Cenomanian – Coniacian zonation (foraminifers and calcareous algae) in the Guerrero – Morelos basin, southern Mexico

Noemí Aguilera-Franco

Instituto Mexicano del Petróleo, Gerencia de Geociencias,
Eje Central Norte Lázaro Cárdenas 152, C.P. 07730, México
naguiler@imp.mx

ABSTRACT

A biostratigraphic zonation of the Cenomanian–Coniacian rocks of the Guerrero–Morelos basin (southern Mexico) is proposed. The stratigraphic distribution of 70 species of calcareous algae and benthic and planktonic foraminifers is used to characterize four Zones that in ascending order are: Pseudorhapydionina dubia TRZ (Total Range Zone); Whiteinella archaeocretacea IRZ (Interval Range Zone); Helvetoglobotruncana helvetica TRZ, and Marginotruncana sigali IRZ.

The top of P. dubia (upper Cenomanian) is marked at the last appearance of the marker fossil, which closely corresponds to the last appearance of most miliolid benthic foraminifers. Over most of the area, the transition from shallow–marine limestones up into pelagic facies occurs within the W. archaeocretacea Zone (uppermost Cenomanian–lowermost Turonian). A characteristic of this zone is the scarcity of both benthic and planktonic foraminifers, including the zonal marker. Most large benthic foraminifers disappear in the lower part of this zone. The changes observed within the W. archaeocretacea Zone reflect the successive stages of the platform drowning.

The H. helvetica (lower–middle Turonian) is characterized by the presence the nominal taxon, dicarinellids, praeglobotruncanids, whitenelids and hedbergelids. This zone is recognized in the Mexcala Formation and represents deposition in fully pelagic conditions. Toward the central and eastern part of the area in shallow–open marine facies (Cuautla Formation), this zone is represented by an assemblage characterized by hippuritids, echinoids (crinoids and roveacrinids), gymnocodiacean and udoteacean algae and scarce planktonic foraminifers.

The Marginotruncana sigali (upper Turonian–Coniacian) was defined with the last appearance of H. helvetica, whilst its top was difficult to recognize. Toward the central and eastern part of the area, this zone is represented in shallow–open marine facies (Cuautla Formation) by an assemblage dominated by the hippuritid Vaccinites gosaviensis, solitary corals, gymnocodiacean algae, calcisphaerulids and very scarce planktonic foraminifers.

The Cenomanian–Turonian boundary lies in the lower part of the Cuautla Formation. The appearance of hippuritid mollusks and the diversification of whiteinellids can be used to mark this boundary.

Key words: Cenomanian, Coniacian, zonation, Guerrero–Morelos, basin, Mexico.

RESUMEN

Se propone una zonificación para el Cenomaniano–Coniaciano en la cuenca de Guerrero–Morelos (sur de México). Con base en la distribución estratigráfica de 70 especies de algas calcáreas, foraminíferos bentónicos y planctónicos, se identificaron cuatro zonas representadas por Pseudorhapydionina dubia (Zona de Rango Total), Whiteinella archaeocretacea (Zona de Intervalo), Helvetoglobotruncana helvetica (Zona de Rango Total) y Marginotruncana sigali (Zona de Intervalo).

La cima de Pseudorhapydionina dubia, (Cenomaniano superior), está marcada por la última aparición del fósil índice, la cual coincide con la última aparición de la mayoría de foraminíferos bentónicos (miliólidos). En la mayor parte del área, la transición de calizas marinas someras a las facies pelágicas se presenta dentro de la Zona de W. archaeocretacea (Cenomaniano superior–Turoniano inferior). Una característica de esta zona es la escasez de foraminíferos planctónicos incluyendo el fósil índice. La mayoría de foraminíferos bentónicos desaparece en la parte inferior de esta zona. Los cambios observados dentro de la Zona de *W. archaeocretacea refleja los estados sucesivos del ahogamiento de la plataforma.*

La Zona de H. helvetica (Turoniano inferior–medio) está caracterizada por la primera aparición de H. helvetica y la presencia de dicarinélidos, praeglobotruncánidos, whiteinélidos y hedbergélidos. Esta zona fue identificada en la Formación Mexcala y representa el depósito en condiciones netamente pelágicas. Hacia el este y la parte centro del área de estudio, en facies marinas someras (Formación Cuautla), esta zona está caracterizada por la presencia de hipurítidos quinodermos, algas gimnocodiáceas y udoteáceas y escasos foraminíferos planctónicos.

*La Zona de Marginotruncana sigali (Turoniano superior–Coniaciano) está caracterizada por la última aparición de H. helvetica, mientras que su cima fue difícil de reconocer. Hacia la parte central y el oriente del área de estudio, esta zona está representada en facies marinas someras abiertas (Formación Cuautla) por un conjunto constituido por hipurítidos (*Vaccinites gosaviensis*) corales solitarios, algas gymnocodiáceas, calcisferúlidos y escasos foraminíferos planctónicos.*

El límite Cenomaniano–Turoniano está representado en la parte inferior de la Formación Cuautla. La presencia de moluscos hipurítidos y la diversificación de whiteinélidos pueden usarse para marcar este límite en el área de estudio.

Palabras Clave: Cenomaniano, Coniaciano, zonificación, Guerrero–Morelos, cuenca, México.

INTRODUCTION

Cretaceous marine sediments exposed in several localities in the Guerrero–Morelos basin of southern Mexico have been the focus of numerous studies in stratigraphy and lithostratigraphy (Fries, 1960; Bolivar, 1963, de Cserna, 1965 and Olea-Gómezcaña, 1965, Ontiveros-Tarango, 1973; Dávila-Alcocer, 1974 and Hernández-Romano, 1995). Although several workers have studied these rocks, the biostratigraphy of the Cenomanian–Turonian succession has received very little attention. Fries (1960) first described in detail the fossil assemblages of the Morelos, Cuautla and Mexcala formations, and assigned to these formations an Albian–Cenomanian, Turonian and Coniacian–Campanian age, respectively. Later, Ontiveros-Tarango (1973) studied the palaeontological assemblage of the Morelos and Mexcala formations in the western part of the basin and assigned an Aptian–Cenomanian age to the Morelos Formation and a Turonian–Campanian age to the Mexcala Formation. Other workers (Alencáster 1980; Alencáster *et al*., 1987; Aguilera-Franco *et al*., 1992; Perrilliat *et al*., 1994) have studied the biostratigraphy of isolated outcrops of the upper Cuautla (Turonian–Santonian) and Mexcala (Coniacian–Campanian) formations. Aguilera-Franco (1995), in Upper Cretaceous rocks of the eastern part of the Guerrero–Morelos basin, recognized the: *Nummoloculina regularis* Zone (lower–middle Cenomanian) and the lower part of the *Whiteinella archaeocretacea* Zone (upper Cenomanian–lower Turonian) in the upper part of the Morelos Formation; and the *Dicarinella* (lower Turonian) because I did not find the nominal taxón and *Helveto-globotruncana helvetica* Zone (middle Turonian) in the lower Mexcala Formation.

Because of the scarcity of marker fossils, previous correlations in this region have been mainly lithostratigraphic. The scarcity of marker fossils in the shallow marine limestones and siliciclastics of the Guerrero–Morelos basin has been the main obstacle for a high-resolution correlation of these rocks. Benthic foraminifers and calcareous algae are commonly used as paleoenviron-mental indicators rather than age index fossils. However, since parts of the Upper Cretaceous succession contain almost exclusively benthic fossils their use as stratigraphic markers is necessary. The transition from Cenomanian shallow marine to Turonian hemipelagic and pelagic facies makes necessary the use of an integrated benthic–planktonic zonation.

BACKGROUND OF THE GUERRERO–MORELOS BASIN

The study area, located in the Guerrero–Morelos basin, is characterized by an Aptian–Maastrichtian sedimentary marine succession that has extensive outcrops in the states of Morelos and Guerrero, in southern Mexico (Figure 1). The stratigraphic column is mainly composed of a thick succession (>800 m) of shallow marine limestones (Morelos and Cuautla formations) that grade upwards to Turonian–Campanian pelagic limestones and siliciclastics of the Mexcala Formation (Fries, 1960; Aguilera-Franco, 1995). These rocks are unconformably overlain by Tertiary

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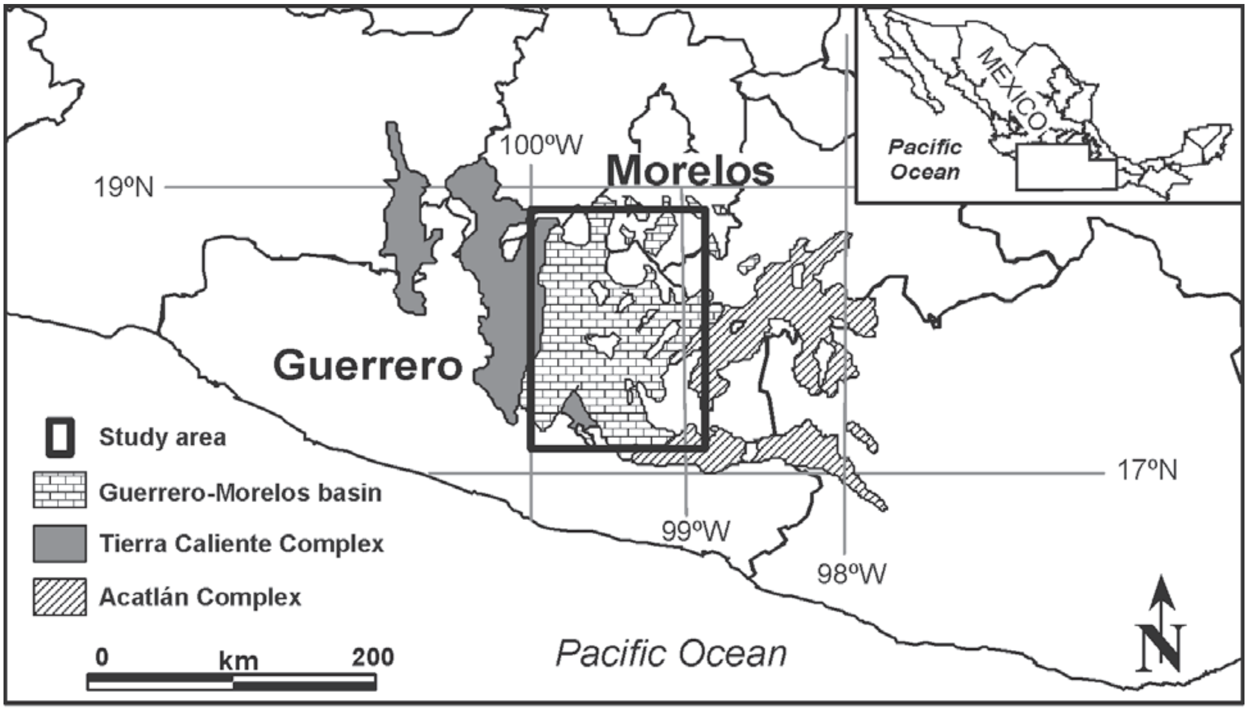

Figure 1. Location of the study area (from Aguilera-Franco, 2000).

continental deposits of the Balsas Group and Quaternary volcanic rocks of the Trans-Mexican Volcanic Belt (Fries, 1960). This work is focused on the biostratigraphy of the upper part of the Morelos and Cuautla formations and the lower Mexcala formation.

