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 belemnitas 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, belemnitas 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 assignation 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

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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 associated 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 Nalnjaeva, 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 Nalnjaeva, 1964 and *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjaeva, 1964. Figure 2 illustrates specimens documented here.

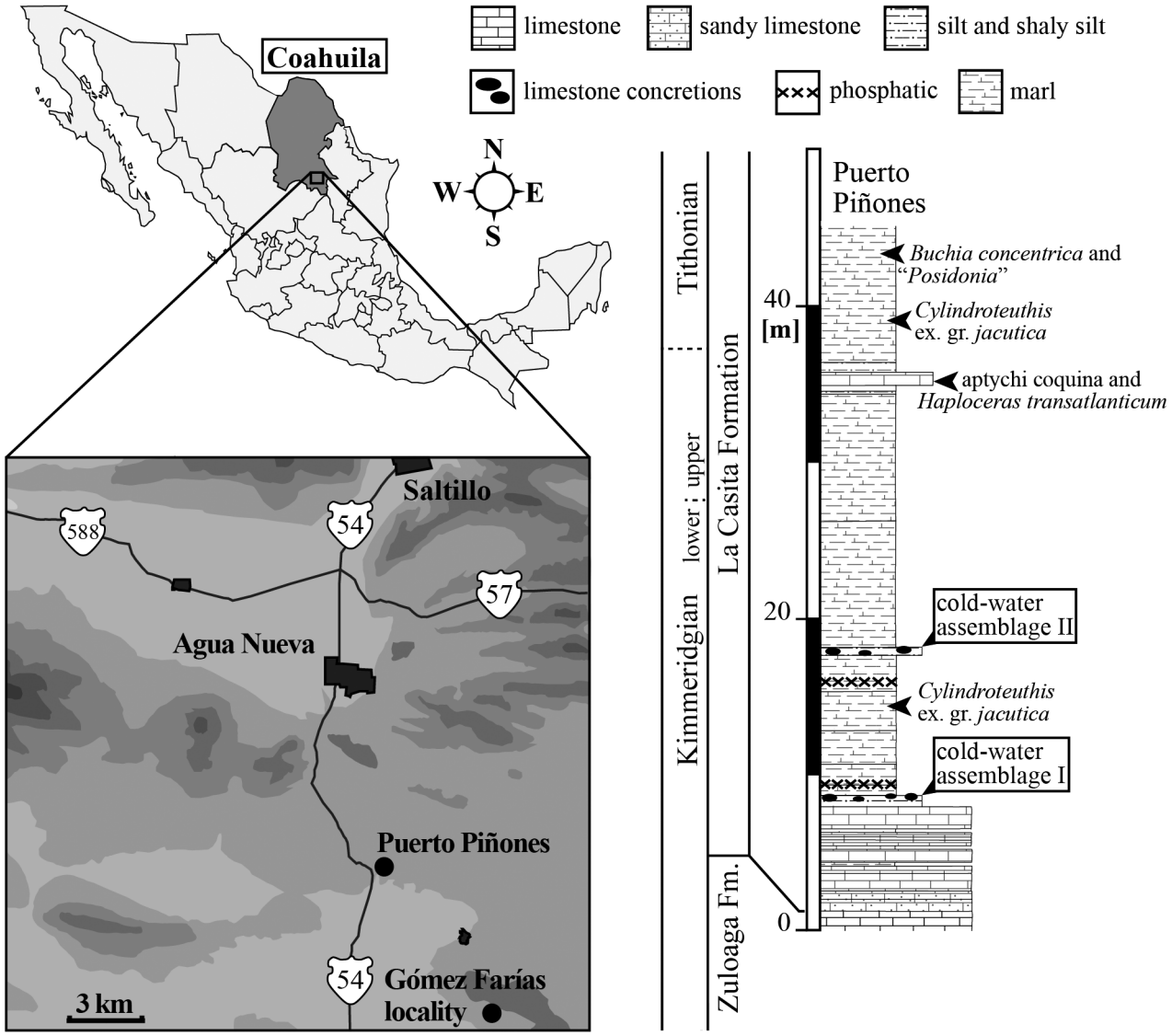

Figure 1. Map of Mexico with inset of northeastern Mexico (left). The Puerto Piñones section is located at N25°02.719`/W101°03.396. The faunal assemblages described here were collected in the lower Kimmeridgian part of the La Casita Formation in limestone concretions within a dark grey silt- to sandstone 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).

