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The Campanian-Maastrichtian rudist bivalves succession in the Chiapas Central Depression, Mexico

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A B S T R A C T

The restudy of the Late Cretaceous rudist fauna of the Chiapas Central Depression, considered Campanian-Maastrichtian with no more precisions in literature, reveals that, in fact, three successive rudist assemblages occur: (1) a lower one, early and middle Campanian, in the uppermost part of the Sierra Madre Formation (distinguished as Suchiapa Formation); (2) a middle one, early Maastrichtian, in the upper part of the Ocozocoautla Formation; and (3) an upper one, late Maastrichtian, in several horizons within the Angostura Formation. Published data on planktic and benthic foraminifers and inoceramid bivalves, as well as new findings of ammonites, helped bracketing the age of the three rudist assemblages. Their stratigraphic position fits with a depositional model assuming a basal carbonate platform fragmented into blocks each following a different tecto-sedimentary evolution: (1) a drowned block constituting the Tuxtla Gutiérrez Basin, deepening towards the neighbor raised block and receiving terrigenous material from the emerged Sierra Madre de Chiapas, that, after a long hiatus, was filled up and, subsequently, a marginal shallow carbonate platform, surrounded by a detritic belt and prograding towards the basin, installed on top; (2) a raised block constituting a high where, after a long hiatus, an insular shallow carbonate platform installed.

1. Introduction

Besides some older specific papers (Müllerried, 1931a, 1931b, 1933, 1934, 1936a), the Late Cretaceous rudist fauna from Chiapas is mainly known after Alencáster (1971). Alencáster's monograph was based on the copious fossils collected by F. K. G. Müllerried (1891–1952) and kept at the Instituto de Geología in Mexico City. Concerning geography all the studied rudist samples were properly referred to Müllerried's localities, but their stratigraphic relationship was not well known. In fact, geologic maps available at that time only distinguished the Upper, mid, and Lower Cretaceous. Thus, the Late Cretaceous rudist fauna from Chiapas has been traditionally considered Campanian-Maastrichtian, with no more precisions. Other recent taxonomic papers (Alencáster and Michaud, 1991; Alencáster and Pons, 1992; García-Barrera et al., 1998) have not improved its biostratigraphic accuracy.

The Upper Cretaceous stratigraphy of Chiapas has dealt with since long ago (Sapper, 1894, 1899, 1906, 1937; Böse, 1905; Ver Wiebe, 1925; Müllerried, 1930, 1936b, 1942; Imlay, 1944; Gutiérrez Gil, 1956; Webber and Ojeda, 1957) although much confusion and controversy remained concerning the recognized lithologic units, and their correlation and age. Chubb (1959) corrected some of the misconceptions of the earlier authors and tried to "*search for these* [Müllerried's] *localities in the hope of establishing the rudist horizons and correlating them with the lithological succession*". Chubb's work, besides clarifying the lithological succession, represented a considerable advance in understanding the geologic history. He was not equally successful in establishing the rudist horizons and correlating them with the lithological

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succession, probably because Müllerried's rudist localities were rarely recorded with precision, and also because, several of the rudist identifications by this last author and consequently, their age attribution, were erroneous. Most subsequent stratigraphic research on the Cretaceous of Chiapas remained unpublished as internal reports of both the Instituto Mexicano del Petróleo or Petróleos Mexicanos although some relevant data were published (Castro-Mora et al., 1975, Sánchez-Montes de Oca, 1979; Quezada Muñetón, 1990; Alzaga, 1997; Padilla Sánchez, 2007). Steele's (1987) and Waite's (1987) papers focused only on the Sierra Madre Limestone. The doctoral thesis of François Michaud and subsequent papers (Michaud, 1987; Michaud and Fourcade, 1989; Cros et al., 1998) provided an accurate lithostratigraphic framework, a detailed paleogeographic reconstruction, and a reasonable interpretation of the sedimentologic evolution of the Chiapas Cretaceous carbonate platform, based on a significant number of measured and correlated stratigraphic sections from the Chiapas Central Depression.

The main aim of this paper is to provide the inventory of all rudist occurrences in the abovementioned area, their location related to an update of both Michaud's (1987) lithostratigraphic framework and paleogeographic reconstruction, the identification of the different rudist assemblages, and the discussion of their age. The detailed systematic description of all the rudist species is in preparation to be subsequently published elsewhere.

2. Materials and methods

A total number of seven hundred rudist specimens were collected from around thirty-six fossil sites. Identification numbers (P-xxxx) were assigned to each fossil site, which may correspond to a single outcrop or to each particular rudist bed within a stratigraphic section. All of them were correlated, as far as possible, directly in the field or on maps. Rudist specimens were sectioned and studied at the Universidad Nacional Autónoma de México (UNAM) and at the Universitat Autònoma de Barcelona (UAB). Ammonites were also collected and studied.

2.1. Stratigraphy

The Chiapas Central Depression (Fig. 1) is mainly formed by a series of gently dipping synclines of Upper Cretaceous rocks, with Tertiary rocks occupying, in some of them, the cores. The Ocozocoautla, Copoya, and Grijalva synclines are staggered and aligned from W to E with a N 55° W trend, approximately parallel to the Pacific coast line. The first two extend around 40 km each and have a periclinal ending. The last one, the largest and with its northern flank faulted, extends nearly 200 km away towards SE from the E of Tuxtla Gutiérrez.

The Upper Cretaceous oldest rocks cropping out correspond to the limestones of the Sierra Madre Formation, and form the base of

