

Kimmeridgian (Late Jurassic) cold-water idoceratids (Ammonoidea) from southern Coahuila, northeastern Mexico, associated with Boreal bivalves and belemnites

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ABSTRACT

Here we present two early Kimmeridgian faunal assemblages composed of the ammonite *Idoceras* (*Idoceras pinonense* n. sp. and *I. inflatum* Burckhardt, 1906), Boreal belemnites *Cylindroteuthis cuspidata* Sachs and Nalnjaeva, 1964 and *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjaeva, 1964, as well as the Boreal bivalve *Buchia concentrica* (J. de C. Sowerby, 1827). The assemblages were discovered in inner- to outer shelf sediments of the lower La Casita Formation at Puerto Piñones, southern Coahuila, and suggest that some taxa of *Idoceras* inhabited cold-water environments.

Key words: La Casita Formation, Kimmeridgian, idoceratid ammonites, Boreal bivalves, Boreal belemnites.

RESUMEN

Aquí se presentan dos asociaciones de fauna compuestas por los amonites *Idoceras* (*Idoceras pinonense* n. sp. e *I. inflatum* Burckhardt, 1906) con los belemnites Boreales (*Cylindroteuthis cuspidata* Sachs y Nalnjaeva, 1964 y *C. ex. gr. jacutica* Sachs y Nalnjaeva, 1964) y el bivalvo Boreal *Buchia concentrica* (J. de C. Sowerby, 1827). Los fósiles indican una edad del Kimmeridgiano temprano y han sido descubiertos en sedimentos de plataforma marina en la porción inferior de la formación La Casita en Puerto Piñones, en el Sur de Coahuila. Se sugiere que algunas especies de *Idoceras* poblaron ambientes de agua fría.

Palabras clave: Formación La Casita, Kimmeridgiano, amonites *Idoceras*, bivalvos Boreales, belemnites Boreales.

INTRODUCTION

The Jurassic is frequently described as a period of extended global greenhouse conditions and warm temperatures reaching to the poles (e.g., Frakes *et al.*, 1992; Sellwood *et al.*, 2000; Veizer *et al.*, 2000). Nevertheless, recent palaeontological, geochemical and stable isotope studies provide evidence for major climatic oscillations, at least for the Late Jurassic period (e.g., Föllmi, 1995; Lécuyer *et al.*, 2003; Weissert and Erba, 2004; Cecca *et al.*, 2005; Brigaud *et al.*, 2008). A global warming during the mid-Oxfordian (e.g., Riboulleau *et al.*, 1998; Abbink

et al., 2001; Chumakov *et al.*, 2014) was followed by a cool period during the late Oxfordian-early Kimmeridgian (e.g., Jenkyns *et al.*, 2002; Weissert and Erba, 2004) and a long-term gradual warming trend towards the Jurassic-Cretaceous boundary (e.g., Abbink *et al.*, 2001; Lécuyer *et al.*, 2003; Gröcke *et al.*, 2003; Zakharov *et al.*, 2014). Palynological data suggest that the latest Jurassic was also marked by significant fluctuations in paleotemperature and climate (e.g., Abbink *et al.*, 2001).

Upper Jurassic-Lower Cretaceous marine associations containing both Tethyan and Boreal elements [e.g. ammonites, belemnites (*Cylindroteuthis*) and bivalves (*Buchia*)], were described from numerous localities of the Western Cordillera belt from Alaska to California (e.g., Jeletzky, 1965), while Boreal (*Buchia*) and even southern high latitude (Austral) elements (e.g. *Anopaea*) were reported from the upper Tithonian of Cuba (e.g., Myczyński, 1999). The latter author suggested, that their occurrences in Cuba resulted from changing oceanic currents and upwelling of cold water. In Mexico, the Austral bivalve *Anopaea* was only reported from the middle Tithonian La Pimienta Formation at Mazatepec, Puebla (Lecolle de Cantú, 1967) and from the subsurface of Nuevo León, also in Tithonian sediments (Cantú-Chapa, 1989). At Mazatepec, *Anopaea* is associated with the ammonites *Kossmatia victoris* and *Pseudolissoceras zitteli* (Cantú-Chapa, 1967). Reports of Boreal faunal elements (*Buchia*, *Cylindroteuthis*) are more abundant in the Upper Jurassic of Mexico (e.g., Mora *et al.*, 2000; Zell *et al.*, 2013) but stratigraphic assignment to specific intervals of the sediment sequence and taxonomic documentation of associated ammonites are rare. The first Mexican record of *Buchia concentrica* (J. de C. Sowerby, 1827) associated with the ammonite *Idoceras* (*Idoceras* sp.) was provided by Buitrón (1984, p. 93) from the early to ?middle Kimmeridgian La Caja Formation at Sierrecilla de San Antonio, northern Zacatecas.

Late Jurassic cold intervals in northeastern Mexico

Late Jurassic cold-water intervals were recently identified in northeastern Mexico by Zell *et al.* (2013) based on the occurrence of the Boreal belemnite *Cylindroteuthis* in distinctive Kimmeridgian to upper Tithonian units of the Upper Jurassic-lowermost Cretaceous La Caja and La Casita formations. These inner- to outer shelf sediments are widespread in northeastern Mexico and were described by Michalzik (1988), Götte (1990), Goldhammer and Wilson (1991), Adatte *et al.* (1994), Goldhammer (1999), Goldhammer and Johnson (2001) among other authors. The proximal La Casita and the coeval distal La Caja formations are widely known for their abundant and

well-preserved marine vertebrate and invertebrate assemblages. Most taxa are endemic to the ancient Gulf of Mexico but some show affinities with the European Tethys (e.g., Verma and Westermann, 1973; Buchy, 2010; Buchy *et al.*, 2003; Zell *et al.*, 2013, 2014). On the other hand, belemnites assigned to *Cylindroteuthis* and the bivalve *Buchia* are of Boreal origin (Seibertz and Spaeth, 1999, 2008; Mora *et al.*, 2000; López-Caballero, 2009; Pessagno *et al.*, 2009; Zell *et al.*, 2013). These Boreal taxa are present in at least two distinct units of the lower Kimmeridgian and upper Tithonian portion of the La Caja and La Casita formations (Mora *et al.*, 2000; López-Caballero, 2009; Zell *et al.*, 2013), occasionally forming monospecific assemblages. Other taxa (e.g. ammonites) are extremely rare in these units.