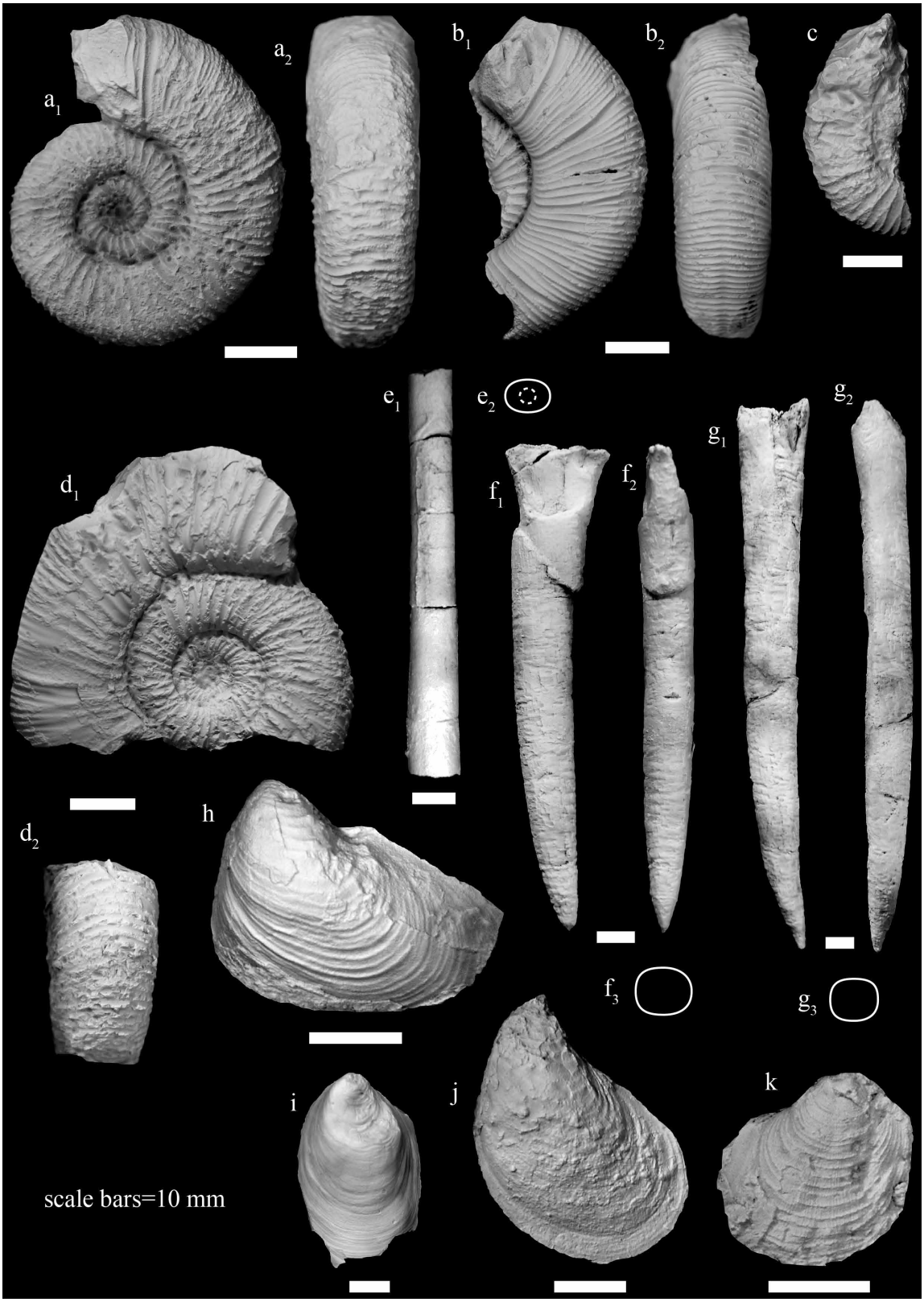

Figure 2. Lower Kimmeridgian assemblage II from the La Casita Formation at Puerto Piñones: a and b, *Idoceras pinonense* n. sp. (a_1, right side, a_2, ventral view, CPC-1429; b_1, right side, b_2, ventral view, CPC-1430); c and d, *Idoceras inflatum* Burckhardt, 1906 (c, left side view, CPC-1431; d_1, left side, d_2, ventral view, CPC-1432); e, *Cylindroteuthis* ex. gr. *jacutica* Sachs and Nalnjaeva, 1964 (e_1, dorsal view, e_2, cross-section drawing at alveolar opening; dashed line indicates position of the phragmocone; CPC-1090); f and g, *Cylindroteuthis cuspidata* Sachs and Nalnjaeva, 1964 (f_1, g_1, dorsal views, f_2, g_2, left lateral views, f_3, g_3, 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 "*Virgatosphinctes*" 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 *Nebrodites* (*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 prorsiradiately. 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 (*Anaucella*) *concentrica* (J. de C. Sowerby, 1827). Buitrón, 1984, p. 93, pl. 1, figs. 4-9.
Buchia (*Anaucella*) *concentrica* (J. de C. Sowerby, 1827). Poulton *et al*., 1988, p. 108, pl. 5.3, figs. 13-20.
Buchia (*Anaucella*) *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 Fe^{3+} 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 Nalnjaeva, 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 Nalnjaeva, 1964 was reported from the Tithonian (Volgian) of Siberia (Sachs and Nalnjaeva, 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 *Aulacomyella*. 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*"-*Aulacomyella* 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

