Revista Mexicana de Ciencias Geológicas, v. 22, núm. 1, 2005, p. 48-64

Maastrichtian shallow-water ammonites of northeastern Mexico

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ABSTRACT

In northeastern Mexico, extensive deltaic and prodeltaic sediment complexes developed during Maastrichtian times, known as the Difunta Group and Escondido Formation in Coahuila and the Northwest of Nuevo León, and the Cárdenas Formation in San Luis Potosí. These sediments contain abundant and diverse invertebrate assemblages, among them the last ammonites in the area, prior to their extinction. Sphenodiscus (S. lobatus, S. pleurisepta) and Coahuilites sheltoni are the dominant elements of this paucispecific fauna and clearly favored shallow water coastal environments. Ammonites other than sphenodiscids are rare and restricted to occasional Baculites ovatus and a single Pachydiscus (Pachydiscus) neubergicus. This early (and possibly early late) Maastrichtian assemblage differs notably from the coeval ammonite fauna of the distal prodeltaic and open marine Méndez Formation in eastern Nuevo León. The latter assemblage is far more diverse (23 species referred to 18 genera) and includes, in addition to typical Gulf of Mexico faunal elements, many Tethyan, cosmopolitan, and even southern high latitude Indopacific species previously unknown from Mexico. Faunal differences between the two nearby outcrop areas are thus clearly related to paleobathymetry and not to paleobiogeography, being Baculites ovatus the only conspecific element.

Key words: ammonites, paleobathymetry, Maastrichtian, Upper Cretaceous, Mexico.

RESUMEN

Durante el Maastrichtiano, complejos deltaicos y prodeltaicos extensos se desarrollaron en el Noreste de México, y se conocen como grupo Difunta y formación Escondido en Coahuila y el Noroeste de Nuevo León, y formación Cárdenas en el Estado de San Luis Potosí. Los sedimentos contienen asociaciones abundantes y diversas de invertebrados, entre ellos los últimos ammonites en la región, previos a su extinción. Sphenodiscus (S. lobatus, S. pleurisepta) y Coahuilites sheltoni son los elementos dominantes de esta fauna pauciespecífica y claramente favorecieron ambientes costeros someros. Ammonites que no pertenecen a los sphenodiscidos son mucho más escasos y se restringen a Baculites ovatus y un sólo ejemplar de Pachydiscus (Pachydiscus) neubergicus. Esta asociación caracteriza al Maastrichtiano temprano (y posiblemente la parte temprana del Maastrichtiano tardío). Difiere notablemente de la fauna coetánea de la formación Méndez del Este de Nuevo León, la cuál fue depositado en ambientes prodeltaicos distales y de mar abierto. La fauna de la formación Méndez es mucho más diversa (23 especies pertenecientes a 18 géneros) e incluye, aparte de elementos faunísticos típicos del Golfo de México, especies tethysianas, cosmopolitas, y hasta especies indopacíficas de latitudes australes altas. Estos elementos habían sido desconocidos en México hasta la fecha. Las diferencias faunísticas entre las dos regiones cercanas del Noreste de México se deben, por lo tanto, a diferencias en la paleobatimetría y no a la paleobiogeografía. El único elemento idéntico es Baculites ovatus.

Palabras clave: ammonites, paleobatimetría, Maastrichtiano, Cretácico Superior, México.

INTRODUCTION

During Campanian–Maastrichtian times, uplift of the Sierra Madre Oriental led to erosion and mobilization of enormous quantities of sediment. Deposition occurred in huge deltaic complexes along the ancient Gulf of Mexico coast and shelf, whereas pelagic sedimentation continued further to the east (Weidie *et al.*, 1972; Goldhammer and Johnson, 2001). Most of the coastal and deltaic sediments of northeastern Mexico have been dated through the occurrences of ammonites, although few formal descriptions exist today. In this study, we present ammonites from the Difunta Group, Escondido Formation, and Cárdenas Formation of northeastern Mexico, and compare these faunas of shallow water deltaic areas to the deep water faunal assemblage of the Méndez Formation (Ifrim *et al.*, 2004).

The Difunta Group

In the Parras and La Popa Basins to the north and west of Monterrey and Saltillo, an important deltaic complex developed, known as Difunta Group (Figure 1). A detailed description of formations and developed facies in this region was given by McBride *et al.* (1974).

In the Parras Basin west of Saltillo, Coahuila, the Cerro del Pueblo Formation at the base of this more than 6,000 m thick complex consists of gray mudstones and sandstones, followed by the red, green and gray mudstones, siltstones and sandstones of the Cerro Huerta Formation (Figure 2). These sediments were deposited on a delta plain flanked by coastal plains. The gray mudstones and sandstones of the Cañon del Tule Formation overlie these marginally marine and terrestrial sediments and are considered to be the first evidence for a major marine transgression. Upsection, a second deltaic progradation led to terrestrial mudstones, siltstones and sandstones of the Las Imágenes Formation. Coastal environment returned with the sandstones, siltstones and mudstones of the Cerro Grande Formation (McBride *et al.*, 1974).

In the eastern Parras Basin, the Los Muertos Formation underlies a sequence of shales and mudstones with intercalated siltstones and sandstones, the Tanque Formation, which was deposited in shallow marine to terrestrial deltaic environments (McBride *et al.*, 1974).

In the La Popa Basin, located to the northeast of the Parras Basin (Figure 1), the basal part of the Difunta Group is formed by interbedded sandstones and siltstones known

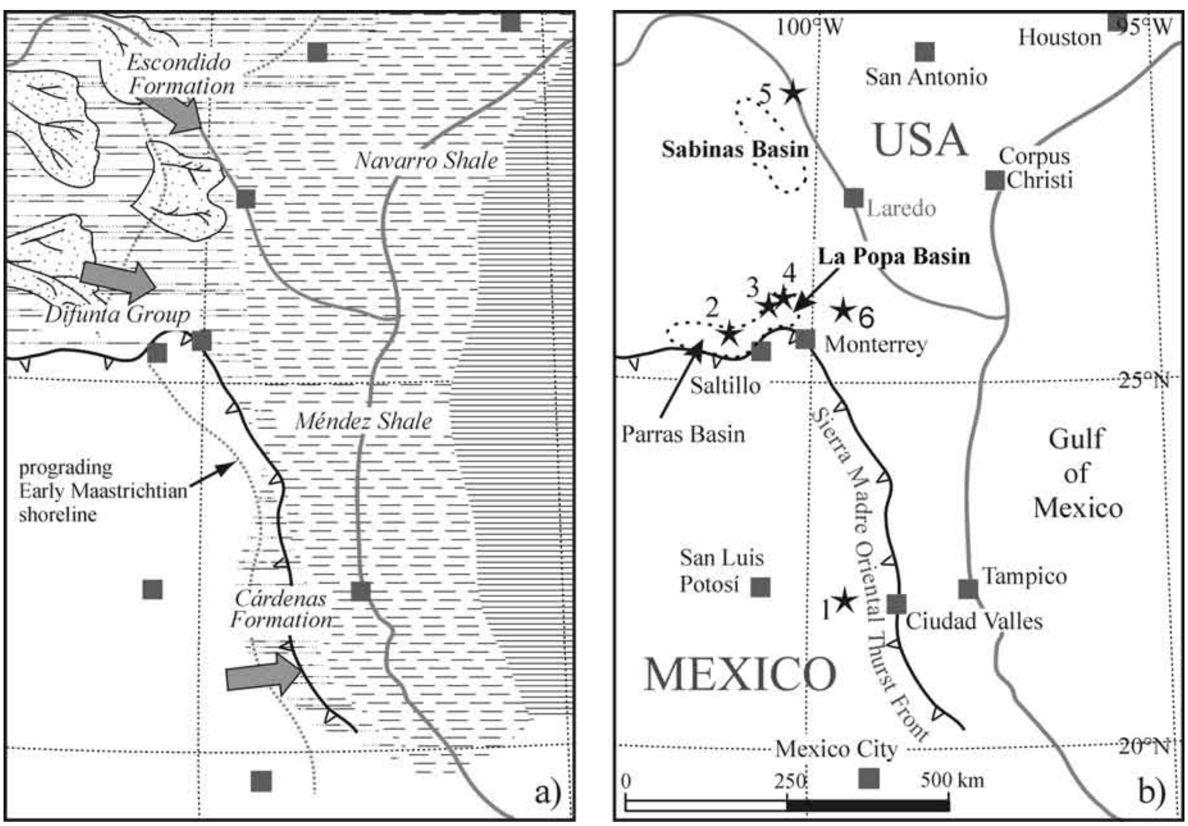

Figure 1. a: Paleogeographic lithofacies map of northeastern Mexico (modified after Goldhammer and Johnson, 2001) with prograding coastline from the northeast and east (modified after Weidie *et al.*, 1972). For the key to lithologies see Figure 2. b: Same map with geographic and paleogeographic elements, and northeastern Mexican ammonite localities. 1: Cárdenas, S.L.P.; 2: Rincón Colorado, Coah.; 3: Reata, Coah.; 4: Mina, N.L.; 5: Eagle Pass, Texas; 6: Loma Los Martinitos near Cerralvo, N.L.

as Los Muertos Formation (Figure 2). The Potrerillos Formation, a thick deltaic complex, overlies the Los Muertos Formation and is composed of several mudstone, siltstone, and sandstone members with intercalated carbonate lentils. The Los Muertos Formation and the lower Potrerillos Formation were dated by ammonites to be Maastrichtian in age (Lawton *et al.*, 2001).