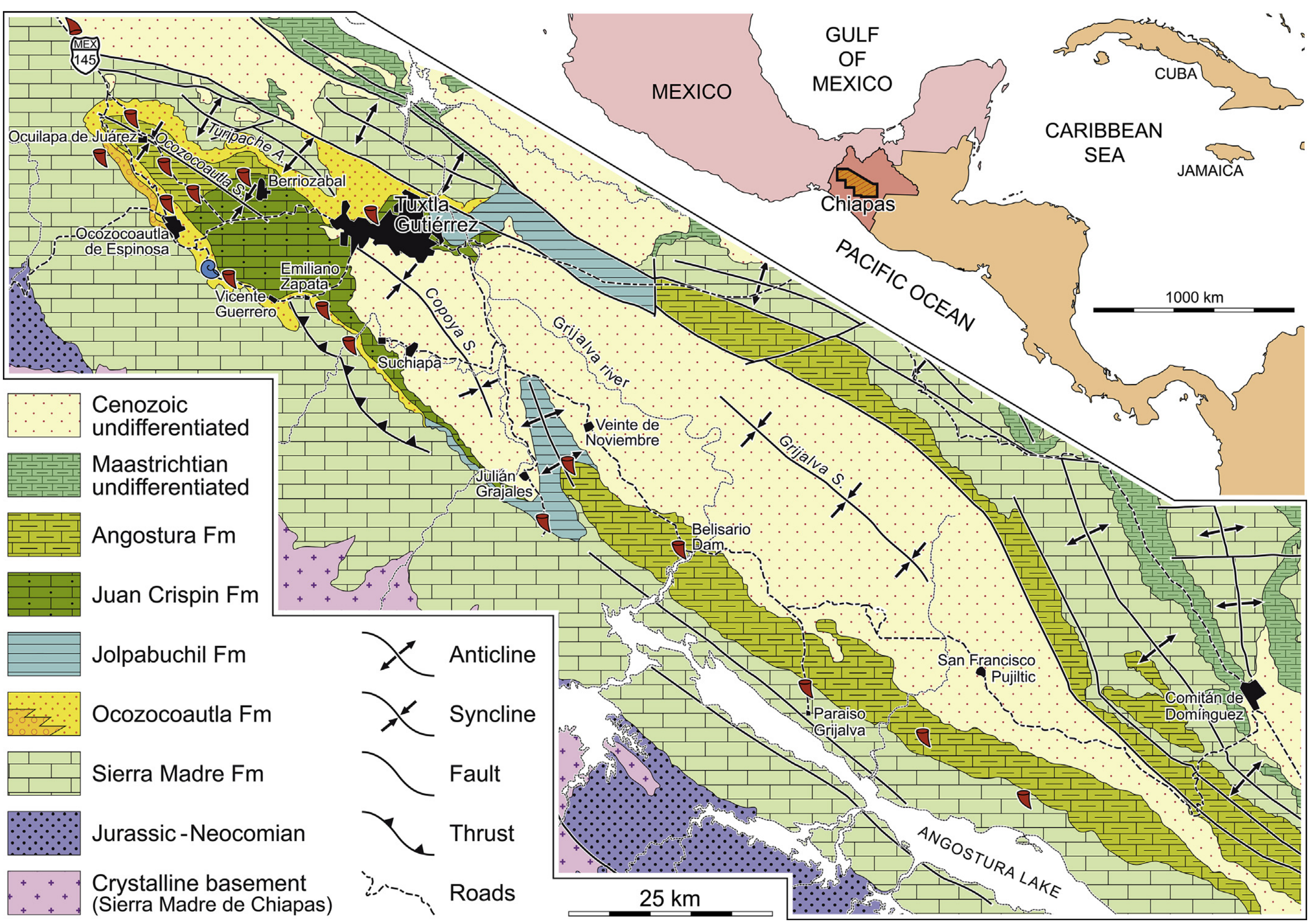

Fig. 1. Schematic geologic map of the Chiapas Central Depression, modified from Servicio Geológico Mexicano (2005). Carta Geológico-Minera 1:250,000. Tuxtla Gutiérrez. S = syncline, A = anticline. Symbols indicate rudist and ammonite localities.

the studied succession. Its uppermost part, the only studied in this work, presents some lithologic and fossil content differences, being differentiated as Suchiapa Formation following Michaud (1987). Above, the Ocozocoautla Formation is composed of a variety of rocks, mainly terrigenous but also limestones, showing remarkable facies changes, both vertical and lateral. Its basin-ward lateral equivalent, the Jolpabuchil Formation is composed of limestones with chert and planktic fossils locally becoming calcareous breccia. Both are partially covered by the limestones of the Angostura Formation and/or the Juan Crispín Formation composed of cross bedded bioclastic limestones, sometimes sandstones.

At the easternmost part of the area, the Ocozocoautla Formation and its lateral equivalents do not appear, nor does the Juan Crispín Formation; the Angostura Formation lies directly above a breccia and a lateritic interval developed on the upper part of the Sierra Madre Formation (Fig. 2A).

The paleogeographic model in Michaud (1987), improved in Michaud and Fourcade (1989), proposed that in the area around Tuxtla Gutiérrez (Chiapas Central Depression), the original "mid Cretaceous" carbonate mega-platform (Sierra Madre Formation), composed of a dolomitic lower member (Aptian-Albian) and a limestone upper member (Cenomanian-Santonian?), fragmented into several blocks each following a different tecto-sedimentary evolution.

A drowned block (Tuxtla Gutiérrez Block), limited by the emerged Sierra Madre de Chiapas basement and the raised Angostura Block, constituted a basin (Tuxtla Gutiérrez Basin) that was filled during Campanian?-Maastrichtian. The basin received terrigenous material from the emerged Sierra Madre and deepened towards the rising Angostura block. Thus, marls with sandy or conglomeratic intercalations were deposited landwards (Ocozocoautla Formation) while pelagic limestones with chert nodules and planktic foraminifers were deposited basin-wards (Jolpabuchil

