1847

Genus *Trochocyathus* Milne Edwards and Haime, 1848

Type species. *Turbinolia mitrata* Goldfuss, 1826 Milne Edwards and Haime, 1848.

Diagnosis. Corallum solitary fixed or free, variably conical, turbinate, ceratoid or discoidal. Costosepta compact finely granulated laterally. Pali opposite all but last cycle in two crowns. Columella fascicular or spongy. Endothecal dissepiments vesicular (Wells, 1958; Baron-Szabo, 2008).

Distribution. Middle Jurassic-Recent (Wells, 1956).

Subgenus *Trochocyathus* (*Trochocyathus*) Milne Edwards and Haime, 1848

Type species. *Trochocyathus* (*Trochocyathus*) *uber* Vaughan and Popenoe, 1935.

Diagnosis. Corallum turbinate to ceratoid. Calices' contour subelliptical to elliptical (Wells, 1956).

Distribution. Middle Jurassic-Recent (Wells, 1956).

Trochocyathus (*Trochocyathus*) *collignoni* (Alloiteau, 1958)
Figure 5A, 5B

1958 Paratrochocyathus collignoni Alloiteau. Ann. Géol. Madagascar, 25, p. 135-136, pl. 31, figs. 3–4.

1984 Paratrochocyathus collignoni Alloiteau. Turnsek *et al*., Palaeont. Am., n. 54, p. 475.

2000 Paratrochocyathus collignoni Alloiteau. Baron-Szabo, Bull. Nat. Hist. Mus., 56, p. 126.

2000 Paratrochocyathus collignoni Alloiteau. Looser, Cat. Cret. Corals, v. 1, p. 60.

2003 Paratrochocyathus collignoni Alloiteau. Turnsek *et al*., Gulf Coast Sec. Found. Spec. Publ. Geol., 1, p. 172, figs. 9j–9k.

Description. Corallum solitary small, turbinated, ceratoid to trochoid and elliptical transversally. Calice monocentric and slightly depressed, elliptical to subelliptical on the upper edge and fixed by a recurved and subcircular pedicel. Costosepta well defined on the calicular margin, continuous, irregularly to regularly spaced and separated by shallow and planed furrows. Septa hexamerally arranged in five incomplete to complete cycles with 48 to 55 units, equal to subequal, laterally smooth and irregularly spaced. The septa from the first and second cycle are thicker, equal, elongated and merged internally in a ring-shaped system of pali around the columella. The third and fourth cycle's septa are laminated and apparently do not merge to the paliform system. The septa from the fifth cycle are smaller, incomplete and delicate. Fosseta subcircular and moderately deep. Columella spongy, delimited by the paliform system. Epitheca, trabecular structures, endothecal and exothecal dissepiments absent.

Occurrence. Madagascar: Ambarimaninga, Albian; United States of America: Finlay and Del Norte Formations, Middle-Upper Albian (Alloiteau, 1958; Turnsek *et al.*, 2003); Brazil: Itamaracá Formation, Lower Mastrichtian (present study).

Material. two specimens (DGEO-CTG-UFPE-1541-A-B) from the Fosforita quarry locality, Olinda City, Pernambuco state, Brazil.

Dimensions. (DGEO-CTG-UFPE-1541-A) h: 22 mm; l: 14 mm; w: 12 mm; cd: 14 mm; s: 55; c: 0.1–0.3 mm; pd: 0.7 mm. (DGEO-CTG-UFPE-I541-B) h: 14 mm; l: 13 mm; w: 0.6 mm; cd: 13 mm; s: 48; c: 0.1 mm.

Discussion. This species that occurs in the Cretaceous of Madagascar and United States of America was originally described in the genus *Paratrochocyathus* Alloiteau, 1958 and was later confirmed by Turnsek *et al*. (2003). According to Baron-Szabo (2000) it is synonymous to the genus *Paratrochocyathus* and *Trochocyathus*, due the similar morphological features of pali and columella, assignment adopted in this work. The specimen studied is similar to *T. woolmani* Vaughan, 1900 from the Cretaceous of United States of America but *T.* (*T.*) *collignoni* possess bigger corallum, ovalate calice and numerous septa (Wells, 1933).

Subgenus *Trochocyathus* (*Platycyathus*) Fromentel, 1863

Type species. *Trochocyathus* (*Platycyathus*) *terquemi* Milne Edwards and Haime, 1857 emend. Wells, 1933.

Diagnosis. Like *T*. (*Trochocyathus*) but corallum discoidal and free (Wells, 1956; Baron-Szabo, 2008).

Distribution. Cretaceous-Recent (Wells, 1956).