Only few formal descriptions of ammonites of the Difunta Group exist today. Wolleben (1977) presented *Baculites ovatus* Say, 1820, *Eubaculites carinatus* (Morton, 1834), *Coahuilites sheltoni* Böse, 1928, and *Sphenodiscus pleurisepta* (Conrad, 1857) from the lower Potrerillos Formation of the La Popa Basin. *Baculites ovatus* Say, 1820 and *Sphenodiscus pleurisepta* (Conrad, 1857) were used by Lawton *et al.* (2001) to determine the Maastrichtian age of the Los Muertos and lower Potrerillos Formations, but without illustration or formal description. Particularly *Sphenodiscus pleurisepta* (Conrad, 1857) is a common species in both formations. Other ammonites from the La Popa Basin were presented by Vega-Vera and Perrilliat (1990): *Sphenodiscus pleurisepta* (Conrad, 1857), *B. ovatus* Say, 1820, and *Pachydiscus* cf. *P. arkansanus* Stephenson, 1941. Vega *et al.* (1995) also listed *Baculites undatus* Stephenson, 1941, and *Solenoceras* sp. from the Potrerillos Formation, but they were not figured or formally described.

Most of our specimens collected in the La Popa Basin are from an outcrop of the lower Potrerillos Formation near Mina, Nuevo León (Figure 1). The fauna consists of *Baculites ovatus* Say, 1820, *Coahuilites sheltoni* Böse, 1928, and undetermined heteromorph ammonites (*Pseudobaculites*, nostoceratids) which are not described herein. McBride *et al.* (1974) and Wolleben (1977) mentioned this locality. *Sphenodiscus pleurisepta* (Conrad, 1857) is abundant elsewhere in the La Popa Basin (McBride *et al.*, 1974; Wolleben, 1977; Vega-Vera and Perrilliat, 1990); here we present individuals from the Tanque Formation south of Reata (Figure 1). From the Parras Basin, we present *Sphenodiscus lobatus* (Tuomey, 1854) collected from the Cerro del Pueblo Formation at Rincón Colorado, 30 km to the west of Saltillo (Figure 1). No associated fauna was collected in any of the Difunta Group localities.

The Escondido Formation

A sediment complex similar to the Difunta Group, but more reduced in thickness, developed during the Maastrichtian further to the north in the Sabinas Basin and Rio Grande Embayment (Figure 1). This unit is called Escondido Formation and consists of bioturbated marls and siltstones interbedded with subarcosic sandstones. Upsection, these sediments grade into sublittoral to inner shelf calcareous or sandy mudstones, siltstones, and siliciclastic limestone (Cooper, 1970, 1971; Sohl *et al.*, 1991).

Maastrichtian ammonites from the Escondido Formation were first described by Böse (1928). This fauna consists of *Coahuilites sheltoni* Böse, 1928 (of which *C. orynskii* Böse, 1928 and *C. cavinsi* Böse, 1928 are synonyms), *Pachydiscus colligatus* (Binkhorst, 1861), *Sphenodiscus aberrans* Böse, 1928, *S. lenticularis* (Owen, 1852) [which is included into the synonymy of *S. lobatus* (Tuomey, 1854), see *e.g.*, Cobban and Kennedy, 1995], *S. intermedius* Böse, 1928 (which is considered to be a synonym of *S. lobatus* (Tuomey, 1854), see for instance Kennedy *et al.*, 1997, p. 4), and *S. pleurisepta* (Conrad, 1857) (and its synonym *S. prepleurisepta).* Cooper (1970, 1971) examined macrofossils in the Sabinas Basin and the Eagle Pass area in Texas and developed a Maastrichtian biostratigraphy based on sphenodiscid ammonites (see discussion below).

Our specimens of *Sphenodiscus pleurisepta* (Conrad, 1857) from the Escondido Formation were collected in the Cuevas Creek section near Eagle Pass (Figure 1). This locality was described in detail by Cooper (1970, 1971). Fossils were collected from bioturbated (*Thalassinoides*) glauconitic siltstones. 15.5 m of unfossiliferous, organic rich shales with thin interbedded siltstones and sandstones overlie the last layer with *S. pleurisepta* (Conrad, 1857), and unconformably underlie a limestone unit with abundant *Venericardia* of the basal Midway Group of Paleocene age (Cooper, 1971). The base of the limestone may represent the Cretaceous–Tertiary boundary. Body chambers and phragmocone camerae of *Sphenodiscus pleurisepta* (Conrad, 1857) are filled with sediment. They are associated with gastropods (*Liopeplum*, *Pugnellus*, *Turritella*) and bivalves (*Cardium*, *Cucullaea* and oysters).

The Cárdenas Formation

Further to the south, in the Sierra Madre Oriental, halfway between Ciudad Valles and San Luis Potosí, a mixed clastic-carbonate sediment succession developed on the paleohigh of the Valles–San Luis Potosí carbonate platform (Figure 1). This unit, the Cárdenas Formation, was deposited during the Maastrichtian (Schafhauser *et al.*, 2003).

In the Cárdenas Formation, ammonites are generally rare. The only ammonites known from the Cárdenas Formation are *Scaphites* sp. and *Solenoceras* sp. listed by Vega *et al.* (1995) without description or illustration. Individuals described in the present paper were collected from sections in the Arroyo de la Atarjea, approximately 3 km north of Cárdenas (Myers, 1968), and along the railway between Cárdenas and La Canoa, at approximately 6 km east of Cárdenas (railway kilometer 619-620, Figure 1). In the Arroyo de la Atarjea section, ammonites occur in the upper part of the lower member of the Cárdenas Formation, whereas they were collected from the lowermost part of the middle member in the section along the railway. Lithologies consist of alternating marls, siltstones and fine-grained sandstones in both sections. At Arroyo de la Atarjea, gastropods (*Pugnellus, Longoconcha*) and fragmented sponges are associated with the ammonites. Foraminiferal assemblages in this section indicate an Early Maastrichtian age (biozone CF 6-7, Figure 3) for the middle

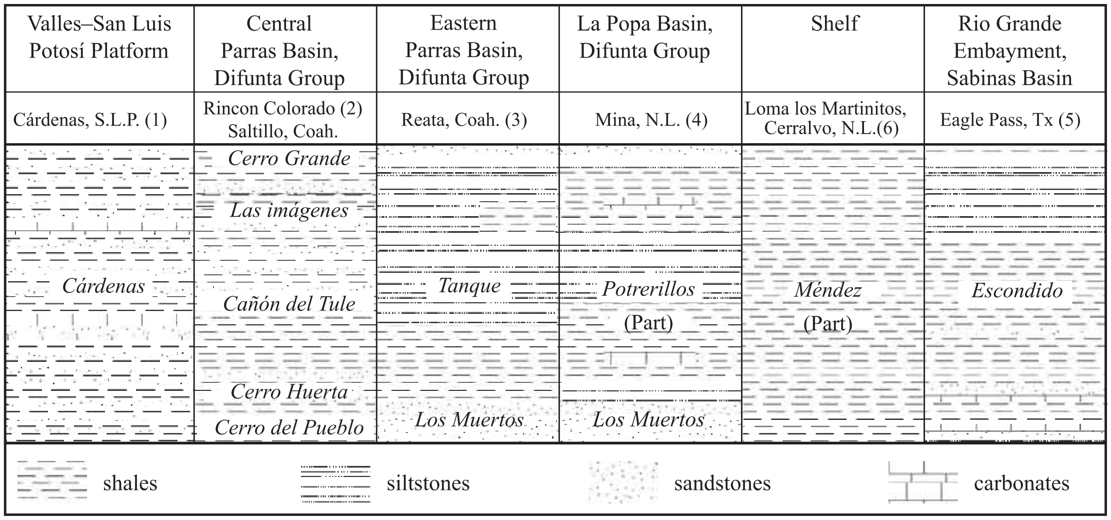

Figure 2. Maastrichtian formations in northeastern Mexico. Units of the Difunta Group and the Escondido Formation were dated through ammonite occurrences (from Cooper, 1970, 1971; Wolleben, 1977; Lawton *et al.*, 2001, and own material). Localities from Figure 1 are shown in their paleogeographic context.

member of the Cárdenas Fm. This assignation does not agree with the middle to late Campanian age proposed by Caus *et al.* (2002), based on the Tethyan benthic foraminifer *Lepidorbitoides minima*, but agrees with the presence of *Pachydiscus (P.) neubergicus* (Hauer, 1858) in this section. Elsewhere, the first appearance datum of this ammonite defines the base of the Maastrichtian (Odin and Lamaurelle, 2001), as will be discussed later.

The Méndez Formation

Uplift and erosion of the Sierra Madre Oriental formed a vast amount of siliciclastic sandstone and siltstone sediments which pushed coastlines of the Cárdenas Formation and Difunta Group towards the east. Open marine conditions persisted east and south of Monterrey in today's coastal plain of eastern Mexico. This Méndez Formation is up to 1,000 m thick and consists of monotonous marls with thin siltstone interlayers. The abundance of planktic foraminifera and marly sediment suggests sedimentation in open marine environments, with water depths of approximately 100 m near Los Ramones, 40 km northeast of Monterrey (Stinnesbeck *et al.*, 1996; Keller *et al.*, 1997), and more than 400 m in the La Sierrita region, 40 km east of Monterrey (Keller *et al.*, 1997; Stinnesbeck *et al.*, 2001).

