

Upper Jurassic ammonites and bivalves from the Cucurpe Formation, Sonora (Mexico)

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ABSTRACT

Four new molluscan assemblages from north-central Sonora indicate that the Cucurpe Formation ranges in age from late Oxfordian to early Tithonian. These assemblages extend the known paleogeographic range of Late Jurassic Tethyan fossil groups several hundred km to the northwest and improve correlation of Upper Jurassic strata in northern Mexico. At Rancho La Colgada, near the town of Tuape, the upper part of the Cucurpe Formation consists of 515 m of shale, siltstone, basaltic flows and minor sandstone. The oldest fossil assemblage is assigned to the Bifurcatus Zone of the lower upper Oxfordian and contains the ammonites *Perisphinctes* (*Dichotomoceras*?) sp., *Sequeirosia*? sp., and the bivalves *Grammatodon* (*Grammatodon*) *hersilius* (d'Orbigny), *Parainoceramus* sp., "*Lucina*" *potosina* Aguilera, "*Lucina*" sp., and *Isocyprina*? sp. The second assemblage is assigned to the lower Tithonian (lower part of the Albertinum/Darwini Zone) and consists of the ammonites *Mazapilites mexicanus* (Aguilera), *Schaireria neoburgensis* (Oppel), *Subplanitoides* sp., and *Glochiceras* (*Lingulaticeras*?) sp. The third fossil assemblage from the uppermost part of the section includes the ammonites *Sublithacoceras* cf. *sphinctum* (Schneid), *Sublithacoceras* sp., and *Pachysphinctes* sp., and the bivalves "*Lucina*" *potosina* Aguilera and *Integricardium* (*Integricardium*) sp. This assemblage belongs to the Semiforme-Verruciferum Zone to Richteri Zone of the middle lower Tithonian. A fourth assemblage is assigned to the lower Tithonian, representing the middle to upper part of the Albertinum-Darwini or the lowermost part of the Semiforme-Verruciferum Zone. This assemblage was collected from the upper part of the Cucurpe Formation at a nearby locality and contains the ammonites *Torquatisphinctes subbleicheri* (Burckhardt), *T.* cf. *lauri* (Aguilera) and *Torquatisphinctes* sp. cf. *T. diversocostatus* (Burckhardt). The absence of Kimmeridgian fossils in the measured section at Rancho La Colgada and a conglomerate between the Oxfordian and Tithonian assemblages combine to indicate an unconformity in the Upper Jurassic interval that omits the Kimmeridgian. A single Kimmeridgian ammonite was recently collected in the Cucurpe Formation about 40 km northwest of the study area.

The reported molluscan fossils have close affinities with Tethyan faunas known from other parts of Mexico, Cuba and western Europe. These affinities indicate a possible connection of these regions with Sonora through the young Central Atlantic Ocean and possible faunal dispersal from east to west; however, eastward dispersal across the paleo-Pacific realm is also a possibility. Some endemic species, such as *Mazapilites mexicanum* and "*Lucina*" *potosina* in Sonora permit correlation with other areas of north-central Mexico and indicate a marine connection throughout the region during the Late Jurassic.

Key words: ammonites, bivalves, Biostratigraphy, Upper Jurassic, Sonora, Mexico.

RESUMEN

Se estudia la fauna de ammonites y bivalvos del Jurásico Superior de la sección Rancho La Colgada que aflora en la región de Tuape, Sonora, y que corresponde a la parte superior de la Formación Cucurpe. El análisis sistemático de los ammonites y bivalvos permitió el reconocimiento de cuatro asociaciones faunísticas. La más antigua se asignó a la Zona *Bifurcatus* del Oxfordiano superior y está caracterizada por los ammonites *Perisphinctes* (*Dichotomoceras*?) sp., *Sequeirosia*? sp., y los bivalvos *Grammatodon* (*Grammatodon*) *hersilius* (d'Orbigny), *Parainoceramus* sp., "*Lucina*" *potosina* Aguilera, "*Lucina*" sp., e *Isocyprina*? sp. La segunda asociación es de edad Tithoniana temprana (parte inferior de la Zona *Albertinum*/*Darwin*) y contiene exclusivamente ammonites: *Mazapilites mexicanus* (Aguilera), *Schaireria neoburgensis* (Oppel), *Subplanitoides* sp., y *Glochiceras* (*Lingulaticeras*?) sp. La tercera asociación reconocida en la parte más superior de la sección estudiada incluye los ammonites *Sublithacoceras* cf. *sphinctum* (Schneid), *Sublithacoceras* sp. y *Pachysphinctes* sp., así como los bivalvos "*Lucina*" *potosina* Aguilera e *Integricardium* (*Integricardium*) sp. A esta asociación se le asigna una edad correspondiente al intervalo de Zona *Semiforme-Verruciferum* a Zona *Richteri*, parte media del Tithoniano temprano. La cuarta asociación reconocida, proveniente de una localidad cercana, está constituida por los ammonites *Torquatisphinctes subbleicheri* (Burckhardt), *T. cf. lauri* (Aguilera) y *Torquatisphinctes* sp. cf. *T. diversecostatus* (Burckhardt), cuya edad es Tithoniano temprano, parte media a alta de la Zona *Albertinum-Darwini* o parte más inferior de la Zona *Semiforme-Verruciferum*.

Los moluscos fósiles encontrados tienen gran afinidad con las faunas del *Tethys* conocidas en otras partes de México, Cuba y Europa Occidental. Estas afinidades indican una posible conexión de esas regiones con Sonora a través del proto-oceano Atlántico Central y una posible dispersión del este al oeste, sin descartar otras posibilidades. Algunas especies endémicas, como *Mazapilites mexicanum* y "*Lucina*" *potosina* de Sonora posibilitan las correlaciones con otras áreas del centro-norte de México, e indican una conexión marina en la región durante el Jurásico tardío.

Palabras clave: ammonites, bivalvos, Bioestratigrafía, Jurásico Superior, Sonora, México.

INTRODUCTION

Upper Jurassic rocks in north-central Sonora include a thick volcano-sedimentary succession near the towns of Cucurpe and Tuape (Figure 1). The first report of this succession, which is locally metamorphosed, was published by Rangin (1977) from Rancho La Colgada, located ~7 km north of Tuape. He reported an incomplete section, "several hundred meters thick" of black and red shale, volcanoclastic rocks and interbedded andesitic flows. Rangin assigned the section to the upper Oxfordian on the basis of ammonites identified as *Perisphinctes* (*Discosphinctes*) cf. *P. (D.) caribeanus* (Jaworski), *P. (Dichotomosphinctes)* cf. *P. (D.) lagunitaensis* (Burckhardt), and *P. (D.) cf. P. (D.) plicatilis* (d'Orbigny). From the same area, Imlay (1980) identified the ammonites *Dichotomosphinctes* and *Discosphinctes* of late Oxfordian age. Araujo-Mendieta and Estavillo-González (1987) assigned strata at nearby El Venado, ~5 km northwest of Rancho La Colgada (Figure 1), to the Cucurpe Formation, and designated this locality as the type section for the formation (northeast corner of the Tuape, Sonora, 1:50,000 quadrangle, H12B81). The type section is structurally complex and incomplete, consisting of 161 m of tuffaceous sandstone, sandstone and siltstone with the late Oxfordian ammonites *Perisphinctes* (*Arisphinctes*) cf. *albeari*, *P. (Dichotomosphinctes)* sp., *P. (Discosphinctes)* cf.

P. (D.) caribeanus, *Perisphinctes* (*Arisphinctes*) cf. *P. (A.) poeyi* and *Perisphinctes* (*Dichotomosphinctes*) cf. *P. (D.) plicatilis* (Araujo-Mendieta and Estavillo-González, 1987). Rodríguez-Castañeda (1984, 1988, 1990) assigned similar rocks of this area to his informal units A and B and reported the ammonites *Perisphinctes* (*Dichotomosphinctes*) cf. *lagunitaensis* (Burckhardt) and *P. (D.) caribeanus* (Jaworski) from unit B. Subsequently, Rodríguez-Castañeda (1991) renamed these Jurassic strata the La Colgada Formation. We refer to these Upper Jurassic strata of the Cucurpe-Tuape region as the Cucurpe Formation, following the rule of priority in the North American Stratigraphic Code (NACSN, 1983).

As part of a major project on the stratigraphy, paleontology, and tectonic significance of the Upper Jurassic rocks of north-central Sonora, the section located at Rancho La Colgada, corresponding to the upper part of the Cucurpe Formation, was mapped and measured (Figures 2 and 3). The Cucurpe Formation is a very thick, deformed succession whose middle and lower parts are exposed at other nearby localities. The present work reports on the stratigraphy and a significant fauna of Oxfordian and Tithonian ammonites and bivalves that were collected from this measured section. Selected specimens are illustrated, and the paleobiogeographic affinities of the molluscan fauna are analyzed.

STRATIGRAPHY

Our measured section at Rancho La Colgada corresponds to the upper part of the Cucurpe Formation. The base of the formation is not exposed near Rancho La Colgada. The Cucurpe Formation is unconformably overlain by a shallow marine clastic succession of uncertain, but possibly Early Cretaceous, age (Rancho La Colgada Formation, González-León *et al.*, 2001). The Rancho La Colgada Formation is gradationally overlain by the Morita Formation and overlying units of the Bisbee Group. The Cucurpe Formation at Rancho La Colgada was deposited in a marine basin (the Altar-Cucurpe sub-basin of the Border rift system, Lawton *et al.*, 2003) that received a considerable amount of sedimentary and volcanic material, including ash fall tuffs and volcanic flows of basaltic composition during the Late Jurassic. We infer a basinal marine setting for this succession, deposited during the early stages of rifting.

The Cucurpe section at Rancho La Colgada is folded, but detailed mapping permitted us to construct a stratigraphic column along the transect indicated in Figure 2. The lowermost 515 m of this section corresponds to the Cucurpe

Formation (Figure 3). The basal part of the measured section consists of 110 m of massive to finely laminated, black to light gray shale with sandstone interbeds as much as 10 cm in thickness. Calcareous nodules and unidentified ammonites, belemnites and bivalves are present within the shale in the lower part of this interval. Sandstone beds are normally graded, tabular, fine grained and have local sole marks. Some sandstone beds are tuffaceous. A single 4.5-m-thick interval of fine-grained, well sorted, yellowish brown sandstone in beds less than 30 cm thick is present in the middle part of this interval.

Overlying the shale-dominated interval is a 30 m thick interval of interbedded volcanic flows and black shale in beds as much as 1.5 m thick. The volcanic flows are basaltic and as much as 15 m thick. The following bivalves, included in sample 99-107 (Figure 3) were collected from the black shale: *Grammatodon (Grammatodon) hersilius* (d'Orbigny), and "*Lucina*" *potosina* Aguilera. The basalt-dominated section is overlain by 18 m of massive to laminated black shale with uncommon thin beds (less than 10 cm thick) of siltstone.