In order to provide a time framework for the sedimentologic evolution of the basin, this work present the biostratigraphy of foraminifers and calcareous algae identified in several sections. This includes the Cenomanian–Coniacian succession, and their relations to the standard global ammonite/planktonic foraminiferal biostratigraphy. The main goal of this paper is to define the stratigraphic distribution of the main marker fossils in the succession and to correlate to the standard foraminiferal biozones. A further objective is to review the Cenomanian–Turonian biostratigraphy and to compare the biotic changes found in this study with those reported world-wide.

Previous biostratigraphic studies in the Guerrero–Morelos basin

From a biostratigraphic point of view, this area has received little attention. Fries (1960) first described in detail the palaeontologic content of the main lithostratigraphic units and assigned them the age. Other authors (Dávila-Alcocer, 1974; de Cserna *et al.*, 1978, 1980; Sánchez-Zavala, 1993) reported diverse fossils and were also able to provide provisional ages or confirm those assigned by Fries (1960). Since Fries publication, two zonations have been proposed in this area (*e.g.*, Aguilera-Franco, 1995; Zamudio-Angeles and Ferrusquía-Villafranca, 1996). The different relationships and ages proposed for the Morelos, Cuautla and Mexcala formations are showed in Figure 2.

Biostratigraphy of the Morelos Formation

The Morelos Formation consists of limestones and dolomites with sporadic argillaceous horizons of Albian–early Cenomanian age (Fries, 1960). The fossils that Fries reported for this unit include microfossils (benthic foraminifers) and scarce macrofossils (mollusks and ostracods). The species of benthic foraminifers reported by Fries (1960) in these rocks include: *Dicyclina schlumbergeri*, *Nummoloculina heimi*, *Spiroloculina* sp., *Nonion* (?) sp., *Lagena* sp., *Dentalina*, *Bigerina* sp., *Dukhania* sp., *Ovalveolina* sp., *Triloculina* sp., *Quinqueloculina* sp., *Cuneolina* sp., *Opthalmidium* sp., *Guttulina* sp., *Cyclammina* sp., *Ammobaculites* cf. *A. cuxleyi*, *Lituola* sp., *Massilina* sp., *Massilina* cf. *planoconvexa*, *Palmula* cf. *P. decorata* and *Turrispirillina subconica* (?). The macrofossils are represented by *Peronidella* sp. cf. *P. ramosissima*, *Epistreptophyllum* sp. cf. *E. budaensis*, *Hyposalenia* (?) sp., *Spondylus* sp., *Ostrea* sp., *Praeradiolites* (?) sp., *Toucasia patagiata* (?) sp., *Toucasia texana* (?), *Nerinea* sp., and *Actaeonella* sp. Between Teloloapan and Iguala (near Petaquillos) large caprinids, including *Caprinuloidea* sp., and probable *Kimbleia* of upper Albian have been observed in rocks of the Morelos Formation (P. Skelton, personal communication, 2000).

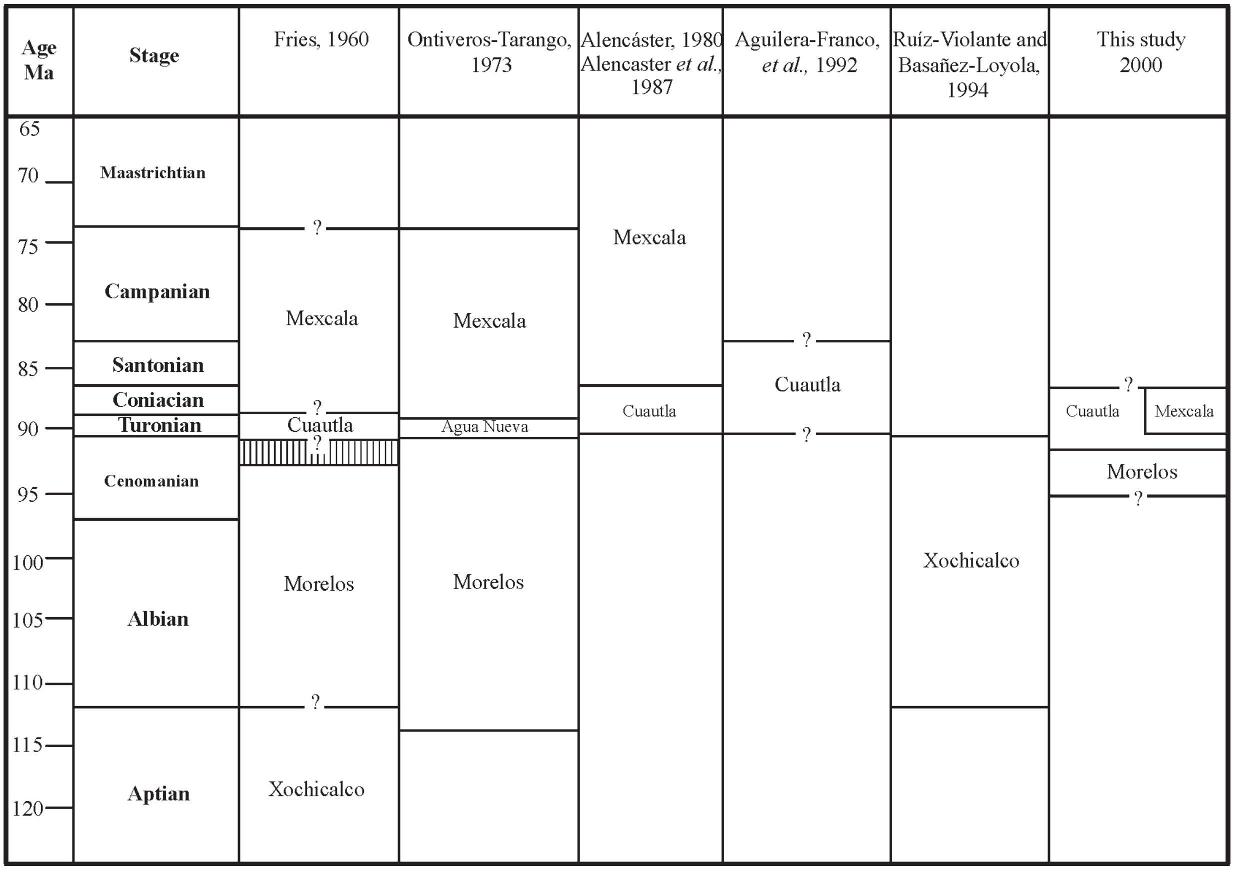

Figure 2. Comparison of Cretaceous lithostratigraphic units of the Guerrero–Morelos basin.

Ontiveros-Tarango (1973), studied rocks of the Morelos Formation cropping out in the north-western part of the basin and reported a microfossil assemblage characterised by benthic (*Nummoloculina heimi*, *N.* sp., *Dictyoconus* sp., *D. walnutensis*, *Dicyclina schlumbergeri*, *Quinqueloculina* sp., *Valvulammina* sp., *Nezzazata* sp.), and planktonic foraminifers, tintinids (*Colomiella recta*, *C. mexicana*), calcisphaerulids (*Pithonella ovalis*, *Calcisphaerula innominata*), and incertae sedis (*Globochaete alpina*, *Microcalamoides* sp.). He assigned a late Aptian to Cenomanian age to this unit, and considered this Formation correlatable to the pelagic facies of the Tamaulipas Superior Formation.

Aguilera-Franco (1995) attempted for the first time a foraminiferal zonation for the Morelos Formation towards the eastern part of the basin. On the basis of benthic foraminifers she recognized the a) *Nummoloculina regularis* (lower–middle Cenomanian), and the b) *Pseudorhapydionina laurinensis* zones (upper Cenomanian). Later, Zamudio-Angeles and Ferrusquía-Villafranca (1996), recognized the *Nummoloculina heimi* Zone with two subzones represented by *Pseudorhapydionina* and *Pseudolituonella reicheli* of upper Albian–Cenomanian–Turonian (?) age.

Biostratigraphy of the Cuautla Formation

The Cuautla Formation consists of limestones and clastic limestones of upper Cenomanian. Fries (1960), studied rocks of the Cuautla Formation and on the basis of the fossil assemblage he assigned a Turonian age. The fossil assemblage that he reported for this unit include dasycladacean (*Dissocladella*, *Acicularia*, *Neomeris* cf. *N.* cf. *N. cretacea*, *Holosporella* cf. *H. siamensis*) and udoteacean algae (*Boueina*), rudists (*Hippurites resectus*, *Hippurites* sp., *Durania cornuspastoris*, *Radiolites mullerriedi*, *Toucasia*), other mollusks, corals, echinoderms and planktonic microfossils (calcisphaerulids and planktonic foraminifers).

Alencáster *et al*. (1987) studied the macrofauna of the eastern part of the basin and assigned an age of late Turonian–Coniacian to rocks of the Cuautla Formation; Aguilera-Franco *et al*. (1992) studied rocks of the Cuautla Formation from the eastern part of the basin and assigned them to a Turonian–Santonian age (referred as Apango Formation).

Biostratigraphy of the Mexcala Formation

A succession of calcareous sandstones, siltstones and shales with clastic limestones was defined by Fries (1960) as the Mexcala Formation. The fossil content that he found in these rocks include macrofossils (*Barroisiceras* sp. *B*. cf. *B. alstadenense*, *B*. cf. *B. haberfellneri*, *Peroniceras* sp., *P*. cf. *P. subtricarinatum*, *Ostoscaphites* cf. *O. geinitzi*, *O*. cf. *O. auritus*, *Crioceras* sp., *Inoceramus* sp., *Peroniceras* sp., *Durania* sp.), benthic (Ammob*a*culites (?) sp., *Spiroplectammina* sp., *Guembelina* sp., *Lamarckina* sp., *Cibicides* sp., *Haplophragmoides* (?) sp., *Gaudyina* sp.) and planktonic foraminifers (*Praeglobotruncana* sp., *Globotruncana fornicata*, *G. scheegansi* among others), calcisphaerulids (*Calcisphaerula* sp., *Stomiosphaera* sp.) and radiolarians. Based on the fossil assemblage he assigned them a Turonian–Campanian age.

Ontiveros-Tarango (1973) studied rocks of the Mexcala Formation towards the northwestern part of the basin and based on the fossil assemblage he also assigned them a Turonian–Campanian age. He also correlated this unit with the Agua Nueva Formation. The palaeontological assemblage that he reported include calcisphaerulids (*Pithonella ovalis*, *Calcisphaerula innominata*, *Stomiosphaera sphaerica*), benthic and planktonic foraminifers (*Hedbergella* sp., *Heterohelix* sp.).

Alencáster (1980) reported some mollusks and assigned a Maastrichtian age to the upper part of the Mexcala Formation. In contrast, recent biostratigraphic and palaeobiological studies of mollusks in the same area suggest a Coniacian age (Perrilliat *et al*., 1994).

