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Events of the Cenomanian-Turonian Succession, Southern Mexico

Eventos de una Sucesión del Cenomaniano-Turoniano del Sur de México

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Abstract

The Cenomanian-Turonian succession of the Guerrero-Morelos basin contains a number of paloecommunities that can be correlated. These palaeocommunities have been recognized and interpreted as the result of environmental disturbances. Some of these bioevents are probably local (platform-wide) and reflect successive stages of the platform drowning, whereas others have equivalents in other parts of the world and are probably linked to global paleoceanographic changes. Bioevents that can be used for correlation are: 1) the last appearance of *Pseudorhapydionina dubia* (94.4Ma); 2) the disappearance of most large benthic foraminifers and calcareous algae (94.2Ma); 3) the first appearance of hippuritid mollusks (93.5Ma); 4) the first appearance of *Helvetoglobotruncana helvetica* (93.0Ma) accompanied by a diversification of keeled planktonic foraminifers. Increase in ^{13}C and TOC values in the deeper-water facies covering the carbonate platform suggests a probable link between the drowning of the platform and the global Cenomanian-Turonian Anoxic Event. The deposition of organic-rich facies in the upper *Whiteinella archaeocretacea* and lower *Helvetoglobotruncana helvetica* Zones is associated with the establishment of oxygen poor and eutrophic conditions.

Keywords: bioevents, stable isotopes, TOC, Cenomanian-Turonian, Southern Mexico

Resumen

Se identificaron una serie de paleocomunidades en la cuenca de Guerrero-Morelos del sur de México. Estas paleocomunidades pueden ser correlacionadas e interpretadas como resultado de cambios ambientales anómalos. Algunos de estos bioeventos son locales y reflejan los diferentes estadíos del hundimiento de la plataforma, mientras que otros tienen equivalentes en otras partes del mundo y posiblemente estén ligados a cambios paleoceanográficos globales. La secuencia de eventos que se identificaron y que tienen valor de correlación son: 1) la ultima aparición de *Pseudorhapydionina dubia* (B1.2=93.83Ma); 2) la desaparición de la mayoría de foraminíferos bentónicos y algas calcáreas (B1.3=93.5Ma); 3) la primera aparición de moluscos hipurítidos (B4=93.31Ma); 4) la primera aparición de *Helvetoglobotruncana helvetica* (B7=93.0Ma) acompañada por una diversificación de foraminíferos planctónicos quillados. El incremento en los valores del isótopo de C^{13} y de Carbón Orgánico Total en las facies profundas, sugiere un relación entre el hundimiento de la plataforma y el Evento Oceánico Anóxico del Cenomaniano-Turoniano. El depósito de sedimentos con materia orgánica en la parte superior de la Zona de *Whiteinella archaeocretacea* y en la parte inferior de la Zona de *Helvetoglobotruncana helvetica* está probablemente asociado al establecimiento de condiciones eutróficas y pobres en oxígeno.

Palabras Clave: bioeventos, isótopos estables, COT, Cenomaniano-Turoniano, Sur de México.

1. Introduction

Earth's prevailing climatic conditions during the Cretaceous was very different than present and past recent climates, as the record indicates that greenhouse conditions peaked in the earliest Turonian (Jenkyns *et al.*, 1994), with the highest sea level stand ever recorded at a maximum of 300 meters above present level (Barnes *et al.*, 1996). In addition to volcanic activity associated with sea floor spreading, it has been postulated that plume-related intraplate volcanism was also an important contributor to high rates of mantle degassing (Tarduno *et al.*, 1991; Kerr, 1998), resulting in a considerably warmer Earth at that time. The Cretaceous elevated temperature may have been caused by high atmospheric CO_2 levels that allowed the development and expansion of tropical climate (Valdes *et al.*, 1996). The Cretaceous also includes one of the most conspicuous and well-documented mass extinction in Earth's history identified at the Cenomanian-Turonian boundary. During this interval several groups of ammonites, mollusks, corals, echinoderms, calcareous nannofossils, planktonic and benthic foraminifers were strongly affected (Kauffman and Hart, 1996; Barnes *et al.*, 1996; Peryt and Lamolda, 1996). This event also coincides with an anomalously high concentration of organic matter, and positive excursions of the $\delta^{13}C$ in biogenic organic marine carbonate (Raup and Sepkoski, 1986a, 1986b; Arthur *et al.*, 1987; Schlanger *et al.*, 1987; Jarvis *et al.*, 1988; Koutsoukos *et al.*, 1990; Jenkyns, 1991; Gusic and Jelaska, 1995; Caus *et al.*, 1993; Ulicny *et al.*, 1993; Peryt and Wyrwicka, 1993; Kauffman and Hart, 1996; Kerr, 1998 among others). The mechanisms put forward to explain this extinction are diverse and include: oceanic anoxia (Schlanger *et al.*, 1987; Arthur *et al.*, 1987), rise (Jenkyns *et al.*, 1980; Jarvis *et al.*, 1988) and fall in sea level (Jeans *et al.*, 1991), salinity stratification (Brass *et al.*, 1982) and an increase in productivity (Jarvis *et al.*, 1988; Vogt, 1989; Hilbretch *et al.*, 1992).

The Cenomanian-Turonian event in the stratigraphic succession of Mexico is so far poorly documented. In some areas, the sediments of that time interval occur as hemipelagic and pelagic facies (Basañez-Loyola *et al.*, 1993; Cantú-Chapa, 1993), although shallow-marine carbonate rocks are the dominant lithology (Enos and Stephens, 1993; Wilson and Ward, 1993).

The Cenomanian-Turonian succession in the Guerrero-Morelos basin in southern Mexico is composed of shallow marine limestones indicative of a platform that became well established since the Early Cretaceous but was drowned during the latest Cenomanian (Hernández-Romano *et al.*, 1997; Aguilera-Franco *et al.*, 2001). Drowning of the platform was apparently related to local tectonic and paleoceanographic changes, compounded with global forcing factors associated with the Cenomanian-Turonian Anoxic Event documented worldwide (Arthur and Schlanger, 1985).

The present work is a detailed study of seven measured sections in the upper part of the Morelos Formation, and the lower part of the Cuautla and Mexcala Formations that coincide with the Cenomanian-Turonian succession. Our goal was to identify changes in the fossil assemblage, lithology and geochemistry within the Cenomanian-Turonian succession of the Guerrero-Morelos basin, and to evaluate their use as stratigraphic markers for local, regional and global correlation.

2. Study Area and Geologic Setting

The study area is located in the southeastern part of the Morelos basin, which is in northern Guerrero State of southern Mexico (Fig. 1). The stratigraphic sequence is composed of a thick succession of more than 800m of shallow-marine limestones of the Morelos and Cuautla Formations that grade upwards into pelagic limestones and siliciclastics of the Mexcala Formation that comprises the Turonian and the Coniacian (Fig. 2). These rocks are unconformably overlain by Tertiary continental deposits of the Balsas Group, as well as by some remnants of Oligocene rhyolitic volcanism, and by Quaternary volcanic rocks of the Trans-Mexican Volcanic Belt (Fries, 1960; Morán-Zenteno, 1994).

2.1 Stratigraphy

The following is a brief description of the lithostratigraphic units of the Morelos and the basal part of the Cuautla and Mexcala Formations that coincide with the Cenomanian-Turonian succession (Fig. 2).

2.1.1. Morelos Formation (Fries, 1960; de Cserna et al., 1980)

Lithology. The Morelos Formation includes a succession of limestones and some dolomites with a reported thickness that varies between 600m and 1000m (Fries, 1960, González-Pacheco, 1991). Bioturbation, planar lamination, fenestral structures and desiccation cracks are the most common sedimentary structures (González-Pacheco, 1991; Hernández-Romano, 1995; Aguilera-Franco, 1995; Aguilera-Franco *et al.*, 1998b).

Petrographically it consists of bioclastic, peloidal and intraclastic packstone-wackestones with abundant microfossils of assemblages that are representative of the inner shelf environment (e.g. miliolids, lituolids, ro-

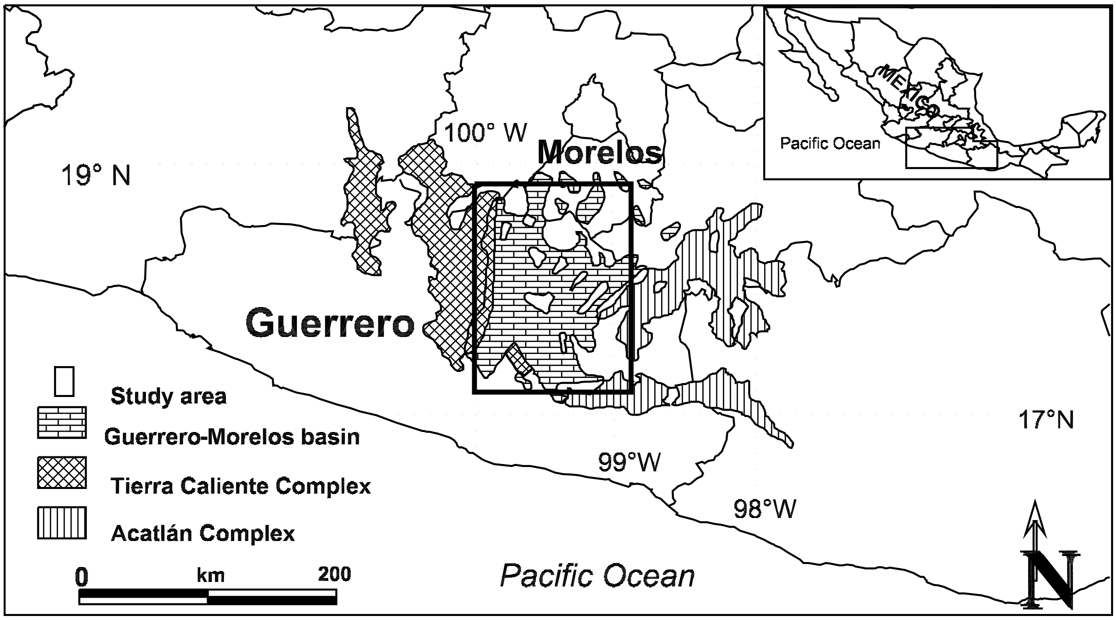

Fig. 1.- Location of the study area. Adapted from Aguilera-Franco *et.al*. (2001).
Fig. 1.- Localización del área de estudio. Modificado de Aguilera-Franco *et al.* (2001).

taliids, discorbiids, dasycladacean, scarce red and other calcareous algae such as *Thaumatoporella parvovesiculifera*). Mollusks (rudists and gastropods), ostracods, scarce echinoderms that are of more restricted environments are also present, and may dominate the limestones (Fries, 1960; Aguilera-Franco, 1995, Aguilera-Franco *et al.*, 1998b; Hernández-Romano *et al.*, 1997a; Hernández-Romano, 1999).

These rocks contain very low terrigenous components, although there are intermittent levels rich in detrital quartz and clays, and varying degree of dolomitization.

Depositional environment. Sedimentological and palaeontological components indicate that limestones of the Morelos Formation were deposited on an epeiric platform under semi-restricted conditions. Intercalation of supratidal, intertidal and subtidal facies dominated most of the platform (Martínez-Medrano, 1994; Hernández-Romano *et al.*, 1997a, Aguilera-Franco *et al.*, 1998a), and commonly occurs as packages of upward-shallowing cycles (Hernández-Romano, 1999, Hernández-Romano *et al.*, 1997b).

Age and relationships. Based on palaeontological data, the Morelos Formation has been assigned an age from the Albian to the upper Cenomanian (Fries, 1960; Aguilera-Franco 1995). This Formation is conformably overlain by limestones of the Cuautla Formation in the central part of the basin (Hernández-Romano, 1999), whereas contact between the two Formations is unconformable toward the northeastern and eastern part of the basin (Fries, 1960). Similarly, this Formation also rests uncomformably over the pre-Cretaceous rocks of the Acatlán Complex toward the easternmost part of the basin, (de Cserna *et al.*, 1981).

2.1.2. Cuautla Formation (Fries, 1960)

Lithology. The Cuautla Formation was formally described by Fries (1960) as a limestone sequence that consists of three main facies types: (1) a 30m succession of limestones of bank facies with characteristics similar to the Morelos Formation, but with a different biota, (2) a 1m succession of thinly bedded laminated limestones, (3) a 3m succession of bioclastic and intraclastic limestones. In the area studied, Hernández-Romano (1999) differentiated two facies types, which he described as informal members, and here we adopt his subdivision as follows:

The Huitziltepec Member makes up the lower part of the Cuautla Formation. Petrographically it consists of bioclastic and peloidal intraclastic packstones-grainstones with intercalated rudist rudstones-floatstones. Common fossils include scarce lituolid benthic foraminifers, dasycladacean, udoteacean, gymnocodiacean and coralline algae, ostracods, echinoderms and crinoids. Scarce calcisphaerulids, and fragments of planktonic foraminifers also occur. This member may correspond to facies 3 described by Fries (1960).