The black shale is overlain by 10 m of volcanic flows in beds as much as 50 cm thick with uncommon thin beds of shale and fine-grained sandstone. Above this, there is a 10 m thick interval of thin-bedded, fine-grained, reddish brown sandstone and siltstone, and dark gray shale, overlain by 27 m of dark gray to dark yellowish brown, massive shale with calcareous nodules, belemnites and ammonites. Ammonites collected from the lower part of this interval (sample 4-9-02, Figure 3) include *Perisphinctes (Dichotomoceras?)* sp. and *Sequeirosia?* sp. of late Oxfordian age. Above the ammonite-bearing shale are 28 m of green basaltic flows in beds as much as 50 cm thick with interbedded tuffaceous shale, and reddish brown, pyritic siltstone. The shale contains the bivalves *Grammatodon (Grammatodon) hersilius* (d'Orbigny), *Parainoceramus* sp., "*Lucina*" *potosina* Aguilera, "*Lucina*" sp., and *Isocyprina?* sp. (sample 99-79; Figure 3). The uppermost part of this interval is composed of a distinctive 1 m thick bed of intraformational conglomerate with clasts less than 5 cm in diameter of dark shale, basalt(?) and abundant reworked ammonites, belemnites and bivalves in a matrix of calcareous siltstone. The clasts and fauna are clearly reworked intrabasinal grains and pebbles.

Above the conglomerate is a 13.5 m thick interval of interbedded moderate reddish brown siltstone, light gray tuffaceous shale and basaltic flows in beds as much as 50 cm thick. Overlying the siltstone are 27 m of interbedded fine-grained, thin-bedded sandstone and grayish brown shale with ammonites, bivalves and belemnites. The sandstone is reddish brown with local horizontal laminations. The shale is finely laminated with concretions that contain bivalves. Ammonites from the lower part of this interval (sample 4-6-10, Figure 3) include *Mazapilites mexicanus* (Aguilera), *Schaireria neoburgensis* (Oppel), *Subplanitoides* sp., and *Glochiceras (Lingulaticeras?)* sp. of early Tithonian age.

The thick ammonite-bearing shale is overlain by a

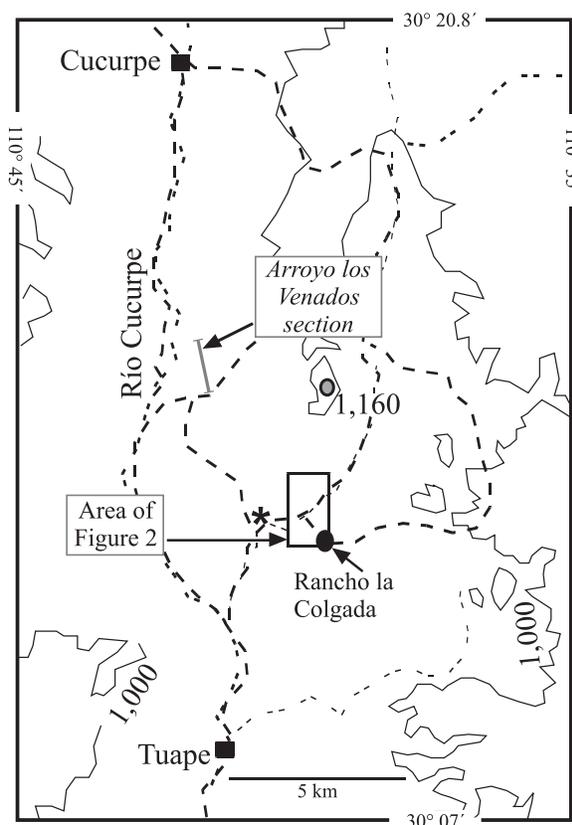


Figure 1. Map of the Tuape-Cucurpe region in north-central Sonora showing the location of measured section at El Venado, designated as the type section of the Cucurpe Formation by Araujo-Mendieta and Estavillo-González (1987). Also shown are location of detailed geologic map in Figure 2, topographic elevations in meters, dirt roads, and the Río Cucurpe. Star indicates ammonite locality in Upper Jurassic strata about two kilometers northwest of Rancho La Colgada.

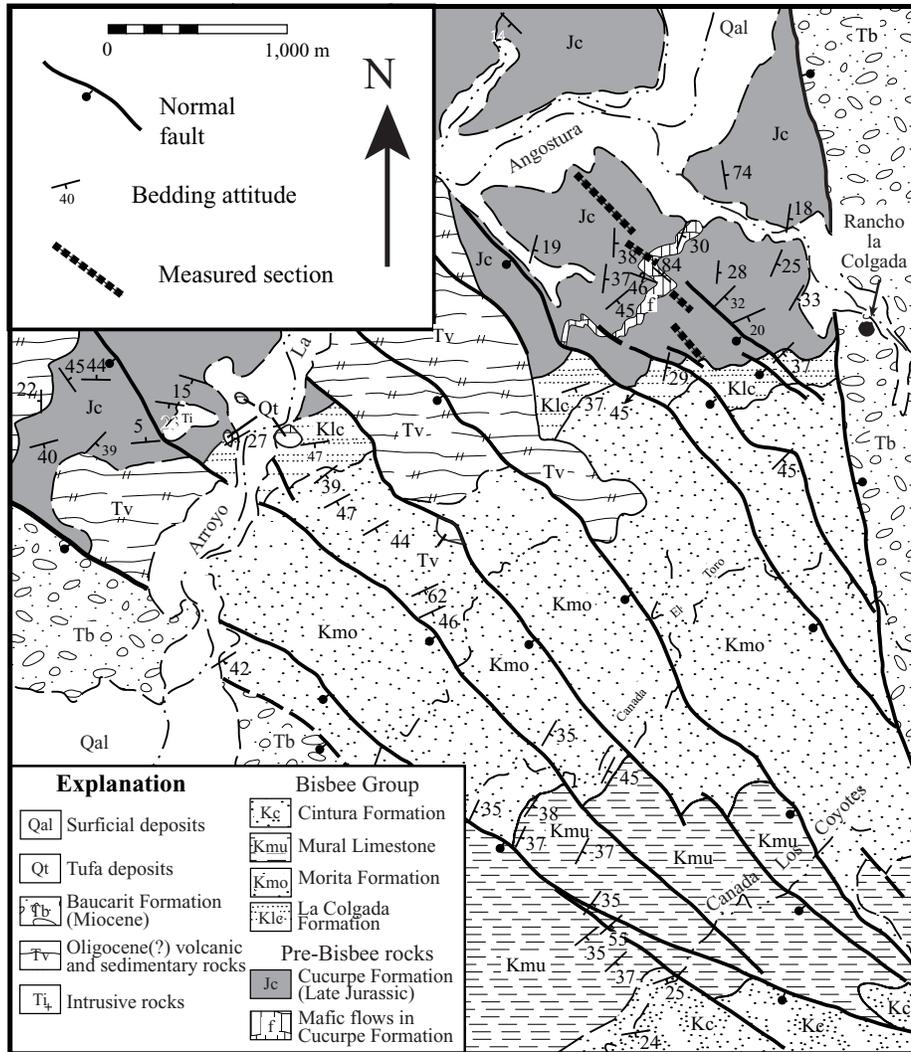


Figure 2. Geologic map of the Rancho La Colgada area in north-central Sonora and location of the measured section of Figure 3.

14 m thick interval of massive, light bluish gray shale with belemnites. Overlying the belemnite shale is a 37.5 m thick interval of basaltic flows, siltstone beds with ammonites, and massive shale with thin interbeds of parallel-laminated red siltstone. Ammonites of this interval (sample 4-6-9) include *Pseudodiscosphinctes* sp. of early Tithonian age. Above the basalt-bearing interval is gray shale, 8 m thick, with calcareous nodules of reddish, ferruginous calcareous siltstone and ammonites that include *Sublithacoceras* sp. (in sample 4-6-8) of late? early Tithonian age. The gray shale is succeeded by 36 m of light brown to pale green shale with interbeds of reddish brown siltstone and subordinate thin volcanic flows. Siltstone beds are as much as 20 cm thick and become increasingly abundant toward the upper part of the interval. Above this is a 15 m thick interval of light bluish gray shale with thin interbeds of fine-grained sandstone and volcanic flows, succeeded by 35 m of grayish red, massive shale, and 15 m of basaltic flows and interbedded shale. The uppermost part of the Cucurpe Formation

consists of 80 m of dark gray to moderate reddish brown, massive shale with ammonites, bivalves and calcareous concretions up to 30 cm in diameter. Bivalves from this interval (sample 99-113) include "*Lucina*" *potosina* Aguilera, and *Integricardium* (*Integricardium*) sp. Ammonites from the upper part of this interval (samples 99-86 and 4-6-7) are of early Tithonian age and include *Sublithacoceras* sp., *Sublithacoceras* cf. *sphinctum* (Schneid), and *Pachysphinctes* sp. (sample 4-6-7).

About 2 km west of the Rancho La Colgada section (location indicated by a star in Figure 1), we collected the following ammonites: *Torquatisphinctes subbleicheri* (Burckhardt), *T. cf. lauri* (Aguilera) and *Torquatisphinctes* sp. cf. *T. diversecostatus* (Burckhardt, 1919), of early Tithonian age.

The absence of Kimmeridgian ammonites in the measured section indicates either the presence of a hiatus where Kimmeridgian deposits are missing, or simply that Kimmeridgian fossils have not yet been found. The

ammonite-bearing intervals of late Oxfordian and early Tithonian age are separated by 60 m of shale, interbedded volcanic flows, and an intraformational conglomerate. The conglomerate contains reworked ammonites, belemnites, and bivalves. On the basis of this physical evidence, we infer the presence of an unconformity in the section that locally omits Kimmeridgian strata.

SYSTEMATIC PALEONTOLOGY

Ammonite taxonomy

Ammonites and bivalves compose the material under study. The material is housed in the Paleontologic Collection of the Estación Regional del Noroeste of the Institute of Geology, UNAM, at Hermosillo, Mexico. In the ammonite descriptions, the following abbreviations are used for measured parameters: (Dm) for the shell diameter of reference, (U) for the diameter of the umbilicus, (H) for the whorl-height, (W) for the whorl-width, (*) for approximate

values, and (++) for the diameter of the phragmocone. All measurements are expressed in millimeters. In the systematic paleontology, we follow the proposals of Arkell *et al.* (1957), Olóriz (1978), Donovan *et al.* (1981), Checa (1985), and Tavera (1985), and the proposal on the use of endings at the superfamily level expressed in the International Zoological Code (2000, p. 123).

Superfamily Haploceratoidea Zittel, 1884
 Family Oppeliidae Douvillé, 1890
 Subfamily Glochiceratidae Hyatt, 1900
 Genus *Glochiceras* Hyatt, 1900
 Subgenus *Lingulaticeras* Ziegler, 1958

Glochiceras (*Lingulaticeras*?) sp.

Figures 4a, 4b, 4c and 5a

Hypotype. ERNO 8030.

Material. A nearly complete specimen with part of the lappet is part of sample 4-6-10, collected from a 2 m thick interval of grayish brown shale in the middle part of the Cucurpe Formation (Figure 3).

Description. Platycone, strongly involute shell. Oval whorl section, higher than wide with maximum whorl-width at the middle flank. Flanks nearly flat, slightly convergent toward the rounded ventral region. Very small umbilical region, vertical umbilical wall, and rounded umbilical edge.

The inner whorls cannot be observed. The ornamentation pattern of the phragmocone is difficult to define due to erosion. A weak ornamentation composed of falcate ribs can be observed in the inner part of the body chamber (Figure 4a), which is smooth toward its outer part. The median groove is absent. The aperture shows the first part of the lappet and no rostrum is observed. The suture line (Figure 5a) is made of rectangular elements. The first lateral lobe is tripartite, deeper than the external and second lobes. The umbilical lobe is quadratic. The first lateral saddle is narrow and divided into two symmetric branches, but the second one is wider with three branches. The umbilical saddle is also divided into two nearly symmetric branches. The outermost suture lines are partially eroded.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8030	26.2	5.0	7.3	13.8	0.19	0.52

Remarks. With its nearly smooth, involute shell, the specimen could be included in the genus *Haploceras*; however, the presence of a peristome with lappet confirms its assignment to *Glochiceras*. Among the recognized subgenera, *Lingulaticeras* is closest. Because this specimen is strongly involute, our identification is preliminary.