Aguilera-Franco (1995) based on planktonic foraminifers recognized the a) *Whiteinella archaeocretacea* (uppermost Cenomanian–lowermost Turonian); b) *Dicarinella* (lower Turonian); and c) *Helvetoglobotruncana helvetica* zones (middle Turonian). Zamudio-Angeles and Ferrusquía-Villafranca (1996), recognized the *Whiteinella*, *Helvetoglobotruncana helvetica* and *Marginotruncana angusticarinata* zones of Turonian–lower Coniacian age.

Due to the poorly constrained chronostratigraphic framework in the basin, the Cenomanian–Turonian boundary has been considered the most reliable chronostratigraphic level in the basin (Hernández-Romano *et al*., 1997; Aguilera-Franco, 1998a, 1998b; Hernández-Romano, 1999). The exact position of the Cenomanian–Turonian boundary lies within the basal Cuautla Formation (Aguilera-Franco, 2000).

MATERIALS AND METHODS

Fifteen stratigraphic sections were analyzed in detail. These sections were measured in the upper part of the Morelos and the lower part of the Cuautla and Mexcala formations. Additional samples from other localities were collected in isolated outcrops in order complete our understanding of facies variation and age (Figure 3). Identification of planktonic and benthic foraminifers and calcareous algae was made from thin sections. For the determination of calcareous algae, the criteria of Bassoullet *et al*. (1975, 1978, 1979), Deloffre and Poignant (1978) Wray (1978), and Deloffre (1992) were followed. The benthic foraminifers were identified according to the criteria of Saint-Marc (1975), Michaud *et al*. (1984), Schroeder and Neumann (1985) and Loeblich and Tappan (1987). The identification of planktonic foraminifers was based on Sliter (1989), some examples are showed in Plate 1. A chart with the total ranges of the identified fossils was constructed (Figure 4). This chart was obtained from the each measured section.

After the identification of the microfossil assemblage, an integrated benthic and planktonic microfossil biostratigraphy was recognized, and a possible correlation with the standard ammonite/planktonic zonations was established (Figure 5).

THE GLOBAL CENOMANIAN–TURONIAN BOUNDARY BIOSTRATIGRAPHY

The chronostratigraphic subdivisions and boundaries of the Cenomanian and Turonian are commonly established using ammonites, inoceramid bivalves, planktonic foraminifers and calcareous nannofossils (Birkelund *et al*., 1990). Ammonite zones provide the finest resolution (Kennedy, 1984; Hancock e*t al.*, 1993), but condensation, breaks in sedimentation and provincialism of the fossil assemblage hamper interregional correlation.

Hancock *et al.* (1993) established an ammonite zonation for the rocks above and below the Cenomanian–Turonian boundary. These authors defined the upper Cenomanian from the base of the *Calycoceras guerangeri*/*naviculare* Zone to the top of the *N. juddii* Zone. The lower Turonian goes from this level to the top of the *M. nodosoides*. In other localities such as Mexico, New Mexico, Arizona, Colorado, Central Tunisia, Nigeria, southern India, Madagascar, and northern Europe the first evolutionary appearance of the ammonite *Pseudaspidoceras flexuosum* Zone is recognized as the beginning of the Turonian (Birkelund *et al.*, 1990; Hancock, 1991, Hancock *et al.*, 1993). In France, after the *N. juddii* Zone in the upper Cenomanian, the *Spinoceras gracile* ammonite IRZ represents the uppermost Cenomanian (Hancock, 1993; Jolet *et al.,* 1997). Hancock *et al.* (1993) has pointed out that an unconformity is present in most European localities in the uppermost Cenomanian.

In many regions, particularly those where ammonites are scarce, the presence of *Inoceramus* is used to mark the Cenomanian, whilst the first appearance of *Mytiloides* spp. is used to draw the CTB (Barnes *et al.*, 1996; Hallam and Wignall, 1997). In some localities, the basal Turonian can be identified by the appearance of the inoceramid bivalve *Mytiloides colombianus* (= *M. opalensis*) (Hancock, 1991).

In the planktonic foraminiferal stratigraphy, the Cenomanian is represented by the *R. reicheli* Total Range Zone (TRZ), the *R. cushmani* TRZ and the lower part of

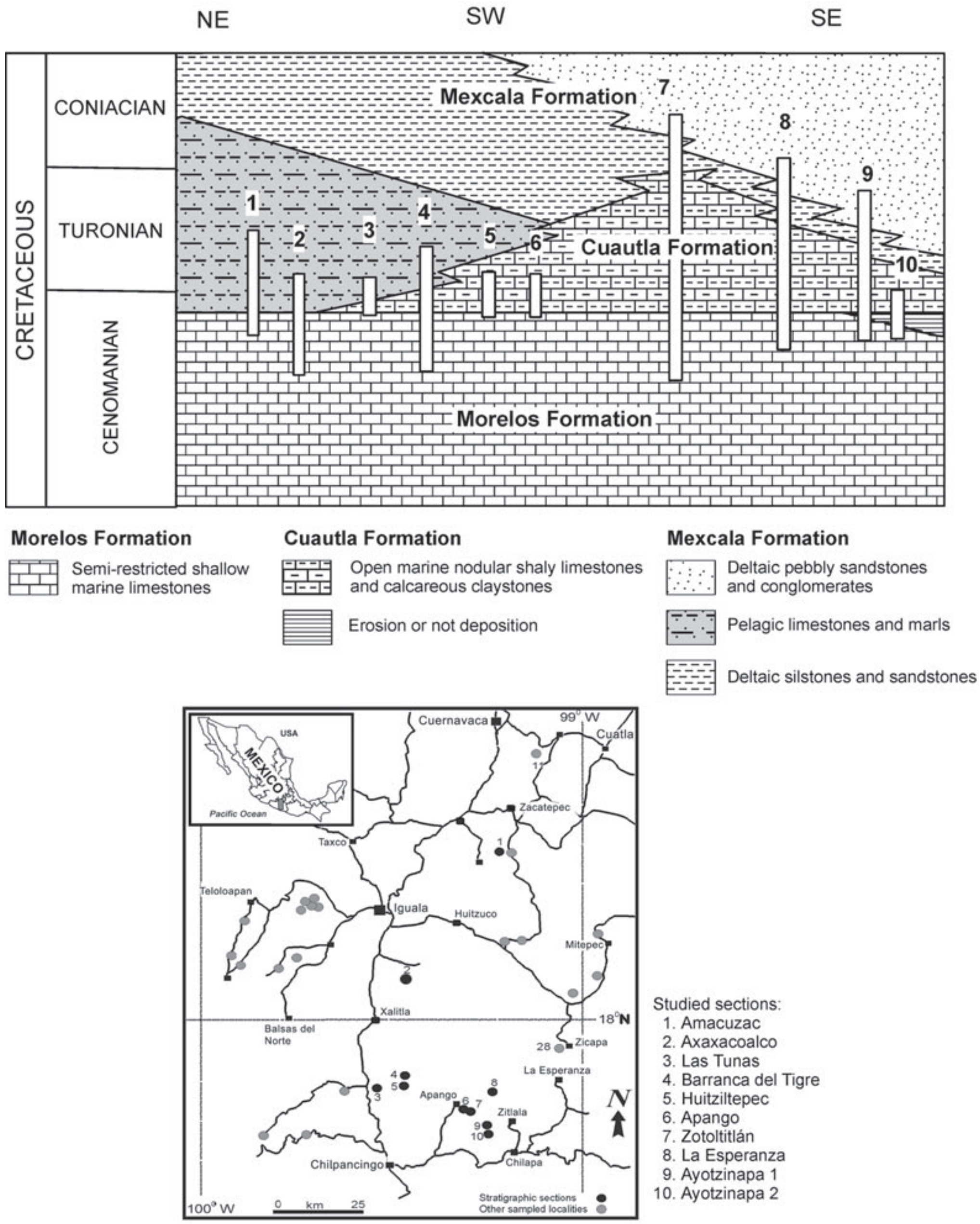

Figure 3. Chronostratigraphic position of measured stratigraphic sections, location of the studied sections, and position of each stratigraphic section and other sampled localities. Modified from Aguilera-Franco (2000).

the *Whiteinella archaeocretacea* IRZ. The Turonian is represented by the upper part of the *W. archaeocretacea* IRZ, the *Helvetoglobotruncana helvetica* TRZ, and most of the *Marginotruncana sigali* IRZ (Sliter, 1989).

In centrral Tunisia (Salaj, 1986), the appearance of *Dicarinella imbricata* has been used to indicate the lower Turonian. In the French Alps, the association of calcisphaerulids, *Whiteinella archaeocretacea*, *W. aprica*, *Praeglobotruncana praehelvetica* and primitive *Marginotruncana* spp. can be used to identify the uppermost Cenomanian or lowermost Turonian (Hart, 1996).

In the uppermost Cenomanian, which corresponds to the N., *juddii* ammonite Zone, the foraminifera *Heterohelix* sp. and *Hedbergella* sp. show a decrease in diversity and are accompanied by abundant calcisphaerulids. In the lowermost Turonian (*W. coloradoense* ammonite Zone), the planktonic foraminifers *Dicarinella* and *Praeglobotruncana,* which disappeared in the upper Cenomanian, tend to appear again (Hart and Leary, 1989; Leary *et al*., 1989; Peryt and Lamolda, 1996).

Carter and Hart (1977) proposed a very detailed zonation for the Cenomanian based on open-marine benthic fora-