Trochocyathus (*Platycyathus*) sp.
Figure 5C

Description. Corallum solitary small, ceratoid to trochoid, transversally discoid. Calice circular, monocentric and shallow. Costosepta straight to sinuous, continuous, irregularly spaced and separated by deep and rounded furrows. Septa hexamerally arranged in four incomplete to complete cycles with 40 to 48 units, equal to subequal, laterally granulated and irregularly spaced. The septa from the first cycle are thicker and more elongated than others. Columella, epitheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

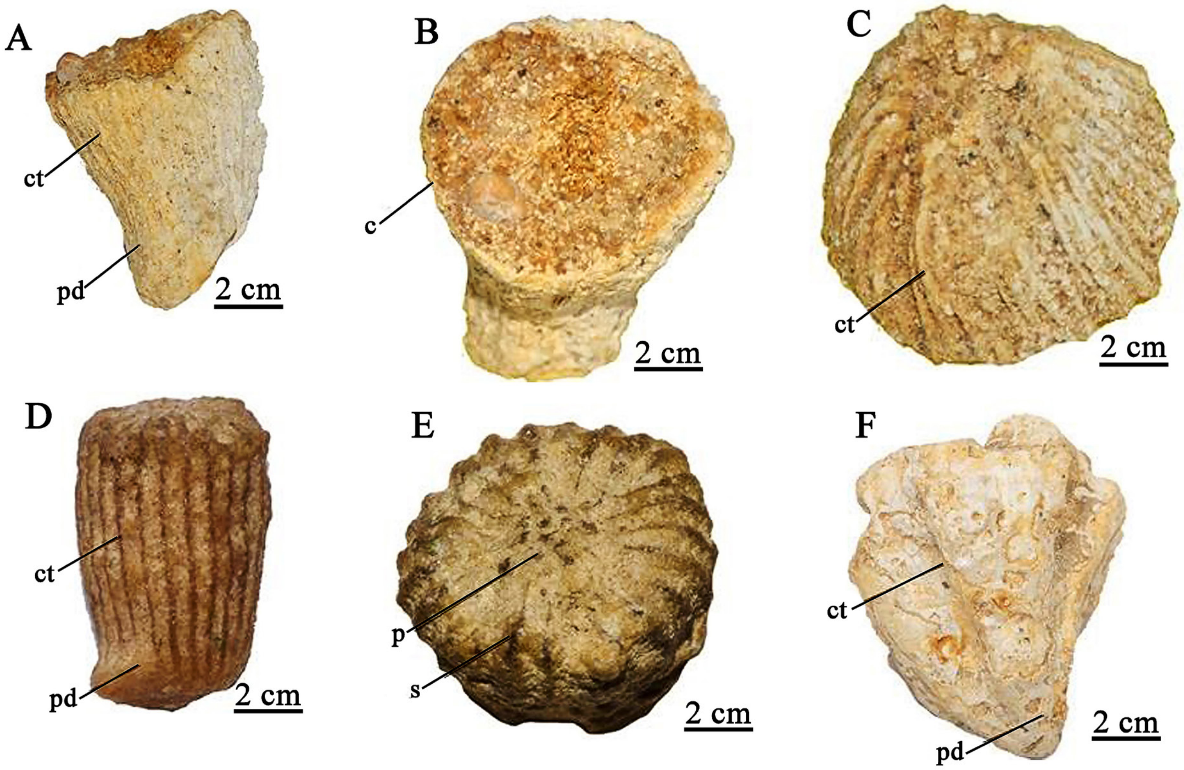

Figure 5. A) *Trochocyathus* (*Trochocyathus*) *collignoni* (Alloiteau, 1958) (DGEO-CTG-UFPE-1541-A): lateral view of corallum ceratoid to trochoid, equidistant costosepta and recurved pedicel; B) *Trochocyathus* (*Trochocyathus*) *collignoni* (Alloiteau, 1958) (DGEO-CTG-UFPE-1541-A): upper surface view of subelliptical calice; C) *T.* (*Platycyathus*) sp. (DGEO-CTG-UFPE-1541-C): lower surface view of discoid corallum and straight to sinuous costosepta; D) *Paracyathus rugosus* Vaughan, 1900 (MN-5421-I): lateral view of corallum cylindrical to trochoid, equidistant costosepta and a well-developed pedicel; E) *Paracyathus rugosus* Vaughan, 1900 (MN-5422-I): upper surface view of discoid calice and a rudimentary pali around the columella; F) *Ceratotrochus* (*Ceratotrochus*) sp. (DGEO-CTG-UFPE-5501): lateral view of corallum ceratoid to trochoid and recurved pedicel; (c: calice; ct: costae; p: pali; pd: pedicel; s: septa).