The genus *Glochiceras* and the subgenus *Lingulati-*

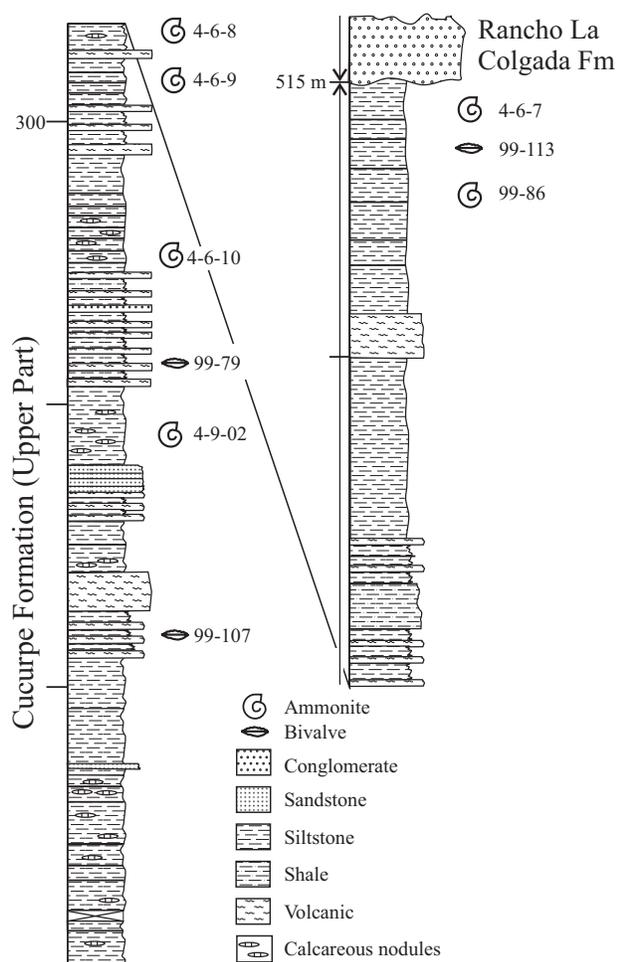
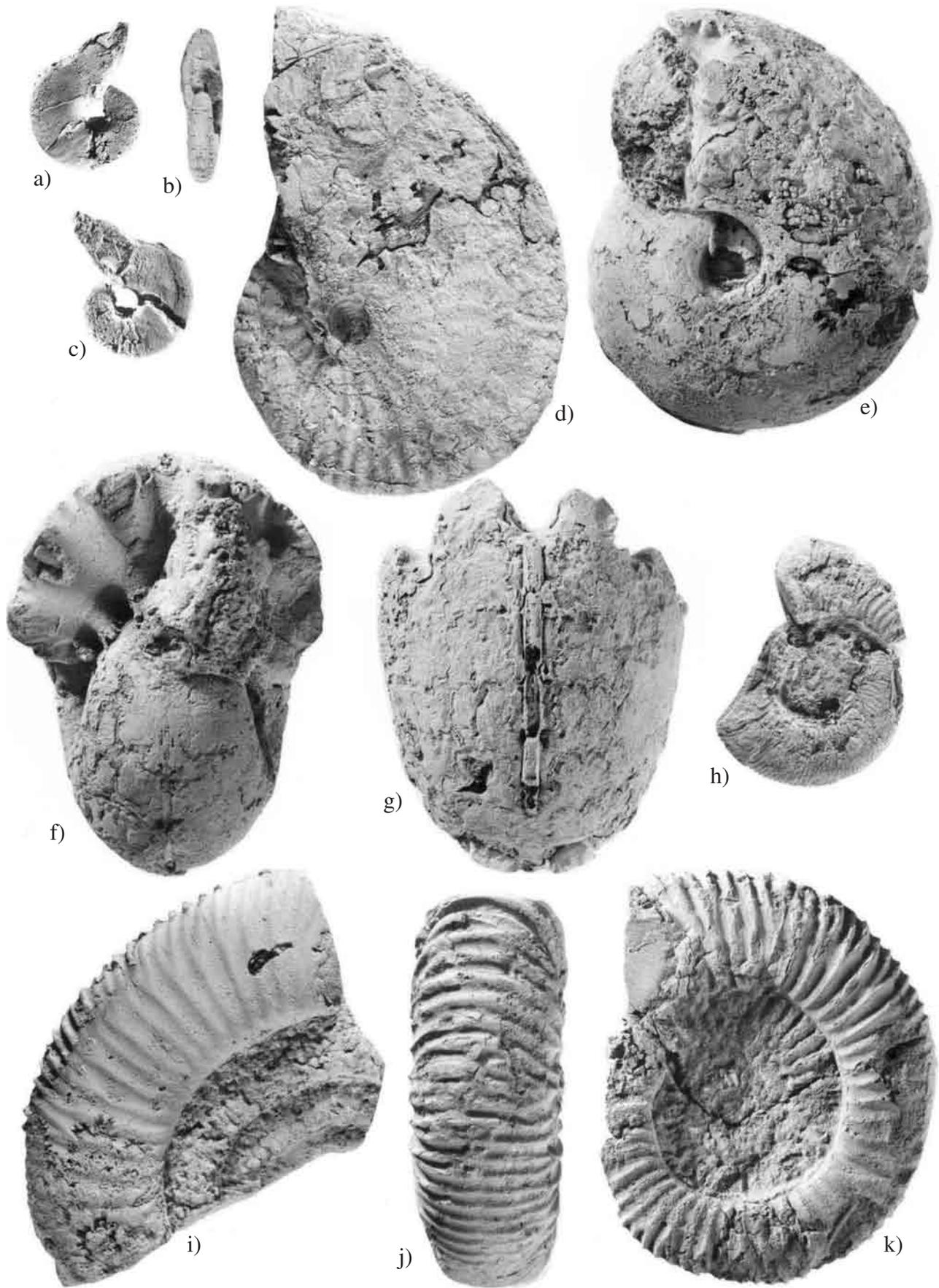


Figure 3. Measured stratigraphic section of the upper part of the Cucurpe Formation at Rancho La Colgada.



ceras have very wide stratigraphic ranges within the Late Jurassic. However, the specimen studied herein lies at the same stratigraphic level as *Mazapilites* and *Schaireria*, forms characteristic of the “*Mazapilites* Assemblage” of Villaseñor *et al.* (2000), and assigned to the lowermost part of the Albertinum/Darwin Zone of the lower Tithonian, an assignment also indicated by this study.

Subfamily Taramelliceratinae Spath, 1928
Genus *Mazapilites* Burckhardt, 1912

***Mazapilites mexicanus* (Aguilera)**

Figure 4d

Pulchellia mexicana Aguilera, in Castillo and Aguilera, 1895, p. 35, pl. 6, fig. 9, pl. 7, fig. 1.

Mazapilites mexicanus (Aguilera). Burckhardt, 1919, p. 6, pl. 3, figs. 1-3; Verma and Westermann, 1973, p. 174, pl. 26, fig. 7; Contreras *et al.*, 1991, p. 59; Olóriz *et al.*, 1999, p. 471, fig. 7f.

Hypotype. ERNO 8031.

Material. One incomplete and eroded specimen. The specimen is part of sample 4-6-10 collected from the middle part of the Cucurpe Formation (Figure 3).

Description. A partially deformed phragmocone. Platycone and involute shell. Lanceolate whorl section, with the maximum width at the middle flank. Flanks are convergent towards the ventral region, which is narrow and sharp. Very small umbilical region with vertical umbilical wall and rounded umbilical edge.

Although the shell is eroded, it possesses ornamentation typical of the genus *Mazapilites*, with strong and falcate primary ribs and some residual ones. The primary ribs are prorsiradial and divided at the middle of the flank, showing backward inflection. At the point of bifurcation, the secondary ribs are thickened and cross the ventral region without interruption.

Due to erosion, the suture line is not well defined at the maximum diameter, but at 60.06 mm it has a quadratic ventral saddle, tripartite ventral lobe, and a slim first lateral saddle.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8031	92.8	8.8	23.9	53.5	0.094	0.44

Remarks. The specimen has the same ribbing pattern as the species *mexicanus* described by Aguilera (in Castillo and Aguilera, 1895), as well as those specimens from the Sierra de Catorce in San Luis Potosí referred to *M. mexicanus* by Verma and Westermann (1973; reillustrated by Contreras *et al.*, 1991) and Olóriz *et al.* (1999). In a recent biostratigraphic revision, Villaseñor *et al.* (2000) assigned an early Tithonian age (earliest part of the Albertinum-Darwin Chron) to an ammonite assemblage with dominant *Mazapilites*. The specimen studied herein occurs with specimens of *Schaireria neoburgensis*, a typical aspidoceratid of the “*Mazapilites* assemblage” described by several authors. The specimen is assigned to the lower part of the Albertinum-Darwin Zone of the lower Tithonian.

Initially *Mazapilites* was considered endemic to Mexico, but it is now known from Cuba. Nevertheless, the genus still has a restricted geographic distribution in both areas: Sierra de Catorce, San Luis Potosí (Castillo and Aguilera, 1895, Verma and Westermann, 1973, Olóriz *et al.*, 1999); Sierra de Santa Rosa and San Matías, Zacatecas (Burckhardt, 1906, Villaseñor, 1991); San Pedro del Gallo, Durango (Burckhardt, 1919), Sierra Norte de Puebla (Hernández, 1996), all in Mexico; and Sierra de los Órganos, Cuba (Myczynski, 1989, 1994; Myczynski and Pszczotkowski, 1994).

Superfamily Perisphinctoidea Steinmann
in Steinmann and Doderlein, 1890
Family Aspidoceratidae Zittel, 1895
Subfamily Aspidoceratinae Zittel, 1895
Genus *Schaireria* Checa, 1985

***Schaireria neoburgensis* (Oppel)**

Figures 4e, 4f, 4g and 5b

Synonymy. To the long synonym list of Checa, 1985, p. 199) should be added:

Nautilus burkarti Aguilera, in Castillo and Aguilera, 1895, p. 12, pl. 21, fig. 3.

Schaireria neoburgensis (Oppel). Fözy, 1995, p. 137, pl. 20, fig. 1; Olóriz *et al.*, 1999, p. 474, fig. 7 a-c; Cecca *et al.*, 2002, p. 360, fig. 233.

Hypotypes. ERNO 8032-8035.

Material. Four specimens: three phragmocones and one revealing part of the body chamber. The specimens are part of sample 4-6-10 (Figure 3).

Figure 4. a-c: *Glochiceras* (*Lingulaticeras*?) sp. ERNO 8030 (a: left lateral view, b: frontal view, c: right lateral view showing the incipient lappet), sample 4-6-10; d: *Mazapilites mexicanus* (Aguilera) ERNO 8031, lateral view, sample 4-6-10; e-g: *Schaireria neoburgensis* (Oppel) ERNO 8032, (e: right lateral view, f: frontal view, g: ventral view), sample 4-6-10; h: *Sequeirosia*? sp. ERNO 8037, lateral view, sample 4-9-2; i: *Perisphinctes* (*Dichotomoceras*?) sp. ERNO 8036, lateral view, sample 4-9-2; j-k: *Torquatisphinctes subbleicheri* (Burckhardt). ERNO 8038 (ventral and lateral views), sample 4-6-12.