Cold-water assemblages at Puerto Piñones

Here, we present two species of the genus *Idoceras* (*Idoceras pinonense* n. sp. and *I. inflatum* Burckhardt, 1906) which are associ-

ated with Boreal taxa (belemnites, *Buchia*) in two distinctive lower Kimmeridgian horizons of the La Casita Formation at Puerto Piñones, southern Coahuila. A detailed stratigraphic section is presented in Figure 1. Assemblage I was collected from a dark-grey silt- to sandstone with limestone concretions at approximately 8 m above the base of the La Casita Formation, 0.3 m below phosphatic marls, and consists of *Idoceras pinonense* n. sp., *I. inflatum* Burckhardt, 1906 and the Boreal belemnite *Cylindroteuthis cuspidata* Sachs and Nalnjäeva, 1964. Assemblage II was identified in dark-grey limestone concretions embedded in dark-grey siltstone at approximately 16 m above the formational base, 2 m above phosphatic marls, and consists of *Idoceras pinonense* n. sp., *I. inflatum* Burckhardt, 1906, the Boreal bivalve *Buchia concentrica* (J. de C. Sowerby, 1827) and the Boreal belemnites *Cylindroteuthis cuspidata* Sachs and Nalnjäeva, 1964 and *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjäeva, 1964. Figure 2 illustrates specimens documented here.

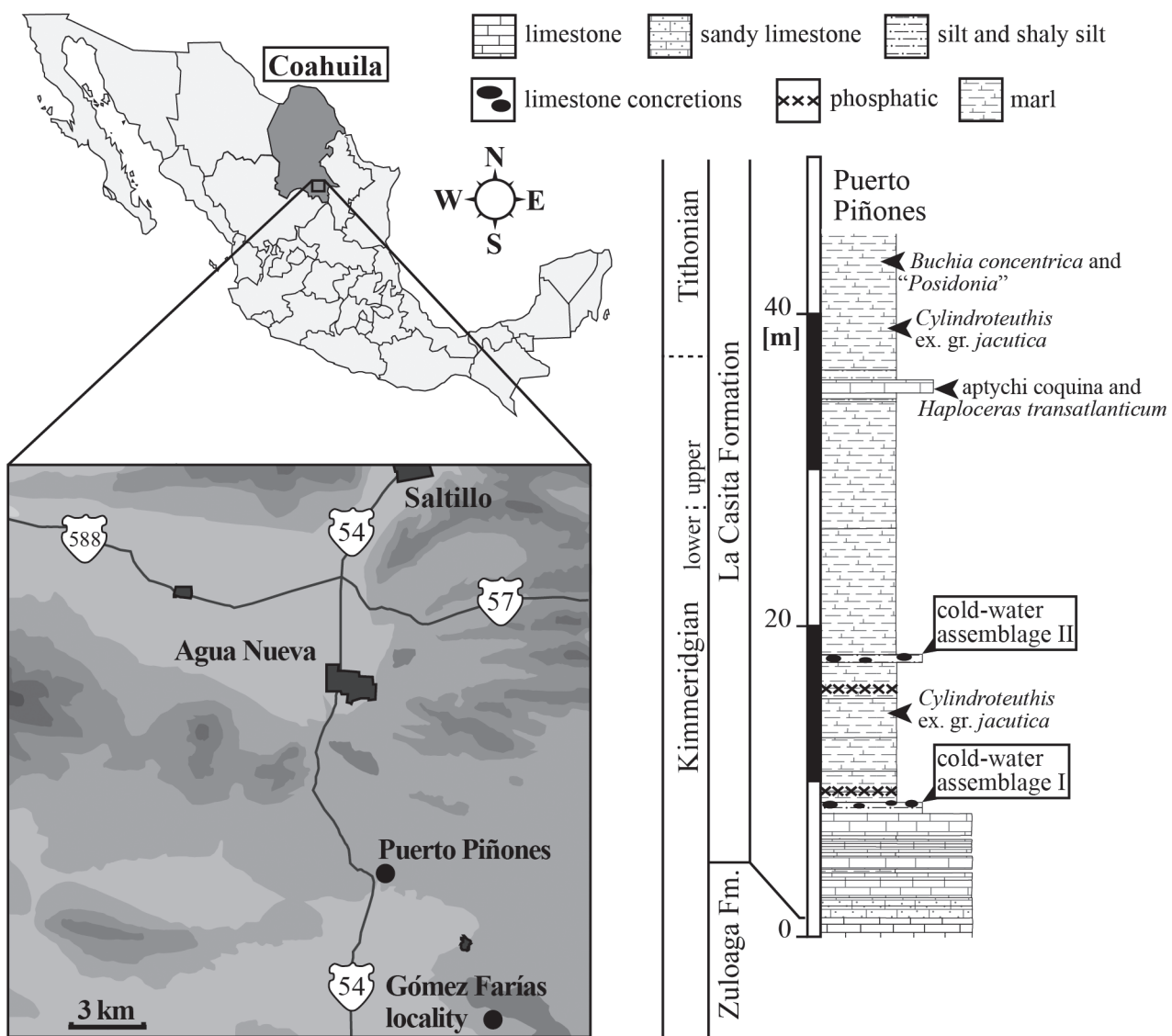


Figure 1. Map of Mexico with inset of northeastern Mexico (left). The Puerto Piñones section is located at N25°02.719'/W101°03.396. The faunal assemblages described here were collected in the lower Kimmeridgian part of the La Casita Formation in limestone concretions within a dark grey silt- to sandstone at about 8 m above the formational base (assemblage I), and in limestone concretions within a dark grey siltstone at approximately 16 m above the formational base (assemblage II); right: sedimentary column of the basal La Casita Formation, with additional information on stratigraphy provided by López-Caballero (2009). Boreal belemnites assigned to *Cylindroteuthis* are abundant below and above (Zell *et al.*, 2013). Base map of Mexico simplified after Instituto Nacional de Estadística y Geografía (2013).