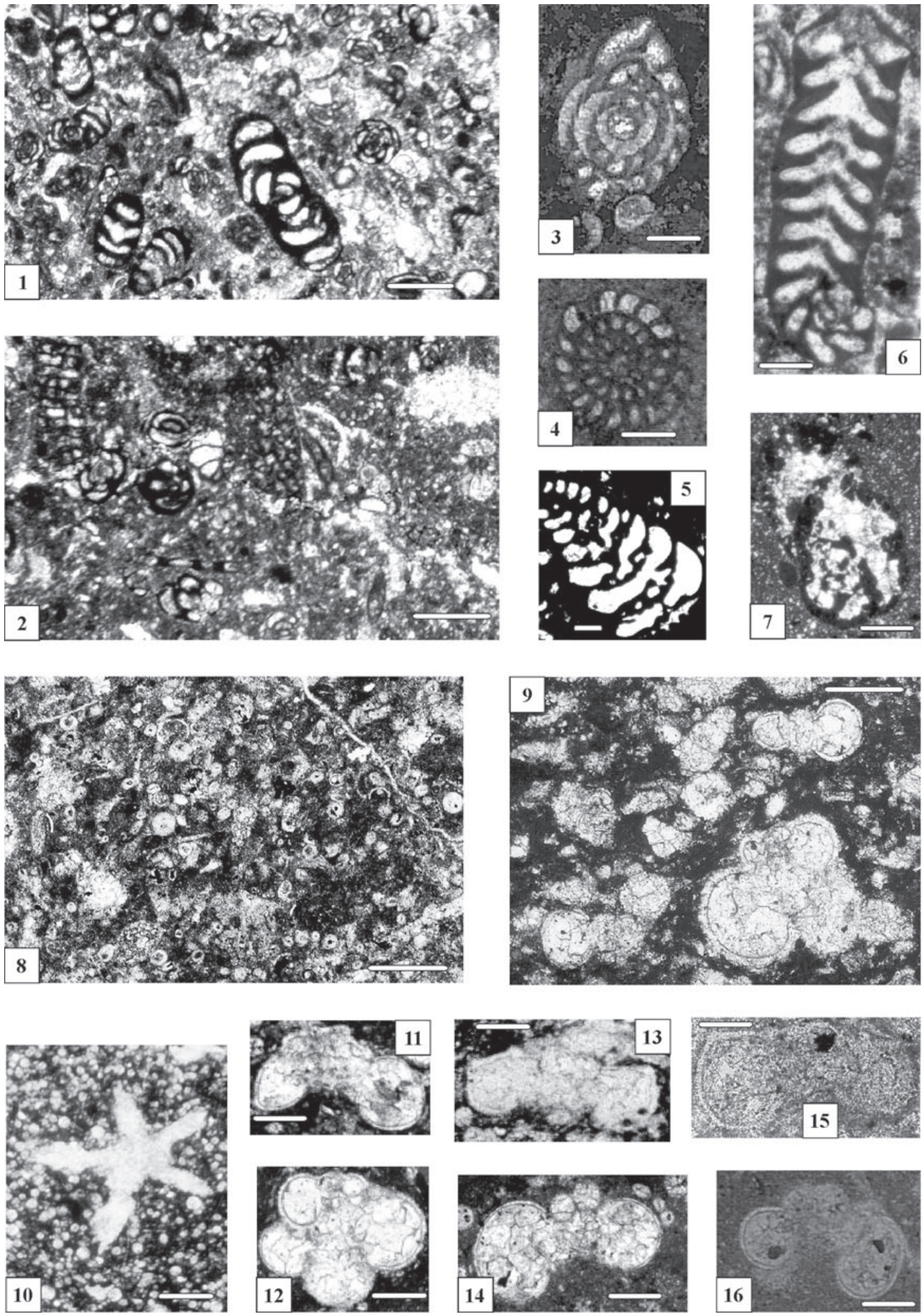

Plate 1. 1) Grainstone–packstone of milioliods and peloids of the Morelos Formation, Ayotzinapa-2, AY-5; 2) foraminiferal/packstone of the Morelos Formation, La Esperanza, NA94-03; 3) *Murgeina apulla*, Ayotzinapa-2, AY-05; 4) *Moncharmontia appeninica*, Axaxacoalco, AX-33; 5) *Chrysalidina gradata*, Barranca del Tigre, BT-16; 6) *Pseudorhapydionina chiapanensis,* Zotoltitlán, Zot-27; 7) *Pseudocyclammina rugosa*. La Esperanza, NA94-24; 8) calciphaerulid/packstone of the Cuautla Formation, Las Tunas, NA96-25; 9) Pckstone with planktonic foraminifera, of the Mexcala Formation, Las Tunas NA96-38; 10) *Roveacrinus* sp.RMCH aff. *rugosus*, Las Tunas, NA96-28; 11) *Whiteinella archaeocretacea*, Barranca del Tigre, BT-28; 12) *Whiteinella paradubia*, Barranca de Tigre, BT-84; 13) *Helvetoglobotruncana helvetica*, Amacuzac, AM-22; 14) *Whiteinella baltica*, Las Tunas, NA96-30; 15) *Helvetoglobotruncana helvetica*. Barranca del Tigre, BT-84; 16) *Whiteinella praehelvetica*, Barranca del Tigre, BT-84. Bar scale=100μ.

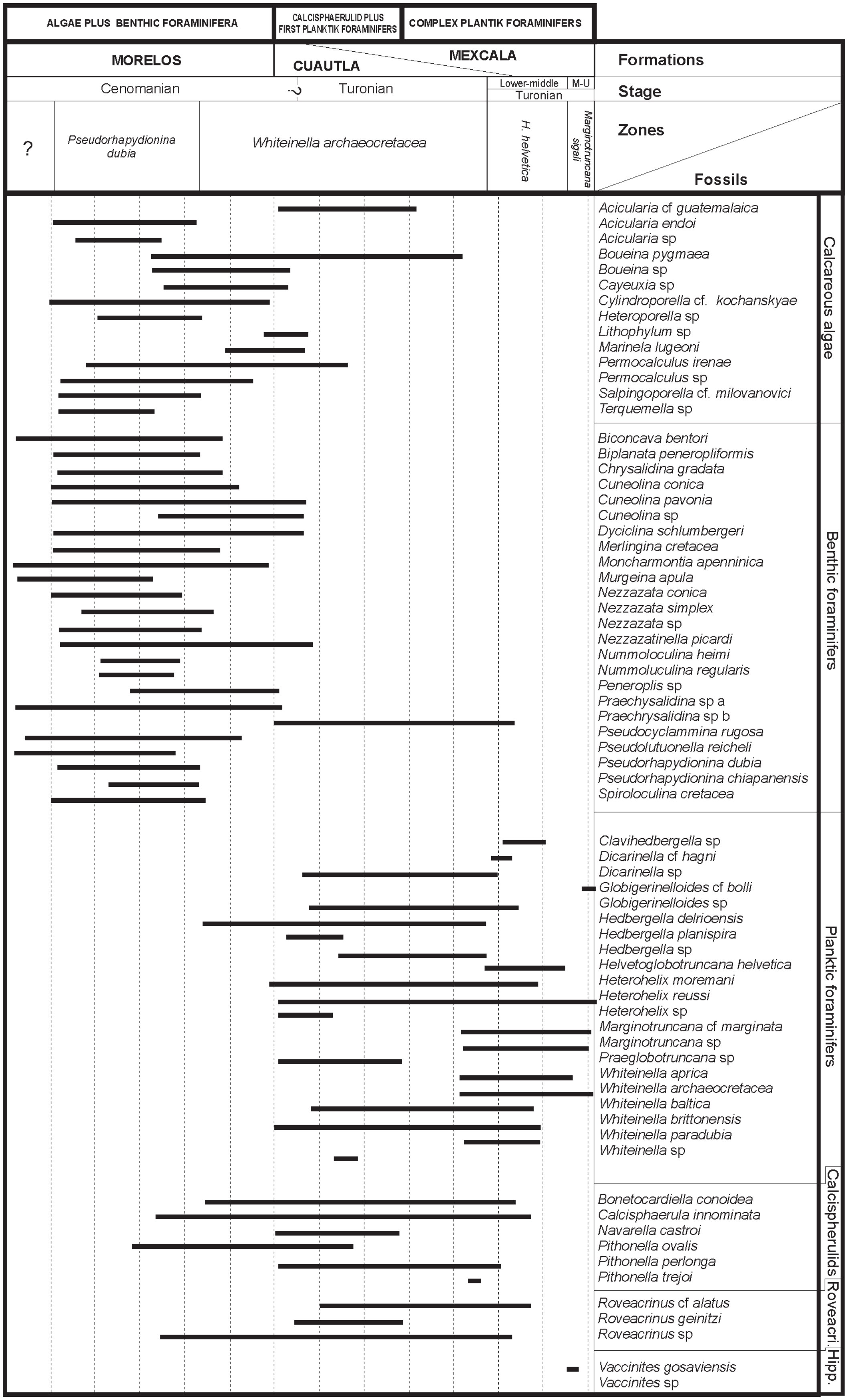

Figure 4. Rang chart for all 70 taxa in the studied sections of the Guerrero–Morelos basin.

minifers from a hemipelagic succession in southern England (Figure 5). Initially they proposed the *Arenobulimina preslii* Zone to straddle the CTB, however, more recent studies in the same locality (Hart, 1996) have placed this boundary higher in the section. The *Arenobulimina preslii*/*Rotalipora cushmani* assemblage Zone of Carter and Hart (1977) is drawn as equivalent to the uppermost part of the *R. cushmani* planktonic foraminiferal Zone.

Lamolda *et al.* (1994) and Peryt and Lamolda (1996) have used the first appearance of the nannofossil *Quadrum gartneri* to mark the CTB, while Luciani and Cobianchi (1999) observed that the first appearance of *Quadrum gartneri* coincides with the first appearance of *Helvetoglobotruncana helvetica* within the early Turonian.

Recently, some authors have noticed that some species of roveacrinids such as *Orthogonocrinus* cf. *apertus* and *Roveacrinus* cf. *geinitzi* can be used as marker fossils for the uppermost Cenomanian (*N. juddii* Zone), while *Roveacrinus* aff. *alatus* (*W. coloradoense* Zone) and *R*. cf. *communis* for the lowermost Turonian (Ferrè and Berthout, 1994; Ferrè *et al*., 1996, 1997).

In shallow-marine facies, the zonations are poorly developed and are highly influenced by provincialism. In the Western Mediterranean Province, the first appearance of hippuritid rudists is thought to occur at the CTB (Philip and Airaud-Crumière, 1991).

Most of the large benthic foraminifers disappear in the upper Cenomanian (Berthou, 1973; Billote, 1985, Caus *et al.*, 1993; Andreu *et al.*, 1996). Floquet *et al.* (in Philip and Airaud-Crumière, 1991) noted that the disappearance of benthic foraminifers occurs at the top of the *M. geslinianum* ammonite Zone in the upper Cenomanian and their disappearance nearly coincides with the top of the planktonic foraminifer *R. cushmani* TRZ. They also noticed that in the uppermost Cenomanian (*N. Juddii Zone)* trochaminids, miliolids and textulariids only represent the benthic foraminifers.

Saint-Marc (1975) and Chiocchini *et al.* (1979) proposed zonations based mainly on benthic foraminifers from shallow-marine facies in Lebanon and central Italy, respectively (Figure 5). Saint-Marc (1975) defined the *Pseudorhapydionina laurinensis* Zone as a unit in the lower part of the upper Cenomanian characterized by the presence of this fossil. He pointed out that this unit corresponds to the total stratigraphic range of this species. For the neritic facies of the uppermost Cenomanian and lowermost Turonian, he proposed the *Cisalveolina fallax* Zone. For the upper part of the middle Cenomanian and the upper part of the upper Cenomanian, Chiocchini *et al.* (1979) considered an assemblage Zone with *P. dubia* and *P. laurinensis*. For the uppermost Cenomanian to the middle Turonian, they proposed the *Chrysalidina gradata*/*Pseudolituonella reicheli* assemblage Zone.

Erba *et al.* (1995) proposed a succession of large benthic foraminiferal events. They located the probable disappearance of *Nummoloculina heimi* and *Cuneolina parva* close to the base of the *R. cushmani* TRZ. The probable disappearance of *Orbitolina* (*Conicorbitolina*) sp. was located in the upper part of the *R. cushmani* TRZ, while the disappearance of *Cuneolina pavonia* low in the *W. archaeocretacea* IRZ.

There are few publications dealing with the biostratigraphy of the CTB in Mexico. The planktonic foraminiferal zones in pelagic facies have been assigned the following chronostratigraphic equivalencies: *W. archaeocretacea*, uppermost Cenomanian to lowermost Turonian; *Dicarinella*, remaining part of the lower Turonian; and *H. helvetica,* middle Turonian (Soto-Jaramillo, 1981). In Cenomanian–Turonian shallow-marine facies, biostratigraphic papers are even scarcer. A few papers describe the fossil assemblage of some intervals and their potential as chronostratigraphic markers, but no zonation has been proposed (Michaud and Fourcade, 1989; Hernández-Romano *et al.*, 1997; Rosales-Domínguez *et al.*, 1997).