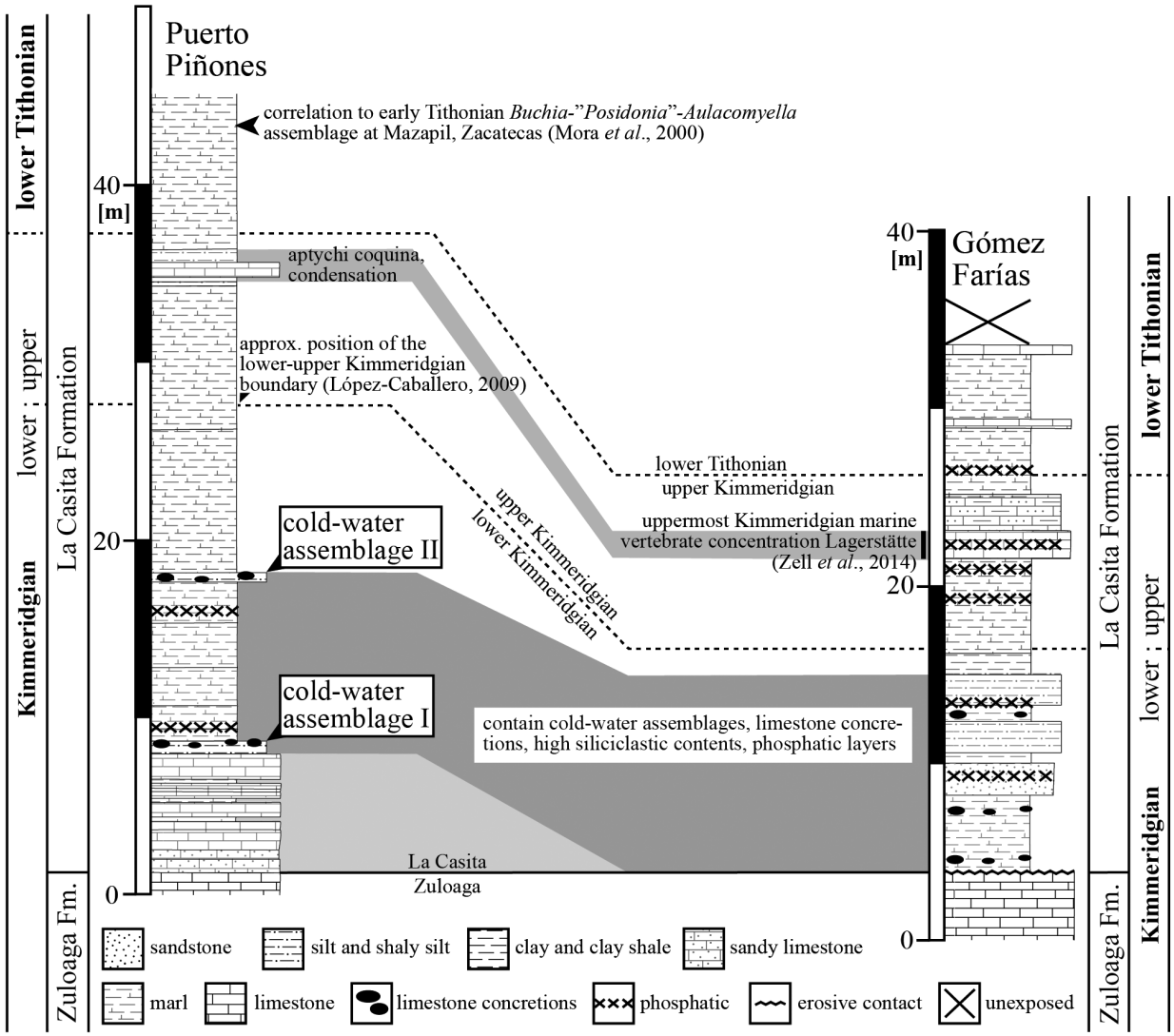

Figure 3. Correlation of the lower La Casita Formation at Puerto Piñones and Gomez Farías, southern Coahuila. The Gomez Farías section is located at approximately 6 km SE of Puerto Piñones (see Fig. 1). Presentation of the Gomez Farías section follows Zell *et al.* (2014), but also includes additional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

Abbink, O., Targarona, J., Brinkhuis, H., Visscher, H., 2001, Late Jurassic to earliest Cretaceous palaeoclimatic evolution of the southern North Sea: Global and Planetary Change, 30, 231-256.

Adatte, T., Stinnesbeck, W., Hubberten, H., Remane, J., 1994, The Jurassic-Cretaceous boundary in Northeastern Mexico. Confrontation and correlations by microfacies, clay minerals mineralogy, calpionellids and ammonites: Geobios, Mémoire Spécial, 17, 37-56.

Anderson, T.F., Popp, B.N., Williams, A.C., Ho, L.Z., Hudson, J.D., 1994, The stable isotopic records of fossils from the Peterborough Member, Oxford Clay Formation (Jurassic): The Geological Society of London Journal, 151, 125-138.