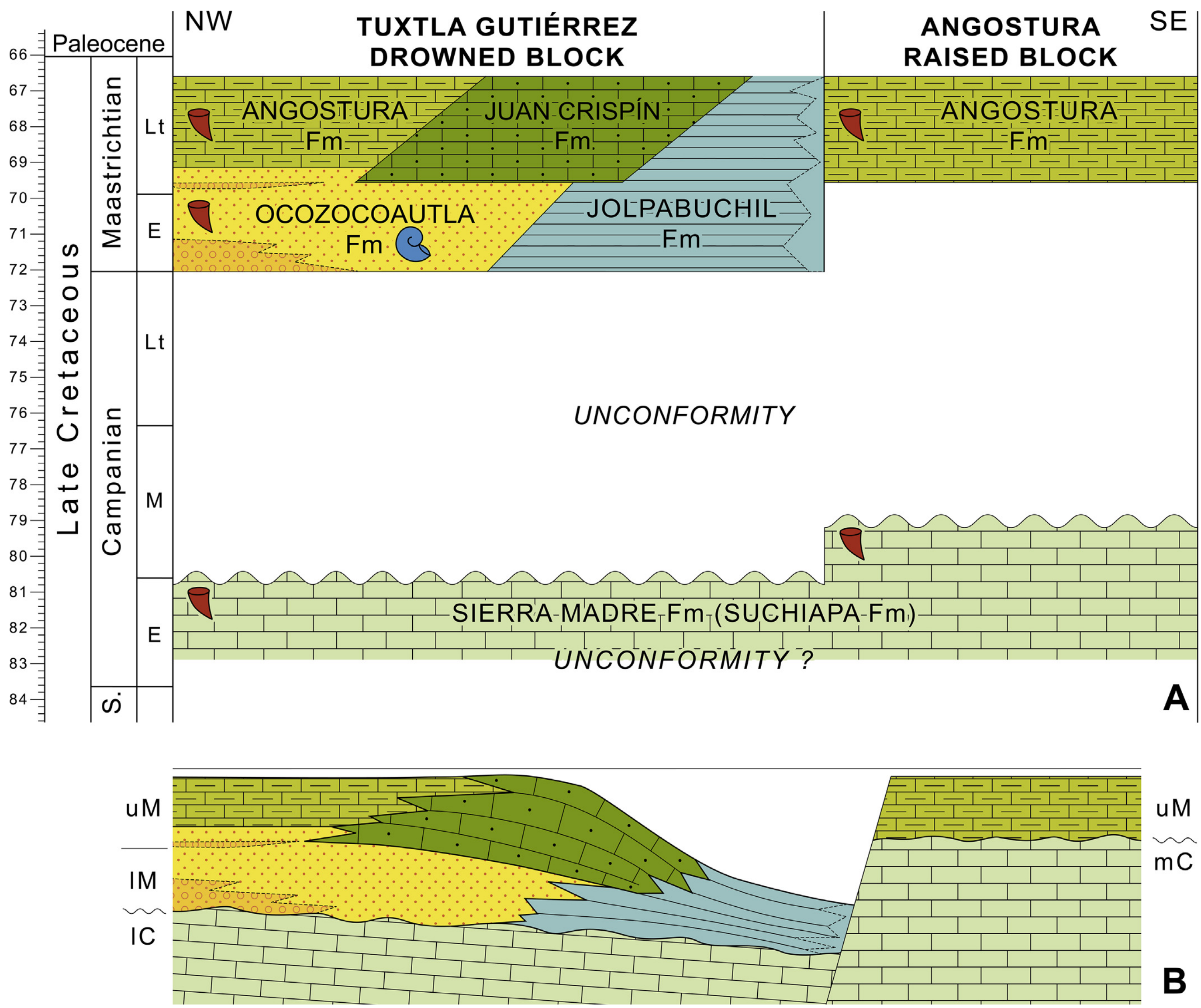

Fig. 2. Stratigraphy of the Chiapas Central Depression. A, Upper Cretaceous lithostratigraphy with, at left, the Standard Chronostratigraphy (TimeScale Creator, TSCreatorPUBLIC-6.4) for reference, S. = Santonian, Lt = late, M = middle, E = early, Fm = Formation, symbols indicate rudist assemblages and ammonite occurrences; B, schematic depositional model based on Michaud and Fourcade (1989, fig. 8), uM = upper Maastrichtian, lM = lower Maastrichtian, mC = middle Campanian, lC = lower Campanian.

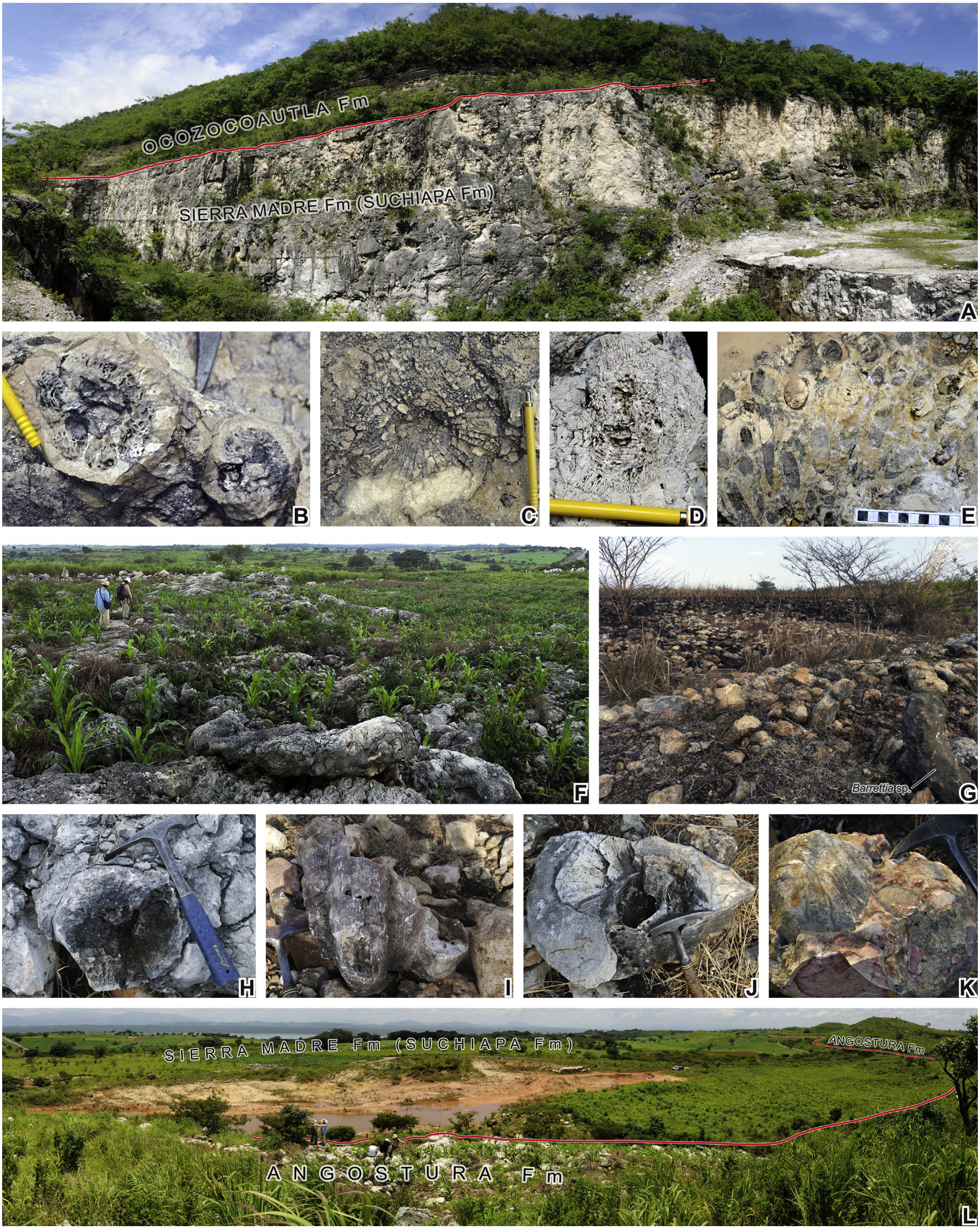

Fig. 3. Lower rudist assemblage of the Chiapas Central Depression. Sierra Madre Formation (Suchiapa Formation). A-E, Rancho El Comiteco quarry, Tuxtla Gutiérrez block. F-L, road from Laja Tendida to Paraíso del Grijalva, Angostura block. A, unconformable boundary between the Sierra Madre Formation (Suchiapa Formation) below and the Ocozocoautla Formation above; B, *Vaccinites vermunti* Mac Gillavry; C, *Barrettia* sp.; D, Antillocaprinidae indet.; E, *Chiapasella* sp; F, corn cultivated on the weathered limestones (and thus intensifying its weathering); G, limestone boulders and large rudist shells accumulated, by generations of farmers, along the margins of corn fields are now the source for collecting isolated rudist specimens, a large *Barrettia* shell is indicated; H, large *Parastroma* sp. specimen included in limestones; I, bouquet of several *Barrettia* sp. specimens; J, incomplete large *Thyrastylon*? *nicholasi* (Whitfield) right valve; K, breccia composed of limestone and rudist shell fragments on topmost part of the Sierra Madre Formation (Suchiapa Formation); L, panoramic view showing exploitation of bauxitic laterites between the Sierra Madre Formation (Suchiapa Formation) below, in the background, and the Angostura Formation above, in the foreground.

Fig. 4. Middle rudist assemblage of the Chiapas Central Depression. Ocozocoautla Formation. A, panoramic view NW of Ocozocoautla showing the Ocozocoautla Formation between the Sierra Madre Formation (Suchiapa Formation), below, and the Angostura Formation, above, symbols indicate location of the rudist bed; B, gastropods bed below the rudist bed; C, rudist bed, specimens of *Chiapasella radiolitiformis* (Trechmann) and *Praebarrettia sparcilirata* (Whitfield) may be recognized; D, large specimen of *Thyrastylon*? *nicholasi* (Whitfield); E, micro-conglomeratic bed following up section the reddish emersion surfaces above the rudist bed.

