

## Biostratigraphic and paleobiogeographic significance of the Darriwilian microfossils from the top of San Juan Formation in the Los Baños de Talacasto section, Central Precordillera (Argentina)

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**ABSTRACT.** The microfossil hosted in the strata of the upper part of the San Juan Formation has been widely studied in several sections to the northward of the Argentinian Central Precordillera. In contrast, the coeval strata at the Los Baños de Talacasto section, in the southern part of the Central Precordillera, have scarce biostratigraphic and sedimentological data. In this work, a conodont association together with single ostracod species are documented for the first time in this section. The record of the *Lenodus crassus* and *L. pseudoplanus* zones confirms the Darriwilian age for these beds and accurately correlates them with equivalent strata of the San Juan Formation studied in several sections of the Central and Eastern Precordillera. The microfacies analysis verifies the presence of *Nuia sibirica* Maslov, 1954, peloids, intraclasts, cyanobacteria, calcareous algae, and a possible microbialite indicating a shallow warm-water subtidal environment, in equatorial to subequatorial climate. This suggests a low latitudes position for Precordillera during the early-middle Darriwilian. The conodont genus *Aurilobodus* Xiang and Zhang is recognized for the first time from the Precordillera, and the *Aurilobodus leptosomatus* An specimens are described and illustrated. This genus shows affinities to the warm water in shallow marine environments of North China, Central Asia, South Tibet, western Thailand, Australia, and Newfoundland, suggesting probable ties between Precordillera and these regions. The record of the ostracod *Pilla nodospinosa* Salas in the study section would agree with the correlation of the top of San Juan Formation with the lower levels of the Las Aguaditas Formation in the Central Precordillera, and also suggests paleobiogeographic links with Eastern Gondwana and Australia regions during the Darriwilian times.

**Keywords:** Conodont, Ostracod, Carbonate, Ordovician, San Juan Formation, Argentina.

**RESUMEN.** Importancia bioestratigráfica y paleobiogeográfica de los microfósiles darriwilianos de la parte superior de la Formación San Juan en la sección de Los Baños de Talacasto, Precordillera Central (Argentina). Los microfósiles presentes en la parte superior de la Formación San Juan han sido ampliamente estudiados en varias secciones de la parte norte de la Precordillera Central Argentina. En contraste, los estratos coetáneos de la sección aflorante en Los Baños de Talacasto, en la parte sur de la Precordillera Central, disponen de escasos datos bioestratigráficos y sedimentológicos. En este trabajo, se documenta por primera vez en esta sección una asociación de conodontes junto con una especie de ostrácodo. La asociación de conodontes identificados permite reconocer las zonas *Lenodus crassus* y *L. pseudoplanus*, que confirman la edad darriwiliana de estos estratos y permite una correlación precisa con estratos equivalentes de varias secciones estratigráficas de la Precordillera Central y Oriental. Mediante el análisis de las microfacies se identificó la

presencia de *Nuia sibirica* Maslov, 1954, peloides, intraclastos, cianobacterias, algas calcáreas y posibles microbialitas que indican un ambiente submareal de aguas cálidas y someras, en un clima ecuatorial a subecuatorial, lo que sugiere una posición latitudinal baja para la Precordillera durante el Darriwiliano temprano-medio. El género de conodonte *Aurilobodus* Xiang y Zhang es reconocido por primera vez en la Precordillera, y se describen e ilustran los ejemplares de la especie *Aurilobodus leptosomatus* An. Este género sugiere afinidades con ambientes marinos de aguas cálidas poco profundos del norte de China, Asia Central, sur del Tíbet, el oeste de Tailandia, Australia y Newfoundland, lo que permite inferir probables vínculos entre la Precordillera y esas regiones. El registro del ostrácodo *Pilla nodospinosa* Salas en la sección de estudio estaría de acuerdo con la correlación de la parte superior de la Formación San Juan con los niveles inferiores de la Formación Las Aguaditas en la Precordillera Central, y también sugiere vínculos paleobiogeográficos con las regiones de Gondwana Oriental y Australia durante el Darriwiliano.

*Palabras clave:* Conodonte, Ostrácodo, Carbonato, Ordovícico, Formación San Juan, Argentina.