CENOMANIAN–CONIACIAN ZONATION IN THE GUERRERO–MORELOS BASIN

On the basis of the distribution of benthic and planktonic foraminifers, a zonation scheme has been established: four zones were identified (Figures 4 and 5). The zonal boundaries were defined by first and last appearances of marker species. For each zone only the most significant microfossils of the assemblage are mentioned. Three different types of zones were identified in this study. 1) Total Range Zone (TRZ), defined as the body of strata representing the total range of occurrence of a particular taxon. 2) A Concurrent–Range–Zone (CRZ) is defined as the concurrent or coincident parts of the range-zones of two or more specific taxon selected from among the total forms contained in a sequence of strata. 3) Interval Range Zone (IRZ) defined as the interval between two distinctive biostratigraphical horizons (Hedberg, 1976).

Because of the marked provincialism of some species of benthic foraminifers and their strong relation to environmental changes, a standard benthic foraminiferal zonation does not exist. Despite the limitation of benthic fossils, some authors working in the Tethyan realm have proposed some benthic foraminiferal zonations that are useful for local and regional correlations (Berthou, 1973; Saint-Marc, 1975; Chiocchini *et al*., 1979). The planktonic zonation presented in this paper is partially based on that of Sliter (1989).

Although the zonation spans an interval from the Cenomanian–Coniacian, this work focuses on the Cenomanian–Turonian transition. Figures 6 to 10 represent the distribution in five of ten studied sections, because they are the most complete. Plate 1 shows some facies and microfossils of the Morelos,Cuautla and Mexcala formations. The zones identified for the Cenomanian–Coniacian succession are described below.

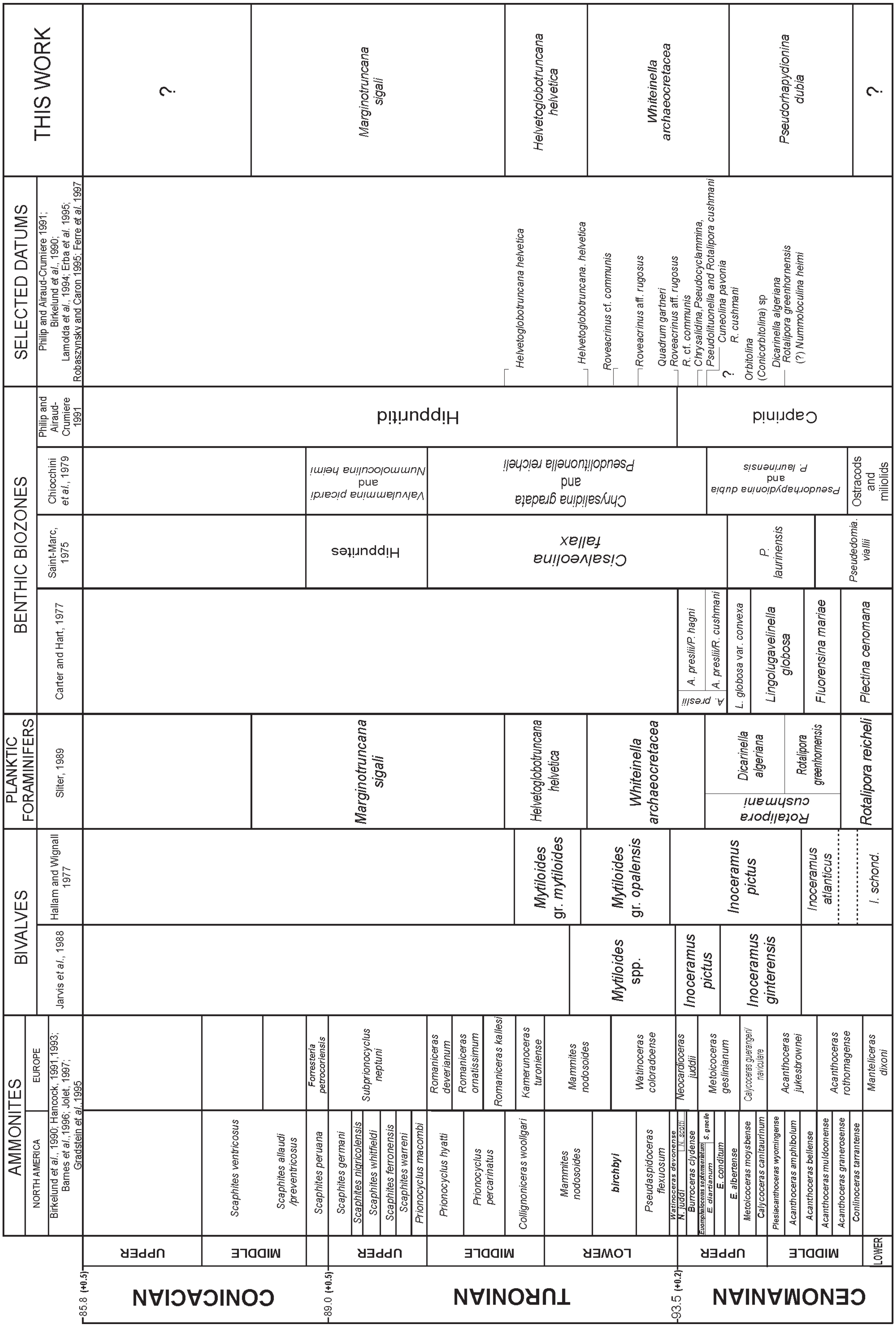

Figure 5. Biostratigraphic schemes of the Cenomanian–Turonian succession around the world and biostratigraphic zonations in the study area.

Pseudorhapydionina dubia Total Range Zone

Definition. Saint-Marc (1975) defined the *Pseudorhapydionina laurinensis* TRZ for the lower part of the upper Cenomanian of Lebanon. Chiocchini *et al.* (1979) considered it as the TRZ of *P. dubia–P. laurinensis* for central Italy. In Europe, *P. dubia* is associated with *P. laurinensis,* while in Mexico, *P. dubia* is associated with *P. chiapanensis.* According to Fourcade (personal communication, 1998), *P. chiapanensis* is an indigenous taxon of Mexican sediments, just as *P. laurinensis* is for European sediments.

In the study area, the total stratigraphic range of *Pseudorhapydionina dubia* defines this zone. In Mexico, this taxon has been reported in the middle–upper Cenomanian sediments associated with *P. chiapanensis* (Michaud *et al*., 1984). This zone is probably equivalent to the *Pseudorhapydionina laurinensis* TRZ of Saint-Marc (1975), together with the *P. dubia–P. laurinensis* TRZ of Chiocchini *et al.* (1979). In pelagic facies, this zone could be equivalent to the *Rotalipora cushmani* TRZ, while, with ammonites, it may be equivalent with the upper part of the *C. guerangeri* and the *M. geslinianum* Zones of Hancock *et al.* (1993).

Author. Chiocchini *et al.* (1979)

Stratigraphic Position. Upper middle–upper Cenomanian. In this work, the *Pseudorhapydionina dubia* TRZ has been assigned to the upper middle–upper Cenomanian. In Mexico, *P. dubia* De Castro has been reported for middle–upper Cenomanian rocks together with *P. chiapanensis* Michaud *et al.* (Michaud e*t al.*, 1984; Aguilera-Franco, 1995). The fossil association in the upper part of the Morelos Formation is similar of that reported from rocks of the upper middle–upper Cenomanian in the Tethyan domain (Berthou, 1973; Saint-Marc 1975; Schroeder and Neumann, 1985). According to these authors, the association of *Biconcava bentori*, *Biplanata peneropli-formis*, *Chrysalidina gradata*, *Pseudocyclammina rugosa* and *Pseudorhapydionina dubia* is common for that interval.

The *P. dubia* TRZ also contains the disappearance of most species of miliolid benthic foraminifers. A disappearance of large benthic foraminifers has been observed in upper Cenomanian rocks associated with the extinction of *Rotalipora greenhornensis* (Birkelund *et al*., 1990). Since the extinction of *R. greenhornensis* occurred just below that of *R. cushmani* and the top of the ammonite *M. geslinianum* Zone lies just above this level, it is very likely that the top of *Pseudorhapydionina dubia* TRZ closely corresponds with the top of the *R. cushmani* TRZ. According to that, the stratigraphic position of this zone could be upper middle–upper Cenomanian.

The disappearance of several species of this group in the upper Cenomanian rocks has also been observed in other Mexican localities (Rosales-Domínguez, personal communication), and has been reported from Lebanon (Saint-Marc, 1975), and the Western Mediterranean Province (Berthou 1973; Bilotte, 1984, 1985; Philip and Airaud-Crumière, 1991; Caus *et al*., 1993; Andreu *et al*., 1996).

Remarks. In the study area, the rocks of this Zone contain high diversity and abundance of large benthic foraminifers and some species of green algae. The benthic assemblage is dominated by miliolids: *Nezzazata conica*, *N. simplex*, *Biconcava*, *Biplanata peneropliformis*, *Merlingina cretacea, Nezzazatinella picardi, Trochospira avnimelechi*, *Moncharmontia apenninica*, *Nummoloculina heimi*, *N. regularis*, *Pseudorhapydionina chiapanensis*, and *P. dubia*, *Murgeina apulla*; the lituolids*: Moncharmontia apenninica, Charentia cuvillieri*, *Cuneolina* sp., *C. conica* and *C. pavonia*, *Dicyclina schlumbergeri*, *Praechrysalidina infracretacea*, *Chrysalidina gradata*, *Pseudolituonella reicheli* and *Pseudocyclammina rugosa,* as well as rotaliids and discorbiids. This assemblage also contains species of calcareous algae include *Acicularia* sp., *Acicularia endo*, *Terquemella* sp., *Salpingoporella* cf. *milovanovici*, *Cylindroporella* cf. *kochanskyae*, *Pseudolithophylum album, Permocalculus* sp., *Boueina* sp., and *Thaumatoporella parvovesiculifera*. Also included in this assemblage are gastropods, rudists (mainly requieniids and scarce radiolitids), ostracods, and spicules of tunicates (*Pienina oblonga*). At the top of this Zone there are scarce calcisphaerulids.

Reference Locality. This zone is very well represented and has its maximum thickness in the Zotoltitlán section located at 6.6 km south-west of the Apango town (Figures 3, 5 and 6). In the section, its contact with the *W. archaeocretacea* Zone is very well represented. This Zone is also well characterized in the sections Axaxacoalco, Barranca del Tigre (Figure 7), La Esperanza (Figure 8), Ayotzinapa 1 (Figure 9) and Ayotzinapa 2. In the last two sections, its upper contact was not very well observed.

Whiteinella archaeocretacea Planktonic Foraminifera Interval Range Zone

Definition. This zone is defined as the Interval Range Zone, from the last appearance of *R. cushmani* Morrow, to the first appearance of *H. helvetica* Bolli (Caron, 1985; Sliter, 1989). In the study area, this zone includes from the last appearance of *P. dubia* to the first appearance of *H. helvetica*. In this work, the last appearance of *P. dubia* may be considered as equivalent to the last appearance of *R. cushmani*.