Formation), including calcareous breccia close to the limit with the rising Angostura block. Some limestone intercalations started in the upper part of the Ocozocoautla Formation, following a coarse terrigenous input, and a marginal shallow carbonate platform (Ocuilapa Platform, Angostura Formation) installed above them, surrounded by a belt of cross-bedded sandy bioclastic limestones (Juan Crispín Formation), prograding basin-wards on the Ocozocoautla and Jolpabuchil formations.

On the raised Angostura Block, and after a long hiatus, an insular shallow carbonate platform (Angostura Platform, Angostura Formation) installed directly above the Sierra Madre Formation.

Michaud's model, although slightly modified due to new observations, best explain in our opinion the Late Cretaceous paleogeography and sedimentologic evolution of the Chiapas Central Depression and is assumed herein (Fig. 2B).

2.2. Localities (Table 1)

Rudist sampling comprised all known rudist sites (Müllerried's localities), all rudist occurrences reported in Michaud's (1987) stratigraphic sections, and several new localities discovered thanks to both the digital cartography facilities available nowadays and the sedimentology and paleogeography understanding of the area acquired throughout Michaud's works (Fig. 1). The uppermost part of the Sierra Madre Formation, distinguished by Michaud (1987) as Suchiapa Formation, and the Ocozocoautla and Angostura formations have been sampled, or its rudist identified in the field where fossil material was poorly preserved or difficult to remove. Rudists were also observed in olistoliths within the Paleocene Soyaló Formation.

3. Rudist assemblages

3.1. Lower rudist assemblage (Fig. 3 and Tables 1 and 2)

Corresponds to the rudist occurrences in the uppermost part of the Sierra Madre Formation, distinguished as Suchiapa Formation following Michaud (1987). Its diversity changes from one locality to another and significant taxonomic differences exist between those of the two westernmost synclines (Tuxtla Gutiérrez block) and the Grijalva syncline (Angostura block) ones.

Rudists identified from the olistoliths of the Paleocene Soyaló Formation, seem to correspond to those in the last localities.

3.2. Middle rudist assemblage (Fig. 4 and Tables 1 and 2)

Corresponds to the rudist occurrences in the upper part of the Ocozocoautla Formation, above a gastropod-rich bed and below reddish surfaces, presumably corresponding to emersion surfaces, followed by a microconglomeratic horizon.

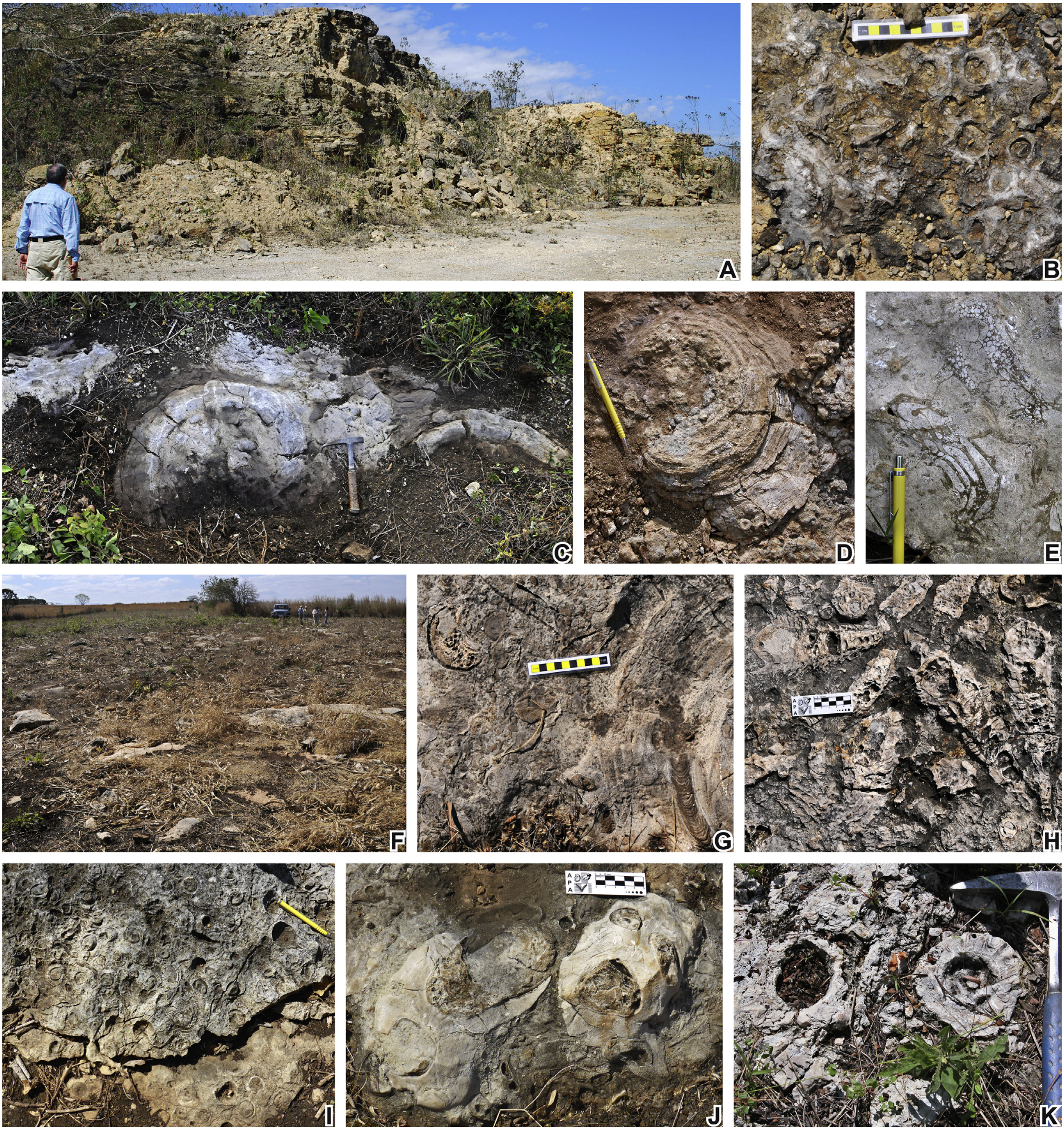

Fig. 5. Upper rudist assemblage of the Chiapas Central Depression. Angostura Formation. A-E, outcrops along road 145, Tuxtla Gutiérrez block. F-K, outcrops in the Angostura block. A, abandoned quarry Cerro Testigo, km 195.5, nearly horizontal strata in quarries offer the only possibility for detailed study; B, a bed upper surface with capped radiolitids, probably an emersion surface; C, several valves of *Titanosarcolites giganteus* (Whitfield) on a bed's upper surface, Búfalo de Piedra, km 187.4; D, specimen of *Titanosarcolites* sp. with both valves' wide extended flanges colonized by corals, Rancho La Peregrina, km 189; E, Antillocaprinidae indet., km 190.3; F, corn field on top of Cerro Verde, only after the harvest season observation of the outcrop is possible; G, *Titanosarcolites giganteus* (Whitfield) and *Chiapasella radiolitiformis* (Trechmann), Cerro Verde; H, long conical "*Radiolites*" *macroplicatus* Whitfield, some with articulated valves, Cerro Verde; I, *Thyrastylon adhaerens* Chubb, Cerro Verde; J, weathered right valves of *Chiapasella radiolitiformis* (Trechmann), Cerro Verde; K, bed's upper surface with large "*Radiolites*" *macroplicatus* Whitfield, Colonia José María Morelos, Belisario Domínguez Dam.