Nodular argillaceous limestones intercalated with calcareous claystones, and shales with abundant open-marine fossils dominate the overlying Zotoltitlán Member. Petrographically, the limestones are bioclastic packstones and floatstones, and minor wackestones with

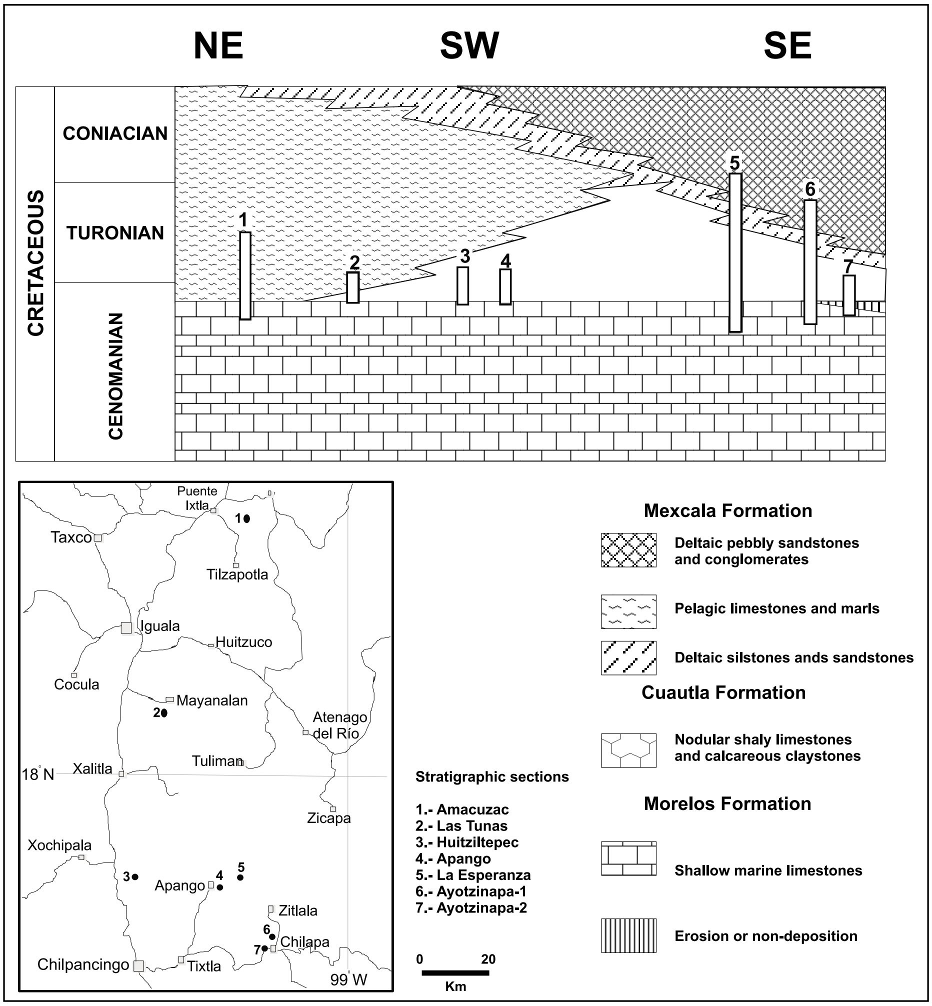

Fig. 2.- Location of the study area and facies relationships among the sections studied. Adapted from Aguilera-Franco *et al.* (2001).

Fig. 2.- Ubicación de secciones y relación de facies de las secciones estudiadas. Modificado de Aguilera-Franco *et al.* (2001).

abundant calcisphaerulids, roveacrinids, udoteacean and gymnocodiacean algae, planktonic foraminifers, corals, rudists, echinoids and brachiopods. Toward the eastern part of the area, the limestones are interbedded with calcareous siltstones and sandstones. These rocks contain an assemblage of abundant and well-preserved macrofossils such as echinoderms, radiolitids, hippuritids, solitary and colonial corals, brachiopods and bryozoans (Aguilera-Franco 1995; Hernández-Romano, 1999).

Depositional environments. Paleontologic and sedimentologic data suggest that the Huitziltepec Member was deposited in an inner ramp, while the Zotoltitlán Member in the middle and outer part of the ramp (Hernández-Romano, 1999). The presence of siltstones and sandstones in the eastern part indicate a provenance of siliciclastics from the east (Aguilera-Franco, 1995, Aguilera-Franco *et al.*, 1998a).

Age and relationships. Fries (1960) assigned a Turonian age to the Cuautla Formation, but also suggested that the basal calcarenitic beds (Huitziltepec Member) could be of Late Cenomanian age. Such age was further confirmed by Aguilera-Franco, (2000); therefore, the age considered for this member is Late Cenomanian. The Zotoltitlán Member passes transitionally upward into pelagic limestones and siliciclastic rocks of the Mexcala Formation (Fries, 1960; Aguilera-Franco *et al.*, 1998a; Hernández-Romano, 1999).

2.1.3. Mexcala Formation (Fries, 1960)

Lithology. The base of the Mexcala Formation is dominated by dark-grey argillaceous limestones classified as bioclastic packstone-wackestone with abundant planktonic foraminifers, calcisphaerulids and radiolarians (Fries, 1960; Hernández-Romano, 1995; Aguilera-Franco *et al.*, 1998b). This succession changes upward into an intercalation of shales, siltstones and sandstones that become conglomeratic towards the top (coarsening up) (Fries, 1960; Dávila-Alcocer, 1974; Aguilera-Franco *et al.*, 1998b).

Depositional environment. Fries (1960), Aguilera-Franco (1995) and Hernández-Romano *et al.*, (1997a) interpreted the basal limestones as pelagic basinal deposits. The shales-siltstones-sandstones are interpreted as prodelta and offshore facies, whereas the sandstones and conglomerates as delta plain facies (Aguilera-Franco 1995; Aguilera-Franco *et al.*, 1998a; Hernández-Romano, 1999).

Age and relationships. The age of the Mexcala Formation varies from latest Cenomanian to probably Maastrichtian (Aguilera-Franco, 1995; Alencáster, 1980), and it is uncomformably overlain by Cenozoic alluvial and volcanic rocks of the Balsas Group (Fries, 1960).

3. Previous interpretations of the Cenomanian-Turonian succession in the Guerrero-Morelos Basin

Previous interpretations of the rocks that include the Cenomanian-Turonian succession have been published since the early 1960's. Fries (1960) interpreted a hiatus or unconformity between the Morelos and Cuautla Formations as middle-upper Cenomanian. His interpretation was supported by the presence of clastic beds and abraded miliolid benthic foraminifers (characteristic of the underlying Morelos Formation) at the base of the Cuautla Formation. He proposed that the lower part of the Cuautla Formation was the result of differential uplift and erosion of the Morelos Formation during middle-late Cenomanian. Shallow marine conditions recurred during the early Turonian allowing deposition of the Cuautla Formation (Fries, 1960).

Ontiveros-Tarango (1973) concurs that shallow marine conditions continued during the late Cenomanian into the Turonian towards the eastern part represented by the Cuautla Formation. Also, he found a drastic change between the shallow marine limestones of the Morelos Formation and the pelagic rocks of the Mexcala Formation, and suggested that similarly an unconformity exists between these Formations. He interpreted the unconformity as a consequence of the effects of the Laramide Orogeny that started during the late Cenomanian and extended into the Turonian. This tectonic event produced a tilting to the west that ended shallow-marine sedimentation in these areas where pelagic sedimentation will occur (Hernández-Romano*, et al.*, 1997b). On the other hand, González-Pacheco (1991) indicated that the sedimentological change from limestones of the Morelos Formation to siliciclastic sedimentation of the Mexcala Formation was the result of intense tectonic activity in the area, but he considered a conformable contact between these Formations.

Other workers (Salinas Prieto, 1986; Aguilera-Franco, 1995; Hernández-Romano *et al.*, 1997) further suggested that there is no significant hiatus between the Morelos Formation and rocks with characteristics of the Cuautla Formation towards the eastern part of the basin. A conformable contact between the Morelos and Mexcala Formations is proposed where the Cuautla Formation is not present (González-Pacheco, 1991; Martínez-Medrano, 1994; Hernández-Romano, 1995, Aguilera-Franco 1995). However these authors did not recognize the rocks that belong to the Cuautla Formation in this area because the relationships between the Morelos and Cuautla formations were difficult to differentiate. Recent detailed biostratigraphic and stratigraphic studies in the northern part of the basin (Morelos State) suggest that a potential hiatus between the Morelos and Cuautla Formations may occur in latest middle Cenomanian or early late Cenomanian (Hernández-Romano *et al.*, 1998).

Recent studies (Hernández-Romano 1997a, Aguilera-Franco *et al.*, 1998b) proposed that the change from Cenomanian semi-restricted shallow-marine sediments to shallow-open marine and Turonian pelagic sediments has been associated with the drowning of the Guerrero-Morelos Platform. They proposed that the interplay of several factors such as tectonic activity (subsidence), rise in sea level, terrigenous supply and adverse environmental conditions (anoxia) can be invoked to explain drowning of the north-central parts of the platform, while shallow open-marine sedimentation continued towards the south-western part.

4. Methods

Seven stratigraphic sections were measured in the upper part of the Morelos Formation (upper middle to upper Cenomanian) and the lower part of the Cuautla and Mexcala Formations (middle to upper Cenomanian, and Turonian) (Fig. 2). The lithology, sedimentary structures and the stratigraphic biological events for all sections are shown in Figure 3 (legend).

The age of the Morelos, Cuautla and Mexcala Formations was constrained with benthic and planktonic foraminifer biostratigraphy (Fig. 4). Graphic Correlation was used to enhance correlation, as well as to establish the completeness of the sections, but it is not discussed in this paper (in preparation). With the use of graphic correlation, patterns of first and last appearances of all taxa were assessed in the section and plotted versus the Composite Database MIDK3.1 (Composite Standard, CS), and graphed with Graphcor. The CS database consists of data from more than 50 published outcrop and drilled-core data from the Tethyan realm (Scott *et al.*, 2000). The ranges of more than 1100 bioevents, planktic and benthic foraminifers, nannofossils, dinoflagellates, ammonites, bivalves, echinoids, calcareous algae, magnetochrons, geochemical events and sequence stratigraphic markers are defined in this database (Scott *et al.*, 2000; and Aguilera-Franco, 2000). The time scale used is that of Sliter (1989); Premoli-Silva and Sliter (1994) and Gradstein *et al.*, (1995).

Using the high-resolution correlation method (HIRES, Kauffman, 1988) biological and chemical events were defined. Bioevents were identified based on the first and last appearances of marker fossils, as well as the abundance and diversity of microfossil assemblages. Diversity of bioclasts and non-bioclasts of the rock components was calculated from thin sections by point counting. Two hundred and eighty seven samples were counted from the Amacuzac, Las Tunas, Huitziltepec, Apango, Ayotzinapa-1, and Ayotzinpa-2 sections. The percentage of these particles was quantified by 300 counts per thin section. The fossil abundance was calculated by adding the percentage of each group of fossils, and species diversity represents the sum of all groups, genera and species recognized in every sample. The ratio of the number of planktonic fauna versus the number of benthic fauna (planktonic/benthic ratio) was used to determine fluctuations in water depth along the succession (Figs. 5 to 11). A summary of all bioevents identified in this study is shown in Figures 12 and 13.

Geochemical events were defined as drastic shifts in the chemical composition of the succession that were consistently found in two or more sections. Stable isotopes and Total Organic Carbon (TOC%) content were used to establish independent geochemical signatures to aid in chronostratigraphic correlation (Fig. 14). Richard Cordfiel, who performed isotopic analyses on 76 samples from Amacuzac, Las Tunas and Ayotzinapa-2, supplied stable isotope data. The samples were selected to enclose the Cenomanian-Turonian succession, and some also include significant bioevents that may be associated with isotopic signals that are known to occur around this time interval. Samples selected for isotopic analyses were characterized initially in thin section under the petrographic microscope. Therefore, all samples selected for isotopic analyses were also examined by Cathodoluminiscence (CL) in order to determine the degree of diagenetic alteration. For diagenetic studies the distinction between dolomite and calcite, as well as the iron content in these minerals were estimated (Morse and Mackenzie; 1990; Marshall, 1992), and only samples not affected by dolomitization or recrystallization and fractures were selected. The main textures of these samples include peloidal/bioclastic wackestone-packstones, and some peloidal/bioclastic mudstone-wackestones of the Cuautla Formation; and bioclastic packstone/wackestones of the lower part of the Mexcala Formation. Samples not affected by dolomitization, non- to dully luminescent, and containing <200 ppm Mn, and Fe of 160 to 490 ppm were selected. In some samples, Fe shows values ranging from 295 to 3500 ppm, which is an indication that the initial carbon isotopes values should be chemically preserved.

The TOC% content was obtained by the wet titration method (Gaudette *et al.,* 1974) and performed on samples from the Amacuzac, Las Tunas and Huitziltepec sections (Fig. 15). All the biological and chemical data used and interpreted in this study are from Aguilera-Franco (2000).

5. Results

5.1. Zonation and Biological events

The zonation used in this study (Fig. 4) is based on first author's PhD dissertation (Aguilera-Franco, 2000) and Aguilera-Franco *et al.*, (2001). In this paper only the main characteristics of the zones are mentioned. The *Pseudorhapydionina dubia* Zone (Middle to Upper Cenomanian 96.55-93.83Ma) contains high diversity and abundance of benthic foraminifers (miliolids) and calcareous algae. The *Whiteinella archaeocretacea* Zone (Uppermost Cenomanian–Lowermost Turonian 93.85-94.0Ma) corresponds to the transition from shallow-marine to hemipelagic and pelagic facies with diverse benthic and planktonic fauna. The *Helvetoglobotruncana helvetica* Zone (Lower to Middle Turonian 94.0-90.8Ma) is characterized by diverse whiteinellids, scarce heterohelicids and hedbergellids, and the reappearance of more keeled planktonic foraminifers.

The bioevents described here are conspicuous changes in species diversity and abundance of the fossil assemblage, as well as the first and last appearance of one or more taxa. The succession of biological events identified in this study and their age to the zones identified are shown in Figs. 12 and 13.