Occurrence. Brazil: Itamaracá Formation, Lower Maastrichtian (present study).

Material. one juvenile specimen (DGEO-CTG-UFPE-1541-C) from the Fosforita quarry locality, Olinda city, Pernambuco state, Brazil.

Dimensions. h: 7 mm; l: 14 mm; cd: 14 mm; s: 40–48; c: 0.1 mm.

Discussion. The morphological features related to corallum, costae, septa and calice allow us to consider it belonging to the *Trochocyathus* genus and *T.* (*Platycyathus*) subgenus (Wells, 1956; Baron-Szabo, 2008). However, the conservation quality of this specimen precludes its classification into a specific level.

Genus *Paracyathus* Milne Edwards and Haime, 1848

Type species. *Paracyathus procumbens* Milne Edwards and Haime, 1848.

Diagnosis. Corallum solitary fixed of free, turbinate, tympanoid, ceratoid or trochoid. Septotheca costate, shallow to deep. Paliform lobes often bi- or trilobated, developed in all cycles but the last one. Columella papillose often indistinguishable from the inner paliform lobes (Wells, 1956; Cairns and Wells, 1987; Cairns, 1995; Baron-Szabo, 2008).

Distribution. Eocene–Recent (Wells, 1956; Cairns and Wells, 1987; Cairns, 1995).

Paracyathus rugosus Vaughan, 1900

Figures 5D, 5E

1900 *Paracyathus rugosus* Vaughan. U. S. Geol. Surv. Mon. 39, p. 109, pl. VIII, figs. 21–21b.

1978 *Paracyathus rugosus* Vaughan. Fernandes, An. XXX Cong. Bras. Geol., 2, p.962, est. I, figs. 5–6.

Description. Corallum solitary small, cylindrical to trochoid with thick and flat base. Calice discoid, monocentric and shallow, subcircular to circular in outline, fixed by a well-developed and rounded pedicel. Costosepta gradually thicker toward the oral extremity, straight to sinuous, equidistant, continuous, and separated by shallow and flat furrows. Septa hexamerally arranged in three complete cycles with 24 units, straight, equal to subequal, equidistant, thicker, moderately spaced and laterally granulated. The septa from the first and second cycle are thicker and continuous, merged internally in a ring-shaped system of six pali around the columella. The third cycle's septa are smaller, laminated and apparently do not merge to the paliform system. Fosseta subcircular and shallow. Columella subtrabecular and continuous, confined to paliform system. Epitheca, trabecular structures and endothecal and exothecal dissepiments absent.

Occurrence. United States of America: Woods Bluff Formation, Lower Eocene (Vaughan, 1900); Brazil: Maria Farinha Formation, Paleocene- Eocene (Fernandes, 1978).

Material. four juvenile specimens (MN 5421-I, MN 5422-I, MN 5423-I e MN 5424-I), from the Maria Farinha river, Maria Farinha district, Paulista city, Pernambuco state, Brazil deposited on the paleoinvertebrates collection at the Museu Nacional/UFRJ.

Dimensions. (MN-5421-I) h: 9 mm; cd: 4.5 mm; pd: 3 mm. (MN-5422-I) h: 6.5 mm; cd: 3.5 mm; pd: 3 mm. (MN-5423-I) h: 7 mm; cd: 4 mm; pd: 2 mm. (MN-5424-I) h: 5 mm; cd: 4 mm; pd: 3 mm.

Discussion. The species *Paracyathus rugosus* Vaughan, 1900 is similar to *P. bellus* Vaughan, 1900, *P. sinuosus* Cairns and Wells, 1987 and *P. vaughani* Gane, 1895 concerning the shape of calice and columella, number and arrangement of septa and paliform lobes, costae, intercostal furrows and tapering of the apical end.

Genus *Ceratotrochus* Milne Edwards and Haime, 1848

Type species. *Turbinolia multiserialis* Michelotti, 1838 emend. Milne Edwards and Haime, 1850.

Diagnosis. Corallum solitary trochoid, fixed or free. Costosepta compact, shallow to deep. Paliform lobes developed in all cycles but the last one. Columella papillose to fascicular. Endothecal dissepiments sparse (Wells, 1956; Cairns and Wells, 1987; Baron-Szabo, 2008).

Distribution. Middle Cretaceous- Recent (Wells, 1956).

Subgenus *Ceratotrochus* (*Ceratotrochus*) Milne Edwards and Haime, 1848

Type species. *Ceratotrochus* (*Ceratotrochus*) *multispinosus* Michelotti, 1838.

Diagnosis. Costosepta extended above the surface of the calices. Columella fascicular (Wells, 1956; Cairns and Wells, 1987).