Figure 2. Lower Kimmeridgian assemblage II from the La Casita Formation at Puerto Piñones: a and b, *Idoceras pinonense* n. sp. (a₁, right side, a₂, ventral view, CPC-1429; b₁, right side, b₂, ventral view, CPC-1430); c and d, *Idoceras inflatum* Burckhardt, 1906 (c, left side view, CPC-1431; d₁, left side, d₂, ventral view, CPC-1432); e, *Cylindroteuthis* ex. gr. *jacutica* Sachs and Naljaeva, 1964 (e₁, dorsal view, e₂, cross-section drawing at alveolar opening; dashed line indicates position of the phragmocone; CPC-1090); f and g, *Cylindroteuthis cuspidata* Sachs and Naljaeva, 1964 (f₁, g₁, dorsal views, f₂, g₂, left lateral views, f₃, g₃, cross-section drawings at mid-part of rostrum; f, CPC-1082, g, CPC-1079); h-k, *Buchia concentrica* (J. de C. Sowerby, 1827) (h, left valve, CPC-1433; i, internal mould of left valve, CPC-1434; j, left valve, CPC-1435; k, right valve, CPC-1436).

The belemnite *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjaeva, 1964 was recently identified in an approximately 5 m thick siltstone unit located between the two assemblages discussed here and in a single layer of about 1 m thickness at approximately 21 m above assemblage II. It was originally assigned to *C. lenaensis* Sachs and Nalnjaeva, 1964 by Zell *et al.* (2013). A red-colored coquina unit of aptychids and the ammonite *Haploceras transatlanticum* Burckhardt, 1906 is present at approximately 17 m above assemblage II and reaches to about 1.2 m thickness. At about 42 m above the formational base, *Buchia concentrica* (J. de C. Sowerby, 1827) was identified, accompanied by a bivalve tentatively assigned to *Bositra* or *Buchia*.

SYSTEMATIC PALEONTOLOGY

The systematic description of ammonites follows Arkell *et al.* (1957), Verma and Westermann (1973) and Wright *et al.* (1996). Abbreviations used: D, diameter; Wh, whorl height; Ww, whorl width; U, umbilical diameter; U/D, umbilical ratio. Ribs were counted adapertural. Bivalve taxonomy follows Cox *et al.* (1969), Zakharov (1987), Bieler *et al.* (2010) and Sha (2012). Abbreviations used for bivalves: H, height; L, length; H/L, height ratio. Synonymy lists are restricted to the most important citations and references used for determinations. Belemnite specimens (CPC-1090, CPC-1082, CPC-1079) were previously described by Zell *et al.* (2013) but were not illustrated. All specimens described here are housed in the *Colección de Paleontología de Coahuila*, at the Museo del Desierto, Saltillo, Coahuila, Mexico. The abbreviation of this collection is CPC.

Class Cephalopoda Cuvier, 1795
Order Ammonoidea Zittel, 1884
Suborder Ammonitina Hyatt, 1889
Superfamily Perisphinctoidea Steinmann, 1890
Family Perisphinctidae Steinmann, 1890
Subfamily Idoceratinae Steinmann, 1890
Genus *Idoceras* Burckhardt, 1906

Type species. *Ammonites balderus* (Oppel, 1863).

***Idoceras pinonense* n. sp.**
(Figure 2a, 2b)

Diagnosis. Evolute idoceratid with abundant constrictions, which are bounded anteriorly by one or two simple and prominent ribs. A simple rib is always situated half-way between two constrictions. Parabolic ribs are present posteriorly to constrictions on the outermost whorl.

Description. Evolute idoceratid, with slightly convergent and convex flanks on inner whorls and nearly straight and parallel flanks on the outermost preserved whorl. The venter is rounded. The whorl section is widest above the umbilical edge. It is oval, compressed, slightly wider than high and somewhat trapezoidal for the outermost preserved whorl. The umbilical region is wide and shallow; the umbilical wall is short and almost vertical, with a pronounced rounded umbilical edge.

Ornamentation of the outermost whorl consists of fine, sharp and densely spaced ribs and shallow wide constrictions. Ribs and constrictions initiate almost radially on the umbilical wall and innermost flank, but they incline forward at mid-flank and they are prorsiradiate at the outer third of the flank. Ribs and constrictions cross the venter without interruption and without a decrease in strength. Most ribs bifurcate at about mid-flank but about one third (31 %) remains simple. Two sets of simple ribs are present; one is situated at about half-way between two constrictions. They are as prominent as neighboring bifurcating

ribs. The second set of simple ribs is always adjacent anteriorly, and occasionally posteriorly, to each constriction. One or two simple ribs, which border the constrictions anteriorly, are the most prominent ribs. At the outermost preserved whorl, specimen CPC-1430 (Figure 2b) exhibits two parabolic ribs with parabolic-node-like swellings situated at the posterior border of the last-preserved two constrictions. One simple rib is present in specimen CPC-1430 (Figure 2b) between a constriction and the simple rib situated in the center between two constrictions. One or two intercalated ribs are present at the posterior side of each constriction. Some ribs initiate between the middle of the flank, others at the ventrolateral shoulder. Ribs are rounded in cross-section, while the majority of ribs is acute at the ventrolateral shoulder and mid-flank of the outermost preserved whorl. Forty six bifurcating ribs (about seven between two constrictions), eight intercalatory ribs, 21 simple ribs and eight constrictions are present on the outermost whorl of specimen CPC-1429 (Figure 2a).