5.1.1. B1 - Disappearance of most large benthic foraminifers and dasycladacean algae (93.5Ma)

The rocks of the *P. dubia* Zone, which includes most of the studied section of the Morelos Formation, contain a high diversity and abundance of euryhaline benthic foraminifers and calcareous algae (Fig. 12**).** Mollusc fragments (gastropods, radiolitids and caprinids) are also abundant. Ostracods are locally abundant and echino-

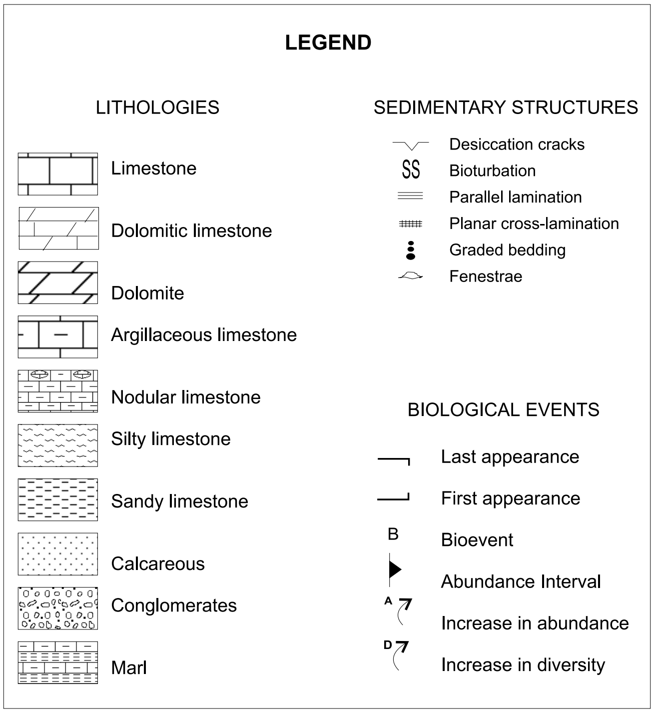

Fig. 3.- Legend of symbols used for lithologies, sedimentary structures and bioevents.

Fig. 3.- Leyenda con los símbolos usados en litologías, estructuras sedimentarias y bioeventos

derm fragments are present in small amounts. This type of fossil assemblage changes close to the top of the Morelos Formation and is characterized by the disappearance of several species of large benthic foraminifers and dasycladacean algae. The most important change is observed in stages B1.1 to B1.3 (Fig. 12) that may represent three stages of a more important event. The first occurs close to the top of the *P. dubia* Zone (93.87Ma), the second at the top of the *P. dubia* Zone (93.83Ma) and the third at the base of the *W. archaeocretacea* Zone (93.5Ma).

5.1.2. B1.1 - Disappearance of several species of miliolids and dasycladacean algae (93.87Ma)

The bioevent characterized by the disappearance of several species of miliolids and dasycladacean algae occurs close to the top of the *P. dubia* Zone that corresponds to the top of the Morelos Formation in the Amacuzac, Ayotzinapa-1 and Ayotzinapa-2 sections (Figs. 5, 10 and 11). It is characterized by the decrease in diversity and the last appearance of some species of miliolid benthic foraminifers such as *Murgeina apula*, *Biplanata peneropliformis*, *Nezzazata conica*, *Nummoloculina heimi*, *N. regularis* and a few dasycladacean algae such as *Acicularia* sp., *Acicularia endoi* and *Salpingoporella* sp.

Interpretation. The miliolid benthic foraminifers and dasycladacean algae are generally found in low energy muddy facies in protected parts of lagoon or tidal ponds in restricted conditions (Basson and Edgell, 1978; Flügel, 1982; Arnaud-Vanneau and Premoli-Silva, 1995). The disappearance of benthic foraminifers and calcareous algae occurs close to the top of the Morelos Formation in intertidal-supratidal facies. Although their disappearance seems to be correlative with a facies change, because they do not appear upward in the subtidal facies, their absence cannot be attributed to an artifact of facies availability. In fact, the disappearance of these species in the upper Cenomanian has also been reported at other localities (Saint-Marc, 1975; Schroeder and Neumann, 1985; Andreu *et al.*, 1996).

Potential for correlation. The last appearance of some species of benthic foraminifers as well as dasycladacean algae occurs in several sections close to the top of the *P. dubia* Zone. Sections in which this bioevent was not observed we surmise that factors such as sample spacing, preservation of benthic biota and facies changes may have been responsible for this discrepancy. However, since this bioevent is present in most of the sections of the upper part of the Morelos Formation, it can therefore be used as a stratigraphic event for correlation at the local scale. Since this bioevent is located in the upper part of the *P. dubia* Zone at 93.87Ma, it is equivalent to the upper part of *R. cushmani* Zone (94.0Ma), which is correlative with the middle part of the *Metoicoceras geslinianum* ammonite Zone of Hancock *et al.* (1993).

5.1.3. B1.2 - Disappearance of Pseudorhapydionina dubia *(93.83Ma)*

The second bioevent is marked by the last appearance of *P. dubia* (top of *P. dubia* Zone), and also by the disappearance of other species of benthic foraminifers such as *P. chiapanensis*, *Pseudolituonella reicheli*, and dasycladacean algae (*Terquemella* sp.). Above this level only fragmented miliolids (*Biconcava bentori*, *Moncharmontia apenninica*, *Nezzazatinella picardi*) and lituolids (*Praechrysalidina infracretacea*, *Peneroplis* sp., *Cuneolina conica*, *C. pavonia*, *Dicyclina schlumbergeri*) persist from the underlying beds (Figs. 4, 8, 10 and 11). The disappearance of *P. dubia* occurs in intertidal-supratidal facies in the upper part of the Morelos Formation.

Interpretation. The disappearance of several species of miliolids together with *P. dubia* can be interpreted as a result of ecological changes (salinity or critical temperature barriers). The presence of thinly bedded intertidal-supratidal facies with common subaerial exposure indicates relatively very low amplitude sea-level variation. Although subaerial exposure could be related to

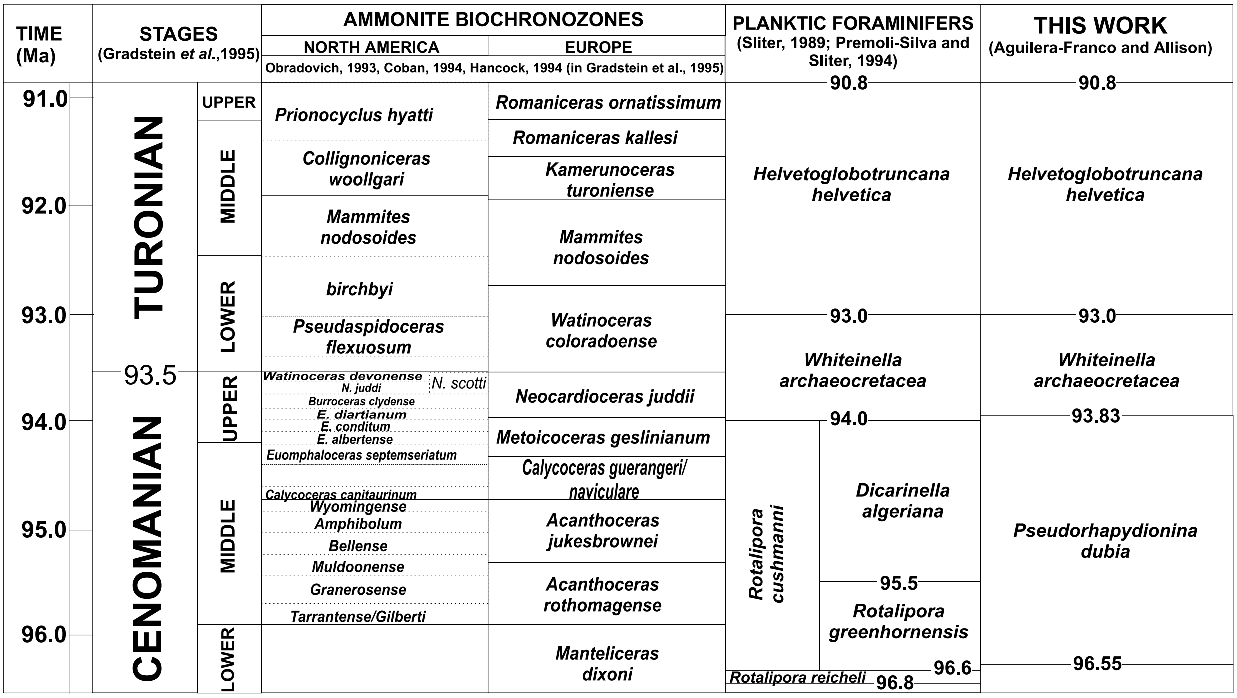

Fig. 4.- Ammonites and planktonic foraminifer biostratigraphic schemes of the Cenomanian-Turonian, and biostratigraphic zonation in the study area.
Fig. 4.- Esquemas bioestratigráficos de amonites y foraminíferos planctónicos del Cenomaniano-Turoniano y zonación bioestratigráfica en el área de estudio.

several factors such as passive filling of accommodation, a drop in sea level, or uplift of the platform (Hernández-Romano, 1999), it seems that low amplitude sea-level fluctuations are more likely to have caused development of subaerial exposure during the Cretaceous greenhouse period. Thus, variations in sea level may have driven some species to extinction, at least at the local basin-wide scale (Aguilera-Franco *et al.*, 2001). Nonetheless, their disappearance was not strictly facies controlled, because these benthic foraminifers and the dasycladacean algae remained absent in the overlying subtidal facies (Amacuzac section, Fig. 5).

Potential for correlation. The bioevent characterized by the disappearance of *P. dubia* occurs in all the sections that include the upper part of the Morelos Formation. The extinction of several species of large benthic foraminifers has also been reported in other Tethyan localities within the upper part of the *Metoicoceras geslinianum* ammonite Zone (Berthou, 1973; Bilotte 1984; Saint-Marc 1975; Philip and Airaud-Crumière 1991; Caus *et al.* 1993; Andreu *et al.* 1996), thus indicating that it is an extinction or bioevent of regional extent. This level that corresponds to the upper part of the *P. dubia* Zone (93.83Ma) is nearly equivalent to the top of the *R. cushmani* planktonic foraminifer Zone (94.0Ma) and with the upper part of the *M. geslinianum* ammonite Zone of Hancock *et al.* (1993).

5.1.4. B1.3 - Last appearance of most large benthic foraminifers (93.5Ma)

This event occurs above the last appearance of *P. dubia* in the following sections: Amacuzac (Fig. 5), La Esperanza (Fig. 9), Ayotzinapa-1 and Ayotzinpa-2 (Figs. 10 and 11), it also corresponds to the level where sediments become dominated with bioclastic and peloidal packstone-wackestone, and some grainstones with very scarce lituolids (*Cuneolina conica*, *C. pavonia*, *Dicyclina schlumbergeri*, and *Peneroplis* sp.) and dasycladacean algae (*Cylindroporella* cf. *kochanskyae*, and *Salpingoporella* cf. *milovanovici*). Succeeding this level of low diversity the fossil assemblage comprises one species each of benthic foraminifer (*Praechrysalidina* sp. b), gymnocodiacean (*Permocalculus* sp.), udoteacean (*Boueina* sp.), coralline (*Marinella lugeoni*) and codiacean algae (*Cayeuxia* sp.). There are also fragments of echinoderms, ostracods, molluscs (gastropods and radiolitids), and very scarce calcisphaerulids.

Interpretation. Lituolid benthic foraminifers are generally found in shallow marine lagoonal environments (Saint-Marc, 1982; Arnaud-Vanneau and Premoli-Silva, 1995). They also occur either with wave-resistant species in coarse sand or during a rise of sea level in lagoons (Arnaud-Vanneau and Premoli-Silva, 1995). The grain-sup-

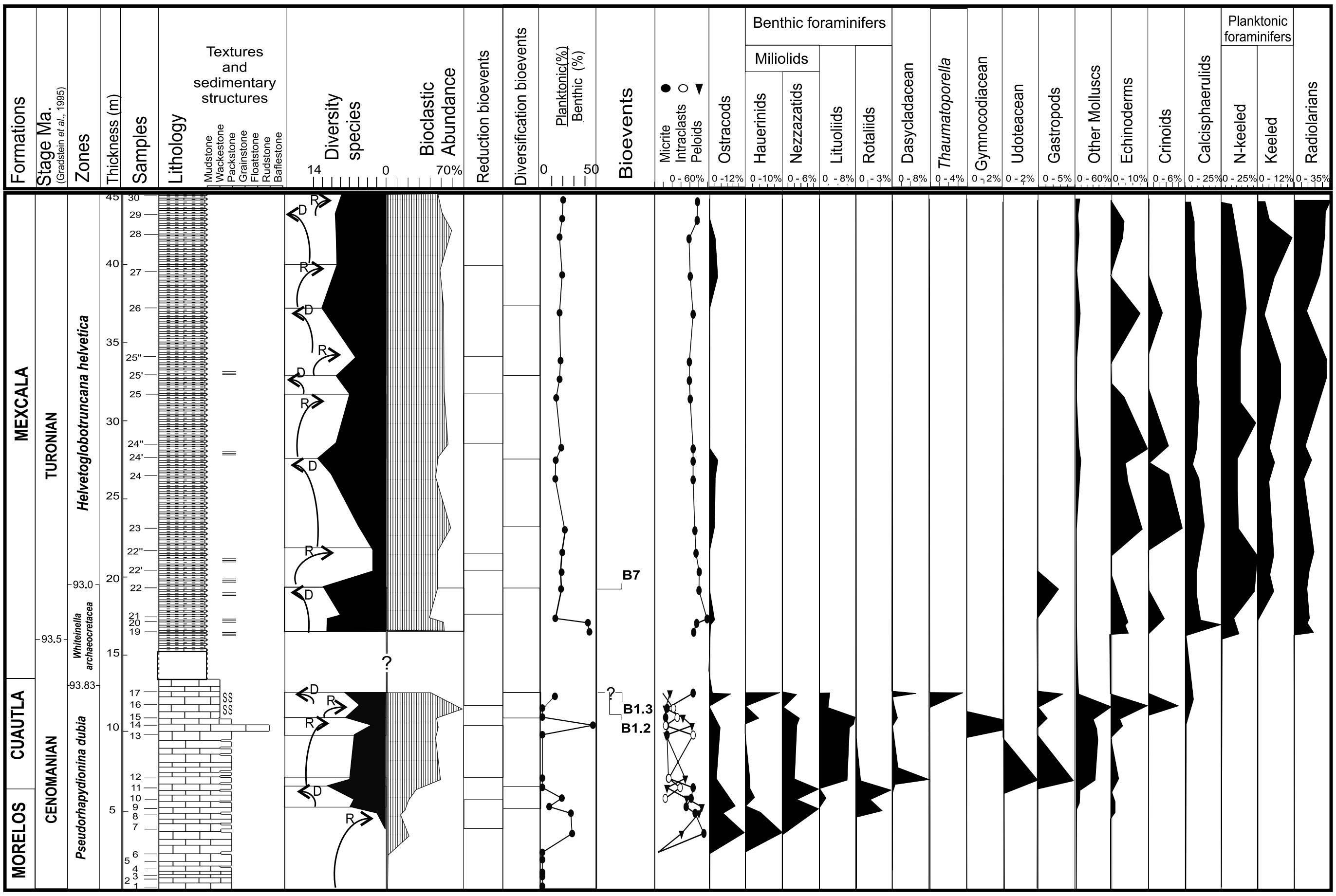

Fig. 5.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Amacuzac section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 5.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Amacuzac. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

ported texture (peloidal packstone-grainstones) in which they are present indicates high-energy conditions associated with a sea-level rise, as corroborated by the presence of more common pelagic forms at this level (e.g. calcisphaerulids). The extinction of most large benthic foraminifers in the study area seems to be related to the earliest stages of platform drowning in the latest Cenomanian. However, the extinction of Cenomanian benthic foraminifers in Tethyan localities has also been interpreted to be the consequence of the Cenomanian-Turonian Oceanic Anoxic Event (e.g. Philip and Airaud-Crumière, 1991; Caus *et al.*, 1993; Andreu *et al.*, 1996).