## 1. Introduction

The Darriwilian conodont biostratigraphy from the Precordillera in western Argentina has experimented a substantial improvement in last years. Several extensive studies on conodonts recovered from different sections in Central and Eastern Precordillera (Heredia and Mestre, 2011, 2013; Feltes *et al.*, 2016; Mestre and Heredia, 2013a, b, 2020a, b; Mestre, 2014; Heredia *et al.*, 2017; Mango *et al.*, 2019; Serra *et al.*, 2017a) suggest affinity to Baltoscandia and South China for this time interval. Recently, Heredia *et al.* (2017) and Mestre and Heredia (2020b) refined the Darriwilian conodont biostratigraphy for the Precordillera, recording the lower and upper boundaries of this stage and documented the following biozones (in ascending order): the *Lenodus antivariabilis*, *Lenodus variabilis*, *Lenodus crassus*, *Lenodus pseudoplanus*, *Lenodus suecicus* (*Pygodus lunnensis* and *Pygodus anitae* subzones), and *Pygodus serra* (with *Eoplacognathus robustus* and *Eoplacognathus lindstroemi* subzones).

Regarding the ostracods, this group remained scarcely documented from Precordillera until the last decades, in which a series of detailed systematic studies were carried out. Most of the known ostracods are from the Las Aguaditas Formation beds (Darriwilian-Sandbian), where species of the major groups (Palaeocopa, Binodicopa, Leiocopa, and Metacopa) have been described (Schallreuter, 1996; Salas, 2002a, b, 2003). Both the Floian and Katian faunas are still poorly known, with only isolated reports (Schallreuter, 1995a, b, c; Schallreuter and Hinz-Schallreuter, 1999; Salas, 2007). These studies, in the Ordovician rocks of the Argentine Precordillera, have shown a relatively high diversity of this fossil group in the area.

The study area (Fig. 1) is located in the Central Precordillera, which is considered as typical thin-skinned fold and thrust belt with a vergence to the east. All previous studied sections in the Central Precordillera (Mestre, 2012; Mestre and Heredia, 2013a, b; Heredia, 2012), where the top of the San Juan Formation outcrops, are located on the western margin of each thrust fault, by the contrary, there is no data of this formation from the eastern margin. The exploration of new areas and sections from the Central Precordillera is an imperative assignment for increasing the knowledge on the Darriwilian basin paleogeography, as well as the microfossil diversity and distribution.

This work provides an integrated analysis of new data on conodont, ostracods, microfacies analysis, and sedimentary features of the uppermost beds of the San Juan Formation in the Los Baños de Talacasto section with the aim to discuss the biostratigraphic and basin correlation, as well as the paleoenvironmental and paleobiogeographic significance of this information.

## 2. Material and Methods

Conodonts and ostracods were collected from 13 samples from limestone beds at 0,5-2 m intervals from the upper part of the San Juan Formation at the Los Baños de Talacasto section (Figs. 1, 2). Initially, 1-2 kg of each sample was dissolved in dilute formic acid with additional material processed if needed, following Stone (1987). The insoluble fraction of each sample was hand-picked for conodonts and ostracods resulting in recovery of *ca.* 100 identifiable conodont elements and 7 ostracods (the specimens are internal molds with poor preservation) (Table 1). Conodonts and ostracods are housed in the collection of the Instituto de Geología “Emiliano Aparicio”