Description. Globose, involute shells, oval depressed whorl sections of kidney-form design. The flanks strongly convex and convergent toward the rounded and wide ventral region. In inner whorls the umbilical region is very small, eccentric with the growth. Wide and convex umbilical wall and rounded umbilical edge. They are smooth forms. The suture line (Figure 5b) has rectangular elements, slightly higher than wide, saddles divided and lobes with three branches; some umbilical elements are present.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8032	84.1 (72.7)	18.1	48.4	40.2	0.21	1.20
ERNO 8033	79.2	14.2	55	40.2	0.17	1.36
ERNO 8034	66.6	10.4	45	37.6	0.15	1.19
ERNO 8035	60.5	10.4	41.7	32.9	0.17	1.26

Remarks. The studied specimens are very similar to the European species (Checa, 1985, among others). The species is typical of the lower Tithonian in the Tethys area. Olóriz (1978) reported a stratigraphic range from the Hybonotum Zone to the Verruciferum Zone, with its acme from the upper part of the Hybonotum Zone to the Albertinum/Darwini Zone. This species has also been recognized in the Burekhardticeras Zone (Checa and Olóriz, 1984; Checa, 1985). Benzaggagh (1996) recognized a wider stratigraphic range from the lower Tithonian to the lowermost part of the upper Tithonian (Simplisphinctes subzone of his Microcantum Zone). In Mexico, *S. neoburgensis* was reported in lower Tithonian rocks (Semiforme/Verruciferum Zone) by Olóriz et al. (1999). Taking into account the recent chronostratigraphic proposal of Villaseñor et al. (2000), the occurrence of *Mazapilites* at the same level, and the absence of *Hybonotoceras hybonotum*, the proposed assignment is the lower part of the Albertinum-Darwini Zone.

The species has been recorded in many localities of the Mediterranean and Submediterranean provinces (Checa, 1985), as well as in Mexico and Argentina.

Family Perisphinctidae Steinman
in Steinmann and Doderlein, 1890
Subfamily Perisphinctinae Steinman
in Steinmann and Doderlein, 1890
Genus *Perisphinctes* Waagen, 1869
Subgenus *Dichotomoceras* Buckman, 1919

Perisphinctes (Dichotomoceras?) sp.
Figures 4i and 5c

Hypotype. ERNO 8036.

Material. A quarter of the shell in which part of the inner, middle and external whorls are preserved. The outermost fragment of the external whorl is part of the body chamber.

The specimen is part of sample 4-9-02 collected from the middle part of the measured section (Figure 3).

Description. The shell is serpenticone and evolute. The whorl section is quadratic-rounded. The flanks are slightly convex toward the ventral region, which is wide. The umbilical wall is vertical and wide, and the umbilical edge is rounded.

Although the preservation of the middle whorls is poor, it is possible to observe some radial and simple ribs, some of them divided above the middle flank. The outermost whorl of the specimen represents part of the phragmocone and part of the body chamber. The ornamentation consists of ribs, the primaries arise in the umbilical edge, and the point of bifurcation is located above the mid-flank. The two branches of the secondary ribs project forward. There are few simple ribs. All of the ribs curve gently forward across the ventral region without interruption.

The suture line (Figure 5c) is composed of a wide ventral saddle and a wide lateral saddle. The lateral and second saddles are asymmetrically divided, the second saddle is higher, and the third saddle is small but wide. The lobes are deep, the first is quadratic and wide, and the second is narrow and trilobate. Only one umbilical lobe can be observed; it is small and projected toward the ventral region.

Remarks. Poor preservation of this specimen precludes confident identification because the characteristic rib curve of the subgenus can not be obtained. However, the prorsiradiate ribs crossing the ventral region without interruption and forming a gentle arc are characters typical of the subgenus *Dichotomoceras*.

The subgenus *Dichotomoceras* is typical of the Bifurcatus Chron in Europe. Gygi and Hillebrandt (1991) have reported this genus from the Bifurcatus Chron of the Cordillera Domeyco in Chile. Thus the probable age of this specimen is late Oxfordian.

Subfamily Passendorferiinae Meléndez, 1989
Genus *Sequeirosia* Meléndez, 1989

Sequeirosia? sp.
Figure 4h

Hypotype. ERNO 8037.

Material. One small and poorly preserved fragment with part of the middle whorls. The specimen is part of sample 4-9-02 (Figure 3).

Description. Serpenticone, evolute shell, rounded whorl section, wide and vertical umbilical wall, and rounded umbilical edge. The middle whorls have fine and dense prorsiradiate ribs arising in the umbilical edge. Due to poor preservation, it is impossible to confirm the bifurcation of

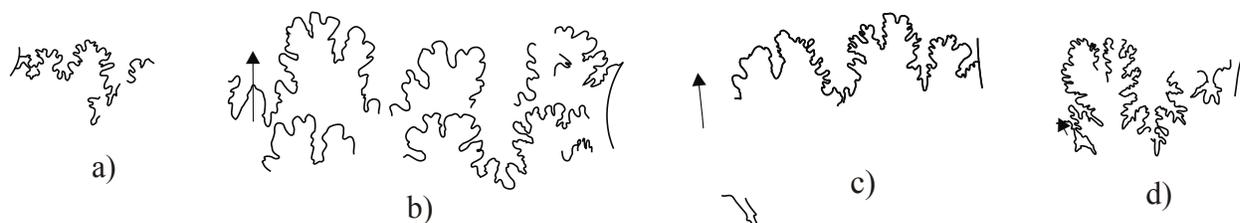


Figure 5. Suture lines of ammonites from the Cucurpe Formation, Sonora. a: *Glochiceras (Lingulaticeras?)* sp., ERNO 8030, X5, Dm = 15 mm; b: *Schaireria neoburgensis* (Oppel), ERNO 8032, X2, Dm = 69.5 mm; c: *Perisphinctes (Dichotomoceras?)* sp., ERNO 8036, X2; d: *Sublithacoceras* sp. aff. *S. sphinctum* (Schneid) ERNO 8044, X2, Dm = 63 mm.

all ribs, but at least some of them show a furcation point at middle or lower flanks. The ribs cross the ventral region without interruption, with an arc toward the aperture. At least three deep constrictions are present, but they do not modify the ribbing pattern. The last part of the preserved fragment displays a less dense ribbing, and the point of division can not be observed.

Remarks. Conclusive taxonomic interpretation of this specimen is precluded by its poor preservation, but the evolute, serpenticone coiling with subcircular section and densely ribbed shell suggest the genus *Sequeirosia*. Olóriz *et al.* (in press) reported a specimen resembling *Passendorferia* or *Sequeirosia* in middle Oxfordian rocks at Tamán, San Luis Potosí, but this specimen has an evolute macroconchiate shell, very different from our specimen.

The studied specimen was collected from the same level as *Perisphinctes (Dichotomoceras?)* sp. and therefore can be assigned to the upper Oxfordian Bifurcatus Zone.

Subfamily Torquatisphinctinae Tavera, 1985

Genus *Torquatisphinctes* Spath, 1924
emend. Olóriz, 1978

Arkell (1956, p. 562) proposed the inclusion of perisphinctids reported by Burckhardt (1919, pl. 5-14, subgenus *Aulacosphinctes*) in the genus *Aulacosphinctoides*. However, Arkell also noted that many of those specimens have abundant simple ribs characteristic of the genus *Torquatisphinctes*. Contreras *et al.* (1991) misinterpreted the statement of Arkell and included all of the specimens described by Burckhardt (1919) in the genus *Aulacosphinctoides*. Verma and Westermann (1973) also included some specimens described by Castillo and Aguilera (1895) in the genus *Aulacosphinctoides*.

As a result of the above history, a wide variety of forms are included in the genus *Aulacosphinctoides* and its morphological delimitation has become rather unclear. The Mexican forms assigned to this genus are no exception to this problem, with the result that specimens having a wide range of morphological characteristics are included in *Aulacosphinctoides*. They include specimens with densely

spaced as well as widely spaced ribs, with simple, bifurcate and even trifurcate ribs, with whorl sections ranging in shape from oval to quadratic, and with ventral regions with or without a furrow. This morphological diversity, scarce specimens, and poor preservation have created a difficult taxonomic problem. In this work, the Mexican forms of Tithonian age with a ventral furrow, such as *boesei*, *symonensis*, and *pervinquieri?*, are excluded from the genus *Aulacosphinctoides*. They probably belong to the genus *Aulacosphinctes sensu lato*. Furthermore, those specimens on which the bifurcation point occurs very high on the flank, such as the species *corona* and *titan*, should be included in the genus *Biplisphinctes*, as recommended by Olóriz (1978) and Villaseñor *et al.* (2000). Specimens with a wide umbilicus, a rounded to sub-rounded whorl section, abundant simple ribs and bifurcate ribs, with a division point at the middle part of the flank or slightly higher, with constrictions, such as aff. *colubrinus?*, and *subbleicheri* are better included in *Torquatisphinctes*. We recommend restriction of the name *Aulacosphinctoides* to specimens with polygyrate ribs, and to those in which the secondary ribs have a typical rursiradiate aspect.

Torquatisphinctes subbleicheri (Burckhardt)

Figure 4j, 4k

Perisphinctes (Aulacosphinctes) subbleicheri Burckhardt, 1919, p. 37, pl. 13, figs 1-5.

Aulacosphinctes subbleicheri (Burckhardt), 1930, p. 69.

?*Aulacosphinctoides subbleicheri* (Burckhardt). Arkell (1956), p. 562.

Aulacosphinctoides subbleicheri (Burckhardt). Contreras *et al.* (1991), p. 59.

Hypotype. ERNO 8038.

Material. One specimen with almost one complete whorl of the body chamber. The specimen is part of sample 4-6-12.

Description. Evolute, serpenticone shell with open coiling, the whorls covering only the most external part of the flank. Umbilical region wide and shallow with high umbilical wall and vertical and rounded umbilical edge. Flanks weakly

concave, ventral region rounded and wide. Rounded whorl section.

The internal and middle whorls are poorly preserved, but it is possible to observe strong and quasi-radial ribs with inter-rib spaces slightly wider than the rib thickness. At the end of the middle whorls is a very high point of furcation. The external whorl belongs to the body chamber and has intercalations of simple, radial ribs, which arise below the umbilical edge and display a weak forward projection. Some ribs are divided into two regular branches in the middle part of the flank. The anterior secondary ribs project slightly backward. There is a more or less constant ribbing pattern, represented by alternating simple and bifurcate ribs, in the first preserved quarter of the body chamber. This pattern changes in a dorsal direction to two simple and two bifurcate ribs. This pattern is altered only by the presence of wide and deep constrictions. Due to differential ribbing between the flanks, the ribs cross the ventral region without interruption to create zig-zag structures.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8038	78.3	40.1	23.7	22.7	0.51	1.04

Remarks. The studied specimen closely resembles *Perisphinctes (Aulacosphinctes) subbleicheri* Burckhardt from the Cañón del Toboso, Zacatecas. At similar diameters it has the same ribbing density (24 internal and 35 external ribs per half whorl). Although it was impossible to observe the constrictions in the umbilical region, a specific character mentioned by Burckhardt (1919), the similarity of its general ornamentation pattern permits its assignment to *T. subbleicheri*.