The Méndez Formation is generally poor in macrofossils. Isolated specimens of the bivalve *Tampsia* (Stephenson, 1941) have been reported, in addition to *Cataceramus* (own collections) and fragments of an unspecified mosasaurid (Aranda-Manteca and Stinnesbeck, 1995). Only a single ammonite, a fragment of *Nostoceras sternbergi*, had been described by Medina-Barrera and Stinnesbeck (1993), until publication of a diverse ammonite assemblage from the Méndez Formation at Loma Los Martinitos near Cerralvo, N.L., northeastern Mexico (locality 6 in Figure 1; Ifrim *et al.*, 2004).

The Cerralvo fauna consists of 23 species referred to 18 genera. More than 1,000 individuals are preserved as goethitic internal moulds. The small size of the fossils is an artifact, as only the inner whorls were filled by goethite and preserved, whereas the outer whorls crushed and dissolved under lithologic overburden and compaction of the host sediment. Benthic and planktic foraminifera in the host sediment indicate deposition in an inner to middle neritic environment during the Early Maastrichtian (biozone CF 7 of Li and Keller, 1998a, 1998b, between 70.39 and 69.56 Ma; Figure 3). The presence of the ammonite *Nostoceras (N.) alternatum* further refines the age of the Cerralvo ammonite assemblage to the *Baculites clinolobatus* zone of the Western Interior (Cobban, 1974; Cobban and Kennedy, 1991b). This age does not only corroborate the age assigned by the microfauna, but further restricts it to the upper biozone CF 7.

Several species of the Cerralvo fauna appear to be endemic in the middle, southern, and/or eastern North American continent and thus represent Gulf of Mexico affinities. These are *Baculites ovatus* Say, 1820, *Nostoceras (N.) colubriformis* Stephenson, 1941, *N. (N.) alternatum* (Tuomey, 1854), *N. (N.) rugosum* Cobban and Kennedy, 1991a, and *Solenoceras reesidei* Stephenson, 1941. *Fresvillia constricta* Kennedy, 1986 has previously been reported only once from northern France (Kennedy, 1986), and was thought to be restricted to boreal Europe. *Brahmaites (Anabrahmaites) vishnu* (Forbes, 1846) and *Hauericeras rembda* (Forbes, 1846) are widespread throughout the low and middle latitudes of the Tethyan and Indopacific region.

The third group of species shows widespread global occurrences throughout all latitudes. These are

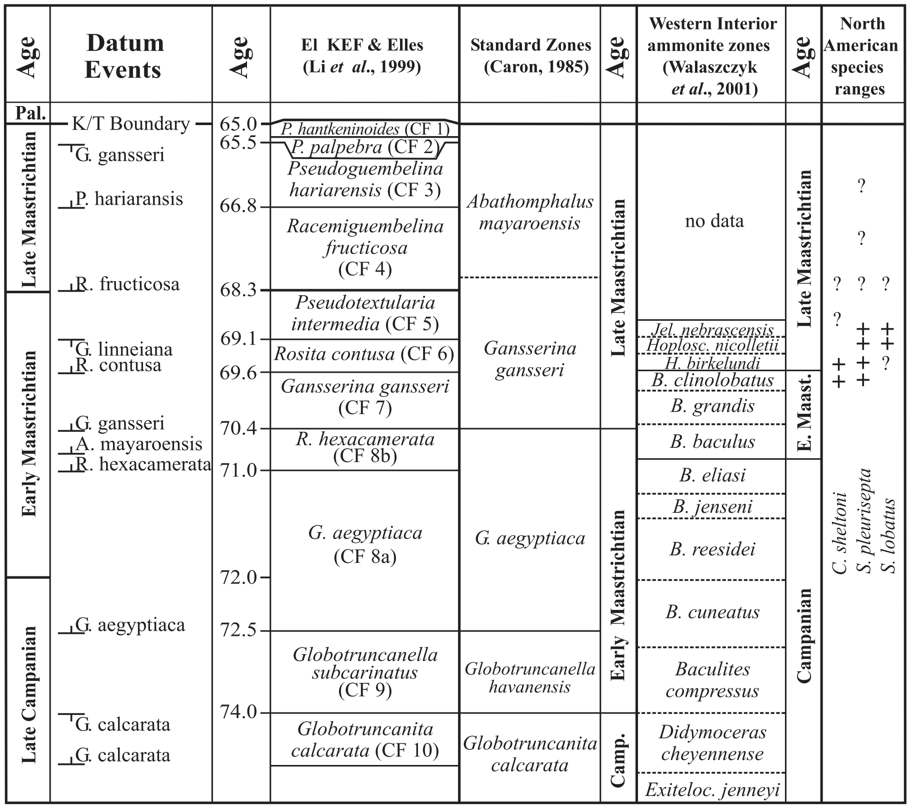

Figure 3. Comparison of stratigraphic zonations of the Maastrichtian based on planktic foraminifera (Caron, 1985; Li *et al.*, 1999) and the Western Interior standard ammonite zonation (Gill and Cobban, 1966; modified by Walaszczyk *et al.*, 2001). Campanian/Maastrichtian boundary from Odin and Lamaurelle (1996), subdivision of the Maastrichtian from Li *et al.* (1999). Species ranges of sphenodiscids from the Western Interior were taken from Cobban and Kennedy (1995), Kennedy *et al.* (1997), and Landman and Cobban (2003).

Diplomoceras cylindraceum (Defrance, 1816), *Hypophylloceras (Neophylloceras)* cf. *H. (N.) surya* (Kossmat, 1895), *Phyllopachyceras forbesianum* (d'Orbigny, 1850), and *Pseudophyllites indra* (Forbes, 1846). In addition, *Anagaudryceras politissimum* (Kossmat, 1895), *Desmophyllites diphylloides* (Forbes, 1846), and *Gaudryceras kayei* (Forbes, 1846) are cosmopolitans that have been recorded from all over the world except for Europe, and they are not considered true generalists.

The most interesting and surprising aspect of the Cerralvo assemblage is the presence of cephalopod species hitherto known from the middle and high latitudes of the Indopacific region, such as India, western Australia, Chile, and Antarctica. *Hypophylloceras (Neophylloceras) hetonaiense* (Matsumoto, 1942), *Fresvillia* aff. *F. teres* (Forbes, 1846), *Zelandites varuna* (Forbes, 1846), and the possible coleoid *Naefia neogaeia* Wetzel, 1930 indicate the influence of cool water in low latitude regions. This is surprising as the diverse rudist assemblage of the Cárdenas Formation, located approximately 350 km to the south, indicates tropical climate (Kauffman, 1973). However, for the upper biozone CF 7, a decrease in global temperature was recorded by Barrera *et al.* (1997) and Li and Keller (1998b). Apparently this drop in temperature led to a mixing of cephalopod assemblages from different latitudes and caused an increase in diversity.

Tetragonites superstes Hoepen, 1921, *Saghalinites cala* (Forbes, 1846), *Pachydiscus (P.)* juv. sp., *Menuites* juv. sp., and *Solenoceras texanum* (Shumard, 1861) are also present in the Cerralvo fauna, but were not considered in this study (for details see Ifrim *et al.*, 2004).

SYSTEMATIC PALEONTOLOGY

Ammonites of the Difunta Group, Cárdenas and Escondido Formations are generally preserved with their shells, though always recrystallized to calcite. They need to weather out of the sediment to be collected. This is why most specimens are fragments, and the shell is usually broken, abraded, or weathered away.

Dimensions: Dimensions are given in mm. Uncertain values due to deformation, and relation resulting from uncertain values, are written in brackets. Abbreviations: D: diameter; WB: whorl breadth; WH: whorl height; U: umbilical diameter; L: length between measured sections.

Suture terminology: The abbreviation of sutural elements corresponds to common terminology: E: external lobe; L: lateral lobe; U: umbilical lobe (some with index: U1, U2, ..); E/L: saddle between external and lateral lobe, etc.

Systematic: The systematic nomenclature corresponds to the Treatise of Invertebrate Paleontology (Wright et al., 1996) to subspecies level.

Synonymies: The original description, important synonyms, and all references used for determination are included. Where possible, more complete synonymy lists are indicated.

Other abbreviations: The registrations are CTMUDE: Type fossil collection of the Museo del Desierto de Coahuila, Saltillo; IMG: Instituto de Geología of the Universidad Nacional Autónoma de México, Mexico City; UKRG: University of Karlsruhe, Institute of Regional Geology; EP Eagle Pass. Other collections mentioned are GBA: collection of the Geologische Bundesanstalt, Vienna; USNM: National Museum of Natural History, Washington, DC.

Order Ammonoidea Zittel, 1884
Suborder Ammonitina Hyatt, 1889
Superfamily Desmocerataceae Zittel, 1895
Family Pachydiscidae Spath, 1922
Genus *Pachydiscus* Zittel, 1884

Type species. *Ammonites Neubergicus* Hauer (1858, p. 12, pl. 2, figs. 1-3) by subsequent designation by Grossouvre (1894, p. 177).