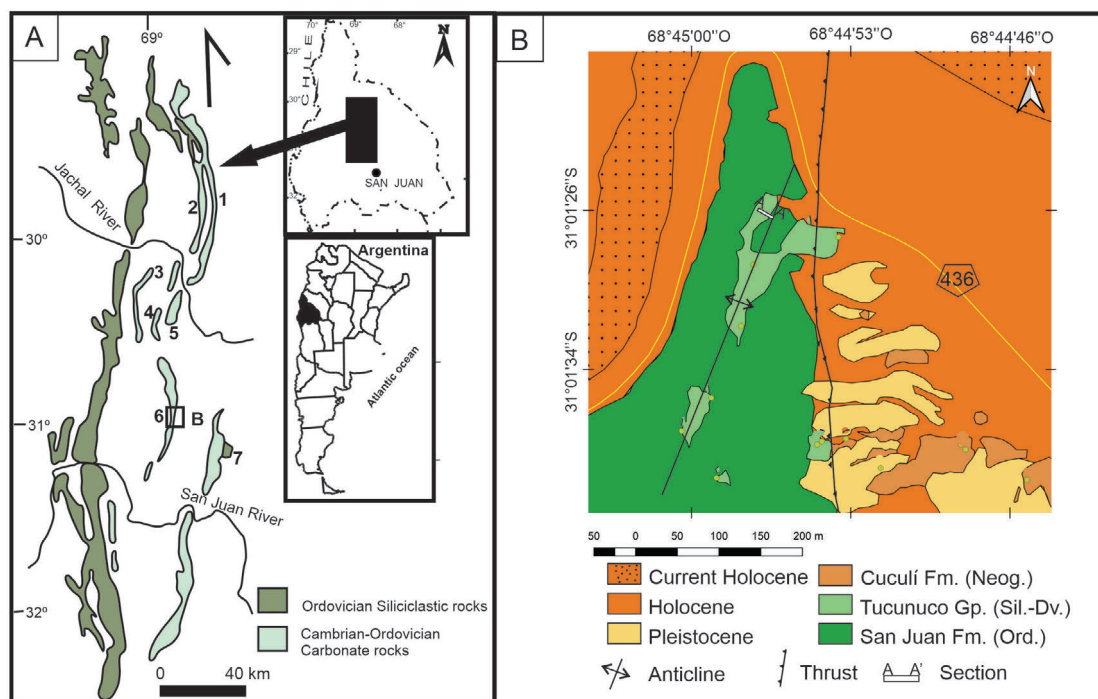


FIG. 1. A. Location of the study area (box B) and other localities mentioned in the text. 1: Del Aluvi3n Creek; 2: Los Amarillitos; 3: Las Aguaditas; 4: Las Chacritas river; 5: Cerro La Chilca; 6: Talacasto; 7: Villicum Range. B. Geology of the Los Ba3os the Talacasto area, AA' shows the location of the studied section.

(INGEO) at the Universidad Nacional de San Juan, under the code-MP. The ostracod specimens were photographed with a SEM microscope in the LAMARX (Laboratorio de Microsp3p3a Electr3nica y An3lisis de Rayos X) laboratory at the Universidad Nacional de C3rdoba, and conodonts with a SEM microscope in the Instituto de Investigaciones Mineras de la Universidad Nacional de San Juan (IIM-UNSJ), Argentina. Eighteen thin and polished sections were made to identify fossils and to analyze the distribution of carbonate components. A petrological investigation of the thin and polished sections was performed using Leica DM2700 microscopes and Lanset binocular microscopes.

### 3. Geological setting

The Precordillera is placed in the western central region of Argentina and extended in north-south direction through La Rioja, Mendoza, and San Juan provinces (28°-33° S). This morphostructural province was defined by Furque and Cuerda (1979), and then

it was divided into three different belts: Western, Central, and Eastern (Ortiz and Zambrano, 1981; Baldis *et al.*, 1982).

The San Juan Formation, mainly developed in Central and Eastern belts of the Precordillera, is composed of fossiliferous limestone, marly limestone and reef, representing a shallow subtidal environment (Keller *et al.*, 1994; Ca3as, 1999). The lower boundary is transitional to the La Silla Formation and is indicated by the first nodular wackestone and packstone containing the characteristic open-sea marine fauna (Keller *et al.*, 1994). The San Juan Formation is diachronically overlain by black shales and laminar mudstones of the Los Azules and Las Aguaditas formations, north and south of the Talacasto range (Carrera and Astini, 1998; Mestre, 2010, 2014). In the Talacasto range, the San Juan Formation is unconformity overlain by the basal paraconglomerate of the La Chilca Formation. This unit is composed of siliciclastic deposits that represent part of the Ordovician-Silurian glacial event of Gondwana (Peralta, 1990; Astini and Piovano, 1992; Asurmendi *et al.*, 2020).