Århus, N., Birkelund, T., Smelror, M., 1989, Biostratigraphy of some Callovian and Oxfordian cores off Vega, Helgeland, Norway: Norsk Geologisk Tidsskrift, 69, 39-56.

Århus, N., Kelly, S.R.A., Collins, J.S.H., Sandy, M.R., 1990, Systematic palaeontology and biostratigraphy of two Early Cretaceous condensed sections from Barent Sea: Polar Research, 8 (2), 165-194.

Arkell, W.J., 1956, Jurassic Geology of the World: London, Oliver and Boyd Ltd., 806 pp.

Arkell, W.J., Furnish, W.M., Kummel, B., Miller, A.K., Moore, R.C., Schindewolf, O.H., Sylvester-Bradley, P.C., Wright, C.W., 1957, Cephalopoda, Ammonoidea, Mollusca 4, Part L, *in* Moore, R.C. (ed.), Treatise on Invertebrate Paleontology: Geological Society of America and University of Kansas Press, L1-L472.

Bieler, R., Carter, J.G., Coan, E.V., 2010, Classification of bivalve Families, *in* Bouchet, P., Rocroi, J.-P. (eds.), Nomenclator of Bivalve Families. Malacologia, 52 (2), 113-184.

Brigaud, B., Pucéat, E., Pellenard, P., Vincent, B., Joachiminski, M.M., 2008, Climate fluctuations and seasonality during the Late Jurassic (Oxfordian-Early Kimmeridgian) inferred from $\delta^{18}O$ of Paris Basin oyster shells: Earth and Planetary Science Letters, 273, 58-67.

Brochwicz-Lewiński, W., 1973, Some remarks on the origin of the subfamily Idoceratinae Spath, 1924 (Perisphinctidae, Ammonoidea): Acta Palaeontologica Polonica, 18(3), 299-320.

Brochwicz-Lewiński, W., Różak, Z., 1976, Oxfordian Idoceratids (Ammonoidea) and their relation to *Perisphinctes* proper: Acta Palaeontologica Polonica, 21(4), 373-390.

Buch, L. von, 1844, Über einige Vesteinerungen aus Moskau: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 536-539.

Buchy, M.-C., 2010, First Record of *Ophthalmosaurus* (Reptilia: Ichthyosauria) from the Tithonian (Upper Jurassic) of Mexico: Journal of Paleontology 84(1), 149-155.

Buchy, M.-C., Frey, E., Stinnesbeck, W., López-Oliva, J.G., 2003, First occurrence of a gigantic pliosaurid plesiosaur in the late Jurassic (Kimmeridgian) of Mexico: Bulletin de la Société Géologique de France 174(3), 271-278.

Buitrón, B.E., 1984, Late Jurassic bivalves and gastropods from Northern Zacatecas, Mexico, and their biogeographic significance, *in* Westermann, G.E.G. (ed.), Jurassic-Cretaceous biochronology and paleogeography of North America: Geological Association of Canada, Special Papers, 27, 89-98.

Burckhardt, C., 1906, La fauna Jurassique de Mazapil avec un appendice sur les fossils de Crétacique inférieur: Boletín del Instituto Geológico de México 23, 1-217.

Burckhardt, C., 1912, Faunes Jurassiques et Cretaciques de San Pedro del Gallo: Boletín del Instituto Geológico de México, 29, 1-261.

Cantú-Chapa, A., 1963, Étude biostratigraphique des Ammonites du centre et de l`est du Mexique (Jurassique supérieur et Crétacé): Mémoires de la Société géologiques de France, 99, new ser. 42, 1-102.

Cantú-Chapa, A., 1967, El límite Jurásico-Cretácico en Mazatepec, Puebla (México): Instituto Mexicano del Petroleo, Tecnología de la Exploración, Sección Geología, Monografía 1, 3-24.

Cantú-Chapa, A., 1989, Precisiones sobre el límite Jurásico-Cretácico en el subsuelo del este de México: Revista de la Sociedad Mexicana de Paleontología, 2 (1), 26-69.

Cecca, F., Martin Garin, B., Marchand, D., Lathuiliere, B., Bartolini, A., 2005, Paleoclimatic control of biogeographic and sedimentary events in Tethyan and peri-Tethyan areas during the Oxfordian (Late Jurassic): Palaeogeography, Palaeoclimatology, Palaeoecology, 222, 10-32.