Subgenus *Pachydiscus* Zittel, 1884

= *Parapachydiscus* Hyatt, 1900, p. 570; *Joaquinites* Anderson, 1958 , p. 218

Type species. As type for genus.

Pachydiscus (Pachydiscus) neubergicus **(Hauer, 1858)**
Figures 4a-c, 5h

Ammonites chrishna Forbes, 1846, p. 103, pl. 9, fig. 2.
Ammonites Neubergicus Hauer, 1858, p. 12 (pars), pl. 2, figs. 1-3 [non pl. 3, figs. 1-3 = *Pachydiscus epiplectus* (Redtenbacher, 1873)].
Pachydiscus (Pachydiscus) neubergicus (Hauer, 1858). Kennedy and Summesberger, 1986, p. 189, pl. 2, figs. 1-2, pl. 3, figs. 1-3, pl. 4, figs. 1-5, pl. 5, figs. 1, 4-5, pl. 6, figs. 1-2, 5, pl. 15, figs. 7-8, fig. 5a,b (with full synonymy); Kennedy, 1986, pl. 4 fig. 3; Kennedy *et al.*, 2000, p. 9, fig. 4u-w.

Type. The lectotype is GBA 1858.01.6, which comes from the Early Maastrichtian of Neuberg, Steiermark, Austria. It is the original of Hauer, 1858, pl. 2, figs. 1-3, by subsequent designation of Grossouvre, 1894, p. 209. The specimen was refigured by Kennedy and Summesberger, 1986, pl. 3, figs. 1-3, and Kennedy, 1986, pl. 4, fig. 3.

Description. The shell is moderately involute and expands at a moderate rate. The test is little compressed, with a WB/WH ratio of about 0.85. The umbilicus spans 29% of the diameter. The vertical umbilical wall arches widely into slightly convex and convergent flanks. Greatest whorl breadth is below mid-flank. The venter is widely rounded. The flanks display approximately six sigmoidal primary ribs per half whorl. The ribs are concave on the umbilical shoulders, rectiradiate on the dorsal flank, and they bend convexly backwards at mid-flank. They cross the ventrolateral shoulders in a wide concavity and weaken towards the venter. Up to a diameter of about 9 cm, the two ventrolateral secondary ribs are parallel to the primaries. At a diameter of 10 cm, the shell displays at least one secondary between each primary rib. At a shell diameter of 12 cm, the primary ribs flatten and become straighter on the outer flanks, while secondary ribs are more distant and seem to weaken. Unfortunately the shell is badly weathered and crushed in this part. The suture line is partially visible and corresponds to that of the genus.

Material. One deformed, weathered specimen from the base of the middle member of the Cárdenas Formation at the railway section east of Cárdenas.

Dimensions	D	WB	WH	WB/WH	U	U/D
IMG 8671	108.0	36.6	43.0	0.85	31.4	0.29
Maximum diameter	(149.2)	37.9	(50.8)	(0.75)	(48.6)	(0.33)

Occurrence. All species discussed below are Maastrichtian in age. *Pachydiscus (P.) neubergicus*, which appears to be conspecific with our specimen, is the index fossil for the Early Maastrichtian (Christensen *et al.*, 2000; Odin and Lamaurelle, 2001). In North America, the species was recorded only once from the Navesinsk Formation of New Jersey (Kennedy *et al.*, 2000).

Discussion. *Pachydiscus (Pachydiscus) neubergicus* Hauer from the Mexican Cárdenas Formation presents the slightly compressed whorl section of the type material of *P.* (*P.*) *neubergicus* (Hauer, 1858), although ornamentation is more typical of *P.* (*P.*) *jacquoti* Seunes (1891) with one or two ventrolateral rib between two moderately distant primary ribs.

The type material of *Pachydiscus (Pachydiscus) neubergicus* is slightly compressed, with a WB/WH ratio between 0.72 and 0.78. Shape of its primary ribs corresponds to that observed in our specimen, with nine primary ribs per half whorl in the Mexican specimen and in the type material, but it differs in the higher number of secondary ribs: eighteen per half whorl in the lectotype, whereas thirteen are recognized in the last half whorl of the Mexican specimen (but at this diameter our specimen is larger than the lectotype). *P.* (*P.*) *neubergicus* is subdivided into two subspecies which differ in ornamentation of adult shells.

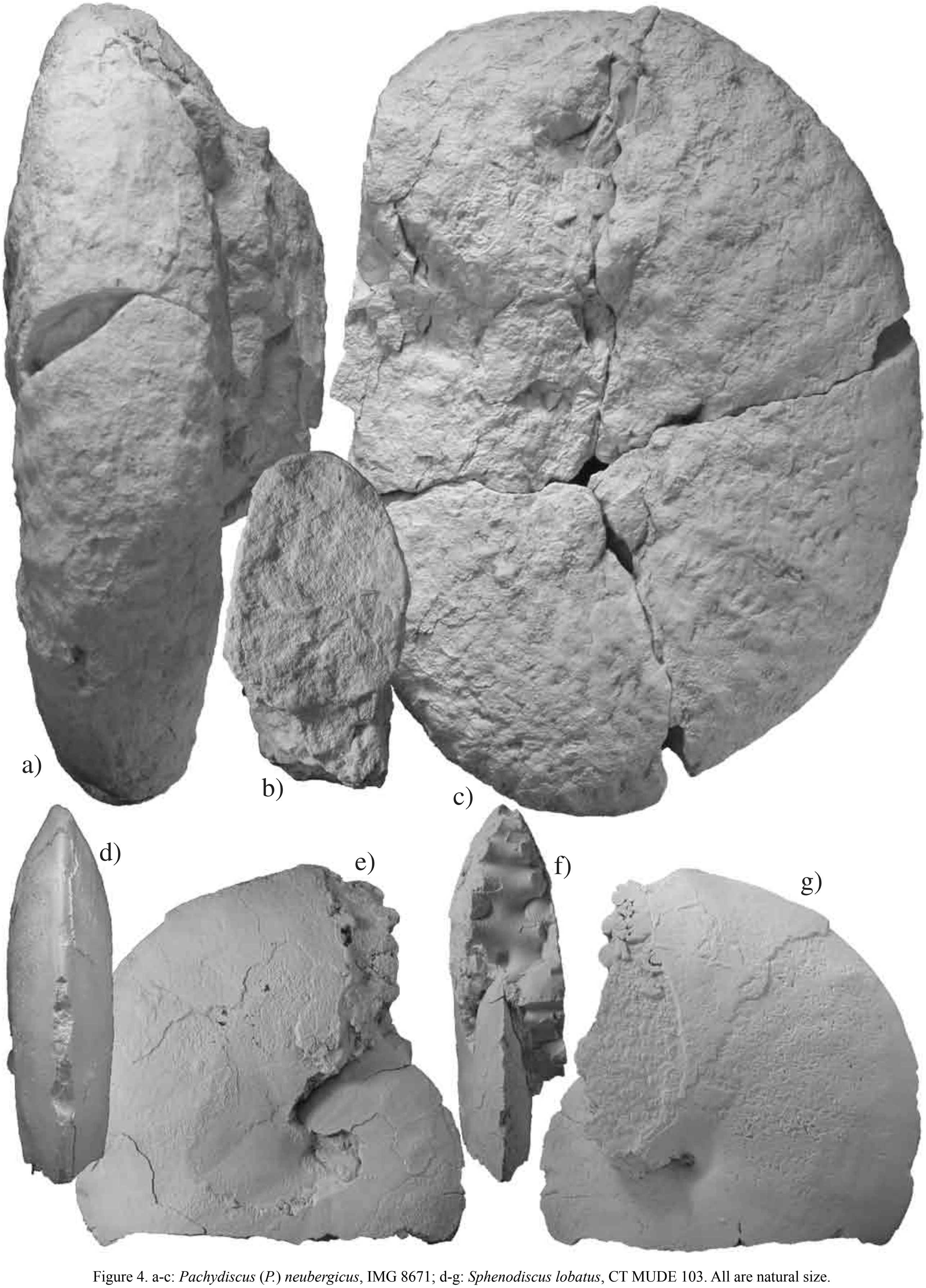

Figure 4. a-c: *Pachydiscus* (*P.*) *neubergicus*, IMG 8671; d-g: *Sphenodiscus lobatus*, CT MUDE 103. All are natural size.