Stratigraphic Position. Upper Cenomanian–lower Turonian.

Author. Bolli (1966), = *Praeglobotruncana gigantea* Zone.

Remarks. This zone straddles the Cenomanian/Turonian boundary and it is referred to as the zone of “grosses

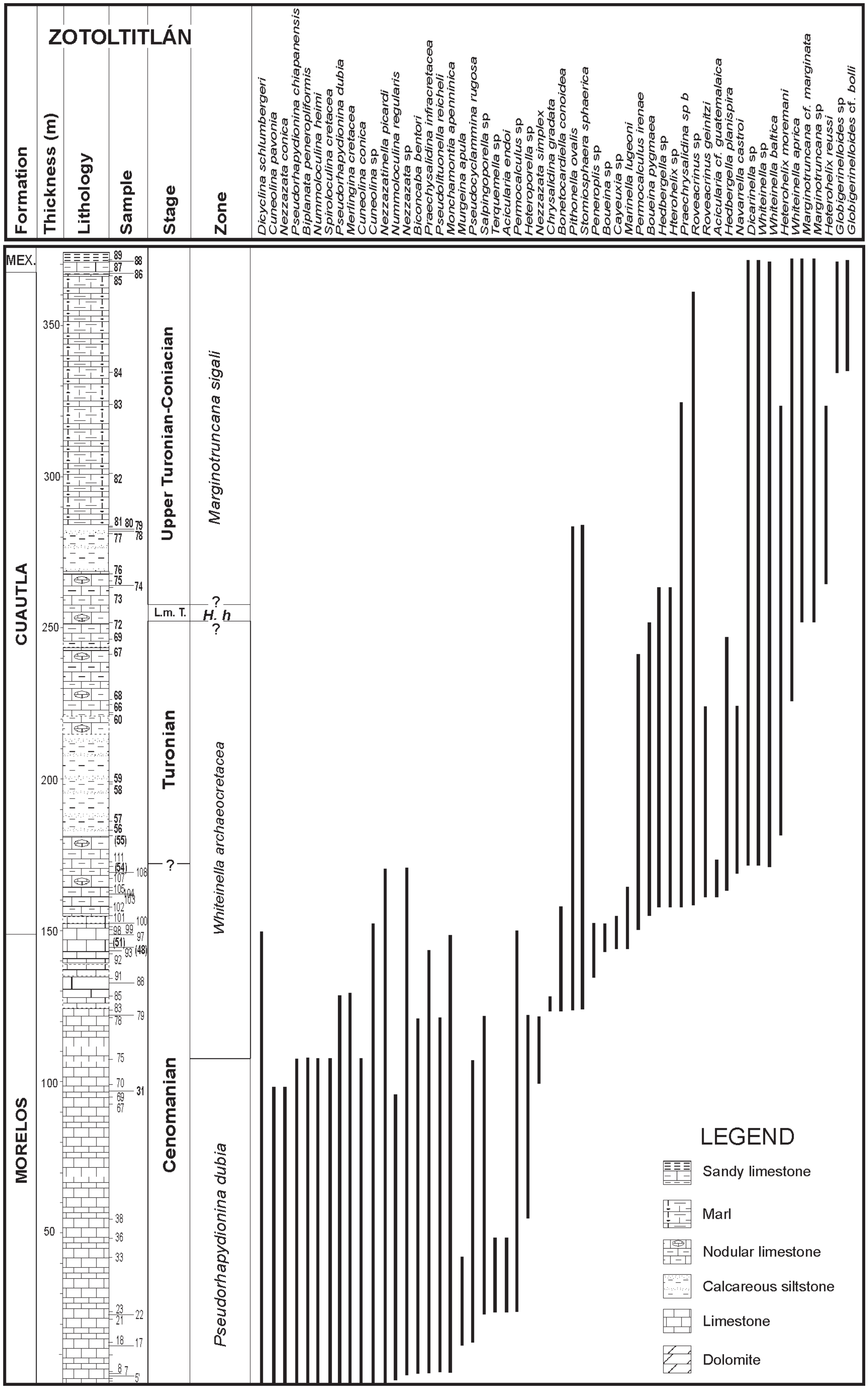

Figure 6. Lithological section of the Zotoltitlán section showing the zones and the stratigraphic distribution of main microfossils.

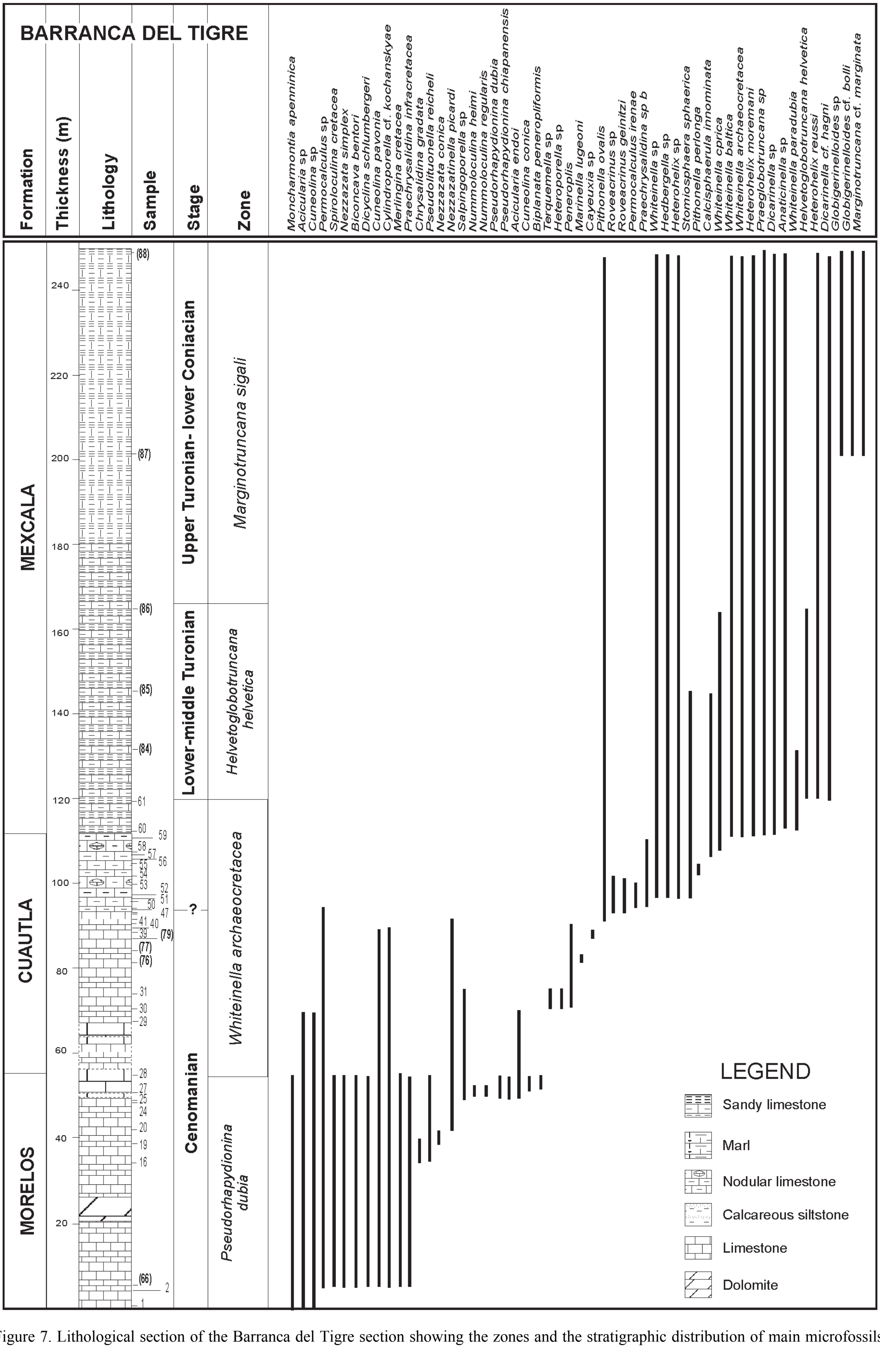

Figure 7. Lithological section of the Barranca del Tigre section showing the zones and the stratigraphic distribution of main microfossils.

globigérines" in the literature (Robaszynsky and Caron, 1995). In addition to a diversification of species of *Dicarinella*, this zone contains a low-diversity assemblage represented by rare specimens of *Hedbergella* and *Whiteinella* and the scarcity of the zonal marker. The low-diversity assemblage may be related to the widespread deposition of organic-rich sediments related to the Oceanic Anoxic Event (Sliter, 1989; Robaszynsky *et al*., 1990; Premoli-Silva and Sliter, 1994; Venkatachalapathy and Ragothaman, 1995). Other authors in the Boreal realm have assigned to this zone an early Turonian age (Caron, 1985; Venkatachalapathy and Ragothaman, 1995).

The *W. archaeocretacea* Zone in the study area corresponds to the transition from shallow-marine to hemipelagic and pelagic facies. It is characterized by drastic changes in the fossil association. Its base coincides with the disappearance of most large benthic foraminifers. In the lower part of this zone, there is a scarcity of fossils mainly due to the dominance of intertidal–supratidal facies with common sub-aerial exposure features in all the sections. This zone contains two conspicuous fossil assemblages.

The lower part of the *W. archaeocretacea* Zone is characterized by the last appearance of the *Cuneolina pavonia.* Scarce and poorly diversified miliolids, textulariids and calcareous algae characterize this interval. The benthic biota at this level includes *Cuneolina conica*, C. *pavonia*, *Peneroplis* sp., *Dicyclina schlumberger*, *Praechrysalidina* sp., *Boueina pygmaea* Pia, *Permocalculus* sp., *Cayeuxia* sp., *Cylindroporella* cf. *kochanskyae*, and *Lithophylum* sp.

A common characteristic of this part of the zone is the gradual upward decrease in diversity and the disappearance of most large benthic foraminifers and calcareous algae. The scarcity of fossils is probably due to the dominance of intertidal–supratidal facies.

Floquet (1987, in Philip and Airaud-Crumière, 1991) has pointed out that the disappearance of most large benthic foraminifers in upper Cenomanian sediments occurs in two steps. First, at the top of the *M. geslinianum* ammonite Zone, and base of *W. archaeocretacea* planktonic foraminifer Zone, some species of benthic foraminifers such as *Praealveolina*, *Chrysalidina*, *Pseudocyclammina* and *Pseudolituonella* disappeared. The second step is registered in the *N. juddi* ammonite Zone where just some trochaminids and *Textularia* are present, and these disappeared in the lowermost Turonian.

In this study, the disappearance of large benthic foraminifers seems to have occurred in three stages. The first stage corresponds to the disappearance of most miliolid species, the second, with the disappearance of *P. dubia*, and the third within this sub-zone. Since the disappearance of large benthic foraminifers has been reported in the uppermost Cenomanian within the *N. juddi* Zone, it seems that the top of this sub-zone could be considered as uppermost Cenomanian.