The specimen is different from *Aulacosphinctoides potosinus* (Aguilera) of Verma and Westermann (1973) due to its lack of trifurcate ribs, greater evolution, and wider rib spacing. Burckhardt (1919) initially recognized the species in grey limestone beds of early Tithonian age at Cañón del Toboso, Zacatecas. The fauna studied by Burckhardt (1919) was included by Villaseñor et al. (2000) in their "Parastreblites-Torquatisphinctes Assemblage," which assigned it to the lower Tithonian, in the middle to upper part of the Albertinum-Darwini Zone and probably extending into the lowermost part on the Semiforme-Verruciferum Zone. An early Tithonian age is inferred herein for the studied specimen, although all the faunal elements of this association are not present.

Torquatisphinctes sp. cf. *T. lauri* (Aguilera)

Figure 6a

Perisphinctes lauri Aguilera, in Castillo and Aguilera, 1895, p. 26, pl. 16, figs. 2,3.

Perisphinctes transitorius? Oppel. Castillo and Aguilera, 1895, p. 30, pl. 21, fig. 5.

Perisphinctes aguilerai Burckhardt, 1906, p. 110, pl. 27,

figs. 6-9.

Aulacosphinctoides lauri (Aguilera). Verma and Westermann, 1973, p. 179, pl. 27, figs. 2-5; Contreras et al., 1991, p. 59.

Hypotype. ERNO 8039.

Material. One eroded and slightly deformed phragmocone. The specimen is part of sample 4-6-12, collected from the upper part of the Cucurpe Formation at a locality 2 km west of the La Colgada section (indicated by an asterisk in Figure 1).

Description. The shell is planulate, with tight coiling covering half of the previous whorl. The umbilical region is small and deep, the umbilical wall high and vertical. The umbilical edge is rounded. The oval whorl section is higher than wide.

The poorly preserved ornamentation consists of simple and bifurcate ribs. They arise slightly below the middle part of the umbilical wall, where they are slightly retroverse. Across the flank, the ribs are directed forward. Primary ribs arise in the middle part or below the umbilical wall where they are slightly rursiradiate, changing their course across the flanks where they are gently directed forward. The ribs are divided at the middle flank, with symmetric branches crossing the ventral region. Two narrow and deep constrictions are present in the last whorl of the phragmocone.

Measurements.

Specimen	Dm	U	W	H	O/D	W/H
ERNO 8039	65.3	22.4	22.7	27.8	0.34	0.81

Remarks. Poor preservation precludes detailed study of the ribbing style and the suture lines, but the shell ornamentation pattern (ribs and constrictions) resembles that of *Perisphinctes aguilerai* (Burckhardt, IGM 243, included in the synonymy), and those of specimens IGM 23 and IGM 2751 of Verma and Westermann (1973), although those specimens are more strongly inflated. Verma and Westermann (1973) did not note the presence of constrictions in their specimens, although they are present in both specimens IGM 23 and 2751, at least in their inner whorls.

Parent (2003) noted that the Mexican forms of *Torquatisphinctes* gr. *lauri-potosinus* (Aguilera)-*inversum* (Spath) closely resemble *T. proximus* (Steuer) from Argentina. Parent (2003) also noted that fauna from Symón in Burckhardt (1919) includes many morphospecies resembling *T. proximus*, although *T. proximus* is slightly younger than the Mexican species.

The rocks containing the studied specimen are assigned to the lower Tithonian, in the middle to upper part of the Albertinum-Darwini Zone and/or the lowermost part of the Semiforme-Verruciferum Zone. This assignment results in correlation of this specimen with the "Parastreblites-Torquatisphinctes Assemblage" of Villaseñor et al. (2000).



Figure 6. a: *Torquatisphinctes* sp. cf. *T. lauri* (Aguilera) ERNO 8039, lateral view, sample 4-6-12; b-c: *Torquatisphinctes* sp. cf. *T. diversecostatus* (Burckhardt). ERNO 8040, (ventral and lateral views), sample 4-6-12; d: *Pachysphinctes* sp.. ERNO 8041, left lateral view, X 0.75, sample 4-6-7.

Parent (2003) noted that the Mexican faunas of *Torquatisphinctes* gr. *lauri-potosinus* (Aguilera)-*inversum* (Spath) probably pertain to the Darwini Zone. In addition, the recent biostratigraphic reinterpretation of Olóriz et al. (1999) for the Virgathosphinctinae Beds of Verma and Westermann (1973), where the *lauri* species was collected (*sensu* Verma and Westermann, 1973), is in accordance with this zone assignment. However, Olóriz et al. (1999) interpreted the Virgathosphinctinae Beds as condensed, discontinuous deposits. Furthermore, the recognition of *P. aguilerai* Burckhardt in the “calcaries phosphoritiques rougeâtres” as synonymous with *T. lauri*, the presence of the studied specimen in the same level as *Torquatisphinctes subbleicheri* (Burckhardt), and the recent chronostratigraphic interpretation of Villaseñor et al. (2000) are strong arguments for this biostratigraphic interpretation.

***Torquatisphinctes* sp. cf. *T. diversecostatus*
(Burckhardt)
Figure 6b, 6c**

Perisphinctes (*Aulacosphinctes*) *diversecostatus* Burckhardt, 1919, 34, pl. 12, figs. 1, 2, 4, 5.
Aulacosphinctes diversecostatus Burckhardt, 1930, p. 69.
Aulacosphinctoides diversecostatus (Burckhardt). Arkell, 1956, p. 562; Contreras et al., 1991, p. 59.

Hypotype. ERNO 8040.

Material. One poorly preserved specimen with eroded internal whorls, with three quarters of the whorl being body chamber. The specimen is part of sample 4-6-12.

Description. The shell is of medium size, with rounded quadratic whorl section, convergent flanks, and wide ventral region. The umbilical region is wide and shallow, with vertical umbilical wall and a rounded but weakly pronounced umbilical edge. The suture line is not well preserved.

Due to erosion, the ornamentation of the internal and middle whorls is not clear, but there are suggestions of ribs which lack evidence of bifurcation before the line of involution. Ornamentation consists of simple and bifurcate ribs, which arise in the middle part of the umbilical wall where they project slightly backward, changing across the flanks where they are recti-radiate. The point of division is evident in the second third of the flank. The inner part of the body chamber is characterized by alternating simple and bifurcate ribs, changing outward to an alternation of two bifurcate per one simple rib. There are deep and oblique constrictions.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8040	74.6 *	36.6	25.6	23.4	0.49	1.08

Remarks. The specimen has a high bifurcation point like

Biplisphinctes, but the common primary ribs and its more involute shell justify its inclusion in *Torquatisphinctes*. The specimen is very similar to *Perisphinctes* (*Aulacosphinctes*) *diversecostatus* Burckhardt (1919, pl. 12, figs. 1, 2, 4, 5). At similar diameters they show similar whorl sections and rib number. It differs from the species *subbleicheri* in the inter-rib spacing and strength and density of ribs, as well as in the more quadratic whorl section. *T. lauri* has a more complex style of ribbing and is more involute. This specimen was collected from the same level as the two previous species. Therefore, the interpreted assignment is lower Tithonian (lower and middle part of the Albertinum/Darwin Zone to lower part of the Semiforme/Verruciferum Zone). This species was recognized in the “Fosforitas grises” in Symón, Zacatecas (Burckhardt, 1919).

Genus *Pachysphinctes* Dietrich, 1925
emed. Olóriz, 1978

***Pachysphinctes* sp.
Figure 6d**

Hypotype. ERNO 8041.

Material. A very large and eroded phragmocone. The specimen was collected in the upper part of the Cucurpe Formation (sample 4-6-7 in Figure 3).

Description. Serpenticone, evolute shell that covers less than half the flank. The whorl section is rounded, as high as wide, with a vertical and well developed umbilical wall, and rounded umbilical edge. Notwithstanding the eroded state of preservation, it is possible to observe the ornamentation, which in the internal and middle whorls is composed of simple and dense ribs. It is not possible to observe where the ribs are divided. They arise in the umbilical wall running forward, forming a gentle arc. In the external whorls of the phragmocone the primary ribs are stronger and at least some of them are divided low on the flank. In the first quarter of the last whorl a constriction or reinforcement is present. In the last quarter of the whorl the ribs are reinforced even on the middle part of the flank. Because their point of division is not clear, they may be divided in several branches or may be residual ribs. The proportion of internal versus external ribs is high.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8041	215	103.2	68	68	0.48	1.0

Remarks. The poor preservation renders a detailed observation of the ribbing style impossible. Moreover, because the studied specimen is a phragmocone, the ornamental modifications in the body chamber cannot be evaluated. However, the last part of the phragmocone shows

a clear tendency to more widely spaced and reinforced ribs in the lower part of the flank.

In general, the specimen is similar in growth pattern and ribbing to the genus *Pachysphinctes*, in which the whorl section shows a proportion $W/H = 1$, and the degree of involution falls into the general features shown in *Pachysphinctes* ($U/D = 48 - 54\%$). The specimen is similar to the larger forms of the genus, for example *P. robustus* Spath, *P. grandti* Spath, and *P. mayor* Spath, but the studied specimen has more densely ribbed internal whorls.

The genus *Pachysphinctes* has a long biostratigraphic range from the upper Kimmeridgian to the lower Tithonian in the Mediterranean area (Spain), Madagascar, and in Kachchh (India). At Rancho La Colgada, it was collected in the uppermost levels of the section below the rocks provisionally assigned to the Cretaceous, so it is tentatively assigned an early Tithonian age (Semiforme/Verruciferum Chron) or younger (Richteri Chron) in consideration of the record of this genus in Spain (Olóriz, 1978). Also, the studied specimen was collected stratigraphically above *Sublithacoceras* sp. aff. *S. sphinctum* (Schneid), here assigned to the early Tithonian. A more complete faunal collection is needed to be conclusive in this regard.

Subfamily Lithacoceratinae Zeiss, 1968
Genus *Pseudodiscosphinctes* Olóriz, 1978

***Pseudodiscosphinctes* sp.**

Figure 7a

Hypotype. ERNO 8042.

Material. A shell fragment, showing one fracture. The specimen is part of sample 4-6-9 from the middle part of the Cucurpe Formation (Figure 3).

Description. Serpenticone, semi-evolute shell, rounded sub-quadratic whorl section, slightly higher than wide. The flanks converge toward the ventral region. Shallow and deep umbilical region, with large and almost vertical umbilical wall, and rounded umbilical edge. The internal whorls are not preserved, and no suture lines were observed in the external whorl. Information on aperture is not available.

The ornamentation consists of ribs arising in the umbilical edge with a slightly rursiradial direction and changing quickly to prorsiradial. Slightly above the middle flank, all ribs are divided into two symmetrical branches. Two wide and deep constrictions are present in the last quarter of the shell. These constrictions are preceded by a polyplocoid rib. The ribs cross the ventral region without interruption to form a subtle arc.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8042	96.7	37.4	28.3	32.1	0.39	0.88

Remarks. Poor preservation precludes determination of this specimen at the species level. Assignment to the genus *Pseudodiscosphinctes* rather than to the genus *Discosphinctoides* was based on similarities of our specimen to the former, such as the whorl section form, the whorl height and umbilicus diameter, as well as the ribbing pattern characterized by deep bifurcate ribs. *Discosphinctoides* is more evolute and the ribs are predominantly bifurcate with higher division points.