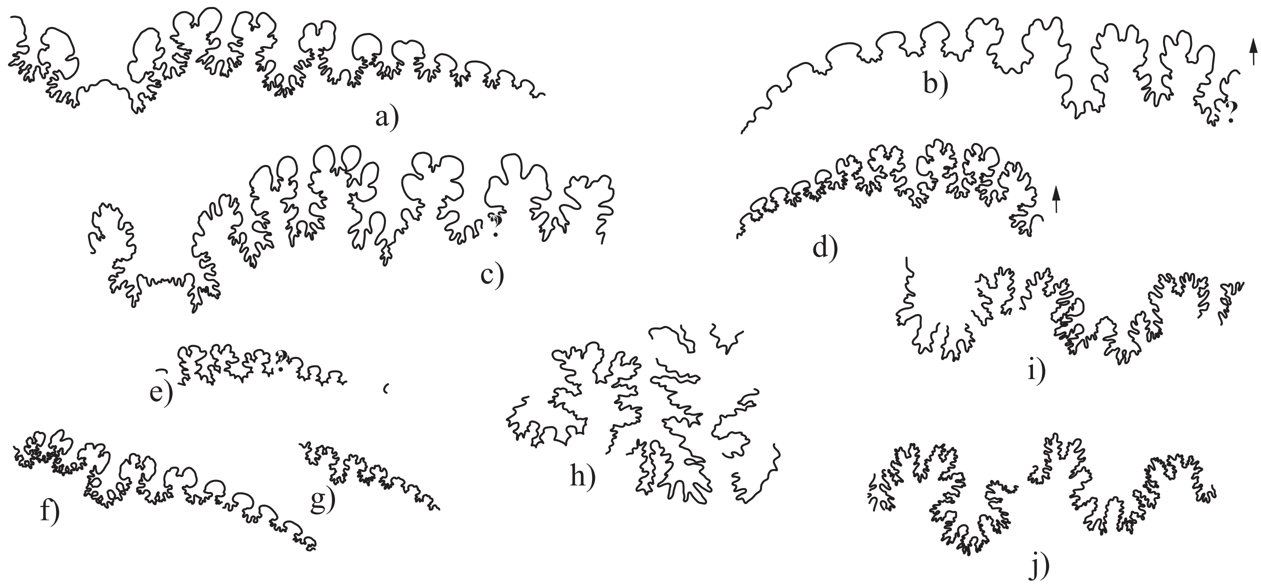

Figure 5: Suture lines. a-d: *Sphenodiscus lobatus* (a: CT MUDE 107; b: CT MUDE 102; c: CT MUDE 104; d: CT MUDE 103); e: *Sphenodiscus pleurisepta*, IMG 8672; f-g: *Coahuilites sheltoni* (f: CT MUDE 116; g: CT MUDE 106. h: *Pachydiscus* (*P.*) *neubergicus*, IMG 8671; i-j: *Baculites ovatus*. (i: CT MUDE 113; j: CT MUDE 114). All suture lines are natural size.

See Henderson and McNamara (1985), Kennedy and Summesberger (1986), and Ward and Kennedy (1993) for discussion of subspecies.

Pachydiscus (Pachydiscus) jacquoti Seunes is also similar. In this species, 10 to 12 primary ribs are present per whorl with one or two ventrolateral ribs, and ornamentation is comparable to that of our specimen. However, whorl section of the type material is considerably less compressed in *P.* (*P.*) *jacquoti* than in our specimen, and the WB/WH ratio of *Pachydiscus (Pachydiscus) jacquoti* is 0.95 to 1.20, compared to a WB/WH ratio of 0.85 in the Cárdenas specimen. None of the subspecies of *Pachydiscus (Pachydiscus) jacquoti* are close to our specimen. They differ in ornamentation during late ontogeny (Henderson and Mcnamara, 1985; Kennedy, 1986; Stinnesbeck, 1986; Ward and Kennedy, 1993). The higher density of ventrolateral ribs, the shape of primaries and a similar whorl section relate the Cárdenas species closer to *P.* (*P.*) *neubergicus* than to *P.* (*P.*) *jacquoti*, although the density of the primary ribs is less than that of *P.* (*P.*) *neubergicus*. The disappearance of secondary ribbing is most probably an artifact due to mechanical abrasion, because faint traces of ribs remain visible on the shell of our specimen.

Superfamily Acanthocerataceae Grossouvre, 1894
Family Sphenodiscidae Hyatt, 1900
Subfamily Sphenodiscinae Hyatt, 1900
Genus *Sphenodiscus* Meek, 1871

= *Austrosphenodiscus* Olsson, 1944, p. 266 (108)

Type species. *Ammonites lenticularis* Owen (1852, p. 579, pl. 8, fig. 5; non Phillips, 1829, pl. 6, fig. 5), by original designation, = *Ammonites lobata* Tuomey, 1854, p. 168

***Sphenodiscus lobatus* (Tuomey, 1854)**
Figures 4d-g, 5a-d, 6a-e, 7d-f

Ammonites lenticularis Owen, 1852, p. 579, pl. 8, fig. 5.
Ammonites lobata Tuomey, 1854, p. 168.
Sphenodiscus lenticularis (Owen). Böse, 1928, p. 293, pl. 14, figs. 9-11.
Sphenodiscus tirensis Stephenson, 1941, p. 435, pl. 93, figs. 1-3; pl. 94, figs. 1-2.
Sphenodiscus lobatus (Tuomey). Cobban and Kennedy, 1995, p. 12, figs. 6.2-6.3, 8.4, 8.6-8.11, 12.18-12.19, 16.16-16.17 (with additional synonymy); Kennedy and Cobban, 1996, p. 802, figs. 2.4-2.6, 2.13-2.14, 2.19-2.21; Kennedy *et al.*, 1997, p. 4, figs. 3-8, 9a-i, 10.

Type. The holotype is lost (*fide* Stephenson, 1941, p. 434). It was from Noxubee County, Mississippi.

Description. Compressed, involute, oxycone shell with a tiny umbilicus of about 3% of the diameter. The venter is fastigiate or narrowly rounded and grades into slightly convex flanks. Maximum whorl breadth is at midflank. Towards the umbilicus the flank is slightly concave. The shell surface is smooth or may bear faint, low, broad, concave ribs which are crescent on the outer flank but, straight on the inner flank where visible. Our material contains some body chambers, but no complete aperture is preserved. The first lateral saddle of the suture line, E/L, is trifid, auxiliary saddles are numerous and entire with the exception of the outer one or two.

Material. 34 specimens from the Cerro del Pueblo Formation at Rincón Colorado, Coahuila.

Dimensions	D	WB	WH	WB/WH	U	U/D
CT MUDE 108	(76.0)	21.5	45.6	0.47	2.0	(0.03)
CT MUDE 107	(85)	23.7	51.9	0.46	2.0	(0.02)
CT MUDE 105	119.3	32.9	72.3	0.46	3.9	0.03
CT MUDE 102	(145)	38.7	85.8	0.45	4.0	(0.03)
CT MUDE 104	(155)	38.2	88.6	0.43	5.9	(0.04)
CT MUDE 101	163.6	47.7	93.0	0.51	4.6	0.03

Occurrence. This Maastrichtian species was described from the Escondido Formation in northeastern Mexico and Trans-Pecos, Texas (Böse, 1928), Alabama, and Mississippi (Cobban and Kennedy, 1995), and northeast Texas (Kennedy and Cobban, 1993b). Other records are from North Carolina, Maryland, New Jersey, Israel and Nigeria (*fide* Cobban and Kennedy, 1995). In the Western Interior, *S. lobatus* was recorded from the *Hoploscaphites nicolletii* and *Jeletzkytes nebrascensis* ammonite zones and may also exist in the *H. birkelundi* zone (see Kennedy *et al.*, 1997).

Discussion. According to Cobban and Kennedy (1995) and Kennedy *et al.* (1997), this species is morphologically variable. Kennedy *et al.* (1997) include *S. lenticularis intermedius* into the synonymy of *S. lobatus. Sphenodiscus pleurisepta*, another common species in the Gulf of Mexico area, clearly differs by a stronger ornamentation.

Sphenodiscus pleurisepta **(Conrad, 1857)**

Figures 5e, 7a-c, 8a-d, h-i

Ammonites pleurisepta Conrad, 1857, p. 159, pl. 15, fig. 1
Ammonites pedernalis Binkhorst, 1861, p. 21 (pars), pl. 5a1, figs. 1a, b only
?Sphenodiscus pleurisepta (Conrad). Böhm, 1898, p. 193-197, pl. 7, figs. 1, 1a-b.
Sphenodiscus pleurisepta (Conrad). Böse, 1928, p. 304, pl. 17, figs. 2-5; Wolleben, 1977, p. 392, pl. 3, fig. 24; Kennedy and Cobban, 1993b, p. 58, figs. 1a-c, 2, 3t (with additional synonymy); Cobban and Kennedy, 1995, p. 12, fig. 8.5 (with full synonymy); Kennedy *et al.*, 1996, p. 11, figs. 4a, 5-12; Kennedy *et al.*, 1997, p. 9, figs. 9j, 11-14; Landman and Cobban, 2003, p. 17, figs. 12-15.
Sphenodiscus aff. *S. pleurisepta* (Conrad). Stephenson, 1941, p. 436, pl. 95, figs. 1-4.

Type. The holotype is USNM 9888, which is the specimen of Conrad (1857, p. 159, pl. 15, fig. 1) by original designation. This specimen is said to be from "Jacun, 3 miles below Laredo", although it may have been found in the Escondido Formation of the Rio Grande region in Maverick County, Texas (see Stephenson, 1941, 1955).

Description. The shell is oxycone and very involute (U/D is about 0.04) with an intermediate expansion rate. The whorl section is compressed, with WB/WH approximately 0.30. The overhanging umbilical walls bend narrowly into slightly concave inner flanks. Whorl breadth is greatest at mid-flank. The outer flanks converge towards the very narrowly rounded venter. The test is faintly ornamented with a row of bullae at mid-flank (4 to 5 per quarter whorl) and a row of weak crescent ventrolateral ribs (6 to 7 per quarter whorl). The two rows are linked by feeble ribs. The suture line is moderately incised. The E/L saddle is incised by two adventive lobes.

Material. Nine crushed fragments of phragmocones from the base of the middle member of the Cárdenas Formation in the Arroyo de la Atarjea and at the railway section near Cárdenas, one fragment from the Tanque Formation south of Reata, Coahuila, ten specimens from the upper Escondido Formation at Cuevas Creek near Eagle Pass, Texas.