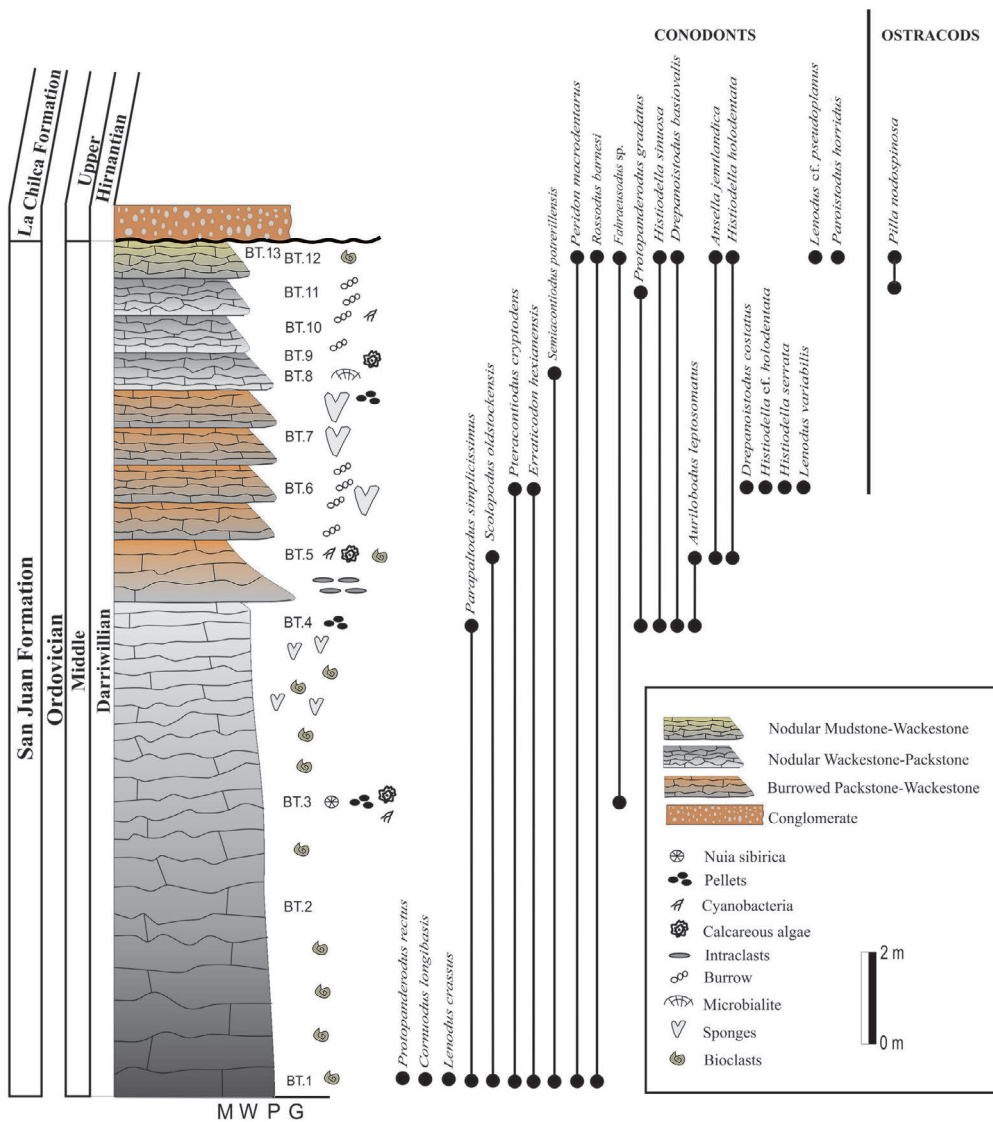


FIG. 2. Stratigraphic column of the upper levels of the San Juan Formation at the Los Baños de Talacasto section, showing the sampled beds and vertical distribution of the conodonts and ostracods species recovered.

The fossil contents, in the Los Baños de Talacasto section (Fig. 1), have been carefully studied over the years (Beresi, 1986; Sánchez *et al.*, 1996; Carrera, 1997; Carrera and Ernst, 2010). However, several topics have not been explored in this section, such as conodont biostratigraphy and carbonate microfacies analysis except by Gallardo (2018).

Sánchez *et al.* (1996) conducted a paleoenvironmental and paleoecological analysis based on sponges and

brachiopods of the *Athiella* brachiopod biozone, in the Cerro Viejo, Cerro La Chilca, Talacasto (Baños de Talacasto) and Villicum sections of the San Juan Formation (Fig. 1). These authors recognize a shallow subtidal environment with intermittent high energy conditions associated with a soft substrate in the Talacasto section. On other hands, based on sponge paleoecology studies, Carrera (1997) recognized three sponge biofacies for the San Juan Formation, they

TABLE 1. DISTRIBUTION AND ABUNDANCE OF CONODONT AND OSTRACOD SPECIES PER SAMPLE FROM THE STUDY SECTION.