Chumakov, N.M., Zakharov, V.A., Rogov, M.A., 2014, Did an ice sheet exist in northeast Asia at the Middle-Late Jurassic Boundary? (Critical remarks on the article by Y. Donnadieu et al. (2011) "A mechanism for brief glacial episodes in the Mesozoic Greenhouse"): Stratigraphy and Geological

Correlation, 22 (6), 655-658.
Contreras-Montero, B., Martínez-Cortez, A., Gómez-Luna, M., 1988, Bioestratigrafía y sedimentología del Jurásico Superior en San Pedro del Gallo, Durango, México: Revista del Instituto Mexicano del Petróleo, 20, 5-29.
Cox, L.R., 1953, Lower Cretaceous Gostropoda, Lamellibranchia and Annelida from Alexander I
Land (Falkland Islands Dependencies). Falkland Islands Dependencies Survey Scientific Reports, No. 4, 14 pp.
Cox, L.R., Newell, N.D., Branson, C.C., Casey, R., Chavan, A., Coogan, A.H., Dechaseaux, C., Fleming, C.A., Haas, F., Hetlein, L.G., Keen, A.M., LaRocque, A., McAlester, A.L., Perkins, B.F., Puri, H.S., Smith, L.A., Soot-Ryen, T., Stenzel, H.B., Turner, R.D., Weir, J. 1969, Systematic descriptions, *in* Moore, R.C., Teichert, C. (eds.), Treatise on Invertebrate Paleontology Part N, Volume 1, Mollusca 6, Bivalvia; N227-N489. Geological Society of America and University of Kansas Press, Lawrence, 489 pp.
Cragin, F.W., 1905, Paleontology of the Malone Jurassic Formation of Texas: United States Geological Survey Bulletin, 266 (C), 1-172.
Cuvier, G. 1795, Second Mémoire sur l'organisation et les rapports des animaux à sang blanc, dans lequel on traite de la structure des Mollusques et de leur division en ordre, lu à la société d'Histoire Naturelle de Paris, le 11 prairial an troisième [30 May 1795]. Magazin Encyclopédique, ou Journal des Sciences, des Lettres et des Arts, 1795 [1. année] 2, 433-449.
del Castillo, A., Aguilera, J.G., 1895, Fauna fósil de la Sierra de Catorce, San Luis Potosí: Boletín de la Comisión Geológica de México, 1, 1-55.
Dera, G., Brigaus, B., Monna, F., Laffont, R., Pucéat, E., Deconinck, J.-F., Pellenard, P., Joachimski, M.M., Durlet, C., 2011, Climatic ups and downs in a disturbed Jurassic world: Geology, 39, 215-218.
Dzyuba, O.S., 2004, Belemnites (Cylindroteuthidae) and biostratigraphy of the Middle and Upper Jurassic of Siberia, *in* Shurygin, B.N. (ed.), Novosibirsk: Publishing House of SB RAS, Department "Geo", 203 pp. (in Russian with English summary)
Dzyuba, O.S., 2012, Belemnites and Biostratigraphy of the Jurassic-Cretaceous Boundary Deposits of Northern East Siberia: New Data on the Nordvik Peninsula: Stratigraphy and Geological Correlation, 20(1), 53-72.
Föllmi, K.B., 1995, 160 m.y. record of marine sedimentary phosphorus burial: coupling of climate and continental weathering under greenhouse and icehouse conditions: Geology, 23, 859-862.
Frakes, L.A., Francis, J.E., Syktus, J.I., 1992, Climate Models of the Phanerozoic: Cambridge University Press, New York, 274 pp.
Goldhammer, R.K., 1999, Mesozoic sequence stratigraphy and paleogeographic evolution of north east Mexico, *in* Bartolini, C., Wilson, J.L., Lawton, T.F. (eds.), Sedimentary and tectonic history of north central Mexico: Geological Society of America, Special Papers, 340, 1-31.
Goldhammer, R.K., Wilson, J.L., 1991, Part 2 – Tectonic Framework, *in* Goldhammer, R.K., Lehmann, P.J., Todd, R.G., Wilson, J.L., Ward, W.C., Johnson, C.R. (eds.), Sequence Stratigraphy and Cyclostratigraphy of the Mesozoic of the Sierra Madre Oriental, Northeast Mexico – A Field Guidebook: Society of Economic Paleontologists and Mineralogists Foundation, Gulf Coast Section, 3-6.
Goldhammer, R.K., Johnson, C.A., 2001, Middle Jurassic-Upper Cretaceous paleogeographic evolution and sequencestratigraphic framework of the northwest Gulf of Mexico Rim, *in* Bartolini, C., Buffler, R.T., Cantú-Chapa, A. (eds.), The Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins, and Petroleum Systems: The American Association of Petroleum Geologists Memoir 75(3), 45-81.
Götte, M., 1990, Halotektonische Deformationsprozesse in Sulfatgesteinen der Minas-Viejas-Formation (Ober-Jura) in der Sierra Madre Oriental, Nordost-Mexiko: Darmstadt, Germany, University of Darmstadt, Ph.D. thesis, 270 pp.
Gray, J.E., 1854, A revision of the arrangement of the families of bivalve shells (Conchifera). Annals and Magazine of Natural History, ser. 2, 13(77), 408-418.
Gröcke, D.R., Price, G.D., Ruffell, A.H., Mutterlose, J., Baraboshkin, E., 2003, Isotopic evidence for Late Jurassic-Early Cretaceous climate change: Palaeogeography, Palaeoclimatology, Palaeoecology, 202, 97-118.