Dimensions	D	WB	WH	WB/WH	U	U/D
IMG 8667	-	8.6	31.9	0.27	-	-
CT MUDE 117	-	17.6	38.8	0.45	-	-
UKRG EP 4	74.8	(14.3)	40.2	(0.36)	4.1	0.05
IMG 8668	85.5	16.2	47.8	0.34	2.9	0.03
UKRG EP 2	113.4	(22.7)	61.7	(0.37)	4.8	0.04
UKRG EP 6	116.7	25.3	68.8	0.37	3.1	0.03

Occurrence. This Maastrichtian species is common to abundant in the Cárdenas and Escondido Formations in Trans-Pecos, Texas, and northeastern Mexico (Böse, 1928; Stephenson, 1941, 1955). It was also described from northeastern Texas (Kennedy and Cobban, 1993b), Mississippi and Alabama, Missouri (Stephenson, 1955), Tennessee (Kennedy and Cobban, 2000), and Maryland (Kennedy *et al.*, 1997). In the Western Interior, this species was recorded from the *Baculites clinolobatus* to *Jeletzkytes nebrascensis* ammonite zones (*e.g.*, Kennedy *et al.*, 1996; Landman and Cobban, 2003).

Discussion. *Sphenodiscus pleurisepta* differs from the almost smooth *S. lobatus* by its stronger ornamentation. It differs from *Coahuilites sheltoni* Böse by a narrower whorl section (smaller WB/WH ratio) and a much more acute venter at comparable diameters.

Genus *Coahuilites* Böse, 1928

Type species. *Coahuilites sheltoni* Böse, 1928, p. 283, pl. 13, fig. 7, by original designation.

Coahuilites sheltoni **Böse, 1928**

Figures 5f-g, 8e-g, k-m, 9a-c

Coahuilites sheltoni Böse, 1928, p. 283, pl. 13, figs. 4-11. Wolleben, 1977, p. 390, pl. 3, fig. 20; Cobban and Kennedy, 1995, p. 12, figs. 2.8-2.9, 7.1, 8.1-8.3 (with full synonymy);

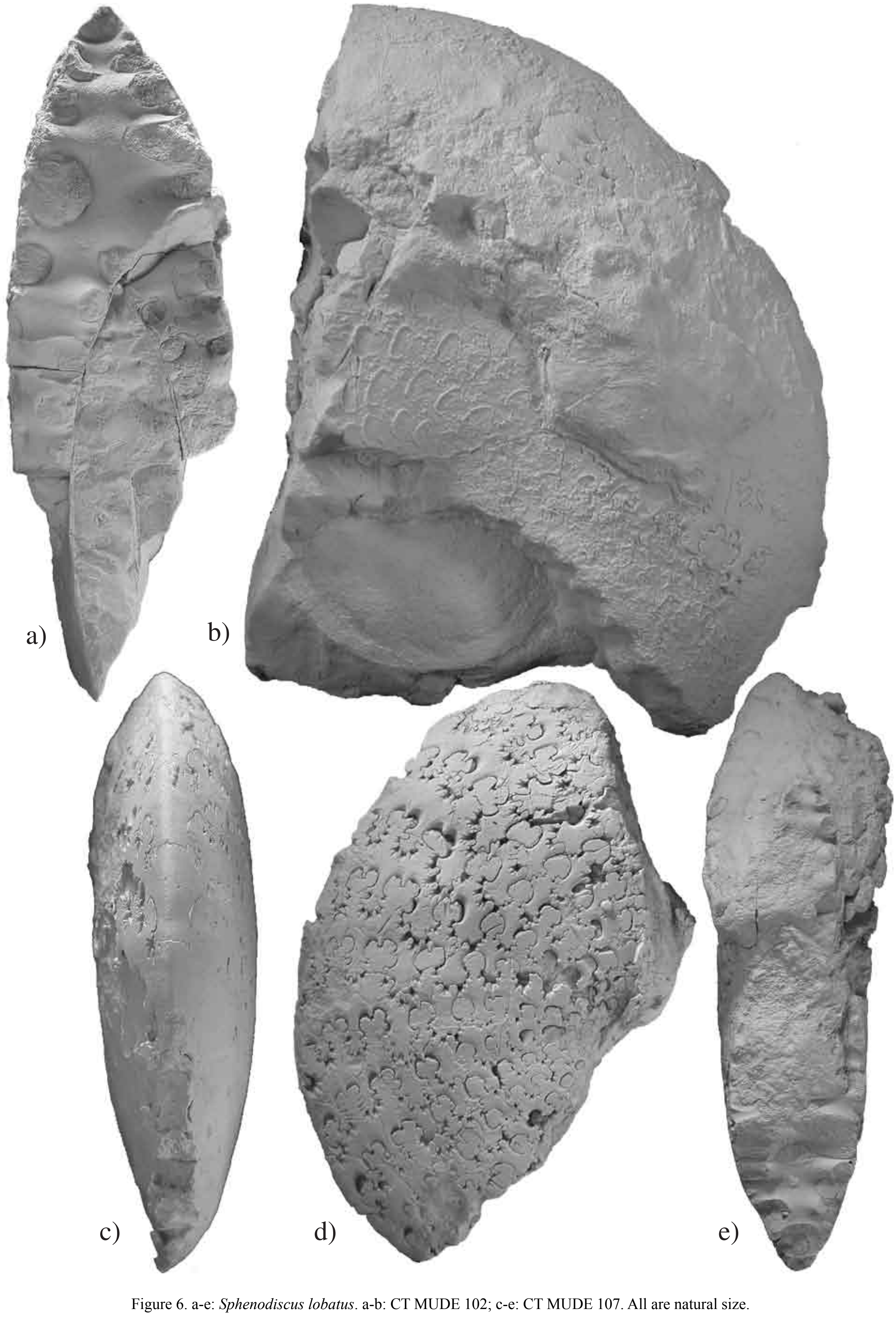

Figure 6. a-e: *Sphenodiscus lobatus*. a-b: CT MUDE 102; c-e: CT MUDE 107. All are natural size.

Kennedy *et al.*, 1996, p. 6, figs. 2, 3, 4b; Landman and Cobban, 2003, p. 13, text-figs. 7-10.
Coahuilites orynskii Böse, 1928, p. 287, pl. 14, figs. 1-3.
Coahuilites cavinsi Böse, 1928, p. 290, pl. 14, figs. 4-8.

Type. The holotype, by original designation, is the original of Böse, 1928, pl. 13, fig. 7. It comes from the Escondido Formation, 5 km south of Alamo Viejo near Villa de Juárez, Coahuila, Mexico.

Description. The shell is involute and compressed. The steep umbilical wall bends narrowly into subparallel flanks. When juvenile, ventrolateral shoulders are widely rounded and the venter fastigiate, whereas during later ontogenetic stages ventrolateral shoulders are more narrowly rounded, and the venter is flattened. The greatest breadth is at mid-flank. There are seven to eight tubercles at mid-flank which are strong and slightly bullate. They give rise to low, flat, falcoid ribs which link the inner tubercles to an outer row of strong, conical tubercles on the ventrolateral shoulders. The venter is smooth. The suture line is moderately incised and becomes more simple towards the umbilicus. The broad E/L is moderately incised, and subdivided by two adventive lobes. L/U2 with minor incision. Ventralmost saddles of auxiliaries are moderately incised, dorsal ones are entire.

Material. One specimen from the Potrerillos Formation near Mina, N.L., one from Saltillo, Coahuila, two fragments from basal middle member of the Cárdenas Formation at the railway section east of Cárdenas.

Dimensions	D	WB	WH	WB/WH	U	U/D
CT MUDE 106	60.5	11.9	29.3	0.41	3.8	0.06
IMG 8669	-	14.5	-	-	-	-
IMG 8670	-	17.6	-	-	-	-
CT MUDE 115	85.7	(25.0)	47.1	(0.53)	4.2	0.05
CT MUDE 116	116.1	(31.0)	64.2	(0.48)	5.7	0.05

Occurrence. Where properly dated, the species is Maastrichtian in age. Records are from Mississippi and Alabama (Cobban and Kennedy, 1995), the Escondido Formation of northern Mexico and Trans-Pecos, Texas (Böse, 1928), the Western Interior of Colorado and Wyoming (*Hoploscaphites birkelundi* and *Baculites clinolobatus* zone; Landman and Cobban, 2003), and now from the Cárdenas and Potrerillos Formations of northeastern Mexico.

Discussion. We agree with Cooper (1970), and Cobban and Kennedy (1995) and regard *C. orynskii* and *C. cavinsi*, also designated by Böse (1928), as synonyms of *C. sheltoni*.

Suborder Ancyloceratina Wiedmann, 1966
Superfamily Turrilitaceae Gill, 1871
Family Baculitidae Gill, 1871
Genus *Baculites* Lamarck, 1799

= *Homaloceratites* Hupsch, 1768, p. 110 (*nom. binom.*); *Euhomaloceras* Spath, 1926, p. 80

Type species. *Baculites vertebralis* Lamarck (1801, p. 103) by subsequent designation of Meek (1876, p. 391).