The ornamentation of the inner whorls is similar to that of the outermost whorl, except for slightly wider-spaced ribs. Sutures are only fragmentarily visible.

Etymology. The species name “pinonense” derives from the locality Puerto Piñones, from which both specimens were collected.

Types. Holotype CPC-1429 is a three-dimensionally preserved, almost complete specimen (Figure 2a). Paratype CPC-1430 is a whorl fragment preserved three-dimensionally (Figure 2b). The type material was collected by one of us (WS) in the La Casita Formation at Puerto Piñones, 16 m above the boundary between the Zuloaga and the La Casita formations (Figure 1).

Measurements. The most complete specimen (CPC-1429, Figure 2a) from assemblage II (Figure 1) is here used for dimensions; D=39 mm, U=17.3 mm, U/D=0.44, Wh=12.8 mm, Ww=13.4 mm.

Occurrence. The genus *Idoceras* is abundant and well known in Mexico from early to early late Kimmeridgian strata and is represented by numerous species (summarized by Pessagno and Martin, 2003, and Villaseñor *et al.*, 2012). Reports of idoceratids are rare from younger stratigraphic intervals (e.g., Schumann, 1988; Zell *et al.*, 2014). The two specimens of *Idoceras pinonense* n. sp. were collected from lower Kimmeridgian strata of the La Casita Formation at Puerto Piñones, at approximately 8 m and 16 m above the formational base (Figure 1). The species is associated with *Idoceras inflatum* Burckhardt, 1906 (Figure 2c-2d), with the bivalve *Buchia concentrica* (J. de C. Sowerby, 1827) (Figure 2h-2i) and with the belemnites *Cylindroteuthis cuspidata* Sachs and Nalnjaeva, 1964 (Figure 2f-2g) and *C. ex. gr. jacutica* Sachs and Nalnjaeva, 1964 (Figure 2e).

Discussion. The species is morphologically similar to *Idoceras densicostatum* Imlay (1939, p. 40, pl. 8, figs. 3-5) from the Kimmeridgian “*Idoceras* beds” of the La Casita Formation at La Escondida, south of Soledad, Nuevo León. Compared to our specimens, *Idoceras densicostatum* Imlay, 1939 is less evolute, the whorls are more compressed, the whorl section is widest at the umbilical edge, constrictions are more strongly curved towards anteriorly and the venter is almost smooth. Our specimens resemble “*Virgatospinctes*” cf. *denseplicatus* (Waagen), described by Imlay (1943, p. 535, pl. 89, figs. 1-4) from the Upper Jurassic of the Placer de Guadalupe district, eastern Chihuahua. The latter is less evolute and has a lower portion of bifurcating ribs (about one-third) as compared to simple ribs. In addition, ribbing is denser and ribs incline stronger forward on the flanks; they cross the venter nearly in transverse direction. The two parabolic ribs with parabolic-node-like swellings situated at the outermost preserved whorl of our largest specimen CPC-1430 (Figure 2b) indicate that the final body chamber is preserved. A similar aperture was documented for the Oxfordian *Nebroditites* (*Enayites*), in which three parabolic nodes associated with constrictions were interpreted to characterise the final body chamber

(Brochwicz-Lewiński and Różak, 1976). Parabolic ribs and parabolic-node-like swellings are not present in specimen CPC-1429 (Figure 2a), which is smaller than CPC-1430.

***Idoceras inflatum* Burckhardt, 1906**

(Figure 2c, 2d)

Idoceras inflatum Burckhardt, 1906, p. 65, pl. 8, figs. 5-8.

Description. Evolute idoceratid; inner whorls with convergent and convexly rounded flanks and outermost preserved whorl with nearly flat and parallel flanks. The venter is rounded. The whorl section is rounded to slightly depressed ovate, slightly wider (Ww=15.5 mm) than high (Wh=14 mm), widest at mid-flank. The umbilical region is wide and shallow, the umbilical wall pronounced and vertical, the umbilical edge is rounded.

Fine to prominent unequally spaced ribs are present on the outermost preserved whorl. Ribs initiate radially on the umbilical wall; they incline forward on the umbilical shoulder and are nearly straight to about mid-flank where they slightly bend forward and pass the outer third of the flanks and the venter prorsiradially. Ribs cross the venter without interruption or decrease in strength. Most ribs bifurcate slightly above the middle of the flank, while about every fifth (19 %) remains simple. A single trifurcating rib is preserved on the outermost whorl. Intercalated ribs of unequal strength initiate between mid-flank and the ventrolateral shoulder. Ribs are rounded in cross-section. Specimen CPC-1432 (Figure 2d) presents 30 bifurcating ribs, four intercalated ribs and seven simple ribs on the outermost whorl. Ornamentation of inner and outer whorls seems to be identical. Sutures are not visible in the present material.

Material. Two three-dimensionally preserved fragmented specimens (CPC-1431 and CPC-1432).

Occurrence. *Idoceras inflatum* Burckhardt, 1906 was previously known only from the Kimmeridgian *Idoceras* Beds of the La Casita Formation at Vereda del Quemado, Mazapil region, Zacatecas (Burckhardt, 1906).