This genus has also been reported from Spain. It has a wide stratigraphic range from the upper Kimmeridgian (Beckeri? Zone) to the lower Tithonian (Burckhardtceras Zone). Based on the fact that it was found stratigraphically above *Mazapilites* and *Schaireria*, and below *Sublithacoceras* cf. *sphinctum* (Schneid), and *Pachysphinctes* sp., the studied specimen is considered to lie within the interval represented by the Semiforme/Verruciferum Zone to the Richteri Zone.

Genus *Subplanitoides* Zeiss, 1968

***Subplanitoides* sp.**

Figure 7b

Hypotype. ERNO 8043.

Material. A poorly preserved specimen with the right flank eroded. The specimen is part of sample 4-6-10 (Figure 3).

Description. Shell of medium size, semi-evolute, oval whorl section, flanks convergent toward the wide, rounded to acute ventral region. The umbilical region is wide and shallow, the weak umbilical wall with a rounded umbilical edge.

Ribs present on the last whorl of the left flank are fine and dense, mainly simple and bifurcate. There is a trifurcate rib in the last part of the whorl with the point of division slightly above the middle flank. A narrow and shallow constriction is also present. It is preceded by a trifurcate rib and followed by two simple ribs. Data on aperture and suture line are absent.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8043	107	45	27.3	35.5	0.42	0.76

Remarks. The studied specimen is similar to Submediterranean forms studied by Zeiss (1968) belonging to the genus *Subplanitoides*, in particular those species with dense and fine ribbing such as *schneidi*, *oppeli* and *waltheri*. However, the specimen studied has a greater diameter than the European species (Zeiss, 1968; Olóriz, 1978), which influences the density of its ribbing which is also slightly greater. Poor preservation does not permit a more precise taxonomic assignment.

The specimen was found at the same levels as

Mazapilites and *Schaireria*, and taking into account the biochronostratigraphic proposal for similar faunas (Villaseñor et al., 2000), it is assigned to the lower part of the Albertinum-Darwini Zone. Regarding the paleobiogeographic distribution, the genus *Subplanitoides* has been reported in Submediterranean as well as Mediterranean areas.

Genus *Sublithacoceras* Spath, 1925

***Sublithacoceras* sp. aff. *S. sphinctum* (Schneid)**

Figures 7c and 5d

cf. *Perisphinctes* (*Aulacosphinctes*?) *coesposus* Schneid, 1915, p. 34, pl. 12, fig. 3, no. pl. 3, fig. 2.

cf. *Sublithacoceras sphinctum* Donze and Enay, 1961, p. 92, pl. 13, fig. 1.

?*Sublithacoceras* cf. *sphinctum* Donze and Enay, in Enay and Geysant, 1975, p. 44.

Sublithacoceras sp. cf. *Sublithacoceras sphinctum* (Schneid). Olóriz, 1978, p. 585, pl. 42, fig. 2.

Hypotypes: ERNO 8044-8046.

Material. One partially preserved specimen including part of middle whorls and body chamber, and two fragments. The specimens are part sample 99-86 from the upper part of the Cucurpe Formation (Figure 3).

Description. Medium-sized, evolute shell, covering just one third of the flank, and oval whorl section with flanks convergent toward the ventral region. Wide umbilical region with a vertical umbilical wall and rounded umbilical edge. The ornamentation of the internal whorls consists of bifurcate ribs with some polygyrate ribs present on the body chamber. The ribs arise at the middle part of the umbilical wall and project backward in the umbilical edge. In one of the fragments (ERNO 8045), the ribs are weakly sinuous with the division point in the middle part of the flank. It is possible to observe a constriction. In the other fragment (ERNO 8046) the division occurs higher on the flanks. The polygyrate ribs are divided in the first quarter and then near the middle part of the flank. All ribs cross the ventral region without interruption to form a weak arc. The constrictions are narrow but deep. The suture line is not complete (Figure 5d), and is represented by a quadratic external saddle and deep external lobe. The first lateral saddle is narrow at the base and divided into two symmetrical brache,: the first lateral lobe is triphid.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8044	99.5 *	41.5 *	33	36.8	0.41	0.89

Remarks. Due to the rounded ventral region, the whorl sections of the studied specimens are more oval than the

European specimens. Moreover, the rib density is lower with slightly wider inter-rib spaces. However, the specimens show a similar style of rib division and constrictions. More complete material is needed for a more specific assignment, but the morphological affinity to *S. sphinctum* is well supported.

The species has been recorded in the lower Tithonian of France. In Spain it has been collected from rocks of the Burckhardtceras Zone. Taking into account European age interpretations and the stratigraphic position of the studied specimen, an early Tithonian age (Semiforme/Verruciferum Chron to Richteri Chron) is plausible.

***Sublithacoceras* sp.**

Figure 7d

Hypotypes. ERNO 8047-8050.

Material. Three very eroded and weakly deformed specimens. The specimens are part of sample 4-6-8 from the middle part of the Cucurpe Formation and one fragment that is from sample 99-86 in the upper part of the formation (Figure 3).

Description. Due to the poor preservation it is not possible to observe the ribbing pattern in detail, but there are simple and furcated ribs which are very dense. Toward the aperture, the ribbing is stronger and more widely spaced (ERNO 8048). The whorl section is only present in specimens ERNO 8049 and 8050, where it is oval, higher than wide.

Measurements.

Specimen	Dm	U	W	H	U/D	W/H
ERNO 8047	119	35.3	35.8	53.6	0.29	0.66
ERNO 8048	95.5	33.9	31.4 *	39.3	0.35	0.79
ERNO 8049	89.3	31.9	32	34.8	0.35	0.66

Remarks. Poor preservation prevents assignment of these specimens to the species level. However, the shell structure and ribbing pattern are similar to those of the proposed genus. The genus *Sublithacoceras* has been recognized in the early Tithonian in several regions of Europe, including France, Germany, and Spain. Its stratigraphic range varies from place to place, from the upper part of the Semiforme/Verruciferum Zone to the Burckhardtceras Zone. In the study area, the specimens were collected in upper stratigraphic levels, between *Sublithacoceras* sp. aff. *S. sphinctum* (Schneid) and *Pachysphinctes* sp. This stratigraphic position permits the assignment of an early Tithonian age (Semiforme/Verruciferum Chron to Richteri Chron).

Bivalve taxonomy

Family Paralleodontidae Dall, 1898
Genus *Grammatodon* Meek and Hayden, 1860

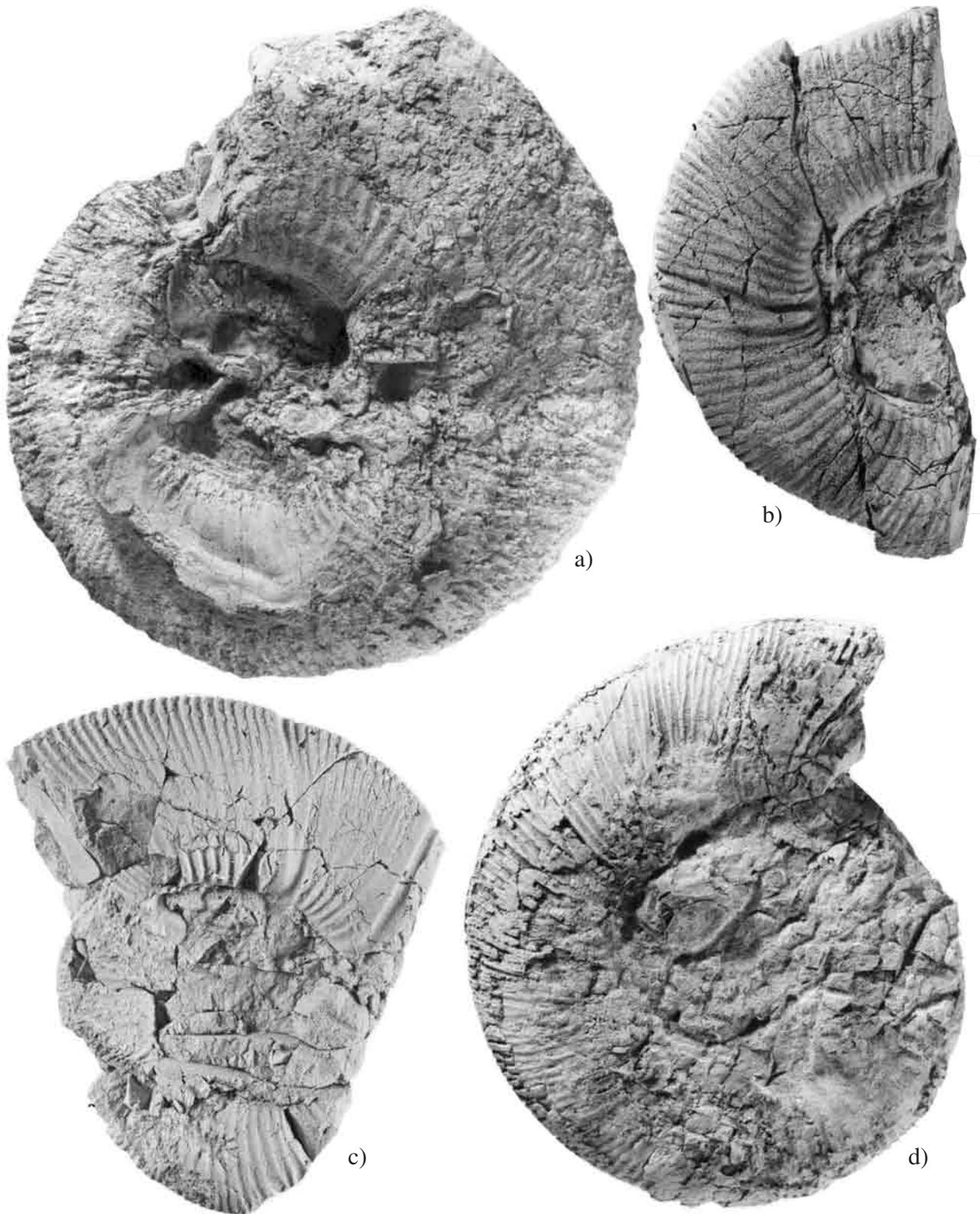


Figure 7. a: *Pseudodiscosphinctes* sp. ERNO 8042, lateral view, sample 4-6-9; b: *Subplanitoides* sp. ERNO 8043, left lateral view, sample 4-6-10; c: *Sublithacoceras* sp. ERNO 8047, right lateral view, sample 4-6-8; d: *Sublithacoceras* sp. aff. *S. sphinctum* (Schneid) ERNO 8044, right lateral view, sample 99-86.

Subgenus *Grammatodon* s. s.

***Grammatodon (Grammatodon) hersilius* (d'Orbigny)**

Figures 8a, 8b

Arca hersilia d'Orbigny, 1850, p. 368, no. 343.

Arca (Macrodon) montaneyensis de Loriol, 1901, p. 83, pl. 5, figs. 12-14.

Arca hersilia d'Orbigny. Cottreau, 1927p. 59, pl. 47, figs. 12-13.

Parallelodon (Grammatodon) montaneyensis (de Loriol). Arkell, 1930, p. 341, pl. 15, figs. 6, 6a.

Grammatodon delicatulus Imlay, 1940, p. 400, pl. 53, figs. 22-25.

Grammatodon crassilineatus Imlay, 1940, p. 401, pl. 53, figs. 16-19.

Grammatodon reticulatus Imlay, 1940, p. 401, pl. 53, figs. 20-21.