3.3. *Upper rudist assemblage (Fig. 5 and Tables 1 and 2)*

Corresponds to the rudist occurrences in the Angostura Formation, in several rudist beds and with successive emersion surfaces.

4. Ammonites

Ammonites have been collected, in the marls of the lower part of the Ocozocoautla Formation (Fig. 1A, Table 1), from an abandoned quarry W of Vicente Guerrero (P-1365). Five different taxa have

Table 1
Fossil localities sampled and/or referred in this work.

Sample	longitude, latitude	Outcrop name	Location	Syncline (flank)	Tectonic block	Muellerried's locality	Rudist assemblage	Age
Upper part of the Sierra Madre Formation (Suchiapa Formation)								
P-1313	93° 27′ 6.4″ W, 16° 49′ 54.22″ N	Piedra Parada	SW of Oculiapa	Ocozocoautla (S)	Tuxtla Gutiérrez		Lower	Early Campanian
P-1363	93° 13′ 30.53″ W, 16° 40′ 37.34″ N	SW of Emiliano Zapata	SW of Emiliano Zapata	Copoya (S)	Tuxtla Gutiérrez		Lower	Early Campanian
	93° 9′ 31.21″ W, 16° 38′ 42.54″ N	Suchiapa river	W of Suchiapa	Copoya (S)	Tuxtla Gutiérrez		Lower	Early Campanian
	93° 1′ 10.37″ W, 16° 29′ 39.76″ N	Santo Domingo river	W of Julián Grajales	Copoya (S)	Tuxtla Gutiérrez		Lower	Early Campanian
P-1322	92° 56′ 37.28″ W, 16° 25′ 36.76″ N	S of Julián Grajales	S of Julián Grajales	Copoya (S)	Tuxtla Gutiérrez		Lower	Early Campanian
P-0754	93° 8′ 34″ W, 16° 46′ 38.31″ N	Rancho El Comiteco quarry	N of Tuxtla Gutiérrez	Copoya (N)	Tuxtla Gutiérrez		Lower	Early Campanian
P-1315	92° 38′ 49.73″ W, 16° 15′ 36.25″ N	road to Paraíso del Grijalva	Laja Tendida to P. del Grijalva	Grijalva (S)	Angostura		Lower	Middle Campanian
P-1316	92° 38′ 11.5″ W, 16° 15′ 15.94″ N	road to Paraíso del Grijalva	Laja Tendida to P. del Grijalva	Grijalva (S)	Angostura	30 Vega del Paso	Lower	Middle Campanian
P-1317	92° 38′ 3.94″ W, 16° 15′ 18.18″ N	road to Paraíso del Grijalva	Laja Tendida to P. del Grijalva	Grijalva (S)	Angostura		Lower	Middle Campanian
P-1360	92° 24′ 14″ W, 16° 8′ 5.85″ N	road to El Santuario	SSE of San Francisco Pujiltic	Grijalva (S)	Angostura		Lower	Middle Campanian
Ocozocoautla Formation								
P-0743	93° 22′ 52.49″ W, 16° 46′ 55.41″ N	Campo de Tiro	NW of Ocozocoautla	Ocozocoautla (S)	Tuxtla Gutiérrez	6 Ocozocoautla	Middle	Early Maastrichtian
	93° 22′ 53.79″ W, 16° 46′ 56.24″ N	Omaña and Pons (2003)	NW of Ocozocoautla	Ocozocoautla (S)	Tuxtla Gutiérrez		Bentic forams	Maastrichtian
P-1358	93° 22′ 44.9″ W, 16° 46′ 35.58″ N	Los Chamaquitos	NW of Ocozocoautla	Ocozocoautla (S)	Tuxtla Gutiérrez	6 Ocozocoautla	Middle	Early Maastrichtian
P-1365	93° 19′ 48.32″ W, 16° 42′ 48.85″ N	abandoned quarry	W of Vicente Guerrero	Ocozocoautla (S)	Tuxtla Gutiérrez		Ammonites	Early Maastrichtian
P-0753	93° 25′ 35.72″ W, 16° 53′ 22.27″ N	km 178.2, road 145	Ocozocoautla to Las Choapas	Ocozocoautla (N)	Tuxtla Gutiérrez		Middle	Early Maastrichtian
	93° 23′ 35.23″ W, 16° 53′ 23.96″ N	Omaña (2006)	NE of Oculiapa	Ocozocoautla (N)	Tuxtla Gutiérrez		Planktic forams	Early Maastrichtian
P-1323	93° 16′ 10.23″ W, 16° 41′ 44.48″ N	Rancho NW of Vicente Guerrero	NW of Vicente Guerrero	Copoya (S)	Tuxtla Gutiérrez		Middle	Early Maastrichtian
P-1362	93° 12′ 43.84″ W, 16° 40′ 34.21″ N	E of Emiliano Zapata	E of Emiliano Zapata	Copoya (S)	Tuxtla Gutiérrez		Middle	Early Maastrichtian
Angostura Formation								
P-0757	93° 19′ 24.81″ W, 16° 46′ 33.31″ N	Cerro Testigo (km 195.5)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-0758	93° 19′ 21.68″ W, 16° 46′ 35.36″ N	Cerro Testigo (km 195.5)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-0760	93° 19′ 23.37″ W, 16° 46′ 33.49″ N	Cerro Testigo (km 195.5)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-1369	93° 20′ 56.97″ W, 16° 48′ 1.33″ N	Old quarry (km 195.3)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-0748	93° 22′ 11.27″ W, 16° 48′ 38.12″ N	Rancho La Peregrina (km 189)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-1355	93° 22′ 7.42″ W, 16° 48′ 27.14″ N	Rancho La Peregrina (km 189)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
	93° 22′ 10.27″ W, 16° 48′ 39.38″ N	Filkorn et al. (2005); Loeser (2012)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez		corals	Late Maastrichtian
P-0761	93° 22′ 38.06″ W, 16° 49′ 36.73″ N	Búfalo de Piedra (km 187.4)	Ocozocoautla to Las Choapas	Ocozocoautla (S)	Tuxtla Gutiérrez	59 Oculiapa	Upper	Late Maastrichtian
P-1364	93° 19′ 41.19″ W, 16° 43′ 13.72″ N	W of Vicente Guerrero	W of Vicente Guerrero	Ocozocoautla (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-1366	93° 16′ 50.41″ W, 16° 48′ 17.24″ N	Quarries	W of Berriozábal	Ocozocoautla (N)	Tuxtla Gutiérrez	19 Berriozábal	Upper	late Maastrichtian
P-1367	93° 17′ 23.17″ W, 16° 48′ 49.64″ N	Quarries Rancho El Tesoro	NW of Berriozábal	Ocozocoautla (N)	Tuxtla Gutiérrez	19 Berriozábal	Upper	Late Maastrichtian
P-1368	93° 17′ 27.99″ W, 16° 48′ 44.71″ N	Quarries Rancho El Tesoro	NW of Berriozábal	Ocozocoautla (N)	Tuxtla Gutiérrez	19 Berriozábal	Upper	Late Maastrichtian
P-1361	93° 12′ 44.64″ W, 16° 40′ 44.43″ N	E of Emiliano Zapata	E of Emiliano Zapata	Copoya (S)	Tuxtla Gutiérrez		Upper	Late Maastrichtian
P-1356	92° 56′ 7.15″ W, 16° 31′ 20.38″ N	Cerro Verde	W of Veinte de Noviembre	Grijalva (S)	Angostura		Upper	Late Maastrichtian
P-1357	92° 56′ 0.7″ W, 16° 31′ 26.5″ N	Cerro Verde	W of Veinte de Noviembre	Grijalva (S)	Angostura		Upper	Late Maastrichtian
P-0957	92° 47′ 2.07″ W, 16° 23′ 54.85″ N	Colonia José María Morelos y Pavón	SW of Belisario Domínguez Dam	Grijalva (S)	Angostura		Upper	Late Maastrichtian
P-1311	92° 39′ 0.53″ W, 16° 16′ 36.33″ N	road to Paraíso del Grijalva	Laja Tendida to P. del Grijalva	Grijalva (S)	Angostura		Upper	Late Maastrichtian
P-1318	92° 31′ 8.93″ W, 16° 12′ 19.72″ N	SW of San Francisco Pujiltic	SW of San Francisco Pujiltic	Grijalva (S)	Angostura		Upper	Late Maastrichtian
P-1320	92° 30′ 39.49″ W, 16° 12′ 55.76″ N	SW of San Francisco Pujiltic	SW of San Francisco Pujiltic	Grijalva (S)	Angostura		Upper	Late Maastrichtian
Soyaló Formation (Paleocene)								
P-144	93° 31′ 42.42″ W, 17° 1′ 10.09″ N	Quarry near Cacahuanó (km 158)	Ocozocoautla to Las Choapas				Lower assemblage?	