Potential for correlation. The bioevent characterized by the last appearance of several lituolids and dasycladacean algae was observed in several sections where it occurs very close to the base of the Cuautla Formation in the lower part of the *Whiteinella archaoecretacea* Zone (Fig. 11). This bioevent was not observed toward the eastern part of the basin because the interval (base of Cuautla Formation) in which they are present is eroded. Results from graphic correlation indicate that bioevent B1.3 (93.5Ma) is equivalent to the top of the *Neocardioceras juddii* ammonite Zone (Fig. 4) of Hancock *et al.* (1993). Furthermore, it corresponds to the major extinction of benthic foraminifers in the uppermost Cenomanian that is coeval with the lower part of the *W. archaeocretacea* Zone (e.g. Philip and Airaud-Crumière, 1991; Caus *et al.*, 1993; Andreu *et al.*, 1996), as shown in Figures 5, 9, 10, and 11. This bioevent was also observed in other sections of the area studied and, therefore, is a synchronous interval for the uppermost Cenomanian (Hernández-Romano, 1999; Aguilera-Franco, 2000). Since bioevent B1.3 is coeval with other well-defined bioevents of the uppermost Cenomanian in other parts of the world, it can be used as a good marker for regional and global correlation.

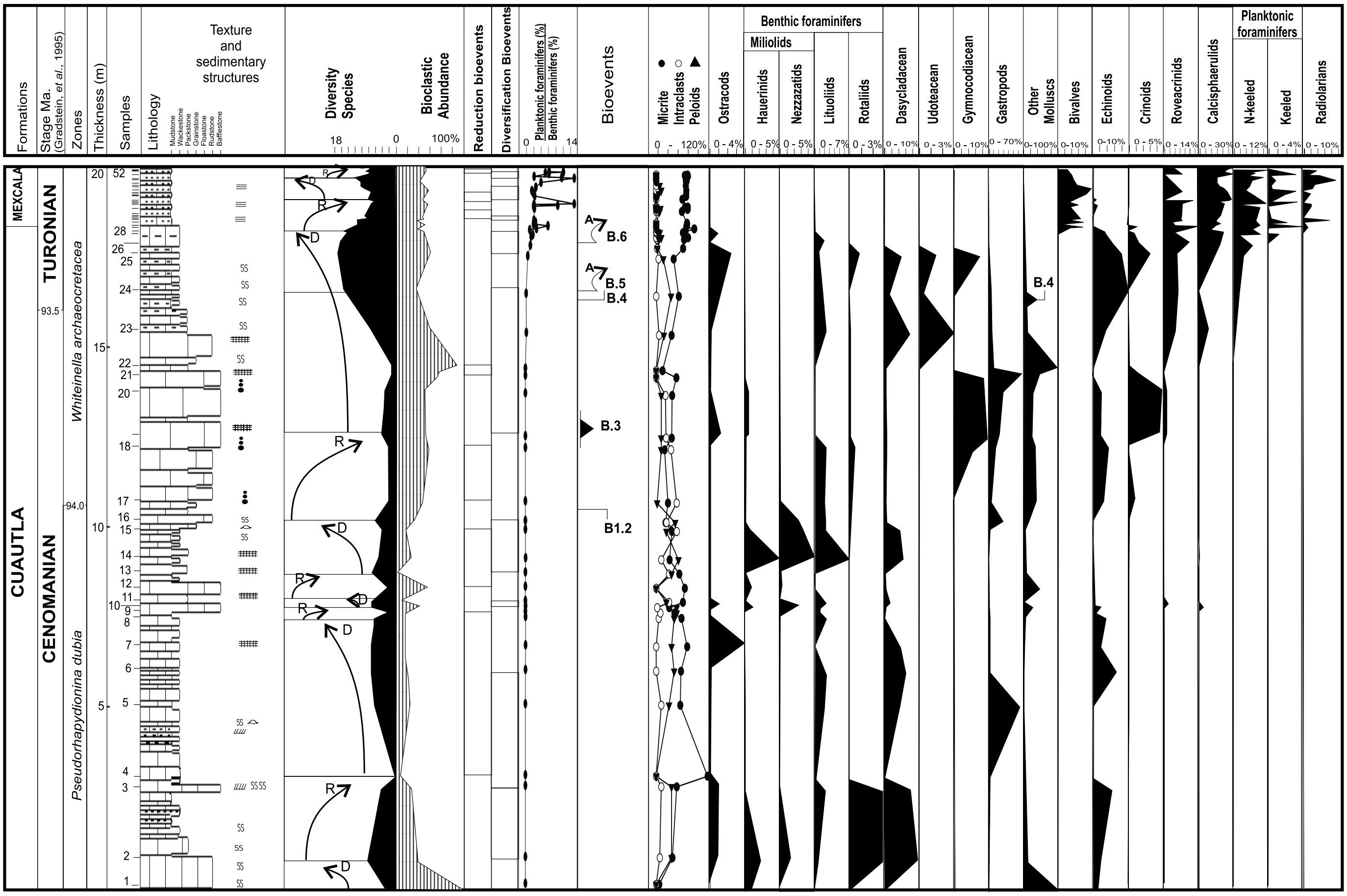

Fig. 6.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Las Tunas section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 6.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Las Tunas. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

5.1.5. B2 - Abundance peak of calcisphaerulids (93.4Ma)

Bioevent B2 is characterized by an abundance peak of calcisphaerulids, which occurs in the lower part of the *W. archaeocretacea* Zone. This bioevent was observed only in the Ayotzinapa-1 section (Fig. 10), but Hernández-Romano, 1999 reported that the same bioevent also occurs in the Axaxacoalco and Zotoltitlán sections, and suggested that their abundance may be related to the Cenomanian-Turonian Oceanic Anoxic Event. The abundance of calcisphaerulids was also observed in pelagic facies toward the western part of the basin in the Chichihualco section (Aguilera-Franco, 2000), 2m above the last appearance of several species of *Rotalipora* (uppermost Cenomanian).

Interpretation. Calcisphaerulids are inhabitants of open marine environments, and are characteristics of hemipelagic deposits (Andri, 1972; Banner, 1972; Bein and Reiss, 1976; Masters and Scott, 1978; Trejo, 1983; Dali-Ressot, 1989). They are also considered opportunistic taxa during biotic crises (Caus *et al.*, 1993; Brasier, 1995; Hart, 1996), thus their presence in intertidal-supratidal facies indicates an invasion of these shallow-marine waters together with an increase in nutrient supply (e.g. Brasier, 1995; Hernández-Romano, 1999; Luciani and Cobianchi, 1999).

Potential for correlation. The B2 bioevent (93.4Ma) occurs after the disappearance of most large benthic foraminifers (bioevent B1.3, 93.5Ma) very close to the base of the Cuautla Formation (lower part of the *Whiteinella archaeocretacea* Zone). Similarly, this bioevent has also been reported in other Tethyan localities after the disappearance of most species of benthic foraminifers within the *Neocardioceras juddii* ammonite Zone, which is indicative of the uppermost Cenomanian (Jarvis *et al.*, 1988; Leary *et al.*, 1989; Hart and Leary, 1991; Philip and Airaud-Crumière, 1991; Caus *et al.*, 1993; Hart, 1991, 1996; Kauffman and Hart, 1996). Bioevent

B2 was observed in only one section of the study area, however it seems to have a wider distribution because it was observed by Hernández-Romano (1999) in two other sections of the Guerrero-Morelos basin. A more detailed study is needed in order to test its true potential as a reliable stratigraphic marker in this basin.

5.1.6. B3 - Beds with an abundance peak of gymnocodiacean and/or udoteacean algae (93.43 to93.8Ma)

Bioevent B3 occurs in the *W. archaeocretacea* Zone and is characterized by a new change in the fossil community (Figs. 6, 7, 8, 10 and 11) that shows an abundance peak of udoteacean (*Boueina pygmaea*) and gymnocodiacean algae (*Permocalculus irenae*). In addition to algae, pelagic organisms such as calcisphaerulids (*Pithonella ovalis*), small non-keeled planktonic foraminifers (*Hedbergella delrioensis*, *Hedbergella planispira*), heterohelicids (*Heterohelix moremani*, *Heterohelix reussi*), mollusc and brachiopod fragments, as well as benthic organisms such as foraminifers (*Praechrysalidina* sp.) are also present. In the eastern part of the area (e.g. Ayotzinapa 1, Fig. 10; and Ayotzinapa 2, Fig. 11), beds where the B3 event is identified are characteristically richer in terrigenous material, and udoteacean and gymnocodiacean algae dominate the fossil assemblage. Furthermore, ataxophagmiid benthic foraminifers (*Praechrysalidina* sp.), solitary corals, gastropods, hippuritids, brachiopods, echinoderms and crinoids are also common.

Interpretation. The algal beds are indicative of changes in ecological conditions most likely associated with an increase in nutrient supply and a transitional (mesotrophic) stage, between oligotrophic and eutrophic stages. Similar associations have been observed in recent environments where an increase in nutrient supply coincides with change in the biotic community from phototrophic animal-plant symbionts to heterotrophic suspension-feeders (e.g. Birkeland, 1987; Hallock *et al.*, 1988). The presence of pelagic microfossils suggests that sea level

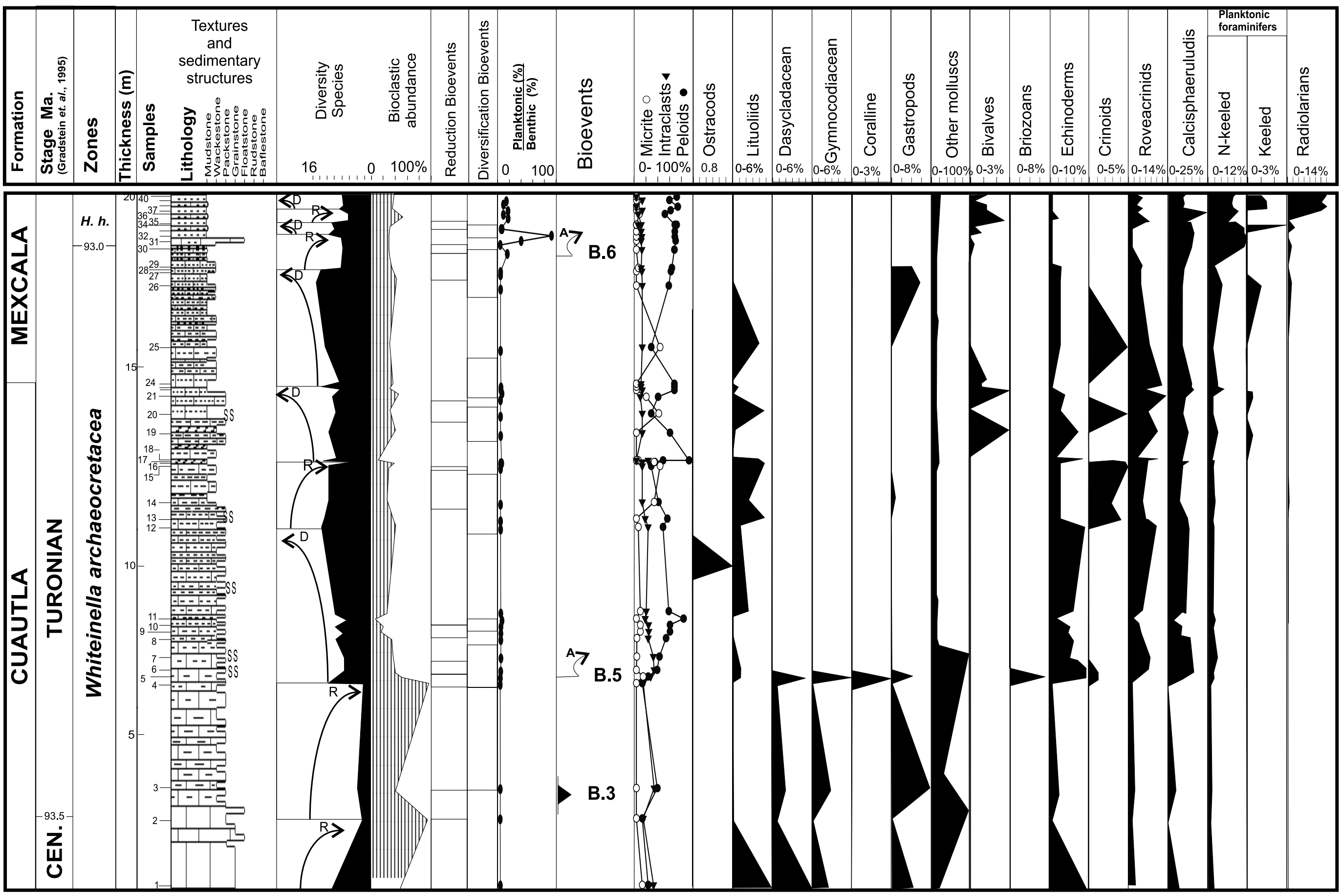

Fig. 7.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Huitziltepec section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 7.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Huitziltepec. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