Hallam, A., 1978, Eustatic cycles in the Jurassic: Palaeogeography, Palaeoclimatology, Palaeoecology, 23, 21-32.
Hyatt, A., 1889, Genesis of the Arietitidae: Smithsonian Contributions to Knowledge, 673, 1-238.
Imlay, R.W., 1939, Upper Jurassic Ammonites from Mexico: Bulletin of the Geological Society of America, 50, 1-78.
Imlay, R.W., 1940, Possible interoceanic connections across Mexico during the Jurassic and Cretaceous periods: Proceedings of the 6th Pacific Science Congress, 1, 423-427.
Imlay, R.W., 1943, Upper Jurassic ammonites from the Placer de Guadalupe district, Chihuahua, Mexico: Journal of Paleontology, 17(5), 527-543.
Imlay, R.W., 1955, Jurassic mollusks from northern Alaska: Geological Survey Professional Paper, 274-D, 69-96.
Imlay, R.W., 1959, Succession and speciation of the pelecypod *Aucella*: United States Geological Survey, Professional Papers, 314-G, 155-169.
Imlay, R.W., 1961, Late Jurassic ammonites from the western Sierra Nevada, California: Shorter Contributions to General Geology, Geological Survey Professional paper, 374-D, 1-30.
Imlay, R.W., 1965, Jurassic marine faunal differentiation in North America: Journal of Paleontology, 39, 1023-1038.
Instituto Nacional de Estadística y Geografía, 2013, Online: URL: http://www.inegi.org.mx (status 23/05/2013).
Jeletzky, J.A., 1965, Late Jurassic and Early Cretaceous Fossil Zones of the Canadian Western Cordillera, British Columbia: Geological Survey of Canada Bulletin, 103, 1-70.
Jenkyns, H.C., Jones, C.E., Gröcke, D.R., Hesselbo, S.P., Parkinson, D.N:, 2002, Chemostratigraphy of the Jurassic system: applications, limitations and implications for palaeoceanography: Journal of the Geological Society, London, 159, 351-378.
Lahusen, J.I., 1888, Über die russischen Aucellen: Trudy Geologicheskogo komiteta, 8 (1), 1-46.
Lecolle de Cantú, F., 1967, *Inoceramus bassei* sp. nov. del Tithoniano de Mazatepec, Puebla (México): Instituto Mexicano del Petroleo, Tecnología de la Exploración, Sección Geología, Monografía 1, Publicación no. 7AI-11, 31-32.
Lécuyer, C., Picard, S., Garcia, J.-P., Sheppard, S.M.F., Grandjean, P., Dromart, G., 2003, Thermal evolution of Tethyan surface waters during the Middle-Late Jurassic: evidence from $\delta^{18}O$ values of marine fish teeth: Paleoceanography, 18(3), 1076, 1-16.
Linnaeus, C., 1758, Systema Naturae Per Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species, Cum Characteribus, Differentiis, Synonymis, Locis. Laurentii Salvii, Holmiae (Stockholm), 824 pp.
López-Caballero, I., 2009, Bioestratigrafía y Tafonomía de la sección estratigráfica Puerto Piñones (Jurásico Superior) del área de Saltillo, Coahuila, México: Mexico, D.F. Universidad Nacional Autónoma de México Master thesis, 143 pp.
Marinov, V.A., Meledina, S.V., Dzyuba, O.S., Urman, O.S., Yazikova, O.V., Luchinina, V.A., Zamirailova, A:G., Fomin, A.N., 2006, Biofacies of Upper Jurassic and Lower Cretaceous Sediments of Central West Siberia: Stratigraphy and Geological Correlation, 14 (4), 418-432.
Michalzik, D., 1988, Trias bis tiefste Unter-Kreide der nordöstlichen Sierra Madre Oriental, Mexiko: Darmstadt, Germany, University of Darmstadt, Ph.D. thesis, 247 pp.
Michalzik, D., Schumann, D., 1994, Lithofacies relations and palaeoecology of a Late Jurassic to Early Cretaceous fan delta to shelf depositional system in the Sierra Madre Oriental of north-east Mexico: Sedimentalogy, 41, 463-477.
Mitchell, S.F., 2005, Eight belemnite biohorizons in the Cenomanian of northwest Europe and their importance: Geological Journal, 40, 1-20.
Mora, A. De la, Olóriz, F., González-Arreola, C., 2000, ´Autochthonous´ bivalve assemblages and palaeoecologic interpretation in the Upper Jurassic-Lowermost Cretaceous La Caja Formation from the Cañón de San Matías (Zacatecas, México): Comptes Rendus de l`Academie des Sciences, Paris, Earth and Planetary Sciences 331, 741-747.
Mullerried, F.K.G., 1946, Geología del estado de Nuevo León: Sobretiro de los Anales del Instituto de Investigaciones Cientificas de la Universidad de Nuevo León 1(2), 1-83.
Myczyński, R., 1999, Inoceramids and buchiids in the Tithonian deposits of western Cuba: a possible faunistic link with South-Eastern Pacific: Studia Geologica Polonica, 114, 77-92.
Nunn, E.V., 2007, Late Jurassic to Early Cretaceous stable isotope and geochemical records from the northern high latitudes: implications for