Table 2
Rudist taxa identified in this work. The list is not complete, and some taxa appear in open nomenclature, because the use of several specific names requires a discussion in depth far beyond the scope of this work.

Upper rudist assemblage (Tuxtla Gutiérrez and Angostura blocks)
Antillocaprina pugniformis (Palmer)
Antillocaprina trilobata (García Barrera and Avendaño)
Caenosarcolites oddsensis (Stephenson)
Caenosarcolites scholaris Mitchell
Eosarcolites radiatus Mitchell
Titanosarcolites giganteus (Whitfield)
Antillocaprinidae indet.
Plagioptychus sp.
Mitrocaprina sp.
"Radiolites" macroplicatus Whitfield
Biradiolites cardenasensis Böse
Biradiolites? sp.
Bournonia cancellata (Whitfield)
Chiapasella radiolitiformis (Trechmann)
Thyrastylon adhaerens (Whitfield)
Middle rudist assemblage (Tuxtla Gutiérrez block)
Praebarrettia sparcilirata (Whitfield)
Plagioptychus muellerriedi Alencáster
Biradiolites cardenasensis Böse
Chiapasella radiolitiformis (Trechmann)
Huasteca ojanchalensis (Myers)
Thyrastylon? nicholasi (Whitfield)
Trechmannites rudissimus (Trechmann)
Lower rudist assemblage (Angostura block)
Alencasteria macrotubularis Mitchell
Stellacaprina? macgillavryi (Alencaster)
Antillocaprinidae indet.
"Postcaprinula" Alencáster (in collection)
Barrettia monilifera Woodward
Whitfieldiella gigas (Chubb)
Parastroma trechmanni Chubb
Plagioptychus sp.
Mitrocaprina sp.
Alencasterites mooretownensis (Trechmann)
Bournonia baileyi Chubb
Biradiolites? sp.
Thyrastylon? nicholasi (Whitfield)
Lower rudist assemblage (Tuxtla Gutiérrez block)
Antillocaprinidae indet.
Barrettia sp. *cf. B. ruseae* Chubb
Vaccinites vermunti Mac Gillavry
Radiolites acutocostata (Adkins)
Potosites tristantorresi Alencáster and Pons
Chiapasella sp.

been identified: *Pachydiscus* (*P.*) *neubergicus* (Hauer) and *Diplomoceras cylindraceum* (Defrance), both biostratigraphically significant and *Gaudryceras mite* (Hauer), *Pseudoxybeloceras* sp. and massive *Pachydiscus* indet., with a longer stratigraphic range.

The single specimen of *Pachydiscus* (*P.*) *neubergicus* is a broken internal mold, with no more than three-quarters of its whorl preserved, and a diameter of about 116 mm (Fig. 6C). Ribs arise as bullae in the umbilicus and sweep backwards being concave in the umbilical wall. Crossing the umbilical shoulder they strength and are straight. From these arise the primary ribs slightly prorsiradiate crossing the venter in narrow convexity. This incomplete specimen shows eleven primary ribs. Commonly one or two secondary ribs, with the same shape of the primaries, appear at different points around the middle of the flank so we count about thirty ventral ribs. The shape of the specimen, style of ornamentation, and rib density fit with those of *neubergicus* species.

The FAD of *Pachydiscus* (*P.*) *neubergicus* is considered to mark the base of the Maastrichtian (Odin and Lamaurelle, 2001). The species extends throughout the lower Maastrichtian elsewhere, although in some places it has been recorded in the lower upper Maastrichtian (Kennedy and Summesberger, 1986), and in the upper Maastrichtian (Kennedy and Herderson, 1992; Ward and Kennedy, 1993). The species has a wide geographic distribution as reviewed by Hancock (1991) and Hancock and Kennedy (1993): Austria, Poland, Ukraine, Armenia, Denmark, Germany, France, Spain, Nigeria, Zululand, Madagascar, and southern India. In North America it has been recorded in New Jersey (Kennedy et al., 2000) and in South America, in Brazil (Stinnesbeck et al., 2012). In northeastern Mexico it has been previously recorded and described from the Cardenas Formation, near Cárdenas town by Ifrim et al. (2005).

A big size weathered internal mold with a diameter of around 450 mm can be attributed to the massive *Pachydiscus* forms described in Matsumoto (1959). Unfortunately the ornamentation is not visible due to the bad preservation. These forms range from the lower Campanian (*P. duelmensis* (Schlüter)) to the lower Maastrichtian (*P. epiplectus* (Redtenbacher)).

Diplomoceras cylindraceum (Defrance) is identified after a 21 mm long slightly oval in section specimen preserved as an internal mold (Fig. 6E). Where visible ribs are thin, very dense, straight annular, and prorsiradiate. The ornamentation corresponds with that of the species.