***Baculites ovatus* Say, 1820**
Figures 5i-j, 9d-l

Baculites ovata Say, 1820, p. 41
Baculites ovatus Say. Cobban, 1974, p. 3, pl. 1, figs. 1-32, pl. 2, figs. 1-14, pl. 3, figs. 1-6, 9-11, Figure 4 (with full synonymy); Wolleben, 1977, p. 389, pl. 3, fig. 22; Kennedy and Cobban, 1993a, p. 426, text-figs. 12.3-4, 14.5, 14.12, 14.15-17, 14.20, 14.22-42, 15.1-12, 15.14-24; Vega *et al.*, 1995, p. 347; Ifrim *et al.*, 2004, pl. 3, figs. 1-3; text-figs. 11a-e, 12a-d.
?Baculites ovatus Say. Vega-Vera and Perrilliat, 1990, p. 19, pl. 4, figs. 1-2.

Type. The holotype, by original designation of Say (1820, p. 41), was recorded at the Academy of Natural Sciences, Philadelphia. According to Cobban (1974, p. 4), it may be lost.

Description. Straight phragmocone with moderate expansion rate and ovate whorl section. The dorsum is widely rounded to flattened and passes into more or less widely rounded shoulders. Convex flanks converge towards the venter which is also rounded. Where shell is preserved, faint crescent ribs are observed dorsolaterally. Suture line with broad, moderately incised, subquadrate to moderately rounded bifid saddles and lobes with phylloid terminations. Distance between sutures varies from overlapping to full separation of lobe lines.

Material. Six fragments from the Potrerillos Formation, 5 km north of Minas, N.L.

Dimensions	WB	WH	WB/WH	L
CT MUDE 111	22.5	33.2	0.68	-
CT MUDE 112	25.1	37.5	0.67	-
CT MUDE 113	29.8	37.9	0.79	33
	31.2	41.0	0.76	

Occurrence. Baculites ovatus has been recorded from the Late Campanian of the basal Navesinsk Formation in New Jersey (Cobban, 1974) and the Saratoga Chalk in Arkansas (Kennedy and Cobban, 1993a). In Mexico, it was described from the Maastrichtian part of the Potrerillos Formation in the La Popa Basin (Wolleben, 1977; Vega *et al.*, 1995, but only listed), and the Early Maastrichtian of the Méndez Formation (Ifrim *et al.*, 2004).

Discussion. The ovate whorl section and weak ornamentation are characteristic of this species.

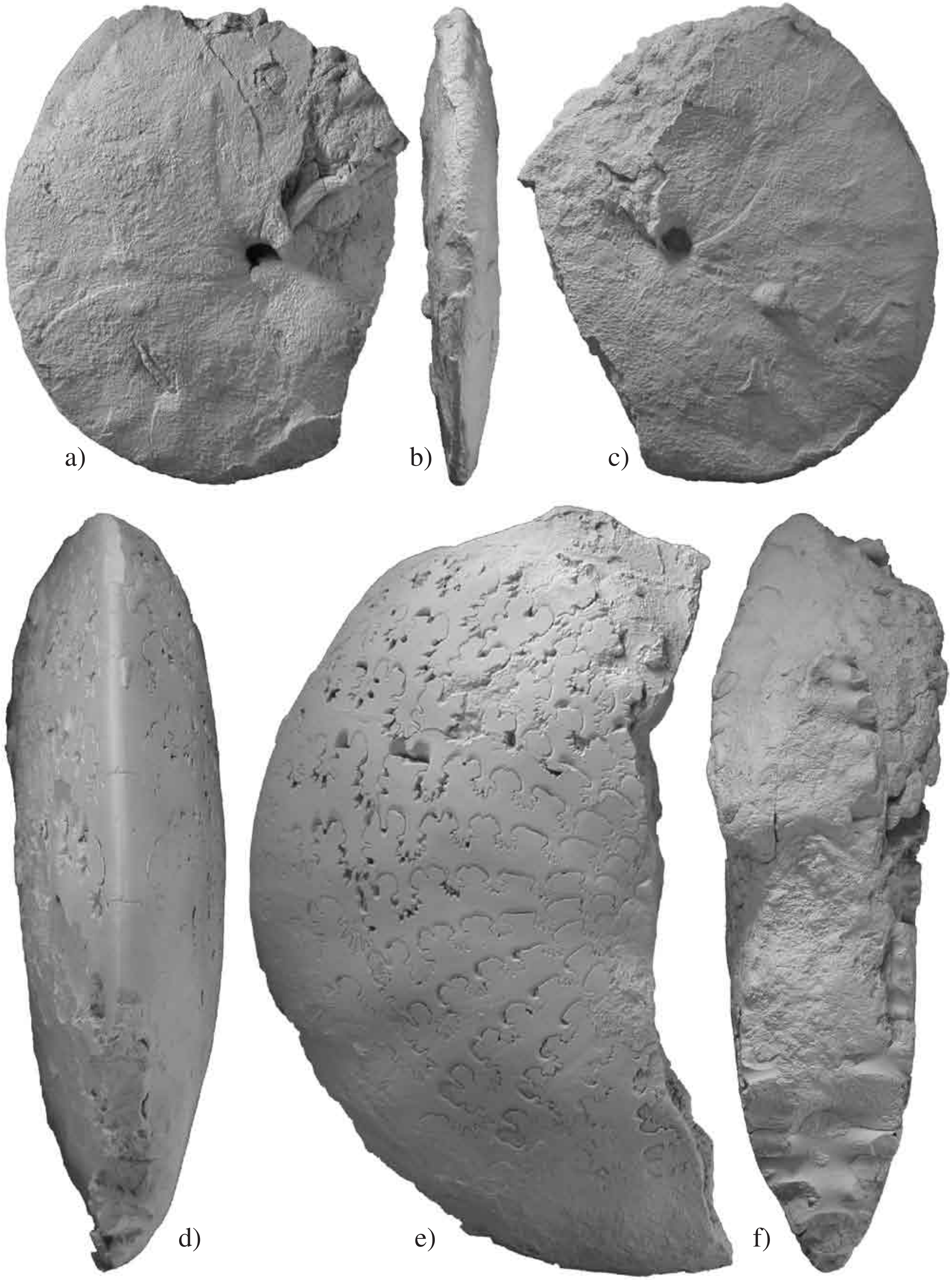

Figure 7. a-c: *Sphenodiscus pleurisepta*, IMG 8668; d-f: *Sphenodiscus lobatus*, CT MUDE 110. All are natural size.

AGE OF THE AMMONITE ASSEMBLAGES

At present, it is extremely difficult to subdivide the uppermost Cretaceous shallow water units in northeastern Mexico other than by lithostratigraphy and sequence stratigraphy. Biostratigraphical index fossils such as planktic or large benthic foraminifera are extremely rare in the shallow water and marginally marine deltaic Difunta Group, the Escondido and Cárdenas Formations. Their invertebrate fossil assemblages are dominated by bivalves and gastropods with imprecise stratigraphic ranges, which are highly dependant on changes in facies. In consequence, correlation to well-dated coeval open marine deposits (*e.g.*, the Méndez Formation) is tentative at most. Under these circumstances, ammonites, although rare and little diverse, are important to assign a Maastrichtian age to the sediments and further subdivide the sequence.

Stratigraphy of sphenodiscids

The stratigraphy of sphenodiscids was first studied by Böse (1928) who suggested the following zonation for the Maastrichtian of northeastern Mexico on the base of ammonite ranges from the Escondido Formation (for synonymy see systematic descriptions):
Sphenodiscus pleurisepta (youngest)
Coahuilites cavinsi
Sphenodiscus intermedius
Sphenodiscus lenticularis
Coahuilites sheltoni (oldest).

Cooper (1970, 1971) reduced the zones of Böse to three, due to synonyms of species names and erratic order of zones:
Sphenodiscus pleurisepta (youngest)
Coahuilites sheltoni
Sphenodiscus intermedius (oldest).

However, in the Early Maastrichtian of the Western Interior, the three species co-occur, contrasting with their separate occurrences in the Escondido Formation. For instance, in the Early Maastrichtian of Colorado and Wyoming (Kennedy *et al.*, 1996; Landman and Cobban, 2003), the stratigraphic ranges of *Sphenodiscus lobatus*, *S. pleurisepta*, and *Coahuilites sheltoni* appear to overlap in the Early Maastrichtian (Figure 3), although no outcrop is known to us in North America where the two *Sphenodiscus* species co-occur in the same locality, and none can be identified with certainty in the current literature. For instance, in our material of the Difunta Group and the Cárdenas Formation, both *S. lobatus* and *S. pleurisepta* co-occur with the rare *Coahuilites sheltoni*, but we never identified the two *Sphenodiscus* species in one sediment layer or even outcrop.

Therefore, it appears to us that the two species of *Sphenodiscus* exclude each other, and that their different levels of stratigraphic occurrence in the Escondido Formation reflect environmental preferences, rather than to correspond to species ranges. In consequence, the sphenodiscid zonation established by Cooper (1970, 1971) is certainly useful within the Escondido Formation, but it cannot be fully applied to other Maastrichtian outcrop areas. Sphenodiscid ranges in the United States Western Interior may also not correspond to full species ranges. In this region, Early Maastrichtian marine sediments containing ammonites grade into terrestrial sediments without ammonites (Figure 3; Walaszczyk *et al.*, 2001).