Parallelodon (Grammatodon) montaneyensis (Loriol). Alencáster and Buitrón, 1965, p. 17, pl. 5, fig. 9.

Grammatodon (Grammatodon) hersilius (d'Orbigny, 1850). Duff, 1978, p. 37, pl. 2, figs. 18, 20, 24.

Grammatodon delicatulus Imlay. Buitrón, 1984, p. 93, pl. 1, figs. 1-3.

Grammatodon (Grammatodon) hersilius (d'Orbigny, 1850). Fürsich and Werner, 1988, p. 117, pl. 2, fig. 1.

Hypotypes. ERNO 8051-8052.

Material. External moulds of one left valve and one right valve from sample 99-107 and one external mould of a left valve from sample 99-79 (Figure 3); upper Oxfordian.

Description. Large for the genus, equivalve and moderately inflated shell with umbones situated about one-third of shell length from the anterior. Outline subrectangular, height about two-thirds of length. Long, straight dorsal margin meeting straight and oblique posterior margin at an obtuse angle; anterior margin curving evenly into slightly convex ventral margin. Sharp, slightly curved umbonal carina running from umbo to the well-defined postero-ventral corner of the shell. Flanks of shell covered by radial riblets of subequal strength and faint intercalatories. Four to five strong radial ribs in the anterior part of the shell; up to eight radial riblets in the posterior part. Internal shell features not observed.

Remarks. *G. hersilius* was described in great detail by Duff (1978), who also discussed the affinities to other European species of *Grammatodon*. On the basis of subtle differences in the style of ribbing, Imlay (1940) erected three new species of *Grammatodon* from the Upper Jurassic (Oxfordian to Kimmeridgian) of Mexico, *G. delicatulus*, *G. crassilineatus*, and *G. reticulatus*. These differences are regarded here as being within the range of intraspecific variation of a single species. The studied material from Sonora, the three species

of Imlay (1940), and *G. montaneyensis* from the Oxfordian of the Petlalcingo region in the state of Puebla, eastern Mexico (Alencaster and Buitrón, 1965), agree very well with *G. hersilius* from western Europe and are regarded herein as being conspecific. In Europe, *G. hersilius* is known from the Oxfordian of France (d'Orbigny, 1850; Cottreau, 1927), the middle Oxfordian of Switzerland (de Loriol, 1901), the Callovian to Oxfordian of Great Britain (Arkell, 1930; Duff, 1978), and the Oxfordian to Kimmeridgian of Portugal (Fürsich and Werner, 1988). The age of the species in western Europe and Mexico corresponds very well with the upper Oxfordian age of the Sonoran specimens as is indicated by ammonites (see above).

Family Inoceramidae Giebel, 1852

Genus *Parainoceramus* Cox, 1954

***Parainoceramus* sp.**

Figure 8c

Hypotype. ERNO 8053.

Material. One external mould of a right valve from bed 99-79; upper Oxfordian.

Description. Relatively small, moderately inflated specimen of suboval commissural outline. Posteriorly subalate, wing not clearly differentiated from body of shell. Hinge margin straight, covering about three-fourth of shell length. Posterodorsal angle rounded, obtuse, posterior margin convex passing into evenly curved ventral margin. Anterior area at roughly right angle to plane of commissure. Surface ornament of weak, regularly spaced commarginal folds and fine growth lines.

Family Lucinidae Fleming, 1828

Genus *Lucina* Bruguière, 1797

***“Lucina” potosina* Aguilera**

Figures 8d, 8e, 8f, 8g

Lucina potosina Aguilera, in Castillo and Aguilera, 1895, p. 6, pl. 4, figs. 2, 3, 6, pl. 5, figs. 11-14. Cragin, 1905, p. 72, pl. 13, figs. 4-5; Imlay, 1940, p. 408, pl. 55, fig. 7; Alencáster and Buitrón, 1965, p. 29, pl. 7, figs. 9-10.

Hypotypes. ERNO 8054-8089.

Material. Five articulated shells and one external mould of a left valve from sample 99-107 (Figure 3); two articulated shells and one external mould of a right valve from sample 99-79 (Figure 3); 26 articulated shells and one right valve from sample 99-113 (Figure 3); upper Oxfordian to lower Tithonian.

Description. Medium-sized, moderately inflated shell with submesially placed and slightly prosogyrous umbones. Outline suboval, longer than high. Postero-dorsal margin straight to weakly convex, posterior margin somewhat truncated, remaining shell margins well rounded. Lunule elongated and narrow, moderately excavated, escutcheon

very narrow and elongated. Ornamentation in most specimens strongly abraded, but originally consisting of coarse, unevenly spaced, commarginal growth lamellae and fine growth lines.

Remarks. As the internal shell characters, in particular

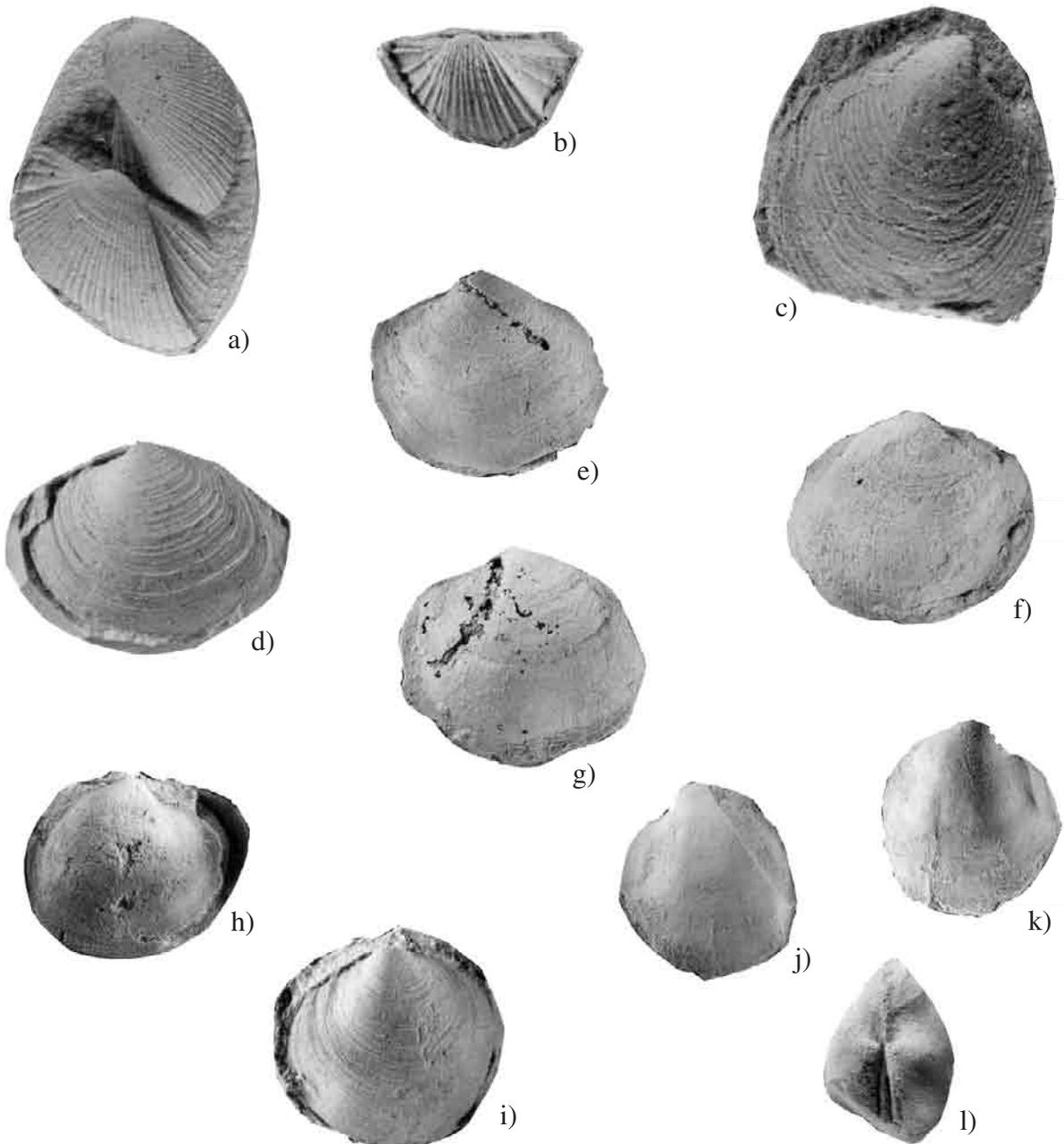


Figure 8. a-b: *Grammatodon (Grammatodon) hersilius* (d'Orbigny), a: ERNO 8051, latex cast of left and right valve, sample 99-107; b: ERNO 8052, latex cast of left valve, sample 99-79; c: *Parainoceramus* sp. ERNO 8053, latex cast of right valve, sample 99-79; d-g: "*Lucina*" *potosina* Aguilera; d: ERNO 8054, latex cast of left valve, sample 99-107; e: ERNO 8055, articulated specimen, left valve view, sample 99-79; f: ERNO 8056, articulated specimen, right valve view, from sample 99-113; g: ERNO 8057, articulated specimen, left valve view, sample 99-113; h: "*Lucina*" sp. ERNO 8090, internal mould of right valve, sample 99-79; i: *Integricardium (Integricardium)* sp. ERNO 8091, latex cast of single valve, sample 99-113; j-l: *Isocyprina* sp. ERNO 8093, articulated specimen (j: left valve view; k: right valve view; l: dorsal view), sample 99-79. All X1.2.

the hinge and muscle scars, are unknown, the species cannot be assigned to any of the Jurassic genera of the family. A subspecies of "*L.*" *potosina*, "*Lucina*" *potosina metrica* Cragin (1898, p. 817; 1905, p. 73, pl. 13, figs. 6-10; Alencáster and Buitrón, 1965, p. 29, pl. 7, figs. 7-8), was assigned to *Codakia* (*Epilucina*) by Buitrón (1984), but it remains unclear on which morphological features this identification was founded. Based on a comparison of the intraspecific variability of the studied specimens and literature data, morphologically very similar species include *Lucina*? *emarginata* Cragin (1905, p. 74, pl. 13, figs. 1-2) and *Lucina planiuscula* Cragin (1905, p. 75, pl. 13, fig. 3) from the upper Jurassic Malone Formation of western Texas as well as *Lucina coetoi* Aguilera (*in* Castillo and Aguilera, 1895, p. 7, pl. 5, figs. 1-2) from the upper Jurassic of San Luis Potosí, Mexico. A revision of North American Upper Jurassic lucinids, however, is beyond the scope of the present study. "*L.*" *potosina* is known from the Kimmeridgian to Tithonian of Mexico (Imlay, 1940; Alencáster and Buitrón, 1965; Buitrón, 1984) and the Kimmeridgian-Tithonian of Texas (Cragin, 1905).

"*L.*" *potosina* is a dominant macrobenthic element in the section, particularly in bed 99-113. The prevalence of articulated shells is indicative of autochthonous assemblages. Extant (and presumably most fossil) members of the lucinids live in symbiosis with chemoautotrophic, sulfide-oxidizing bacteria (*e.g.*, Vetter *et al.*, 1991), and therefore require a balanced juxtaposition of oxygen and H₂S. This is in agreement with sedimentological evidence, *e.g.*, black shale deposition in sample 99-107 (Figure 3), suggesting oxygen-deficient environmental conditions with free H₂S within the sediment.

"*Lucina*" sp.