Diplomoceras cylindraceum expands throughout the Maastrichtian, and may even appear in the upper Campanian (Hancock and Kennedy, 1993). It may be considered a worldwide species present in high and low latitudes of both hemispheres, Europe, Arctic Siberia, Japan, South Africa and Madagascar, southern India, Australia, North America (Alaska, British Columbia, and California), South America (Chile, Argentina, Brazil), and Antarctic Peninsula (Ward and Kennedy, 1993). In northeastern Mexico it has been identified in the Parras Basin, Coahuila (Ifrim et al., 2010) and at El Zancudo, Nuevo Laredo, Tamaulipas (Ifrim and Stinnesbeck, 2013)

An internal mold corresponding to a one-quarter of whorl has been identified as *Gaudryceras mite* (Hauer) (Fig. 6A, B). Flanks are not symmetric due to crushing and its deduced diameter is about 210 mm. The ornamentation is the characteristic one of this species: fine, dense, and flexuous like lirae. From the umbilical area they seem like sweep forward until the inner flank where becoming rursiradiate and on the outer flank again becoming prorsiradiate to cross the venter in a slight convex peak. Lirae branch one or twice around the umbilical shoulder and/or in the inner flank.

This species has a worldwide distribution (France, Spain, Angola, Zululand Madagascar, southern India and South-Antarctic Islands (Kennedy and Summesberger, 1979) and ranges from the Turonian to the Maastrichtian. In Mexico it has only been quoted in the Coniacian of El Rosario (Coahuila, northeastern Mexico) (Stinnesbeck et al., 2005).

An internal mold of *Pseudoxybeloceras* sp. has been identified. The specimen is a crushed straight shaft fragment 18 mm long (Fig. 6D). The ornamentation consists of fine, rather distant, annular ribs. Each rib wears a small pointed tubercle forming a row at each ventrolateral side.

The genus ranges from the Turonian to the Campanian. The species *Pseudoxybeloceras* (*Parasolenoceras*) *interruptum* (Schlüter) is upper Campanian and could reach the lower Maastrichtian (Kennedy, 1993). The genus is known from Europe, Japan, Sakhalin, South Africa, Madagascar, North America and New Zealand.

Even the low number of taxa, the presence of *P.* (*P.*) *neubergicus* and *Diplomoceras cylindraceum* in the assemblage suggests an early Maastrichtian age for these sediments.

5. Discussion

Citations of biostratigraphic relevant fossils, although lacking description or figuration, are profuse in regional geology or stratigraphic papers on the Upper Cretaceous of the Chiapas Central Depression. Moreover, some taxonomic papers on its planktic and benthic foraminifers and inoceramid bivalves are available (Bolaños

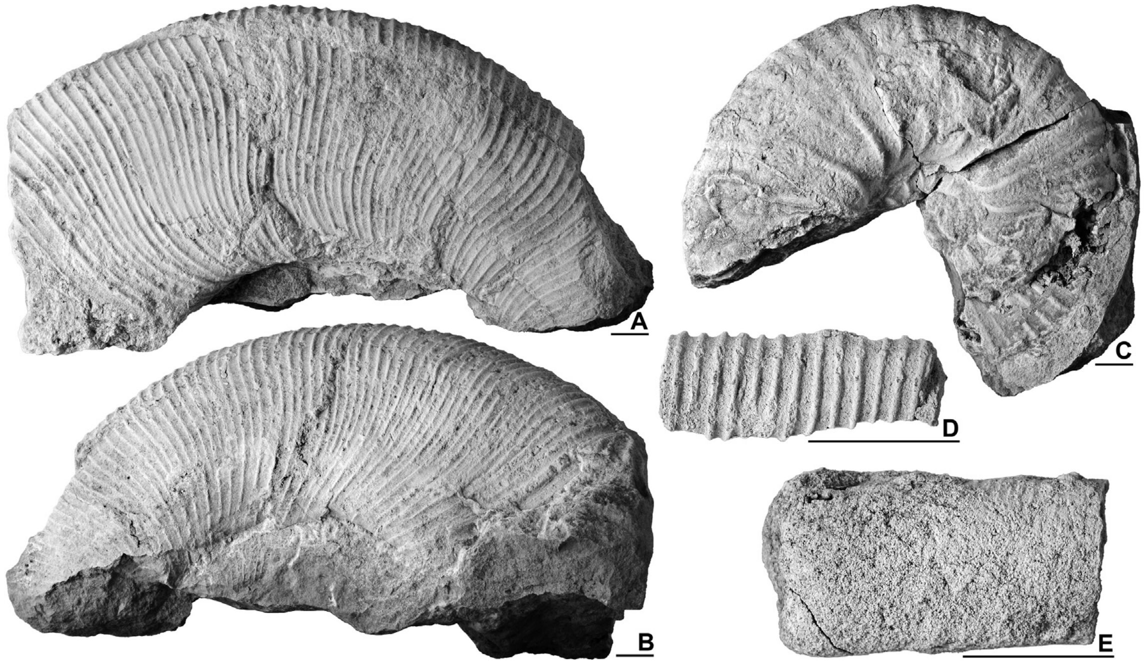

Fig. 6. Ammonites of the Chiapas Central Depression. Abandoned quarry W of Vicente Guerrero, Ocozocoautla Formation, scale bars = 10 mm. A-B, *Gaudryceras mite* (Hauer), PUAB 81864, viewed by both lateral sides. C, *Pachydiscus (P.) neubergicus* (Hauer), PUAB 81865, lateral view. D, *Pseudoxybeloceras* sp., PUAB 81866, the lateral/ventral view shows the rows of ventrolateral tubercles. E, *Diplomoceras cylindraceum* (Defrance), PUAB 81867, ribs are visible on top right of the specimen.

and Buitrón, 1984; Michaud, 1984; Waite, 1987; Omaña and Pons, 2003; Alencáster and Omaña, 2006; Omaña, 2006). All these references have been considered, together with the new data on ammonites and the admitted rudists distribution in other areas of the Caribbean Province, in order to discuss the age attributed to the recognized assemblages.

5.1. *Age of the lower rudist assemblage*

Most of the rudist taxa identified in the localities of the Ocozocoautla and Copoya synclines (Tuxtla Gutiérrez block) coincide with those in the Temazcal limestones at San Luis Potosí, central Mexico (Pons et al., 2010) and also with those in the Clifton limestones at the Central Block of the Lucea Inlier, Jamaica (Mitchell et al., 2011), both attributed to the lower Campanian. Rudist fauna in the localities of the Grijalva Syncline (Angostura block) is more diversified, than that in the former synclines, although lacking some of such taxa and including most of those present in the *Barrettia* limestones of the Haughton Hall Limestone at the Green Island Inlier, the Glenbrook Formation at the Grange Inlier, and the Stapleton Formation at the Sunderland Inlier, Jamaica (Mitchell et al., 2011), attributed to the middle Campanian.