After the disappearance of most large benthic foraminifers (top of *Cuneolina pavonia* sub-zone), there is an assemblage dominated by abundant calcareous algae (dasycladacean, gymnocodiacean and udoteacean), calcisphaerulids and scarce non-keeled planktonic foraminifers. Because this interval seems to be diachronous in the basin, no sub-zone is proposed. The bioclasts recognized from the assemblage include dasycladacean (*Acicularia* cf. *guatemalaica*), udoteacean (*Boueina pygmaea*) and gymnocodiacean algae (*Permocalculus irenae*), lituolid benthic foraminifers (*Praechrysalidina* sp.), calcisphaerulids (*Pithonella ovalis, Calcisphaerula innominata, Stomiosphaera sphaerica*), roveacrinids (*Roveacrinus geinitzi*), and planktonic foraminifers (*Heterohelix* sp., *Heterohelix reussi, H. moremani*, *Hedbergella* sp., *Hedbergella delrioensis*, *H. planispira*. At this level, the *Hedbergella/Whiteinella* transition was recorded locally for the first time.

The upper part of the *Whiteinella archaeocretacea* Zone, is characterized by the reappearance of dicarinellids and praeglobotruncanids which become progressively more common together with large-sized whiteinellids ("grosses globigérines"). Abundant thin-shelled bivalves and opportunistic roveacrinids (*Roveacrinus* sp., *R. geinitzi* and *R.* cf. *alatus*) are common. Scarce radiolarians and calcisphaerulids (*Bonetocardiella conoidea*, *Pithonella ovalis, Pithonella trejoi*, *Calcisphaerula innominata, Navarrella castroi*, *Stomiosphaera sphaerica*) are also present. In this interval there are other species of planktonic foraminifers, including *Whiteinella* sp., *W. archaeocretacea, W. aprica, W. brittonensis*, *H. delrioensis*, *Heterohelix reussi*, *Praeglobotruncana* sp., *Dicarinella* sp. and *D. algeriana*. The presence of these dicarinellids and praeglobotruncanids and the abundance of whiteinellids has been commonly reported for the latest Cenomanian–earliest Turonian interval (Caron, 1985; Leary *et al*., 1989; Robaszinsky and Caron, 1995; Hart, 1996; Tur, 1996). According to this, and to the stratigraphic position of these beds within the succession, is seems that part of the *Whiteinella archaeocretacea* Zone is located in the lowermost Turonian.

Reference Locality. The *W. archaeocretacea* Zone is very well represented in the Zotoltitlán section (Figure 6) , which can be considered its type locality. In fully pelagic facies, the upper part of this zone is represented in the Amacuzac (Figure 10) and Las Tunas sections.

Helvetoglobotruncana helvetica Total Range Zone

Definition. Total Range Zone of *Helvetoglobotruncana helvetica*.

Stratigraphic Position. In this study, this zone is lower to middle Turonian according to the total stratigraphic range of the *H. helvetica*. According to Hancock *et al*. (1993), the base of this zone corresponds to the middle part of *Mammites nodosoides* ammonite Zone (early Turonian), while its top may be located approximately at the top of the

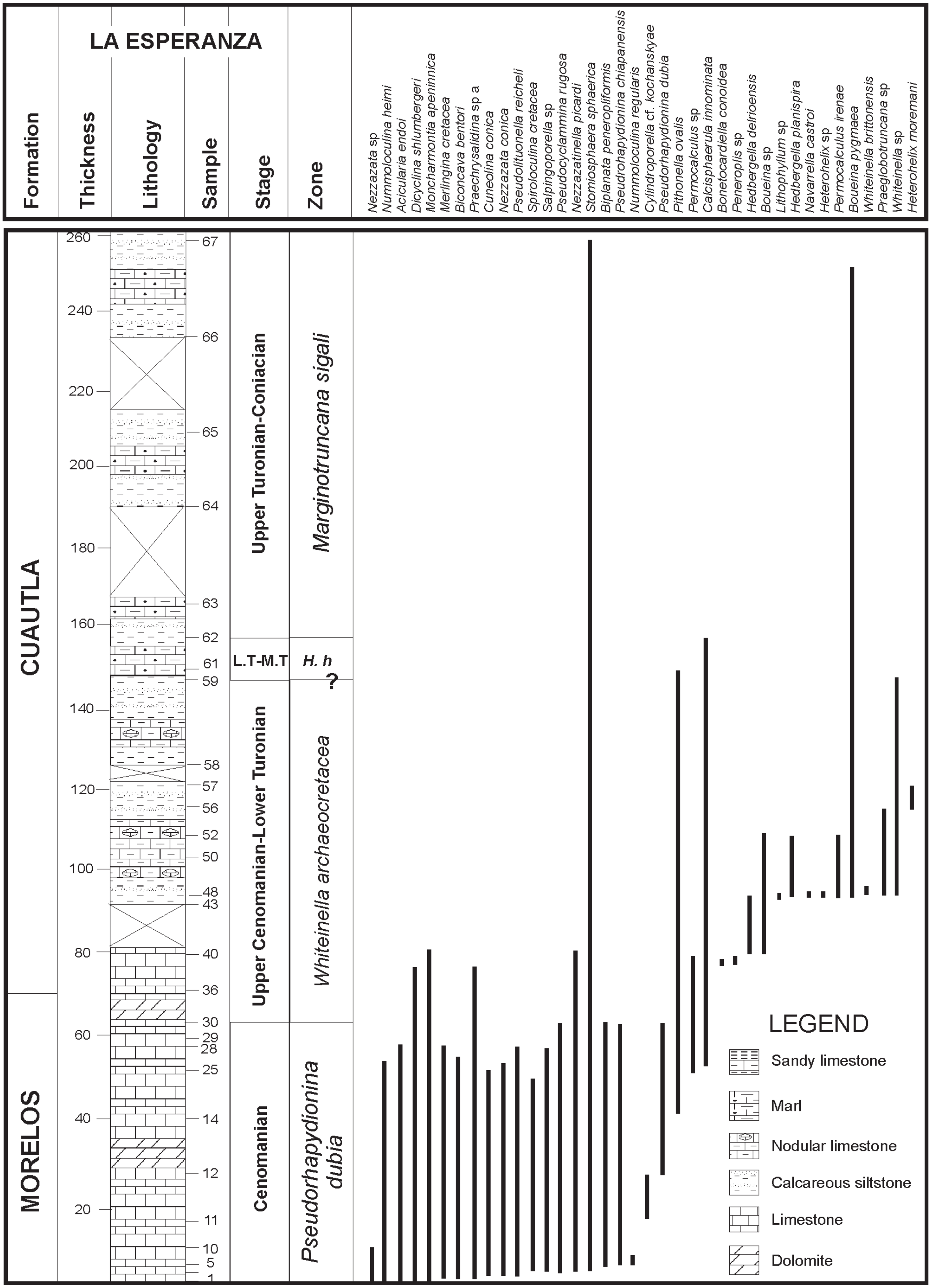

Figure 8. Lithological section of the La Esperanza section showing the zones and the stratigraphic distribution of main microfossils.

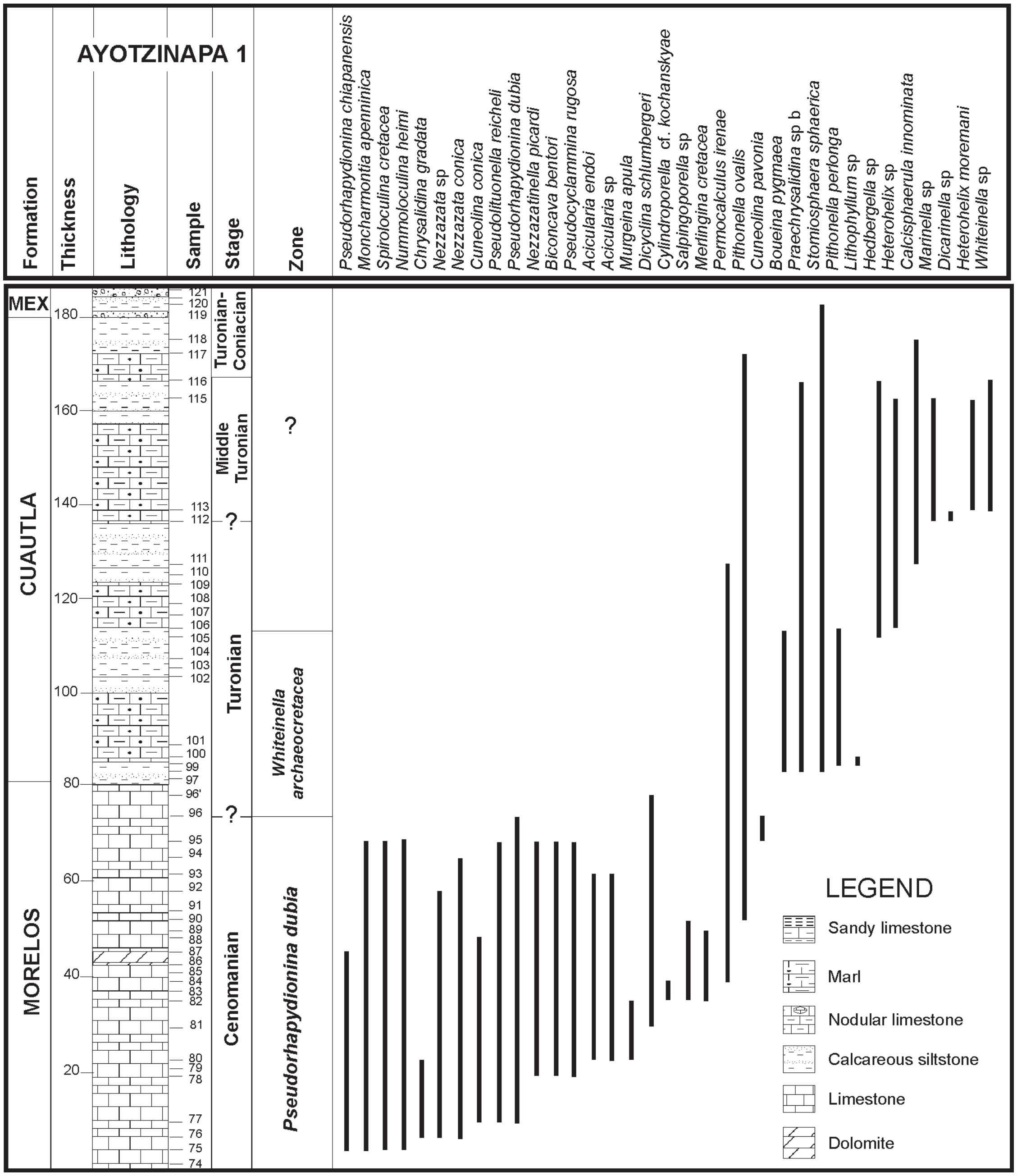

Figure 9. Lithological section of the Ayotzinapa 1 section showing the zones and the stratigraphic distribution of main microfossils.

Collignoniceras woollgari ammonite Zone and slightly above the *Romaniceras kallesi* ammonite Zone (middle Turonian, Tethyan realm).

Author. Dalbiez (1955).