Discussion. Our specimens exhibit all characteristics of *Idoceras inflatum* described by Burckhardt (1906, p. 65, pl. 8, figs. 5-8). They also resemble *Idoceras* cf. *hospes* Neumayr described by Burckhardt (1906, p. 46, pl. 10, figs. 8-10) from the Upper Jurassic of Mazapil, northern Zacatecas, but this taxon differs in more regularly spaced and slightly more pronounced ribs, by an almost smooth venter and by a compressed ovate whorl section.

Class Bivalvia Linnaeus, 1758

Order Pectinida Gray, 1854

Superfamily Buchioidea Cox, 1953

Family Buchiidae Cox, 1953

Genus *Buchia* Rouillier, 1845

Type species. *Avicula mosquensis* von Buch, 1844.

***Buchia concentrica* (J. de C. Sowerby, 1827)**

(Figure 2h-2k)

Plagiostoma concentrica J. de C. Sowerby, 1827 in: Sowerby and Sowerby, 1812-1846, p. 113, pl. 559, fig. 1.

Aucella concentrica (J. de C. Sowerby, 1827). Imlay, 1959, p. 157, pl. 16, figs. 1-10.

Buchia concentrica (J. de C. Sowerby, 1827). Zakharov, 1981, p. 64, pl. 3, figs. 1-12.

Buchia (Anauella) concentrica (J. de C. Sowerby, 1827). Buitrón, 1984, p. 93, pl. 1, figs. 4-9.

Buchia (Anauella) concentrica (J. de C. Sowerby, 1827). Poulton *et al.*, 1988, p. 108, pl. 5.3, figs. 13-20.

Buchia (Anauella) concentrica (J. de C. Sowerby, 1827). Mora *et al.*, 2000, fig. 3.

Description. Distinctly inequivalve shell; the left valve is strongly convex, the right valve only slightly convex to almost flat, with strongest convexity in the umbonal region. The posterodorsal margin is long and slightly convex. The anterodorsal margins are shorter and slightly convex. Anterior, posterior and dorsal margins are rounded convex. Opisthogyrous umbones curve inward and are situated anteriorly at about one-third of the shell length. The outline of our specimens is variable; two left valves (Figure 2h, CPC-1433; H=25.4 mm, L=28.5 mm, H/L=0.89) and the right valve (Figure 2k, CPC-1436; H=18.4 mm, L=18.5 mm, H/L=0.99) are inversoid, whereas the internal mould of a left valve in Figure 2i indicates an obliquoid outline. A prominent posterior wing is fragmentarily preserved on the left valve of CPC-1433 (Figure 2h). The ornamentation consists of regularly spaced, distinct and acute concentric ribs crossed by slightly less prominent radial ribs (CPC-1436, Figure 2k). With increasing shell size, ornamentation becomes more distinct. Internal features are not visible.

Material. Two three-dimensionally preserved almost complete left valves (CPC-1433 and CPC-1435), one internal mould of a left valve (CPC-1434), and one almost complete right valve (CPC-1436); all from assemblage II (see Figure 1).

Occurrence. *Buchia concentrica* (J. de C. Sowerby, 1827) was considered to be a Boreal faunal element by Poulton *et al.* (1988) and is common in the upper Oxfordian-lower Kimmeridgian of northern Eurasia and northern North America (e.g., Imlay, 1961; Poulton *et al.*, 1988; Århus *et al.*, 1989). Rare upper Kimmeridgian occurrences from the region are summarized by Surlyk and Zakharov (1982). In Mexico, *Buchia concentrica* (J. de C. Sowerby, 1827) was first described by del Castillo and Aguilera (1895) from the early to ?middle Kimmeridgian of San Luis Potosí and Zacatecas. According to Buitrón (1984) the taxon is a common constituent of the early Kimmeridgian to early late Kimmeridgian "lower shale member" of the La Caja Formation at San Pedro del Gallo, Durango, while Pessagno *et al.* (1999) reported the taxon from the early late Kimmeridgian "Unit E" of the La Caja Formation at Mazapil, northern Zacatecas. It was further identified by López-Caballero (2009; pl. 8, fig. L) in the latest Kimmeridgian Beckeri Zone at Puerto Piñones and by Mora *et al.* (2000) in the lower Tithonian La Caja Formation at Cañón San Matías, northern Zacatecas.

Discussion. *Buchia concentrica* (J. de C. Sowerby, 1827) is distinguished from *Buchia tenuistriata* (Lahusen, 1888), described by Buitrón (1984, p. 93, pl. 1, figs. 10-14) from the late Kimmeridgian of Zacatecas, by stronger, less acute and wider-spaced concentric ribs. In addition, concentric ribs of *B. tenuistriata* (Lahusen, 1888) are less regularly spaced.

DISCUSSION

Age and depositional environment of assemblages described here

The two faunal assemblages described here from Puerto Piñones, southern Coahuila, were deposited in inner- to outer shelf sediments (e.g., Michalzik, 1988; Goldhammer and Johnson, 2001) of the lower La Casita Formation. The lower portion of the La Casita Formation is reported to contain abundant *Idoceras* between 11.5 m and 18 m above the formational base (López-Caballero, 2009). These taxa were described by López-Caballero (2009) and assigned to *Idoceras zacatecanum* Burckhardt, 1906, *I. cf. densicostatum* Imlay, 1939, *I. cf. lorioli* Burckhardt, 1906, *I. cf. tamaulipanum* Imlay, 1939 and *I. sp. gr. durangensis* Burckhardt, 1906. Layers containing these taxa were assigned

by the author to range from the early Kimmeridgian Hypselocyclum-Divisum Zones to possibly the earliest late Kimmeridgian lowermost Acanthicum Zone (see Pessagno and Martin, 2003; Villaseñor *et al.*, 2012). Assemblage I is described here from about 8 m above the formational base and represents the lowermost record of idoceratids at Puerto Piñones, whereas assemblage II, collected at 16 m above the formational base, is situated at the upper portion of the *Idoceras* assemblage described by López-Caballero (2009).