Distribution. Middle Cretaceous-Recent (Wells, 1956).

Ceratotrochus (*Ceratotrochus*) sp.

Figure 5F

Description. Corallum solitary small, ceratoid to trochoid, transversally elliptical. Calice subelliptical, monocentric and shallow, fixed by a gentle and subcircular pedicel. Costae gradually thicker toward the oral extremity, continuous, straight to sinuous, equidistant and separated by deep and planed furrows. Septa hexamerally arranged, straight, thick, equidistant and dentated. Columella, epitheca, trabecular structures, paliform lobes and endothecal and exothecal dissepiments absent.

Occurrence. Brazil: Itamaracá Formation, Lower Maastrichtian (present study).

Material. one juvenile specimen (DGEO-CTG-UFPE-5501) from the Fosforita quarry locality, Olinda city, Pernambuco state, Brazil.

Dimensions. h: 18 mm; l: 16 mm; w: 11 mm; s: 6; c: 1–2 mm; pd: 2.5 mm.

Discussion. The morphological features of corallum, costae and pedicel were marked by the generic characteristics recognized in the specimen, and also the septa and columella display a close resemblance to the subgenus *C.* (*Ceratotrochus*) (Wells, 1956; Chevalier, 1961; Cairns and Wells, 1987). The poor conservation quality of the samples, especially on their calice and septal details, justifies its designation as an undefined species.

5. Conclusions

The taxonomy of Upper Cretaceous shallow marine corals from the Itamaracá Formation (Paraíba Basin), the Cenozoic Maria Farinha Formation (Paraíba Basin) and the Pirabas Formation (Bragantina platform) are compared to coral associations of the same age in others areas of the world.

Regarding the Itamaracá Formation, *Actinastrea dickersoni* (Wells, 1941), *Enallhelia* aff. *E. occidentalis* Wells, 1944 and *Trochocyathus* (*Trochocyathus*) *collignoni* (Alloiteau, 1958) are recorded in Cretaceous rocks from Cuba, Venezuela and the United States of America. The indeterminate *Ceratotrochus* (*Ceratotrochus*) sp. and *T.* (*Platycyathus*) sp. belong to European and cosmopolite subgenus respectively. This coralinofauna has affinities with Mexico, southern USA, central Tethys, Central America and Venezuela, reinforcing the view of Filkorn and Pantoja-Alor (2009) of the existence of other possible intermediate biogeographic connecting areas in the Caribbean and South America regions.

The center of origin and diversity of the Cenozoic scleractinian corals is the Caribbean region, with direct ancestors in Europe (Távora *et al.*, 2010). The Paleocene-Oligocene is marked by bioevents of radiation and biogeographic expansion of hermatipic species, resulting in an important development pulse of reefs. During the Miocene the coralinofauna were reduced and tending to endemic. The study of mollusks and decapod crustaceans shows that paleoinvertebrates from the Maria Farinha and Pirabas Formations are related to the Caribbean Biogeographic Province, with well-marked phylogenetic affinity (Távora and Miranda, 2004; Távora *et al.*, 2010).

The coral association of the Maria Farinha Formation is composed by *Actinastrea jukesbrownei* (Wells, 1945), *Stephanocoenia marylandica* (Conrad, 1841), *S. pernambucensis* Fernandes, 1978, colonials and *Paracyathus rugosus* Vaughan, 1900, solitaire. According to Távora and Miranda (2004) and Távora *et al.* (2005) the decapod crustaceans and mollusks fauna are closely related to the Paleocene and Eocene of the Mexico, Trinidad and to the Midway Group (Paleocene) and Castle Haynes Formation (Eocene) of the United States of America.

The fossil reefs and lagoon-environment reefs in the upper rocks of the Maria Farinha Formation present regressive characteristics of high- to low-energy oscillations that may not have favored the great development of a coral fauna or its preservation history.

The scleractinian Flabellidae family from the Pirabas Formation is observed to be more abundant in spite of the other elements that are uncommon to rare. The five taxa cited in this work occur in the synchronous litostratigraphic units of the Caribbean region, in particular from Puerto Rico, Costa Rica, Trinidad, Barbados and Saint Croix, as well as Pliocene-Pleistocene from Bahamas, Dominican Republic and Costa Rica. The continuous temporal distribution of *Caulastraea portoricensis* (Coryell and Ohlsen, 1929) between the Miocene and Pleistocene, and the restricted occurrence of *Stylophora silicensis* Weisbord, 1973 from the Tampa Formation (Florida state, USA) and the cosmopolitan aspect of *Cladocora* sp. are relevant aspects to the biogeographic analysis.

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