palaeoclimate: UK, University of Plymouth, Ph.D. thesis, 441 pp.
Oppel, A., 1862-1863, Palaeontologische Mitteilungen, III. Ueber jurassische Cephalopoden: Palaeontologische Mittheilungen aus dem Museum des koeniglich Bayerischen Staates 1, 163-266.
Pessagno, E.A.Jr., Cantú-Chapa, A., Hull, D.M., Kelldorf, M., Longoria, J.F., Martin, C., Meng, X., Montgomery, H., Urrutia Fucugauchi, J., Ogg, J.G., 1999, Stratigraphic evidence for northwest to southeast tectonic transport of Jurassic terranes in central Mexico and the Caribbean (western Cuba), Chapter 5, *in* Mann, P. (ed.), Caribbean Basins. Sedimentary Basins of the World, 4: Amsterdam, Elsevier Science B. V., 123-150.
Pessagno, E.A.Jr., Martin, C., 2003, Tectonostratigraphic evidence for the origin of the Gulf of Mexico, *in* Bartolini, C., Buffler, R.T., Blickwede, J. (eds.), The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: American Association of Petroleum Geologists Memoir, 79, 46-74.
Pessagno, E.A.Jr., Cantú-Chapa, A., Mattinson, J.M., Meng, X., Mohsen Kariminia, S., 2009, The Jurassic-Cretaceous boundary: new data from North America and the Caribbean: Stratigraphy 6(3), 185-262.
Poulton, T.P., Zeiss, A., Jeletzky, J.A., 1988, New molluscan faunas from the Late Jurassic (Kimmeridgian and Early Tithonian) of Western Canada: Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 379, 103-115.
Price, G.D., Rogov, M.A., 2009, An isotopic appraisal of the Late Jurassic greenhouse phase in the Russian Platform: Palaeogeography, Palaeoclimatology, Palaeoecology, 273, 41-49.
Riboulleau, A., Baudin, F., Daux, V., Hantzpergue, P., Renard, M., Zakharov, V., 1998, Evolution de la paleotempérature des eaux de la plate-forme russe au cours du Jurassique supérieur: Comptes Rendus de l`Académie des Sciences, 326, 239-246.
Rogov, M., Zakharov, V., Kiselev, D., 2009, Molluscan immigrations via biogeographical ecotone of the Middle Russian Sea during the Jurassic: Volumina Jurassica, 6, 143-152.
Rogov, M.A., Poulton, T.P., 2015, Aulacostephanid ammonites from the Kimmeridgian (Upper Jurassic) of British Columbia (western Canada) and their significance for correlation and palaeobiogeography: Bulletin of Geosciences, 90 (1), 7-20.
Rouillier, C., 1845, (untitled article in which *Buchia* is proposed for *Avicula mosquensis*): Bulletin de la Société Imperiale des Naturalistes de Moscou, 18, 289.
Sachs, V.N., Nalnjaeva, T.I., 1964, Upper Jurassic and Lower Cretaceous belemnites of the northern USSR. The genera *Cylindroteuthis* and *Lagonibelus*: Leningrad, Nauka Press, 168 pp. (in Russian).
Salvador, A., Westermann, G.E.G., Olóriz, F., Gordon, M.B., Gursky, H.J., 1993, Meso-America, *in* Westermann, G.E.G. (ed.), The Jurassic of the Circum-Pacific. World and Regional Geology 3: Cambridge, Cambridge University Press, 93-121.
Schumann, D., 1988, Observaciones paleoecologicas en secuencias del Kimmeridgiano/Tithoniano (Formacion La Casita) de Nuevo León, Noreste de Mexico: Actas de la Facultad de Ciencias de la Tierra de la Universidad Autónoma de Nuevo León, 3, 43-59.
Seibertz, E., Spaeth, C., 1999, Range and distribution of belemnites in the Jurassic and Cretaceous of Mexico: A progress report, *in* V International Symposium: Cephalopods - Present and Past: Vienna, 6-9th September, Abstracts Volume, 134 pp.
Seibertz, E., Spaeth, C., 2008. Belemnites (Coleoid cephalopods) in Jurassic and Cretaceous strata of Mexico: state of the art: II Simposio Geocientífico Internacional Linares, Resúmenes, 204-206.
Sellwood, B., Valdes, P., Price, G., 2000, Geological evaluation of multiple general circulation model simulations of Late Jurassic palaeoclimate: Palaeogeography, Palaeoclimatology. Palaeoecology, 156, 147-160.
Sha, J., 2012, A comparison of *Aucellina* between Argentina and NE China: Relationships of bipolar bivalves: Revue de Paléobiologie, Genève, Vol. Spécial 11, 399-407.
Sowerby, J., Sowerby, J. de C., 1812-1846, The Mineral Conchology of Great Britain: London, Vols. 1-7.
Steinmann, G., 1890, *in* Steinmann, G., Doderlein, L. (eds.), Elemente der Paläontologie, Leipzig, 848 pp.