Remarks. The first appearance of *Marginotruncana* occurs within this zone as well as the diversification of this genus, and marks the return of large-keeled planktonic foraminifers represented by species such as *H. helvetica*, *M. coronata*, *M. marianosi*, *M. pseudolineana*, *M. schneegansi,* and *M. sigali* (Sliter, 1989, Robaszinsky and Caron, 1995).

In the study area, the *H. helvetica* Zone is characterized by diverse and common whiteinellids, scarce hedbergellids and heterohelicids. In this zone, an increase in keeled planktonic foraminifers is also observed. The species of planktonic foraminifers include: *Heterohelix moremani*, *H. reussi*, *Hedbergella delrioensis*, *Whiteinella aprica*, *W. archaeocretacea*, *W. brittonensis*, *W. paradubia*, *Dicarinella* sp., *Dicarinella* sp. *Praeglobotruncana* sp., *Marginotruncana sp.,* and *Marginotruncana* cf. *marginata*. Also present are scarce radiolarians and calcisphaerulids.

In shallow open-marine facies (central and eastern part of the study area), this zone corresponds to an assemblage dominated by abundant solitary and colonial corals, mollusks (hippuritids and radiolitids), bryozoans and brachiopods (Sections La Esperanza, Ayotzinapa 1, and Ayotzinapa 2).

Reference Locality. This zone is well-exposed in laminated and black pelagic sediments of the Mexcala Formation outcrops. This zone is very well represented in the Barranca del Tigre (Figure 7) section located 8.0 km east of the town of Xochipala (Figure 3) and can be considered as the type locality of this Zone. This Zone is also well represented in the Amacuzac section (Figure 10) located towards the northern part of the area, 8.3 km south-west of the Yautepec town in the Morelos State.

Marginotruncana sigali Planktonic Foraminifer Interval Range Zone

Definition. This zone has been defined from the last appearance of *Helvetoglobotruncana helvetica* to the first appearance of *Dicarinella concavata* Brotzen (Sliter, 1989). Other authors recognized this zone as *Marginotruncana schneegansi* Interval Range Zone and Partial Range Zone (Robaszinsky and Caron 1995). The appearance of *M. sigali* is marked in the *Romaniceras kallesi* ammonite Zone (middle of the middle Turonian, Tethyan realm, Tunisia), while its top is close to the base of *Dicarinella asymetrica* Zone (Sliter, 1989).

Stratigraphic Position. Upper–middle Turonian – lower Coniacian. The age of this zone is poorly constrained because few samples were taken at that interval. However, the presence of some planktonic foraminifers characteristic of that zone such as *Globigerinelloides* cf. *bolli* and the presence of *Vaccinites gosaviensis* indicates an upper Turonian–lower Coniacian position.

Author. Barr (1972).

Remarks. This zone was first proposed by Barr (1972, in Venkatachalapathy and Ragothaman, 1995) to represent the upper Turonian from Libya. Subsequently, it has been recognized in many localities around the world (Caron, 1985; Sliter, 1989; Robaszynsky *et al*., 1990; Robaszynsky and Caron 1995). The last appearance of *Praeglobotruncana* and the first appearance of *Hedbergella flandrini,* and the large compressed marginotruncanids fall within this zone (Sliter, 1989). Also this zone registered the last appearance of most mid-Cretaceous planktonic foraminifers (Venkatachalapathy and Ragothaman, 1995).

In the study area, this zone was difficult to recognize. Its base was considered from the last appearance of *Helvetoglobotruncana helvetica* while its top was not fully recognized. Within this zone, most species of whiteinellids disappear, which is a common characteristic for this zone (*e.g.*, Premoli-Silva and Sliter, 1994). This zone is located in the upper part of the two stratigraphic sections (Zotoltitlán and Barranca del Tigre, Figures 7 and 8) in pelagic and laminated bioclastic wackestones–mudstones. Significant microfossils include *Whiteinella* sp., *W. baltica*, *W. archaeocretacea*, *H. reussi*, *Globigerinelloides* sp., *Globigerinelloides* cf. *bolli* Pessagno and *Marginotruncana* cf. *marginata*. In open-marine facies (La Esperanza section, Figure 8), this zone probably corresponds with an assemblage dominated by corals, bryozoans, algae and the hippuritid *Vaccinites gosaviensis*, reported for the latest Turonian–early Coniacian (Aguilera-Franco, 1995; Aguilera-Franco *et al*., 1998b).

Reference locality. This zone was recorded in the pelagic facies of the Mexcala Formation but its top was difficult to identify. It is recognized in the Barranca del Tigre section 8.0 km east of the Xochipala town and in the Zotoltitlán section 6.6 km east of the Apango town.

CONCLUSIONS

1) A combined benthic and planktonic foraminiferal biostratigraphy is proposed for the Cenomanian–Coniacian succession of the Guerrero–Morelos basin. Benthic foraminifers and calcareous algae were use to date the Morelos and the lower Cuautla formations, while planktonic foraminifers constrain the age of the Mexcala Formation. The *P. dubia* TRZ was recognized in the upper part of the Morelos Formation. The *Whiteinella archaeocretacea* IRZ, *Helvetoglobotruncana helvetica* TRZ and *Marginotruncana sigali* IRZ were recognized in the Cuautla and Mexcala formations.

2) The disappearance of the zonal marker and most miliolid benthic foraminifers defines the top of *P. dubia* (upper Cenomanian). The top of this zone is equivalent with the *R. cushmani* planktonic foraminiferal Zone and to the upper part of the *C. guerangeri* and the *M. geslinianum* ammonites Zones.

3) The *W. archaeocretacea* IRZ (uppermost Cenomanian–lowermost Turonian) comprises the transition from shallow semi-restricted conditions to open marine, deeper environments. This zone was defined from the last appearance of *P. dubia* de Castro, to the first appearance of *H. helvetica* Bolli. The last appearance of most large benthic foraminifers is registered at the base of this zone and corresponds to the top of the *N. juddii* ammonite Zone. The disappearance of benthic foraminifers is a common event recorded in other Tethyan localities within the *N. juddii* Zone in the uppermost Cenomanian.

4) The *H. helvetica* TRZ (lower–middle Turonian) is characterised by whiteinellids, hedbergellids, dicarinellids, praeglobotruncanids, radiolarian and calcisphaerulids. In

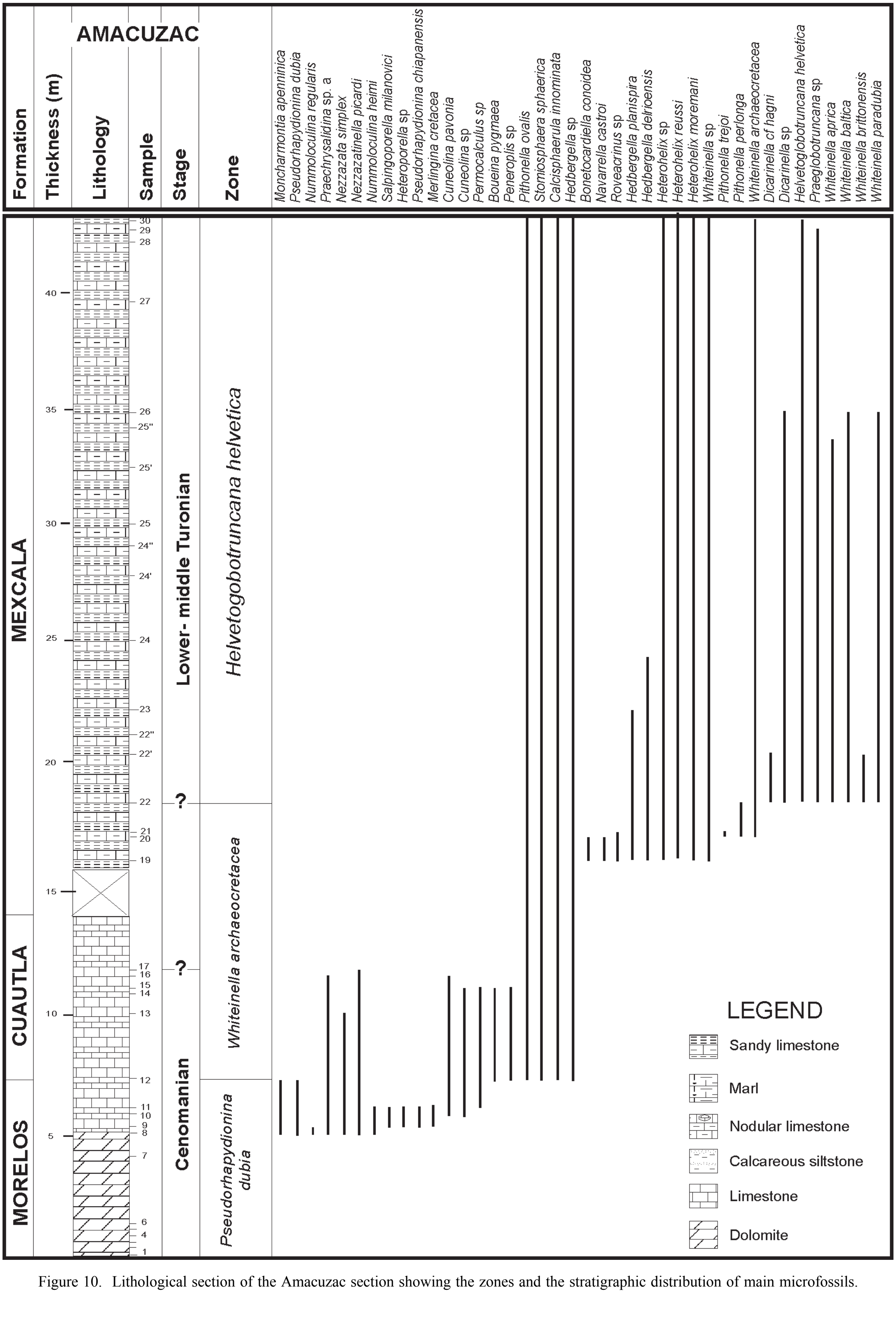

Figure 10. Lithological section of the Amacuzac section showing the zones and the stratigraphic distribution of main microfossils.

shallow open-marine facies (Cuautla Formation), this zone is represented by hippuritids, echinoids, gymnocodiacean, and udoteacean algae and planktonic foraminifers. This zone is equivalent with the lower part of *Mammites nodosoides* and *Calicoceras woollgari* ammonite Zones.

5) The *Marginotruncana sigali* IRZ (upper Turonian–Coniacian) is characterized by the presence of *Whiteinella* sp*., W. baltica, W. archaeocretacea, W. trocoidea*, *H. reussi*, *Globigerinelloides* sp., *Globigerinelloides* cf. *bolli*, and *Marginotruncana* cf. *marginata.* Toward the central and eastern part of the area, this zone is represented in shallow open-marine facies (Cuautla Formation) by an assemblage dominated by the hippuritid *Vaccinites gosaviensis*, solitary corals, gymnocodiacean algae, calcisphaerulids and very scarce planktonic foraminifers. This zone is equivalent with the *Romaniceras kallesi* ammonite Zone.

6) The Cenomanian/Turonian boundary lies at the lower part of the Cuautla Formation. According to the revised CTB biostratigraphy in other parts of the world, the presence of hippuritid rudists, and the diversification of *Whiteinella*, can be used to identify this boundary in the study area.

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