Haploceras transatlanticum Burckhardt, 1906 was identified at Puerto Piñones within a coquina unit accumulating aptychs, at about 17 m above assemblage II described here, or 33 m above the boundary between the Zuloaga and the La Casita formations (Figure 1). This coquina unit clearly reflects sediment condensation. Its red colour, attributed to Fe³⁺ oxides, and the unusual concentration of ammonite shells (e.g. *Haploceras transatlanticum* Burckhardt, 1906) and aptychs welded to each other, are similar to a 1.5 meter thick coquina unit documented from the La Casita Formation of Gomez Farías, southern Coahuila. At Gomez Farías, situated at six kilometres SE of Puerto Piñones, the coquina unit is located at 19 m above the base of the La Casita Formation within the uppermost Kimmeridgian Beckeri Zone (Zell *et al.*, 2014). The Gomez Farías coquinite is documented to contain abundant marine reptilian remains and was interpreted by Zell *et al.* (2014) as a condensational unit. *Idoceras* cf. *schucherti* (Cragin, 1905) and *Haploceras transatlanticum* Burckhardt, 1906 are present in this coquinite. *Haploceras transatlanticum* Burckhardt, 1906 is widespread in northeastern and central Mexico and was reported from the lower Kimmeridgian of Nuevo León (Mullerried, 1946), from the upper Kimmeridgian of Durango (Contreras-Montero *et al.*, 1988; Villaseñor *et al.*, 2000), Tamaulipas (Cantú-Chapa, 1963), Zacatecas, Coahuila and San Luis Potosí (Burckhardt, 1906; Imlay, 1939; Villaseñor *et al.*, 2000; Zell *et al.*, 2014), and from the lower Tithonian of Zacatecas (Burckhardt, 1906; Uhlig, 1911; Imlay, 1939), San Luis Potosí (Verma and Westermann, 1973) and Nuevo León (Imlay, 1939).

According to data summarized by Dzyuba (2004), the belemnite *Cylindroteuthis cuspidata* Sachs and Naljaeva, 1964 ranges from the middle Oxfordian to Kimmeridgian in northern Siberia and north of European Russia. The species was also identified in the early Callovian to early Kimmeridgian of Staffin Bay, Isle of Skye (Nunn, 2007). *Cylindroteuthis* ex. gr. *jacutica* Sachs and Naljaeva, 1964 was reported from the Tithonian (Volgian) of Siberia (Sachs and Naljaeva, 1964; Dzyuba, 2012), but is now known to be common also in distinct lower Kimmeridgian and Tithonian units of the La Caja and La Casita formations (Zell *et al.*, 2013).

The ecologic tolerances of characteristic Boreal *Buchia* spp. vary and some taxa may not imply cold-water environment (e.g., Århus *et al.*, 1990). However, *Buchia concentrica* (J. de C. Sowerby, 1827) is common in northern Eurasia and northern America (e.g., Imlay, 1961; Zakharov, 1981; Poulton *et al.*, 1988; Århus *et al.*, 1989) and is here regarded to indicate cold-water, at least for the seafloor. It is majorly known from the upper Oxfordian-lower Kimmeridgian, but rare upper Kimmeridgian occurrences are also documented (summarized by Surlyk and Zakharov, 1982). Recently, the taxon was identified at Puerto Piñones in the latest Kimmeridgian Beckeri Zone by López-Caballero (2009, pl. 8, fig. L), at about 37 m above the base of the La Casita Formation, and in the lower Tithonian La Caja Formation at Cañón San Matías, northern Zacatecas by Mora *et al.* (2000). The latter authors also identified an early Tithonian horizon containing *Buchia*, “*Posidonia*” and *Aulacommyella*. This horizon is here interpreted to correlate to a level containing *Buchia concentrica* (J. de C. Sowerby, 1827) and a bivalve resembling *Posidonia* at Puerto Piñones, at approximately 42 m above the base of the formation. The presence of *Buchia concentrica* (J. de C. Sowerby, 1827), in assemblage II, indicates that

oxygenation of the bottom water was sufficient for epifaunal colonization of the seafloor, even though hydrodynamics were low in energy (cf. Marinov *et al.*, 2006).

Assemblage II correlates to 15 m below the latest Kimmeridgian (Beckeri Zone) vertebrate Lagerstätten coquina unit of Gomez Farías (Zell *et al.*, 2014) (Figure 3) and to approximately 25 m below the early Tithonian *Buchia*-“*Posidonia*”-*Aulacommyella* assemblage at Cañón San Matías, northern Zacatecas (Mora *et al.*, 2000) (Figure 3).

The two cold-water assemblages described here correlate to the early Kimmeridgian “Lithological Unit II” of the basal La Caja Formation of Mora *et al.* (2000), as documented for Cañón de San Matías, Mazapil region, northern Zacatecas. This unit is approximately 9 m thick and consists of siltstone. Based on ammonites, Mora *et al.* (2000) assigned this unit to the early Kimmeridgian upper Hypselocyclum to lower Divisum Zones.

Lithostratigraphic correlations and taxa identified by López-Caballero (2009) indicate an early Kimmeridgian age and represent the “Lower *Idoceras* Assemblage”, or Hypselocyclum to Divisum Zones (see Villaseñor *et al.*, 2012).

The epifaunal bivalve *Buchia concentrica* (J. de C. Sowerby, 1827), identified in assemblage II of Puerto Piñones is here interpreted to represent an *in situ* record. The mono-specific benthic assemblage and a high organic carbon-content (C_{org}) in the limestone concretion, indicated by dark-color and foul-smelling when split with a hammer, suggest low-oxygen bottom water conditions. These observations coincide with time-equivalent palaeoenvironmental interpretations for the genus *Buchia* in the La Caja Formation at Mazapil (Mora *et al.*, 2000).