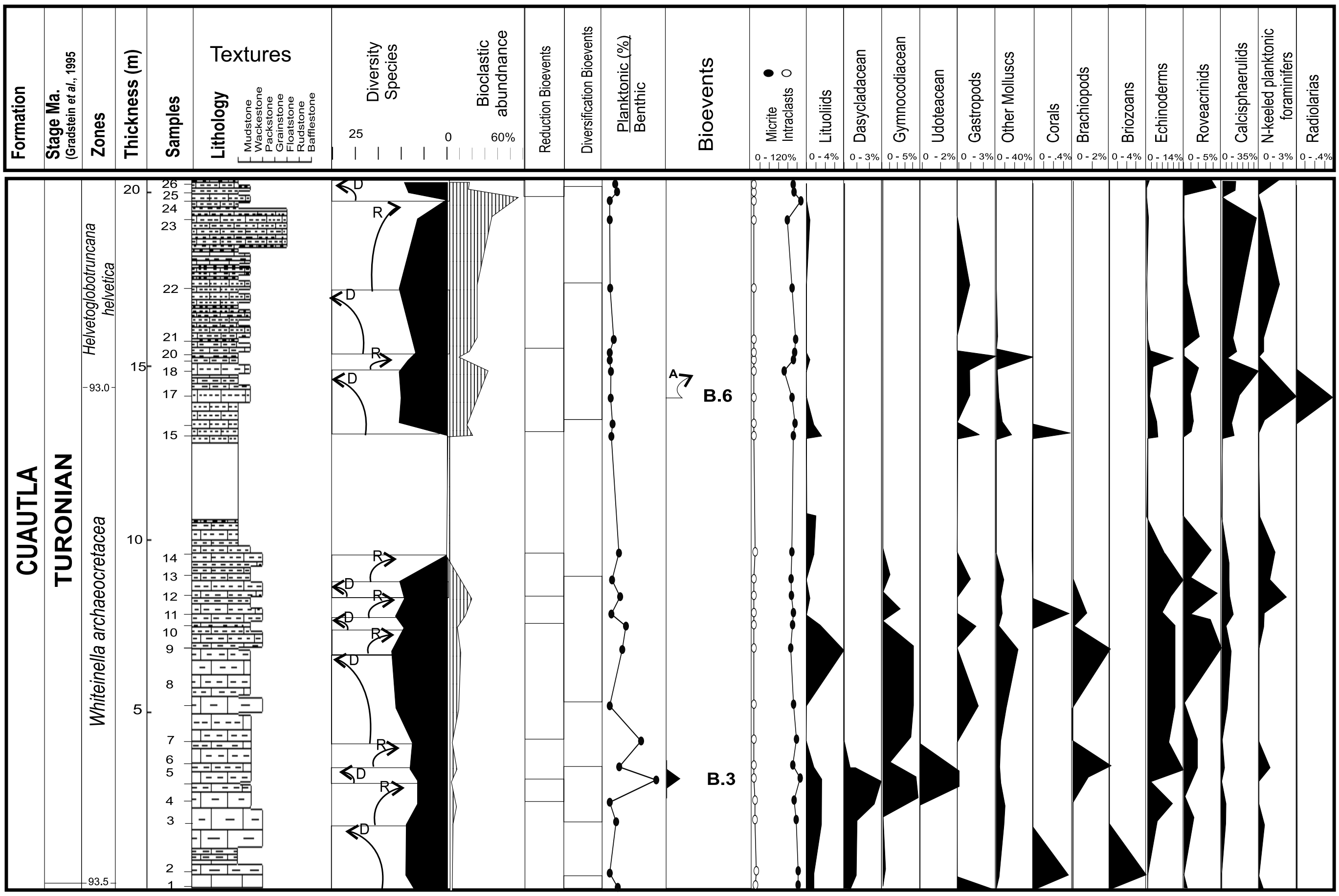

Fig. 8.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Apango section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 8.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Apango. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

rose, and represents the beginning of the deepening of the Guerrero-Morelos platform.

Potential for correlation. Bioevent 3 occurs in the *Whiteinella archaeocretacea* Zone, but seems to be diachronous in the basin (93.4 to 93.8Ma): toward the western part of the area this bioevent may be correlational with the *Neocardioceras juddii* ammonite Zone in the uppermost Cenomanian (e.g. Chichihualco section, Aguilera-Franco, 2000), whereas it correlates with the lower Turonian *Watinoceras coloradoense* ammonite Zone (Hancock *et al.*, 1993) in the central and eastern part of the basin (e.g. Las Tunas section, Ayotzinapa 1 section).

5.1.7. B4 - First appearance of hippuritid rudists (93.31Ma)

The first appearance of hippuritid mollusks is observed in the succession within the middle part of the *W. archaeocretacea* Zone in the Las Tunas section (Fig. 6). This level is represented by hippuritids floatstone with a matrix of intraclastic/grainstones that includes fragments of coralline, codiacean, gymnocodiacean and udoteacean algae, corals and very sparse calcisphaerulids. The presence of hippuritids has only been observed in the lower part of the Cuautla Formation in the Las Tunas section (Fig. 6).

Interpretation. Hippuritid mollusks are not present in the Morelos Formation. The interval where they occur may indicate brief environmental conditions particularly favorable for their colonization. The record of occurrences of hippuritids indicates that they were associated with clear water of normal salinity, and could develop on a muddy substrate such as wackestone-packstones (Ross and Skelton, 1993). Similarly, their association with coralline algae, coral fragments, gymnocodiacean and udoteacean algae and echinoderms in the Cuautla Formation also indicates normal salinity (Flügel, 1982). Beds with hippuritids probably formed during a period when open-marine conditions became established over most of the region and allowed them to colonize wider areas (Aguilera-Franco, 2000).

Potential for correlation. The first appearance of hippuritid rudists is registered in the lower part of the Cuautla Formation at 93.31Ma. Their appearance has been documented at other localities in the lowermost Turonian within the *Watinoceras coloradoense* ammonite Zone (Fig.4) that is correlational with the middle part of the *W.*

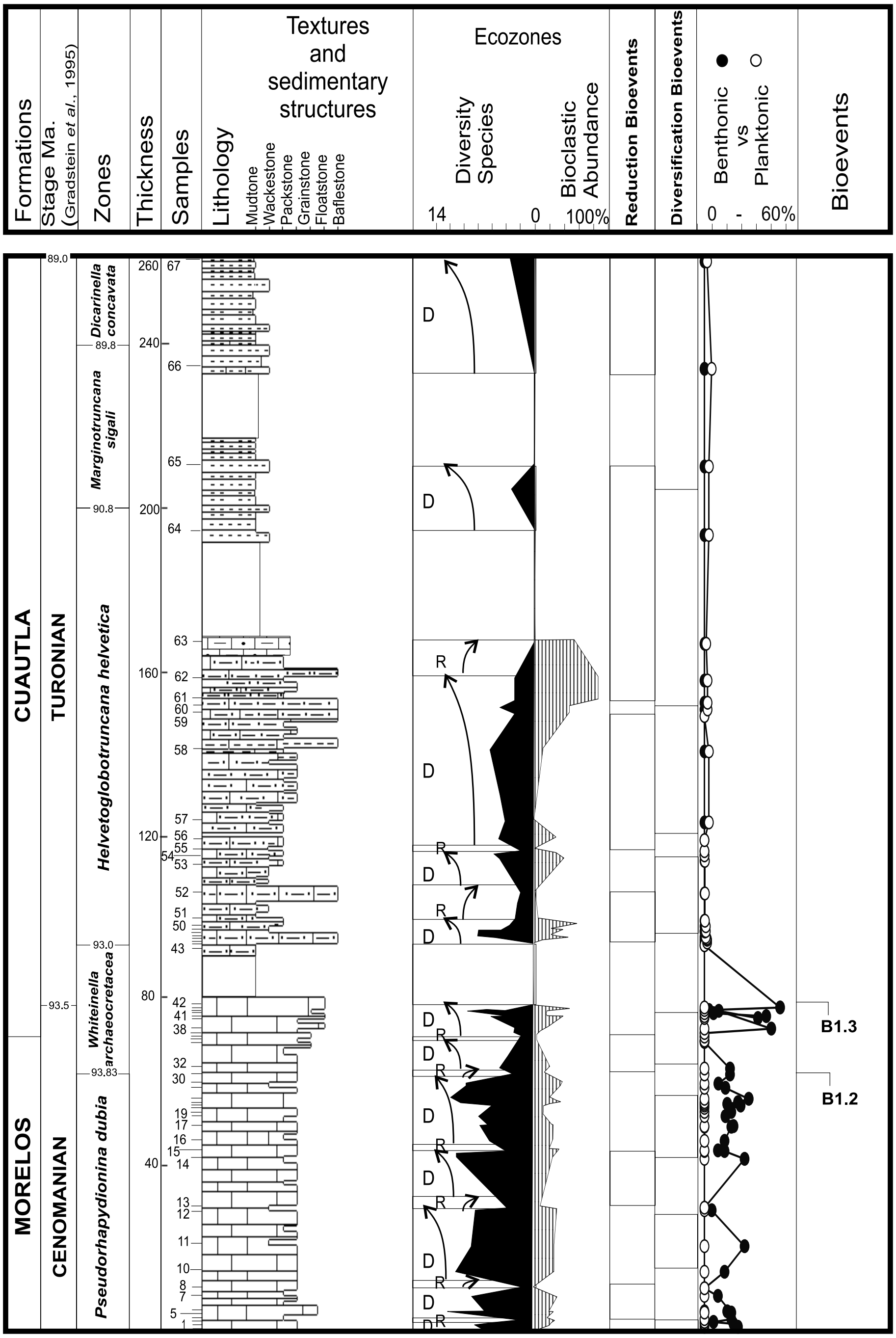

Fig. 9.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in La Esperanza section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 9.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección La Esperanza. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

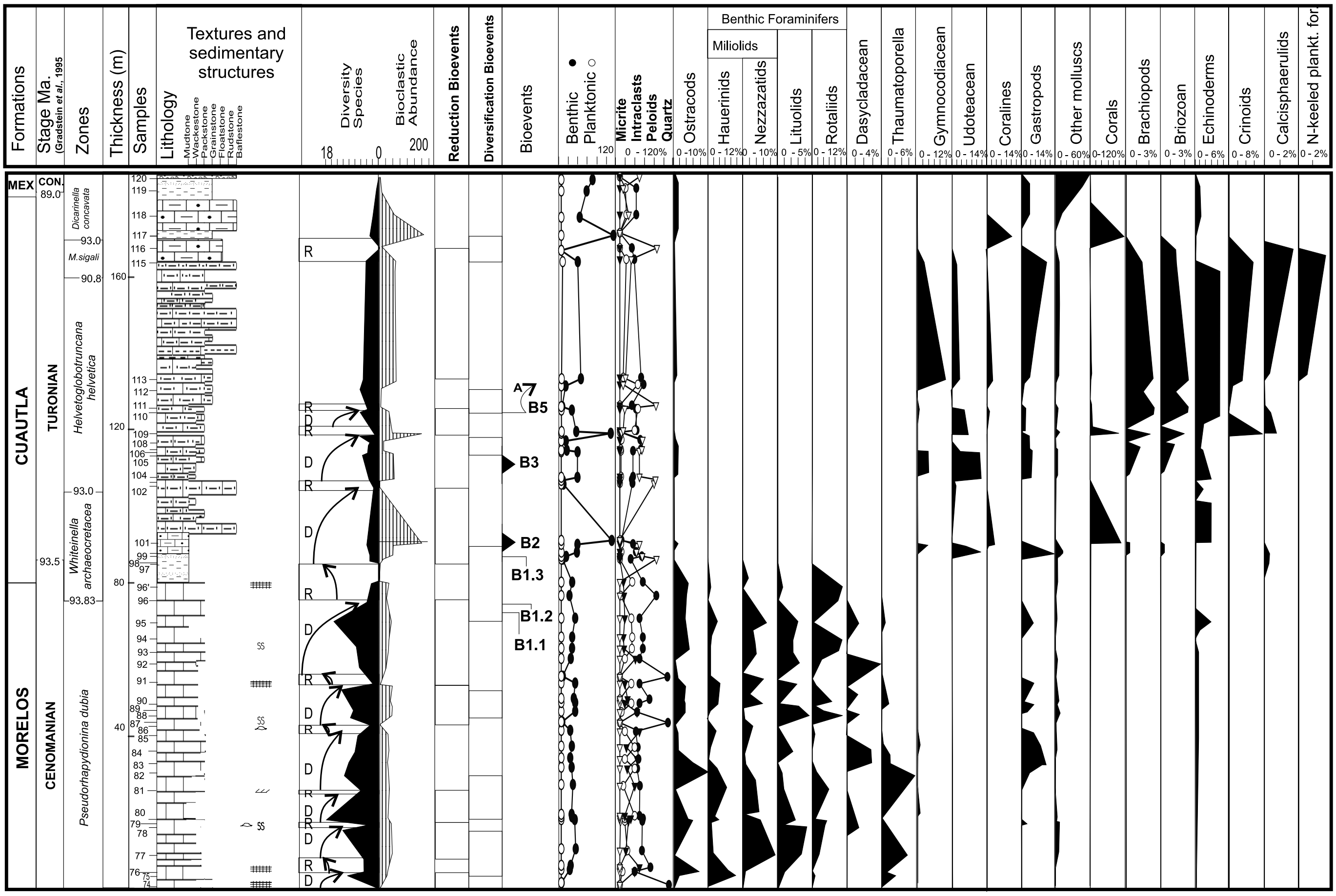

Fig. 10.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Ayotzinapa-1 section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 10.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Ayotzinapa-1. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

archaeocretacea planktic foraminifer Zone (Philip and Airaud-Crumière, 1991). Although the first appearance of hippuritid rudists is considered a good stratigraphic marker in the lowermost Turonian (e.g. Bilotte, 1985; Philip and Airaud-Crumière, 1991; Ross and Skelton, 1993; Barnes *et al.*, 1996), because this bioevent was found in only one section its utility as a marker bed in the basin was limited.