Stevens, G.R., 1967, Upper Jurassic fossils from Ellswoth Land, west Antarctica, and notes on Upper Jurassic biogeography of the south Pacific region: New Zealand Journal of Geology and Geophysics, 10(2), 345-393.
Surlyk, F., Zakharov, V.A., 1982, Buchiid bivalves from the Upper Jurassic and Lower Cretaceous of east Greenland: Palaeontology, 25(4), 727-753.
Uhlig, V., 1911, Die marinen Reiche des Jura und der Unterkreide: Mitteilungen der Geologischen Gesellschaft in Wien, Heft 3, 329-448.
Veizer, J., Godders, Y., Francois, L.M., 2000, Evidence for decoupling of atmospheric CO_2 and global climate during the Phanerozoic eon: Nature, 408, 698-701.
Velasco-Segura, J.A., 2005, Análisis Litológico y estratigráfico de la Formación La Caja en la "Sierra El Jabalí", Saltillo, Coahuila, México: Linares, N.L., Universidad Autónoma de Nuevo León, Master thesis, 120 pp.
Verma, H.M., Westermann, G.E.G., 1973, The Tithonian (Jurassic) ammonite fauna and stratigraphy of Sierra de Catorce, San Luis Potosí, Mexico: Bulletins of the American Paleontology, 63 (277), 107-320.
Villaseñor, A.B., Olóriz, F., González-Arreola, C., 2000, Recent advances in Upper Jurassic (Kimmeridgian – Tithonian) ammonite biostratigraphy of north-central Mexico based on recently collected ammonite assemblages: GeoResearch Forum, 6, 249-262.
Villaseñor, A.B., Olóriz, F., López Palomino, I., López-Caballero, I., 2012, Updated ammonite biostratigraphy from Upper Jurassic deposits in Mexico: Revue de Paléobiologie, Genève, Vol. Spécial, 11, 249-267.
Weissert, H., Erba, E., 2004, Volcanism, CO_2 and palaeoclimate: a Late Jurassic-Early Cretaceous carbon and oxygen isotope record: Journal of the Geological Society, 161, 1-8.
Wierzbowski, A., 2010, On the Oxfordian/Kimmeridgian boundary and its GSSP – current state of knowledge: Volumina Jurassica, 8, 177-182.
Wierzbowski, H., Rogov, M.A., Matyja, B.A., Kiselev, D., Ippolitov, A., 2013, Middle-Upper Jurassic (Upper Callovian-Lower Kimmeridgian) stable isotope and elemental records of the Russian Platform: Indices of oceanographic and climatic changes: Global and Planetary Change, 107, 196-212.
Wright, C.W., Callomon, J.H., Howarth, M.K., 1996, Cretaceous Ammonoidea (revised), *in* Kaesler, R. (ed.), Treatise of Invertebrate Paleontology Part L, Mollusca 4: Geological Society of America/The University of Kansas Press, Boulder/Lawrence 20, 1-362.
Zakharov, B.A., 1981, Buchiids and the Biostratigraphy of Boreal Upper Jurassic and Neocomian: Academy of Sciences of U.S.S.R., Siberian Division, Trudy Institute of Geology and Geophysics, 458, 1-240.
Zakharov, V.A., 1987, The bivalve *Buchia* and the Jurassic-Cretaceous Boundary in the Boreal Province: Cretaceous Research, 8, 141-153.
Zakharov, V.A., Rogov, M.A., 2003, Boreal-Tethyan mollusk migrations at the Jurassic-Cretaceous Boundary rime and biogeographic ecotone position in the northern hemisphere: Stratigraphy and Geological Correlation, 11(2), 152-171.
Zakharov, V.A., Rogov, M.A., Dzyuba, O.S., Zak, K., Kostak, M., Pruner, P., Skupien, P., Chadima, M., Mazuch, M., Nikitenko, B.L., 2014, Paleoenvironments and paleoceanography changes across the Jurassic/Cretaceous boundary in the Arctic Realm: case study of the Nordvik section (North Siberia, Russia): Polar Research, 33, 1-19.
Zell, P., Beckmann, S., Stinnesbeck, W., 2013, Late Jurassic-earliest Cretaceous belemnites (Cephalopoda: Coleoidea) from northeastern Mexico and their palaeobiogeographic implications: Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 270/3, 325-341.
Zell, P., Beckmann, S., Stinnesbeck, W., 2014, Age and depositional conditions of the marine vertebrate concentration Lagerstätte at Gomez Farías, southern Coahuila, Mexico: Journal of South American Earth Sciences, 56, 91-109.
Zittel, K.A. von, 1884, Cephalopoden, *in* Zittel, K.A. von (ed.), Handbuch der Paläontologie, Band 1, Abteilung 2, Lieferung 3, Oldenbourg, Munich and Leipzig, 893 pp.

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