The presence of Boreal taxa in the assemblages I and II of Puerto Piñones is here interpreted to be a result of repeated cold-water ingression into the ancient Gulf of Mexico, as previously suggested by Zell *et al.* (2013).

Idoceratids associated with Boreal faunal elements

A global faunal migration episode is documented for the early Kimmeridgian, known as the “Early Kimmeridgian Boreal spread” (Arkell, 1956; Stevens, 1967; Zakharov and Rogov, 2003). Buchiidae, equally abundant in both the Boreal and the Pacific realms, extended their southern geographic distribution at that time reaching as far south as Mexico (e.g., Imlay, 1940, 1965; Mora *et al.*, 2000; Pessagno *et al.*, 2009). At the same time, ammonites (e.g. *Aspidoceras*, *Epicephalites*, *Kossmatia*) extended their distribution westwards into the Pacific Realm and eastwards into the Mediterranean Tethys (Stevens, 1967, and several sources mentioned therein). The cause of the Kimmeridgian “Boreal spread” is not yet conclusively known, but the bioevent correlates with a worldwide incremental encroachment of seas over continental margins (Hallam, 1978; Rogov and Poulton, 2015). Stable isotope data indicate that the Kimmeridgian was a period of extreme greenhouse conditions (e.g., Rogov *et al.*, 2009; Price and Rogov, 2009; Dera *et al.*, 2011). The Kimmeridgian episode of “Boreal spread” was therefore interpreted to be caused either by a re-organization of water circulation during the break-up of Pangea, or by short-term cooling events (Rogov and Poulton, 2015). We agree with Stevens (1967) and other authors that this “spread” was driven by the expansion of cold-water currents and suggest that these ingressions also included the ancient Gulf of Mexico and adjacent regions.

Here we present the first record of Mexican idoceratids associated with Boreal bivalves and Boreal belemnites. The co-occurrence, in assemblage II, of Boreal bivalves and belemnites, indicates low water temperatures at and near the sea-floor. *Idoceras inflatum* Burckhardt, 1906 and *I. pinonense* n. sp., associated with these Boreal faunal elements, may therefore either (1) have been current-transported post-mortem from warm water regions into cold-water environments of the ancient

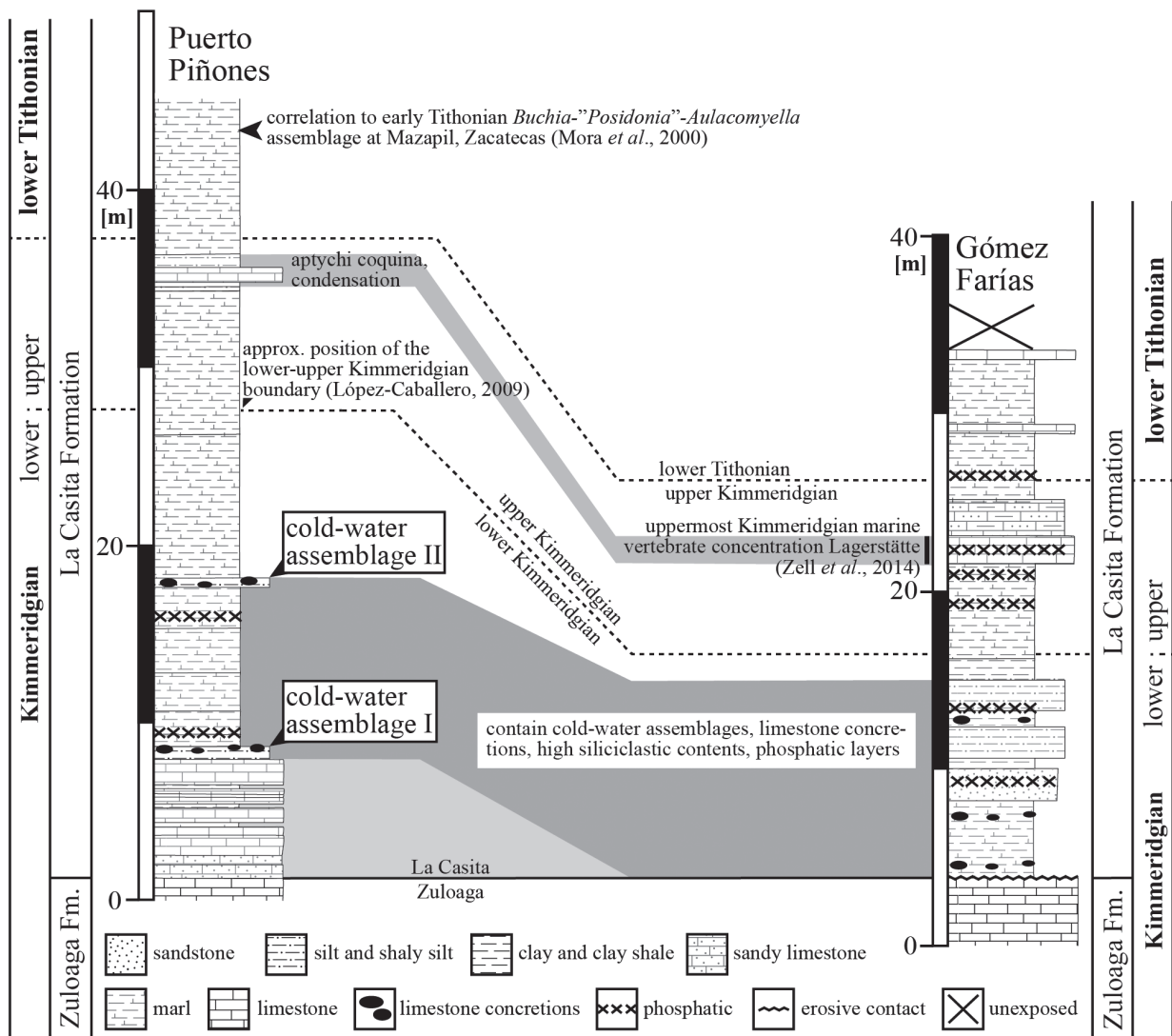


Figure 3. Correlation of the lower La Casita Formation at Puerto Piñones and Gomez Farías, southern Coahuila. The Gomez Farías section is located at approximately 6 km SE of Puerto Piñones (see Fig. 1). Presentation of the Gomez Farías section follows Zell *et al.* (2014), but also includes additional information from Velasco-Segura (2005).