Waite (1987) recognized a shallowing unit (his unit 11) at the uppermost part of the Sierra Madre Formation and dated the upper part of this unit as Coniacian-Santonian by means of an assemblage characterized by the occurrence of *Whiteinella archaeocretacea* Pessagno, exclusive of *Marginotruncana marianosi* Douglas, together with *Dicyclina schlumbergeri* Munier-Chalmas, *Massilina* sp., *Miliola* sp., and *Pseudochrysalidina* sp., as well as corals and radiolitid rudists. None of the biohorizons recognized in Rosales-Domínguez (1998) corresponds to the upper part of the Sierra Madre Formation but to its lower-middle part; the youngest one being indicated as Turonian. The Sierra Madre Formation is considered Aptian–Santonian in the most recent geological maps (Servicio Geológico Mexicano, 2005).

Michaud (1987) proposed the distinction of a different unit, Suchiapa Formation, on top of the Sierra Madre Formation and thus below the Ocozocoautla and Jopabuchil formations, formed by "*massive subreefal white limestones, bioclastic, with rudists and melobesioideae* (red algae) *and abundant fragments of echinoderms and bryozoans,* [...] *with a thickness between 10 and 15 m,* [...] *and late Campanian in age*". There was no indication of a discontinuity at the base suggesting a hiatus, although it is referred in Michaud and Fourcade (1989) and designed in Alencáster and Michaud (1991, fig. 2).

The age of the rudist assemblages is undoubtedly Campanian, but it appears that while the rudist fauna in the western synclines, corresponding to the Tuxtla Gutiérrez block, is early Campanian, the one in the Grijalva syncline, corresponding to the Angostura block, is middle Campanian. In both blocks, rudists appear on the topmost part of the limestones, currently mapped as belonging to the Sierra Madre Formation.

The new evidence on the age of the end of the carbonate sedimentation (regardless of whether named Suchiapa or Sierra Madre formations), as being younger than considered before, and its difference between Tuxtla Gutiérrez and Angostura areas, respectively older and younger, arises some questions on the geology of the region that are far from the scope of this work: is there a discontinuity between the Suchiapa and Sierra Madre formations that makes them distinguishable?; does it exist a hiatus and how long is it?; if so, which is the age of the Sierra Madre Formation topmost?

Some coincidence seems evident between the Suchiapa and Sierra Madre formations of the Chiapas Platform, in southeastern Mexico, and the early Campanian Temazcal limestones and the "mid Cretaceous" El Abra Formation in the Valles-San Luis Potosí Platform, in central Mexico as described in Pons et al. (2010).

5.2. *Age of the middle rudist assemblage*

The Ocozocoautla Formation is mainly composed of fine siliciclastic rocks, marls containing planktic foraminifers as well as inoceramid bivalves and ammonites. In the westernmost outcrops, conglomerates and coarse grain sandstones with microconglomerates occur at the lower part ("*cône detritique sous marin d'Ocozocoautla*" in Michaud, 1987). Also in the western outcrops, a rudist-coral bed, the middle rudist assemblage, occurs at its upper part. It is above a gastropod-rich horizon and below several reddish emersion? surfaces followed by a micro-conglomeratic horizon. Up section, marls include some intercalated limestone beds, and the succession ends with shallow platform limestones containing alveolinid foraminifers and dasycladacean algae of the Angostura Formation.

Most of the rudist taxa are common with those in the lower member of the Cárdenas Formation at San Luis Potosí, central Mexico, considered early Maastrichtian (Pons et al., 2013). They also coincide with several of the rudist listed as occurring in the Guinea Corn Formation at the Central Inlier, Jamaica, attributed to the upper Maastrichtian (Mitchell et al., 2011).

Foraminiferal-lithoclastic grainstones just below the rudist-coral bed at Campo de Tiro section (southern flank of the Ocozocoautla syncline) yielded *Ayalaina rutteni* (Palmer), *Pseudorbitoides rutteni* Bronnimann, *Sulcoperculina dickersoni* (Palmer), and *S. vermunti* (Thiadens), a benthic foraminifers assemblage considered to be Maastrichtian (Omaña and Pons, 2003).

The fine siliciclastics of the lower part of the Ocozocoautla Formation at Turipache section (=El Naranjo section in Michaud, 1987), NE of Ocuilapa de Juárez (northern flank of the Ocozocoautla syncline) yielded a planktic foraminifers assemblage containing *Gansserina gansseri* (Bolli), *Plummerita reicheli* (Brönnimann), *Rugoglobigerina macrocephala* Brönnimann, *R. hexacamerata* Brönnimann, *Globotruncana aegyptiaca* Nakkady, *G. falsostuarti* Sigal, *Contusotruncana plicata* (White), *Pseudoguembelina excolata* (Cushman), *P. kempensis* Esker, and *Pseudotextularia intermedia* de Klanz indicating the upper part of the *Gansserina gansseri* Zone of early Maastrichtian age (Omaña, 2006).

As exposed above, in 4. Ammonites, the ammonite fauna in the marls of the lower part of the Ocozocoautla Formation at the abandoned quarry W of Vicente Guerrero (southern flank of the Ocozocoautla syncline) also indicates the early Maastrichtian.

Consequently, the middle rudist assemblage is considered early Maastrichtian.

5.3. Age of the upper rudist assemblage

Some of its rudists taxa are common with those identified in the upper member of the Cárdenas Formation at San Luis Potosí, central Mexico, considered early late Maastrichtian (Pons et al., 2013). They also coincide with most of the rudist listed as occurring in the Guinea Corn Formation at the Central Inlier, Jamaica, attributed to the upper Maastrichtian (Mitchell et al., 2011).

The inner platform limestones of the Angostura Formation contain abundant microfossils, mainly alveolinacean foraminifers and dasycladacean algae, and several new taxa have been based on material from this unit. These microfossils are currently considered Maastrichtian in the recent literature.

The coral fauna first described by Filkorn et al. (2005) and restudied by Loeser (2012) from the Angostura Formation, at Rancho La Peregrina, on the road 145 from Ocozocoautla to Las Choapas, on the southern flank of the Ocozocoautla syncline (erroneously reported in both papers as Ocozocoautla Formation) is coincident in most taxa with that of several upper Maastrichtian localities in Jamaica.

Consequently, the upper rudist assemblage is considered late Maastrichtian.

6. Conclusions

Three rudist assemblages of different age are distinguished in the Upper Cretaceous of the Central Chiapas Depression: (1) a Campanian lower rudist assemblage in which, an early and a middle sub-assemblages may be considered; (2) an early Maastrichtian middle rudist assemblage; and (3) a late Maastrichtian upper rudist assemblage.

The relationship between the Ocozocoautla and Angostura formations is emended: they are not lateral equivalents but one is above the other; the former is early Maastrichtian while the latter is late Maastrichtian.

At the Tuxtla Gutiérrez block, the Angostura Formation (Ocuilapa marginal platform) and the Juan Crispín Formation (its surrounding belt) overlie the Ocozocoautla Formation and its basinwards lateral equivalent the Jolpabuchil Formation. There is a hiatus between these last and the underlying Sierra Madre Formation (Suchiapa Formation) comprising the middle and late Campanian (Fig. 2A).

At the Angostura block, the Angostura Formation (Angostura insular platform) overlies the Sierra Madre Formation (Suchiapa Formation), with breccia and lateritic bauxites in between. There is a hiatus comprising the late Campanian and the early Maastrichtian (Fig. 2A).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cretres.2015.11.015.