As pointed out earlier, in the study area this bioevent is recorded in the middle part of the *W. archaeocretacea* planktonic foraminifer Zone at 91.31Ma, and by analogy with its record elsewhere it may, therefore, be coeval with the lower part of the *Watinoceras coloradoense* ammonite Zone of Gradstein *et al.,* (1995). We infer that Bioevent 4 may also correlate with beds that contain corals, coralline, udoteacean and gymnocodiacean algae, and scarce calcisphaerulids (e.g. La Esperanza, Ayotzinapa 1 and Ayotzinapa 2 sections), which occur toward the eastern part of the basin, but do not contain hippuritids. As Bioevent B4 suggests, bioherms of corals, stromatoporoids and other skeletonized organisms may form levels that reflect brief geologic intervals that can be used as stratigraphic marker beds (Brett and Baird, 1997).

5.1.8. B5 - Increase in abundance of calcisphaerulids, echinoids and roveacrinids (93.03 to 93.45Ma)

Succeeding Bioevent 4, the overlying beds include Bioevent 5 that is characterized by an increase in abundance of calcisphaerulids, echinoids and roveacrinids , accompanied by more planktonic foraminifers (*Whiteinella baltica*, *W. brittonensis*, *W. paradubia*, *Heterohelix reussi*, *H. moremani*), which are more abundant than in the previous interval (Figs. 6, 7, 8, 10 and 11). Gymnocodiacean and udoteacean algae and non-keeled planktonic

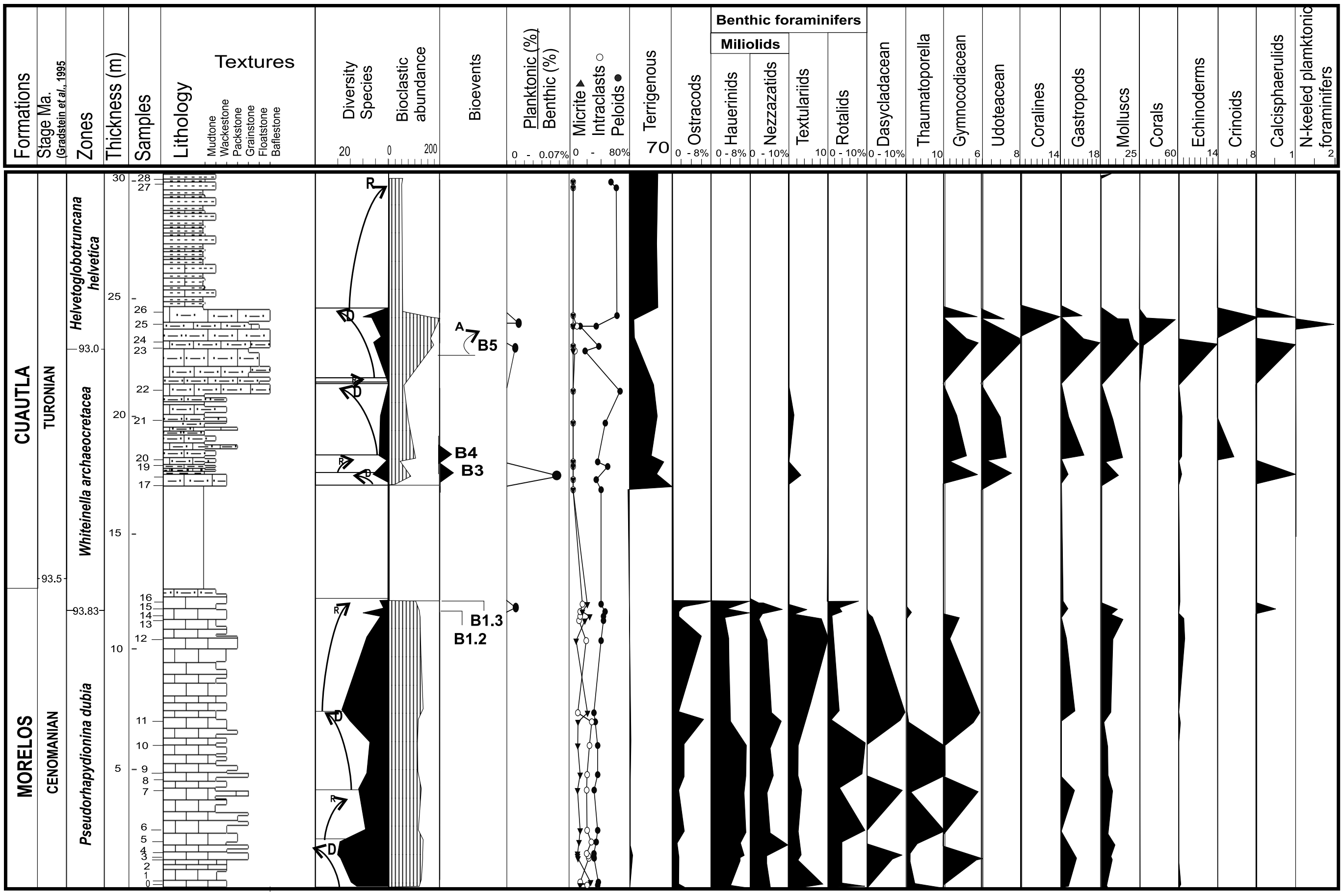

Fig. 11.- Trends in abundance and diversity of the different groups of bioclasts and other grain types in the Ayotzinpa-2 section. The ratios of planktonic versus benthic biota give additional information about paleodepth. Arrows indicate increase or decrease in species diversity.

Fig. 11.- Tendencias de la abundancia y la diversidad de los diferentes grupos de bioclastos y otros tipos de granos en la sección Ayotzinapa-2. Las relaciones planctónicos contra bentónicos dan información adicional acerca de la profundidad. Las flechas indican los aumentos o disminuciones en la diversidad específica.

foraminifers are also common in this interval, whereas calcisphaerulids show a specific diversification (*Calcisphaerula innominata, Pithonella ovalis*, and *Stomiosphaera sphaerica*). Ataxophragmid benthic foraminifers (*Praechrysalidina* sp.), brachiopods, colonial and solitary corals are particularly common within this horizon. This level is also marked by the first appearance of some species of roveacrinids (*Roveacrinus* sp., *R. geinitzi*).

Interpretation. Algal remains, together with increasing proportions of calcisphaerulids, benthic suspension-feeders (echinoids, brachiopods, bryozoans, and roveacrinids), small planktonic foraminifers (heterohelicids, hedbergellids), and biserial benthic foraminifers, suggest an increase in nutrient supply and fully eutrophic conditions (e.g. Birkeland, 1987; Brasier, 1995; Premoli-Silva and Sliter, 1994, Luciani , Cobianchi, 1999). Birkeland (1987) and Hallock (1988) interpreted similar conditions in recent environments, where filamentous algae, ascidians, sponges and bryozoans, dominate the biotic association. There is evidence that when nutrients and food are plentiful, fast-growing filamentous algae, bryozoans and barnacles are superior competitors for space because they can utilize abundant nutrients more effectively than the hermatypic community (Hallock and Schlanger, 1986; Hallock *et al.*, 1988).

A similar interpretation is applicable in the study area, particularly in the central and eastern parts of the platform, where shallow-marine sedimentation continued after the drowning of the northwestern and westernmost parts of the basin in the La Esperanza, Ayotzinapa-1 and Ayotzinpa-2 sections (Figs. 9, 10 and 11). Alternating beds with abundant algal remains and containing a more diverse benthic biota such as solitary and colonial corals, mollusks, brachiopods and echinoderms may indicate fluctuating nutrient levels. The abundance of ataxophragmids benthic foraminifers is widely documented to be

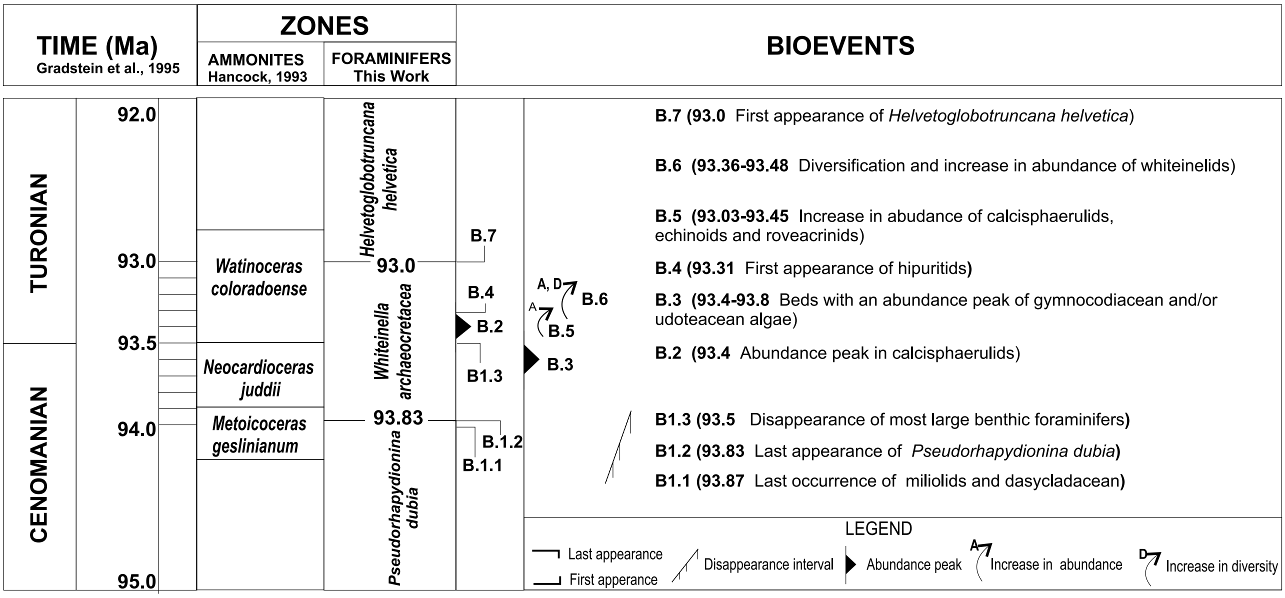

Fig. 12.- Ammonite zones correlated with foraminiferal zones, and bioevents identified in the Cenomanian-Turonian succession of the Guerrero-Morelos basin.

Fig. 12.- Correlación de las zonas de amonitas con las de foraminíferos y eventos biológicos en la sucesión del Cenomaniano-Turoniano de la cuenca de Guerrero-Morelos.

associated with anoxic-dysoxic environments, and their relative abundance has been further used to trace changes in upwelling intensity (Koutsoukous, *et al.*, 1990; Smart and Ramsay, 1995). The deposition of facies rich in non-keeled planktonic foraminifers, which are characteristic of the Boreal province (Gasinski, 1997), in the northwestern and western parts of the basin may indicate a slight drop in global temperature, or possibly the invasion of cooler waters that could also affect carbonate producers.

Potential for correlation. This bioevent was observed within the upper part of the *W. archaeocretacea* Zone. Bioevent (B5) may be diachronous in the basin similar to Bioevent 4, and may reflect progradation of the platform. This bioevent corresponds to the *Watinoceras coloradoense* ammonite Zone (Lower Turonian) of Hancock *et al.* (1993).

5.1.9. B6 Diversification and increase in abundance of whiteinellids (93.36 to 93.48Ma)

Bioevent B6 occurs in the uppermost part of the *W. archaeocretacea* Zone in Las Tunas (Fig. 6), Huitziltepec (Fig. 7) and Apango sections (Fig. 8) where there is an increase in abundance and diversification of whiteinellids such as *Whiteinella aprica*, *W. baltica*, *W. paradubia*, and *W. brittonensis*. There is also a temporary proliferation of small dicarinellids (*Dicarinella* sp.), thin bivalve-shells and roveacrinids (Fig. 6).

Interpretation. The evolution and diversification of planktonic foraminifers is generally associated with times of oceanic stability (Hart, 1980; Leckie 1987, 1989). Intermediate morphotypes (*Whiteinella*, *Dicarinella*, *Praeglobotruncana* and *Helvetoglobotruncana*) are inhabitants of mesotrophic environments and characteristic of low to middle-latitude (Bé, 1977; Hart, 1980; Premoli-Silva and Sliter, 1995; Gasinski, 1997). Simple morphotypes (*Hedbergella*, *Heterohelix*) occupy shallower water and unstable eutrophic environments (Hart, 1980; Premoli-Silva and Sliter, 1995). These forms predominate in high latitudes and in upwelling areas, displaying an opportunistic life strategy (Gasinski, 1997; Luciani and Cobianchi, 1999). The presence of abundant intermediate (whiteinellids, dicarinellids) and simple morphotypes (hedbergellids, heterohelicids) at this level indicates changes in water oxygenation and the transition between eutrophic and mesotrophic conditions. Such changes may be interpreted as one of the final stages of the Cenomanian-Turonian Anoxic Event in this basin.