Gulf of Mexico. Alternatively, (2) *Idoceras* species inhabited warm shallow water areas while Boreal belemnites lived in the deep shelf of the Gulf of Mexico in cold-water. (3) Idoceratids identified here represent opportunistic taxa adapted to both cold and warm water environment, or (4) these idoceratids inhabited low-temperature waters.

Stable isotopic signals of belemnites and ammonites co-occurring in the same layers, indicate that these cephalopods colonized different bathymetric levels. While ammonites may have inhabited the upper part of the water column close to the surface, belemnites were interpreted to be deep-water demersal dwellers (e.g., Anderson *et al.*, 1994; Wierzbowski *et al.*, 2013) although the mode of life of these extinct cephalopods is not conclusively known (cf. Mitchell, 2005).

Idoceras inflatum Burckhardt, 1906 is a rare taxon in Mexico and was previously reported only from the Kimmeridgian La Casita Formation at Mazapil, Zacatecas (Burckhardt, 1906). *Idoceras pinonense* n. sp., is here described for the first time and thus also rare. Among the abundant and diverse idoceratids from the La Casita Formation only these rare species are presently associated with the Boreal taxa reported here. Preservation of the body chamber and aperture of

Idoceras pinonense n. sp. specimen CPC-1430 (Figure 2b) indicates that this shell was not transported long-distance from a warm to a cold-water region. The two assemblages described here from southern Coahuila were deposited in a shelf setting of the La Caja Formation, in water depths not exceeding 200 metres (Michalzik, 1988; Götze, 1990; Goldhammer and Wilson, 1991; Adatte *et al.*, 1994; Michalzik and Schumann, 1994; Goldhammer, 1999; Goldhammer and Johnson, 2001). Vertical temperature differences between the surface and seafloor should therefore be low and insignificant, compared to the water column in deep-marine environments.

The limited stratigraphic distribution of *Idoceras inflatum* Burckhardt, 1906 and *I. pinonense* n. sp., the absence of other ammonite taxa in the two assemblages discussed here, as well as their deposition in a shallow marine environment, may therefore indicate that both idoceratids were taxa adapted to cold-water environments. In contrast, other Mexican idoceratids were affected by cold-water ingressions. The Tethyan genus *Idoceras* first appears in the early Kimmeridgian Planula Zone (cf. Wierzbowski, 2010) of Europe and is also known e.g. from New Zealand, Japan and Africa, as summarized

by Brochwicz-Lewiński (1973). In Mexico, idoceratids represent the most abundant and diverse ammonite group in early Kimmeridgian strata (e.g., Burckhardt, 1906; Salvador *et al.*, 1993; Pessagno *et al.*, 1999; Villaseñor *et al.*, 2000, 2012), including several endemic species (summarized by Salvador *et al.*, 1993). They are, however, increasingly rare in subsequent cold-water units of the La Casita Formation. This decrease in abundance and diversity may have been a consequence of the “Boreal spread” (e.g., Stevens, 1967).

During the past decades, several Boreal *Buchia* “assemblages” were documented from Upper Jurassic strata of Mexico and adjacent regions, but frequently without a precise information on layers of origin. For example, Contreras-Montero *et al.* (1988) identified *Buchia*, among them *Buchia concentrica* (J. de C. Sowerby, 1827), in Kimmeridgian strata of the La Casita Formation at San Pedro del Gallo, Durango. *Haploceras transatlanticum* Burckhardt, 1906, *Idoceras neohispanicum* Burckhardt, 1912, *I. zacatecanum* Burckhardt, 1906, and several other ammonite species, were also collected from the same layers. From San Pedro del Gallo, Durango, *Idoceras* spp., *Haploceras* cf. *fialar* (Oppel, 1863) (and other taxa) and the bivalve *Aucella* ex. gr. *pallasii* Keyserling (= *Buchia mosquensis*; see Imlay, 1955, and Surlyk and Zakharov, 1982, and several sources mentioned therein) were described by Burckhardt (1912, p. 205) from Kimmeridgian sediments of the La Casita Formation, while Imlay (1961) reported on *Subdichotomoceras* sp. and *Perisphinctes* (*Dichotomosphinctes*) sp. co-occurring with *Buchia concentrica* (J. de C. Sowerby, 1827) in the Kimmeridgian of California and Oregon.

CONCLUSIONS

Here, we provide the first record in Mexico of idoceratid ammonites associated with Boreal belemnites and Boreal bivalves. *Idoceras pinonense* n. sp. and *I. inflatum* Burckhardt, 1906 were collected from limestone concretions, situated in two inner to outer shelf marlstone units of the basal La Casita Formation at Puerto Piñones, southern Coahuila. They co-occur with the belemnites *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjaeva, 1964 and *C. cuspidata* Sachs and Nalnjaeva, 1964, and the bivalve *Buchia concentrica* (J. de C. Sowerby, 1827). This unusual faunal assemblage is early Kimmeridgian in age and characterises episodes of cold-water ingression into the Gulf of Mexico. The faunal migration, known as the “Early Kimmeridgian Boreal spread”, decimated warm water assemblages in the Gulf of Mexico region, which were dominated by idoceratid ammonites other than the taxa described here.

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