Age of the ammonites from the Cárdenas Formation

In the railway section east of Cárdenas, the base of the middle member of the Cárdenas Formation has been dated Late Campanian by Caus *et al.* (2002), based on the stratigraphic range of the Tethyan benthic foraminifer *Lepidorbitoides minima*. However, the presence of the planktic foraminifera *Gansserina gansseri* and *Globotruncana linneiana* in the sediments at Arroyo de la Atarjea indicate an Early Maastrichtian age for the middle member of the Cárdenas Formation. Our ammonites from the same outcrop and from coeval sediments in the railway section correspond to the latter interpretation, for instance, our specimen of *Pachydiscus* (*P.*) *neubergicus*. This species is generally used to define the base of the Maastrichtian (Christensen *et al.*, 2000; Odin and Lamaurelle, 2001). *Sphenodiscus pleurisepta* and *Coahuilites sheltoni* also occur in the railway section east of Cárdenas. Through comparison with Western Interior sphenodiscid occurrences, we know that this member of the Cárdenas Formation cannot be older than the *Baculites clinolobatus* zone which is Early Maastrichtian in age. We therefore assign an Early Maastrichtian age to the basal Middle Member of the Cárdenas Formation.

DIFFERENCES IN NORTHEAST MEXICAN AMMONITE FAUNAS

The diverse ammonite assemblage known from the open marine Méndez Formation differs strongly from faunas from the Difunta Group, and the Escondido and Cárdenas Formations, although they are coeval. Among the 18 Cerralvo genera, there are ammonoid groups which are mainly known from open marine facies (*e.g.*, Hewitt and Westermann, 1987; Wiese, 1995), such as Lytoceratina (*Tetragonites*, *Saghalinites*, *Pseudophyllites*) and Phylloceratina (*Hypophylloceras* and *Phyllopachyceras*). Species considered to be generalists are also present, such as *Diplomoceras cylindraceum* (Defrance, 1816), *Phyllopachyceras forbesianum* (d'Orbigny, 1850), and *Pseudophyllites indra* (Forbes, 1846). These species occur worldwide throughout all facies and climatic zones, including the Méndez Formation (Ifrim *et al.*, 2004), but are absent in the Mexican coastal sediment basins. Faunas in the latter areas are dominated by *Sphenodiscus*, considered to be a typical shallow water

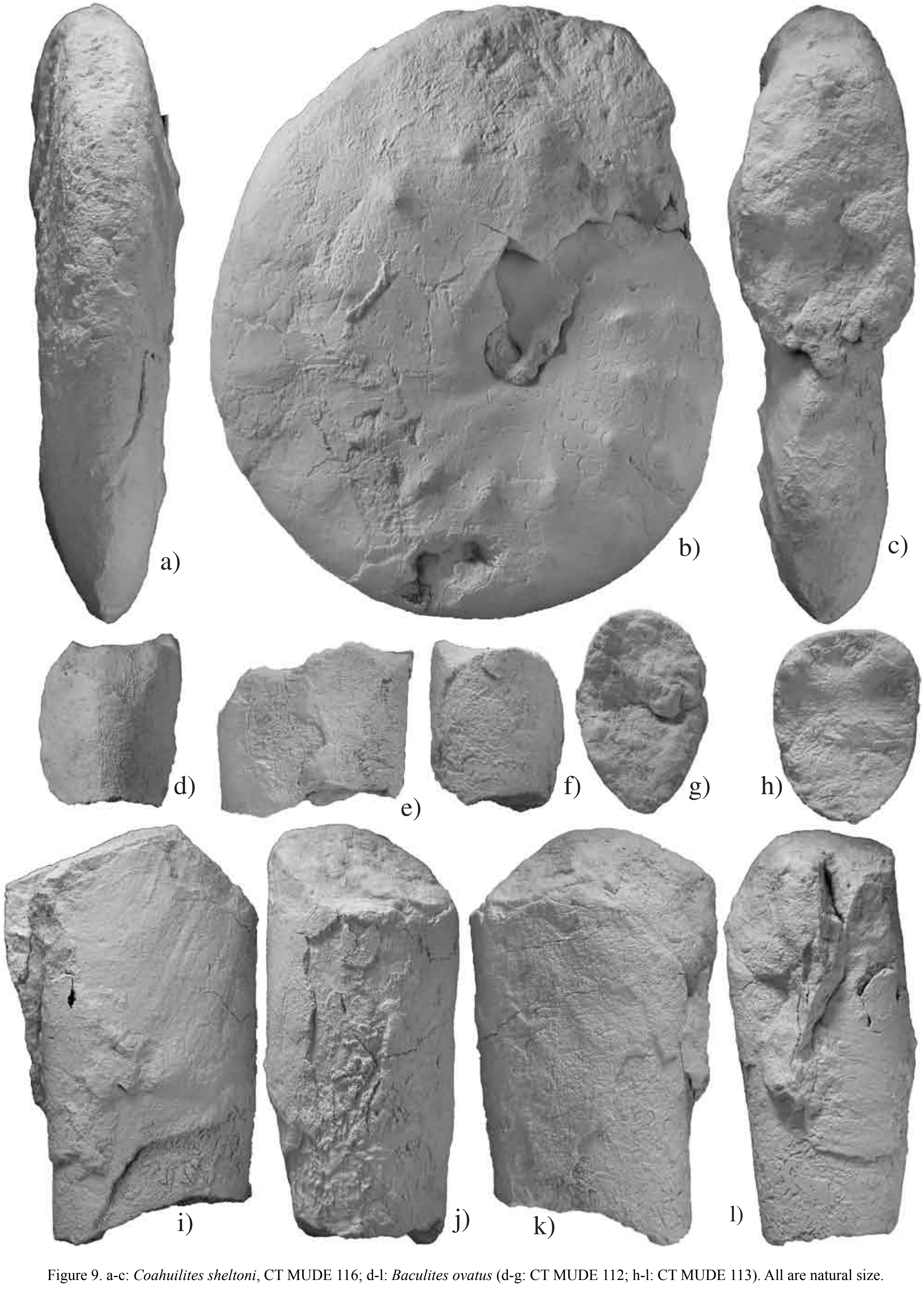

Figure 9. a-c: *Coahuilites sheltoni*, CT MUDE 116; d-l: *Baculites ovatus* (d-g: CT MUDE 112; h-l: CT MUDE 113). All are natural size.

genus (Bayer and McGhee, 1984; Jacobs and Chamberlain, 1996). All other species (*e.g.*, *Coahuilites sheltoni* Böse, 1928) are represented only by few individuals. No ammonites other than sphenodiscids have been recorded from the NE-Mexican coastal basins, with the exception of *Baculites ovatus* Say, 1820 and a single specimen of *Pachydiscus* (*P.*) *neubergicus* (Hauer, 1858). In consequence, even the generalists are absent. The shallow water and coastal environments were not favorable for the majority of ammonite species. The variable lithologies of the Difunta Group (for details see Weidie and Murray, 1967; McBride *et al.*, 1974) suggest frequent changes in temperature, salinity, current directions, or sedimentary input which affected the stability of these environments and excluded species that could not tolerate these changes. This led to specialized faunas which were rich in individuals but low in diversity. On the other hand, all the species recorded from the Difunta Group, Cárdenas and Escondido Formations are known from other North American Maastrichtian outcrops, namely in the Gulf Coast, the Western Interior, and along the Atlantic coast. These ammonites were able to live under the exceptional conditions in coastal shallow water environments, but they were not restricted to them.

CONCLUSIONS

The ammonite species presented here represent the last ammonites in the coastal basins of northeastern Mexico. They are Maastrichtian in age in the Cárdenas Formation and Difunta Group. *Sphenodiscus pleurisepta* may have ranged into the Late Maastrichtian. Comparison to Western Interior species ranges reveals that the biostratigraphy established for the Escondido Formation (Cooper, 1970, 1971) cannot be applied to other Maastrichtian units in the Gulf of Mexico area.

Sphenodiscus and *Coahuilites* are clearly shallow water genera and dominate the assemblages in the coastal sedimentary basins of northeastern Mexico. Open marine species, on the other hand, are very rare (*Pachydiscus*) or generally absent (*Phylloceratina* and *Lytoceratina*), but occur in the coeval open marine Méndez Formation. Differences in diversity between the Cerralvo ammonite assemblage and sphenodiscid-dominated faunas from the Difunta Group, Cárdenas and Escondido Formations are thus clearly related to paleobathymetry, *i.e.*, the shallow-water assemblages are very low in diversity and represent specialization to an environment in which ammonoids could not easily survive.

ACKNOWLEDGMENTS

We are greatly indebted to John D. Cooper for showing us around the Eagle Pass area and the Escondido Formation in southern Texas. We also thank José Guadalupe López Oliva, Arturo González González, and Stefan Götz for discussions on the geology and fossil invertebrate fauna of northeastern Mexico. The Facultad de Ciencias de la Tierra of the Universidad Autónoma de Nuevo León, Linares, and the Museo del Desierto de Coahuila, Saltillo, offered logistical and technical support, and the Instituto Nacional de Antropología y Historia in Mexico City kindly authorized sampling and temporal expedition of the fossil material. Research was supported by the Deutsche Forschungsgemeinschaft grants STI 128/7 and STI 128/9.

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Manuscript received: January 2, 2004
Corrected manuscript received: September 1, 2004
Manuscript accepted: September 12, 2004