Potential for correlation. Bioevent 6 was observed in the uppermost level of the *W. archaeocretacea* Zone. Diversification of the genus *Whiteinella* has also been reported in the upper part of the *W. archaeocretacea* Zone elsewhere in pelagic facies (Premoli-Silva and Sliter, 1995; Luciani and Cobianchi, 1999). This bioevent may also correlate with the upper part of the *Watinoceras*

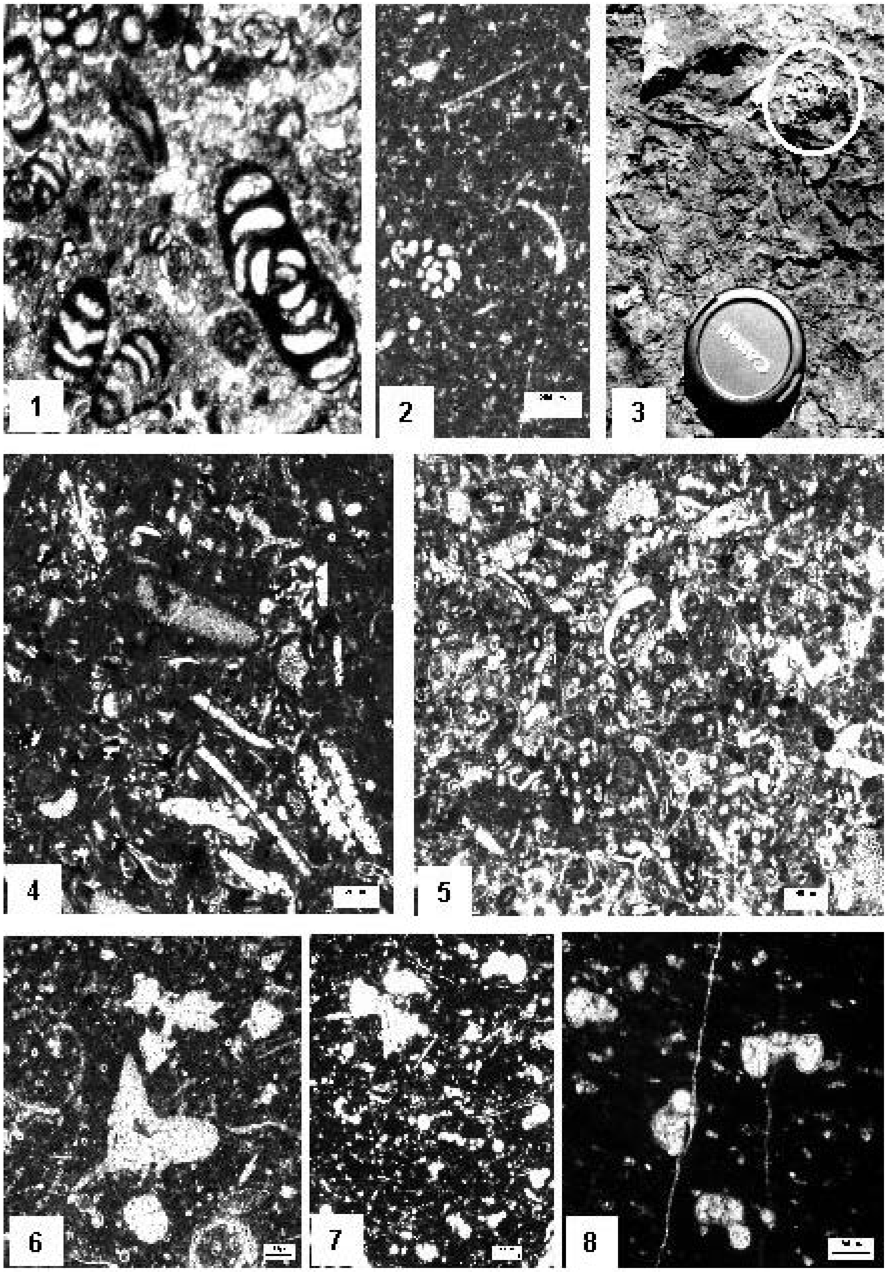

Fig. 13.- Characteristic microfacies illustrating bioevents of the Cenomanian-Turonian succession in the Guerrero-Morelos basin. 1) High diversity and abundance of benthic foraminifers characterize the *Pseudorhapydionina dubia* Zone, Bioevent B1.2, Ayotzinapa section, AY-7. 2) Low diversity and abundance of benthic foraminifers characterize the lower part of the *Whiteinella archaeocretacea* Zone, above Bioevent B1.2, Las Tunas, section NA-6. 3) Hippuritid (circle) and radiolitid floastone, Bioevent B4, Las Tunas section NA-18. 4 and 5) Abundant echinoderm, calcisphaerulids and gymnocodiacean algae, Bioevent B3, Las Tunas section, NA-26. 6 and 7) Increase in abundance and diversification of whiteinellids, roveacrinids and calcisphaerulids, middle *Whiteinella archaeocretacea* Zone, Bioevent B5, Las Tunas (NA-28) and Amacuzac (AM-18) sections, respectively. 8) First appearance of *Helvetoglobotruncana helvetica*, Bioevent B7, Amacuzac section, AM-22.

Fig. 13.- Microfacies caracteristicas ilustrando los Bioeventos del Cenomaniano-Turoniano en la cuenca de Guerrero-Morelos. 1) La Zona de *Pseudorhapydionina dubia* se caracteriza por altas diversidad y abundancia de foraminíferos bentónicos, Bioevento B1.2, sección Ayotzinapa, AY-7. 2) La parte inferior de la Zona de *Whiteinella archaeocretacea*, por encima del Bioevento B1.2, Las Tunas, NA-6, se caracteriza por bajas diversidad y abundancia de foraminíferos bentónicos 3) Floastone de radiolítidos e hipurítidos (círculo), bioevento B4, sección Las Tunas, NA-18. 4 y 5) Abundancia de equinodermos, calcisferúlidos y algas gimnocodiáceas, Bioevento B3, sección Las Tunas, NA-26. 6 y 7) Incremento en la abundancia y diversificación de whiteinélidos, roveacrínidos y calcisferúlidos en la parte media de la Zona de *Whiteinella archaeocretacea*, Bioevento B5, sección Las Tunas NA-28 y sección Amacuzac AM-18. 8) Primera aparición de *Helvetoglobotruncana helvetica*, Bioevento B7, sección Amacuzac, AM-22.

coloradoense ammonite Zone of Hancock *et al.* (1993). Perhaps, Bioevent 6 may have its lateral equivalents in pelagic facies of the basin that correspond to beds with common calcisphaerulids, whiteinellids, hedbergellids, calcisphaerulids, radiolarians and roveacrinids (e.g. Amacuzac section).

5.1.10. B7 First appearance of *Helvetoglobotruncana helvetica accompanied by more keeled planktonic foraminifers (93.0Ma)*

Bioevent B7 is characterized by the first occurrence of *Helvetoglobotruncana helvetica* in the succession of eupelagic facies (basinal environment), and is accompanied by a diversification of intermediate planktonic foraminifers such as dicarinellids, praeglobotruncanids and helvetoglobotruncanids, and was observed in the Amacuzac section (Fig. 5). Whiteinellids diversity remains unaltered but hedbergellids and heterohelicids decrease in abundance. Radiolarian and calcisphaerulids are common to abundant (Fig, 5). This level is distinctive because it is composed of non-bioturbated grey to black laminated limestones with low taxonomic diversity. Towards the eastern part of the area in the Ayotzinapa-1 (Fig. 10) the same stratigraphic level includes a fauna and sediments that indicate an open marine environment (outer ramp), with abundant gymnocodiacean, udoteacean algae, hippuritid mollusks, brachiopods, echinoderms, scarce planktonic foraminifers, and calcisphaerulids.

Interpretation. The increase of more keeled forms suggests a change to more stable oceanic conditions, and the transition from a mesotrophic to an oligotrophic environment (e.g. Premoli-Silva and Sliter, 1994; Luciani and Cobianchi, 1999). The level of Bioevent B7 represents the deepening of the Platform and the final stage of carbonate sedimentation in the northern part of the basin, with the continuation of shallow open-marine facies toward the central and eastern parts of the basin.

Potential for correlation. Bioevent B7 occurs at the base of the Mexcala Formation (Fig. 5), a pelagic facies of early-middle Turonian age, and may have its lateral equivalent in the upper part of the Cuautla Formation, a shallower open-marine facies. On a global scale Bioevent B7, or the first occurrence of *Helvetoglobotruncana helvetica,* has been considered a stratigraphic marker for the early-middle Turonian (e.g. Birkelund *et al.*, 1990; Caus *et al.*, 1993; Drzewiecki and Simo, 1997; Premoli-Silva and Sliter, 1995; Luciani and Cobianchi, 1999). As this bioevent was identified in only one section (Amacuzac) its utility as a marker bed is limited in the basin, where it may have not been observed because of the degree of condensation of the sections. This bioevent may correspond to the upper part of the *Watinoceras coloradoense* and possibly to the base of the *Mammites nodosoides* ammonite Zones of Hancock *et al.* (1993).

5.2. ^{13}C Events

Previous carbon isotope stratigraphic studies performed on rocks from the uppermost Cenomanian to the lowermost Turonian at different sites worldwide reveal high positive $\delta^{13}C$ values (Arthur and Schlanger, 1985; Jenkyns, 1991, among others). Some of these values are synchronous events that appear to be coincident with the extinction of important marker fossils. Thus, the positive spikes are potentially a powerful tool for correlation within that interval (Schlanger, *et al.,* 1987; Hart and Leary, 1989).

Three carbon-isotope profiles derived from the sections studied are shown in Figure 14 (Also, see Fig 2 for their relative positions). Although the samples used for isotopic analyses were not taken at the same equivalent intervals within the three sections, and the values do not correlate well from section to section, the results obtained within 30m of the composite section can be grouped according to their trends, which show both increase and decrease in values.

Based on the biostratigraphic data, the samples analyzed in the sections crossed different levels of the *W. archaeocretacea* Zone, despite hiatuses that present constraints and prevent a clear correlation between the sections. Regardless of the constraints, the results permit to define a composite carbon isotopic profile from the Amacuzac to the Las Tunas and Ayotzinapa-2 sections. The $\delta\,^{13}C$ index observed from the base to the top of the succession can be divided into four intervals with different trends (Fig. 14). The first isotopic interval (11 m; *P. dubia* Zone, upper Morelos Formation) shows a trend toward lighter values from 0.14 to 1.46‰ (Ayotzinapa 2 section). The most positive $\delta^{13}C$ value (1.46‰) coincides with bioevent B1.2 that is characterized by the last appearance of *P. dubia*.

The second isotopic interval begins with the maximum values of isotopic interval 1 and prevails through the *W. archaeocretacea* Zone (lower part of the Cuautla Formation). It is characterized by a trend towards increasing $\delta\,^{13}C$ values as recorded in the lower part of the *W. archaeocretacea* Zone at the Las Tunas section. The results showed four $\delta\,^{13}C$ positive values ranging form 5.39‰, 4.73‰, 4.86‰ to 4.26‰, and a minimum of 3.55‰. The second bioevent B1.3 (last appearance of most lituolids) occurs between the values of 4.26‰ and 3.55‰. The third isotopic interval can be defined within the upper

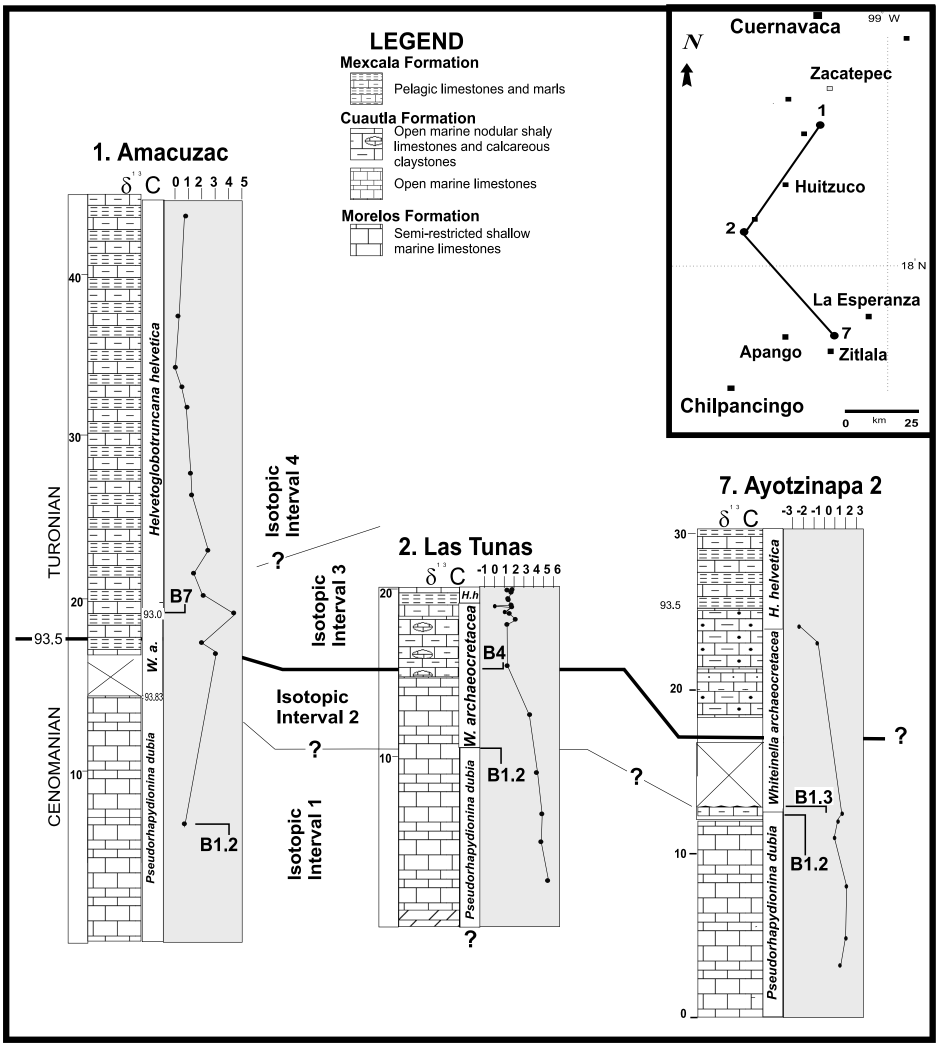

Fig. 14.- Carbon isotope profiles from the Amacuzac, Las Tunas and Ayotzinapa-2 sections.
Fig. 14.- Curvas de isótopos de Carbono en las secciones Amacuzac, Las Tunas y Ayotzinapa-2.

part of the *W. archaeocretacea* Zone (lower Cuautla Formation) where $\delta^{13}C$ values decline sharply from 2.25 and 1.9 to 1.04‰ and 0.96‰. Similar values have been reported from Southern England by Jenkyns *et al.* (1994) and in Spain by Paul *et al.,* (1994) and by analogy we consider this level to coincide with the Cenomanian-Turonian Oceanic Anoxic Event in this basin.