Figure 8h

Lucina sp. cf. *L. radiata* Contejean. Alencáster, 1977, p. 157, fig. 7a, b.

Hypotype. ERNO 8090.

Material. One internal mould of a right valve from sample 99-79 (Figure 3); upper Oxfordian.

Remarks. The specimen seems to belong to the same species as specimens described as *Lucina* cf. *radiata* Contejean by Alencáster (1977) from the Upper Jurassic of Chiapas, Mexico. The poor preservation of all these specimens (abraded internal moulds, no information on internal characters) renders both a specific and generic identification impossible.

Family Cardiidae Lamarck, 1809
Genus *Integricardium* Rollier, 1912
Subgenus *Integricardium* s. s.

***Integricardium* (*Integricardium*) sp.**

Figure 8i

Hypotype. ERNO 8091.

Material. One external mould and one internal mould from sample 99-113 (Figure 3); lower Tithonian.

Description. Relatively small for the genus, moderately inflated, suborbicular to suboval (higher than long) in outline. Umbones narrow, slightly protruding above dorsal margin, orthogyrous and mesial. Anterior, posterior and ventral shell margins well rounded. Shell surface covered by fine irregular growth lines.

Remarks. According to the emended diagnosis given by Fürsich *et al.* (2000, p. 114), *I.* (*Integricardium*) accommodates cardiid species that are similar in shape and dentition to *Protocardia*, but lack radial ornamentation. Features such as the presence of a posterior carina and an equilateral or inequilateral shell are regarded as variable features, which are only diagnostic at the species level. As yet, this taxon has apparently not been described from Mexico. As only two specimens are available and the intraspecific variability is unknown, we keep it in open nomenclature.

Family Arcticidae Newton, 1891

Genus *Isocyprina* Roeder, 1882

***Isocyprina*? sp.**

Figure 8j, 8k, 8l

Hypotype. ERNO 8093.

Material. One double-valved, fragmented internal mould from sample 99-79 (Figure 3); upper Oxfordian.

Description. Specimen moderately inflated, suborbicular in outline, with broad and faintly prosogyrous umbones. Antero-dorsal margin weakly concave, anterior margin evenly convex, posterior margin not preserved. Moderately excavated lunule present.

Remarks. The specimen is similar in size and outline to *Arctica*? *cotoi* (Aguilera) from the Upper Jurassic (Kimmeridgian) of Mexico (Castillo and Aguilera, 1895, p. 8, pl. 5, figs. 4-10; Imlay, 1940, p. 409, pl. 55, figs. 9-10; Alencáster and Buitrón, 1965, p. 27, pl. 7, figs. 4-6; Buitrón, 1984, p. 93, pl. 2, figs. 1-2). It can be separated from this species by the presence of a lunule and by being less inflated. With only a single fragmented internal mould available for study, however, an unquestionable identification is impossible.

DISCUSSION AND CONCLUSIONS

Biochronostratigraphic implications

The molluscan faunas of the upper part of the Cucurpe Formation (Figure 3) in the Tuape region of north-central Sonora define four distinct fossil assemblages, three on the measured section and one at a separate locality to the west of the measured section. Correlation of the four ammonite assemblages with the European biozonal standard and with the recent biochronostratigraphic framework for Mexico (Myczynski *et al.*, 1998; Villaseñor *et al.*, 2000; López-Palomino, 2002; Olóriz *et al.*, in press) is shown in Figure 9.

The lowermost assemblage contains the ammonites *Perisphinctes* (*Dichotomoceras?*) sp., *Sequeirosia?* sp., and the bivalves *Grammatodon* (*Grammatodon*) *hersilius* (d’Orbigny), *Parainoceramus* sp., “*Lucina*” *potosina* Aguilera, “*Lucina*” sp., and *Isocyprina?* sp. The ammonites indicate a late Oxfordian age (Bifurcatus Chron). The second

fossil assemblage contains only ammonites, *Mazapilites mexicanus* (Aguilera), *Schaireria neoburgensis* (Opell), *Subplanitoides* sp., and *Glochiceras* (*Lingulaticeras?*) sp. These ammonites indicate an early Tithonian age (early part of the Albertinum/Darwini Chron). The third fossil assemblage, in the uppermost part of the section, consists of the ammonites *Sublithacoceras* sp., *Sublithacoceras* cf. *sphinctum* (Schneid), and *Pachysphinctes* sp., and the bivalves “*Lucina*” *potosina* Aguilera and *Integricardium* (*Integricardium*) sp. The age is also early Tithonian, but corresponds to a younger chron, the Semiforme-Verruciferum Chron or younger Richteri Chron.

From a locality about 2 km west of the Rancho La Colgada section (Figure 1), the ammonites *Torquatisphinctes subbleicheri* (Burckhardt), *T. cf. lauri* (Aguilera) and *Torquatisphinctes* sp. cf. *T. diversecostatus* (Burckhardt) were collected. These ammonites are assigned to the early Tithonian (middle to upper part of the Albertinum-Darwini Zone and/or the lowermost part of the Semiforme-Verruciferum Zone).

OXFORDIAN	EUROPEAN STANDARD		Myczynski <i>et al.</i> (1998)					López-Palomino (2002)	Oloriz <i>et al.</i> (2004)	Villaseñor <i>et al.</i> (this work)		
	ZONES	Subzones	N. Chile	Cuba		Southern U.S.A.		Mexico		Mexico		
			C. Domeyko	S. del Rosario	S. de los Organos	Sierra Nevada	Cotton Valley Field	Sierra Madre Noreste	Este	Taman S.L.P.	Taman S.L.P.	Sonora R. la Colgada section
LOWERMOST UPPER	BIFURCATUS	Grossouvrei		Vi-Cs-”Ds”						TAMI-OXF4 <i>Vinalesphinctes</i>		<i>Dichotomoceras?</i> sp. <i>Sequeirosia?</i> sp.
		Stenocycloides	Vi-Sd-Dch									
MIDDLE	TRANSVERSARIUM	Rotoides										
		Schilli	Gr			Gr				TAMI-OXF3 cf. <i>Larcheria-Cubasphinctes</i>		
		Wartae	Och		evolved Di (?Ge)				upper Di (? Ge)	--- ? --- TAMI-OXF2 <i>Gemellarites</i> --- ? ---		
		Antecedens		evolved Di (?Ge)		Di			Di (?”Ds”)	TAMI-OXF1 <i>Gregoryceras</i> DI	<i>Gregoryceras</i> DI	
		Vertebrale		early Di				lower Di				

Figure 9. Correlation chart showing the new ammonites in Rancho La Colgada Section. Proposal for Tithonian biochronostratigraphy in northern-central Mexico is from Villaseñor *et al.* (2000). Proposal for Oxfordian biochronostratigraphy in America is from Myczynski *et al.* (1998) (for symbols see this paper), López-Palomino (2002), and Olóriz *et al.* (in press). European standards are from Geysant and Enay (1991).

The absence of faunas representing the late late Oxfordian to the earliest Tithonian could mean that (1) strata of this age interval are not preserved; (2) fossils of this age interval are absent due to taphonomic processes; (3) ecological conditions were not favorable for ammonites and bivalves; or (4) fossils remain to be found. As noted above, the fossil-bearing conglomerate lying stratigraphically between strata containing Oxfordian and Tithonian ammonites provides physical evidence for a local unconformity in the Rancho La Colgada measured section. A single early Kimmeridgian ammonite, *Idoceras* cfr. *densicostatum* Imlay, has been recovered from the Cucurpe Formation approximately 40 km northwest of the study area (Mauel et al., 2004), indicating that, at least locally, the formation contains Kimmeridgian strata.

The ammonite faunas recovered to date from the lower Tithonian of Sonora fail to record a stratigraphically complete ammonite zonation. This discontinuous fossil record is similar to Tithonian ammonite records described by Olóriz et al. (1999) and Villaseñor et al. (1994, 2000) from other successions in north-central Mexico, but more fieldwork is necessary in the area to determine if this pattern

of preservation is a result of paleogeographic factors or lack of stratigraphic completeness.

Paleobiogeographic implications

The ammonites described here have close affinities with Tethyan faunas, in particular those reported from France, Germany and Spain. Similarly, the presence of the bivalve *Grammatodon hersilius* in Mexico (Sonora, Coahuila, Durango, Zacatecas, and Puebla), the western Tethys and the epicontinental shelf sea of northwestern Europe indicates a direct connection between these areas through the young Central Atlantic Ocean. Because the first occurrence of this species in Europe (early Callovian) is older than that in Mexico (late Oxfordian), the dispersal of this species was evidently from east to west. Alternatively, dispersal may have taken place eastward across the paleo-Pacific oceanic realm, but present data are insufficient to permit discrimination between these two possibilities.

The fossil assemblages described here represent a range extension into Sonora of some endemic species,

		MEDITERRANEAN PROVINCE	SUBMEDITERRANEAN PROVINCE	NORTHERN-CENTRAL MEXICO	R. LA COLGADA SECTION (this work)		
		ZONES	ZONES	Villaseñor et al. (2000) assemblages	Recognized ammonites		
TITHONIAN	Upper	DURANGITES		to determine			
		MICRO-CANTHUM	TRANSITORIUS			TRANSITORIUS / MICROCANTHUM	
			SIMPLISPHINCTES			SCRUPOSUS	
	Middle	PONTI / BURCKHARDTICERAS		PALMATUS / PUSCHI			
		FALLAUXI	ADMIRANDUM / BIRUNCINATUM	CILIATA			
			RICHTERI	BAVARICUM / PENICILLATUM / ROTHPLETZI			
		SEMIFORME / VERRUCIFERUM				ANDICERAS-KOSSMATIA ASSEMBLAGE	
	Lower	ALBERTINUM / DARWINI		VIMINEUS		PALATINUM	PARASTREBLITES-TORQUATISPHINCTES ASSEMBLAGE
				VIMINEUS			
		TRIPLICATUS / MUCRONATUM		USSELICERAS-FRANCONITES ASSEMBLAGE			
			MAZAPILITES ASS.				
HYBONOTUM / LITHOGRAPHICUM		HYBONOTUM / LITHOGRAPHICUM		HYBONOTICERAS ASSEMBLAGE			

Figure 9. Continued.

Table 1. Biostratigraphically significant ammonites common in Rancho La Colgada section and others areas of Mexico.

Genera	Puebla	San Luis Potosí	Zacatecas	Durango	Sonora
<i>Mazapilites</i>	xx	xx	xx	xx	xx
<i>Torquatisphinctes</i>		xx	xx		xx
<i>Sequeirosia?</i>		xx			xx
<i>Schaireria</i>		xx			xx

such as the ammonite *Mazapilites mexicanum*, to their northernmost occurrences in the Americas. This extension permits correlation of Sonoran strata with outcrops in north-central Mexico, including exposures at San Pedro del Gallo, Durango, Real de Catorce, San Luis Potosí and Mazapil, Zacatecas, as well as with lower Tithonian rocks in Cuba. The distribution of another endemic form, the bivalve "*Lucina*" *potosina*, in Mexico (Sonora, Durango, Zacatecas, San Luis Potosí, and Puebla) and west Texas (Malone Formation) confirms a marine connection between those areas during the Late Jurassic.

In conclusion, the strong similarity between the molluscan faunas of Sonora and north-central Mexico improves stratigraphic correlation between those areas (see Table 1). Furthermore, the present findings indicate extensive faunal exchange both within Mexico and throughout the Tethyan realm during late Oxfordian and early Tithonian time.

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