The fourth isotopic interval can be defined within the *H. helvetica* Zone, and in eupelagic facies. It is characterized by a trend towards increasing $\delta^{13}C$ values, and a marked positive value of 4.42‰ is coincident with the first appearance of *H. helvetica.* Subsequently, values vary from highs between 1.9 and 1.3, to lows between 0.96 and 0.143‰. Similar values have also been reported at the same level elsewhere (e.g. Ulicny *et al.* 1997; Drzewiecki and Simo, 1997).

Interpretation. The ^{13}C anomaly recorded close to the Cenomanian/Turonian transition has been interpreted in other localities to result from increased burial of organic matter (Schlanger and Jenkyns *et al.*, 1976; Scholle and Arthur, 1980; Arthur *et al.*, 1988). Although oceanic anoxia and increase in organic productivity have been proposed to explain the isotopic shift, its nature still remains controversial. On a global scale the ^{13}C anomaly appears to have started at the top of the *R. cushmani* Zone and ended within the *W. archaeocretacea* Zone (Drzewiecki and Simo, 1997).

As shown in Figure 14 apparent ^{13}C anomaly in the Guerrero-Morelos basin starts within the interval above the last appearance of *P. dubia* (B1.2), and persists until the *H. helvetica* Zone. Highest values were found immediately above the *P. dubia* Zone, within the *W. archaeocretacea* Zone, then they drop suddenly and increase again at the top of the *W. archaeocretacea* and the base of the *H. helvetica* Zones. The ^{13}C anomaly at the top of the *W. archaeocretacea* Zone and the basal *H. helvetica* Zone is similar with the situation reported in other localities where there is a drop of $\delta^{13}C$ (Hilbrecht and Hoefs, 1991; Hilbretch *et al.*, 1996; Jenkyns *et al.*, 1994). Also, $\delta^{13}C$ values within the lower part of the *H. helvetica* Zone are very similar to those reported by Jenkyns *et al.* (1994).

Potential for correlation. A ^{13}C anomaly was found in many sections adjacent to, as well as outside the Atlantic Ocean (Scholle and Arthur, 1980; Schlanger *et al.*, 1985), and seems to be universally synchronous within the *W. archaeocretacea* Zone (Scholle and Arthur, 1980; Hart and Leary, 1898; Gale *et al.*, 1993; Jenkyns *et al.*, 1994). In the case of our study of the Guerrero-Morelos Basin, the sections sampled for isotopic analysis correspond to different levels of the *W. archaeocretacea* Zone thus limiting the reliability of correlation among sections. However, on the overall the $\delta^{13}C$ values we obtained are similar to those found in southern England that correspond to both the lower part of the *W. archaeocretacea* Zone and the basal part of the *Helvetoglobotruncana helvetica* Zone, which can be correlated with the uppermost part of the *N. juddii* and the lower part of the *W. coloradoense* ammonite Zones (Jenkyns *et al.*, 1994). Although no prominent shifts in carbon isotope were found in the sections studied, the data suggest a link between the drowning of the platform and the Cenomanian-Turonian Anoxic Event.

5.3 Total Organic Carbon Events

Samples were analyzed for total organic carbon (TOC) from the Amacuzac, Las Tunas and Huitziltepec sections (Fig. 15). TOC values range from 0.03% to 0.61%, and in the Amacuzac section (*P. dubia* Zone) the value is 0.06% (1 sample). TOC values range from 0.06 to 0.3% in the upper *W. archaeocretacea* Zone, in samples taken from bioturbated argillaceous limestones containing calcisphaerulids, radiolarian, small non-keeled planktonic foraminifers (hedbergellids and heterohelicids), and scarce benthic fauna (textulariid, ostracods and mollusc fragments). TOC values range from 0.4 to 0.61% where the rocks consist of non-bioturbated laminated limestones devoid of benthic fauna. These rocks are characterized by abundant and large whiteinellids, hedbergellids, and keeled planktonic foraminifers, radiolarians and calcisphaerulids (Figs. 5 and 6). Within this Zone, carbonate-rich beds exhibit lowest TOC values (0.14%, 0.17% and 0.2%).

TOC values in the upper part of the *W. archaeocretacea* Zone of the Las Tunas section (Fig. 6) range from 0.06 to 0.4%. These rocks consist of dark grey argillaceous limestones with abundant open marine benthic and planktonic fossils. Benthic fossils are represented by mollusks (radiolitids, hippuritids and gastropods), calcareous algae (dasycladacean, gymnocodiacean, udoteacean and coralline algae), benthic foraminifers (textularids), echinoderms and roveacrinids. Planktonic microfossils are represented by calcisphaerulids and non-keeled planktonic foraminifers (hedbergellids, heterohelicids and whiteinellids). TOC values range from 0.2 to 0.5% in the lower part of the *H. helvetica* Zone where the beds consist of grey to black laminated limestones with abundant calcisphaerulids, non-keeled (hedbergellids, heterohelicids, whiteinellids) and keeled planktonic foraminifers, common thin bivalve shells, and roveacrinids. Abundant radiolarians, calcisphaerulids, scarce thin-bivalve shells, and roveacrinids compose the microfossil assemblage in the carbonate-rich limestones. TOC values are very low, and range from 0.02 to 0.2% in the upper part of the *W. archaeocretacea* Zone of the Huitziltepec section.

Interpretation. The TOC values are too low to allow meaningful interpretation, however as can be seen in Figure 15 values increase slightly from the top of the Cuautla Formation to the lower part of the Mexcala Formation. In the lower part of the Mexcala Formation (upper *W. archaeocretacea* and lower *H. helvetica* Zones) sediments are laminar, non-bioturbated and contain sparse, low-diversity benthic fauna (thin-bivalve shells and roveacrinids). These characteristics may indicate that the dark pelagic limestones of the Mexcala Formation were deposited under low oxygen conditions. Deposition of black, organic-rich, laminated sediments lacking bioturbation indicates dysaerobic or anoxic conditions during deposition (Schlanger *et al.*, 1987). These conditions have been associated in other parts of the world (de Graciansky *et al.*, 1984; Schlanger *et al.*, 1987; Jarvis *et al.*, 1988; Jenkyns, 1991; Caus *et al.*, 1993; Ulicny *et al.*, 1993; Ross and Skelton, 1993; Peryt and Wyrwicka, 1993; Hart, 1996; Premoli-Silva and Sliter, 1995; Luciani and Cobianchi, 1999) with the effects of an expanded oxygen-minimum Zone, and referred to by Schlanger and Jenkyns (1976) as the Cenomanian-Turonian Anoxic Event. This may be the case for rocks of the study area and in other parts of the basin as suggested by Hernández-Romano *et al.* (1997a).

Potential for correlation. Most of the samples that were analyzed for TOC correspond to the pelagic facies of the upper part of the *Whiteinella archaeocretacea* and the lower part of the *Helvetoglobotruncana helvetica* Zones. Based on Graphic Correlation, TOC values at the Amacuzac and Huitziltepec sections (0.7% and 0.22%) seem to be synchronous intervals at 92.75Ma within the *Helvetoglobotruncana helvetica* Zone. Since general TOC values suggest low oxygen conditions the synchronous intervals are probably related to the Cenomanian-Turonian Anoxic Event (e.g. Hilbrecht and Hoefs, 1991; Ulicny *et al.*,

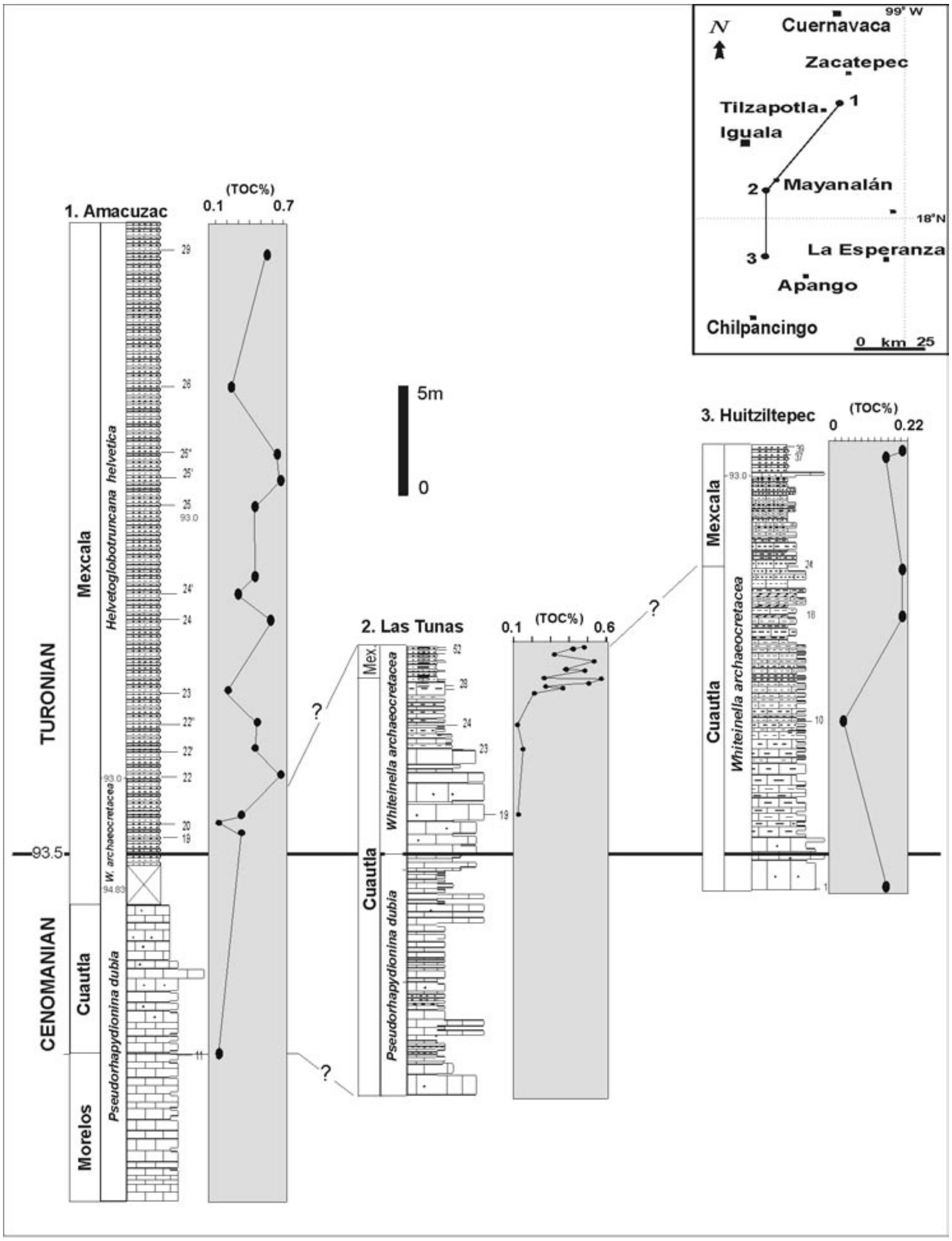

Fig. 15.- Total Organic Carbon profiles for the Amacuzac, Las Tunas and Huitziltepec sections of the Cuautla and Mexcala Formations across the Cenomanian-Turonian succession.

Fig. 15.- Curvas de Carbón Orgánico Total en las secciones Amacuzac, Las Tunas y Huitziltepec de las formaciones Cuautla y Mexcala a través de la sucesión del Cenomaniano-Turoniano.

1994, 1997; Luciani and Cobianchi, 1999, among others). More sections need to be studied for TOC and stable isotopes in order to establish their potential for correlation in the basin.

6. Discussion and Conclusions

Isotope and TOC analyses performed in rock sequences of the Guerrero-Morelos basin revealed no evident geochemical shifts that are sufficiently reliable as stratigraphic markers. However, some signatures seem to be comparable to those found in other areas, and may, therefore, correlate with the Cenomanian-Turonian Boundary Event. Furthermore, because biological events are most consistent, such events observed in the study of the Guerrero-Morelos basin may prove to be more reliable to allow comparison with those observed in other areas of the world around the CTB. The four bioevents that can be used as stratigraphic markers in the basin are as follows:

1.- The last appearance of *P. dubia* (B1.2. =93.83Ma) adjacent to the top of the Morelos Formation. This level is a common event during the Upper Cenomanian that seems to correlate well in several sections of the basin. Bioevent B1.2 is nearly equivalent to the upper *Rotalipora cushmani* foraminifer Zone, and is coeval with the upper part of the *Metoicoceras geslinianum* ammonite Zone of Hancock *et al.* (1993) and Gradstein *et al.,* (1995).

2.- The last appearance of most large benthic foraminifers (B1.3=93.5Ma) close to the base of the Cuautla Formation. The disappearance of most Cenomanian benthic foraminifers occur in the lower part of the *W. archaeocretacea* Zone, in the uppermost Cenomanian, and is equivalent to the upper part of *Neocardioceras juddii* ammonite Zones of Hancock *et al.* (1993) and Gradstein *et al.*, (1995). Bioevent B1.3 is considered to be global since it has been reported at the same level in other Tethyan localities (Philip and Airaud-Crumière, 1991; Caus *et al.*, 1993).

3.- The first appearance of hippuritid rudists (B4=93.31Ma) in the lower part of the Cuautla Formation. This bioevent occurs in the middle part of the *W. archaeocretacea* Zone and corresponds to the *Watinoceras coloradoense* ammonite Zone of Hancock *et al.* (1993) and Gradstein *et al.*, (1995).

4.- The first appearance of *Helvetoglobotruncana helvetica* (B7=93.0Ma) accompanied by a diversification of keeled planktonic foraminifers. This bioevent was found in the lower part of the Mexcala Formation within the middle-lower Turonian.

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