Conodonts	Samples													
	<i>L. crassus</i> Zone											<i>L. pseud Z.</i>		
	BT1	BT2	BT3	BT4	BT5	BT6	BT7	BT8	BT9	BT10	BT11	BT12	BT13	total
<i>Ansellia jemtlandica</i>	-	-	-	2	-	1	-	-	-	-	-	2	-	5
<i>Aurilobodus leptosomatus</i>	-	-	-	1	3	-	-	-	-	-	-	-	-	4
<i>Cornuodus longibasis</i>	1	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Drepanoistodus basiovalis</i>	-	-	-	2	1	5	-	-	-	-	-	1	-	9
<i>Drepanoistodus costadus</i>	-	-	-	-	-	1	-	-	-	-	-	-	-	1
<i>Erraticodon hexianensis</i>	1	-	-	-	-	3	-	-	-	-	-	-	-	4
<i>Fahraeusodus</i> sp.	-	-	1	-	-	5	-	-	-	-	-	1	-	7
<i>Histiodela holodentata</i>	-	-	-	-	1	3	-	-	-	-	-	1	-	5
<i>Histiodela</i> cf. <i>holodentata</i>	-	-	-	-	-	2	-	-	-	-	-	-	-	2
<i>Histiodela serrata</i>	-	-	-	-	-	1	-	-	-	-	-	-	-	1
<i>Histiodela sinuosa</i>	-	-	-	1	-	2	-	-	-	-	-	3	-	6
<i>Lenodus</i> cf. <i>pseudoplanus</i>	-	-	-	-	-	-	-	-	-	-	-	1	-	1
<i>Lenodus crassus</i>	2	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Lenodus variabilis</i>	-	-	-	-	-	2	-	-	-	-	-	-	-	2
<i>Parapaltodus simplicissimus</i>	2	-	-	1	-	-	-	-	-	-	-	-	-	3
<i>Paroistodus horridus</i>	-	-	-	-	-	-	-	-	-	-	-	1	-	1
<i>Periodon macrodentatus</i>	1	-	-	3	-	-	-	-	-	-	-	1	-	5
<i>Protopanderodus gradatus</i>	-	-	-	3	-	4	-	-	-	-	2	-	-	9
<i>Protopanderodus rectus</i>	2	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Pteracantiodus cryptodens</i>	2	-	-	-	-	3	-	-	-	-	-	-	-	5
<i>Rossodus barnesi</i>	2	-	-	-	-	2	-	1	-	-	-	1	-	6
<i>Scolopodus oldstockensis</i>	6	-	-	-	2	-	-	-	-	-	-	-	-	8
<i>Semiacantiodus potrerillensis</i>	4	-	-	-	-	3	-	1	-	-	-	-	-	8
total	23	0	1	13	7	37	0	2	0	0	2	12	0	97
<b>Ostracods</b>														
<i>Pilla nodospinosa</i>	-	-	-	-	-	-	-	-	-	-	2	7	-	9
gen. sp. ind.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

are *Patellispongia* biofacies, recorded in Talacasto, Villicum and Cerro La Chilca section, which represents a middle ramp setting; biofacies of the elongated sponges, that includes several genera such as *Archaeoscyphia*, *Hudsonosponja*, and *Calycocoelia*, recorded in the Cerro Viejo region, developed in the proximal sector of the distal ramp and finally, the roots biofacies that includes roots of elongated sponges in the Las Aguaditas, Las Tunas and Las Chacritas sections (Fig. 1), representing distal ramp above the storm wave action. Based on the distribution of sponges biofacies Carrera (1997) proposed a shallow water environment for the central and southern region of the last meters of the San Juan Formation (Talacasto, Villicum and Cerro La Chilca) which deepening towards the north

(Cerro Viejo) and the west (Las Aguaditas, Las Tunas and Las Chacritas) of the basin.

#### 4. Facies description and environment interpretation

In this work, we logged and described the topmost 17.26 m of the upper part of the San Juan Formation in the Los Baños de Talacasto area. In the study section, the San Juan Formation is composed of fossiliferous nodular wackestone-packstone interbedded with intraclastic grainstone at the base, followed upward by burrowed packstone-wackestone to wackestone-mudstone with increasing fine-grained siliciclastic rocks with chert nodules to the top (Fig. 2). Fossil remains of sponges, brachiopods,

bryozoans, pelmatozoan ossicles, and trilobites are abundant at the base of the section and decrease to the top. However, the sponge size increases in the same direction.

The microfacies analysis allows recognized four main facies along the section:

**Bioclastic wackestone-packstone (BT1-BT4 samples):** This microfacies is generally light to medium grey with diverse and abundant fossil fauna. The bioclastic and carbonate components consist of remains of brachiopods, pelmatozoan ossicles, gastropods,

sponges, trilobites, ostracods, *Nuia sibirica* (Maslov, 1954) (Fig. 3A), algae, cyanobacteria (Fig. 3A), and pellets. The matrix is micritic, grey in color, locally which is recrystallized and cemented by sparite.

**Intrabioclastic grainstone (BT5 sample):** This microfacies is composed of poorly sorted grainstone light to medium grey in color. The bioclasts include remains of pelmatozoan ossicles, gastropods, bryozoans, trilobites, brachiopods (Fig. 4A), algae (Fig. 3B-D) and cyanobacteria (Fig. 4B). Some bioclasts show geopetal infilling and others have

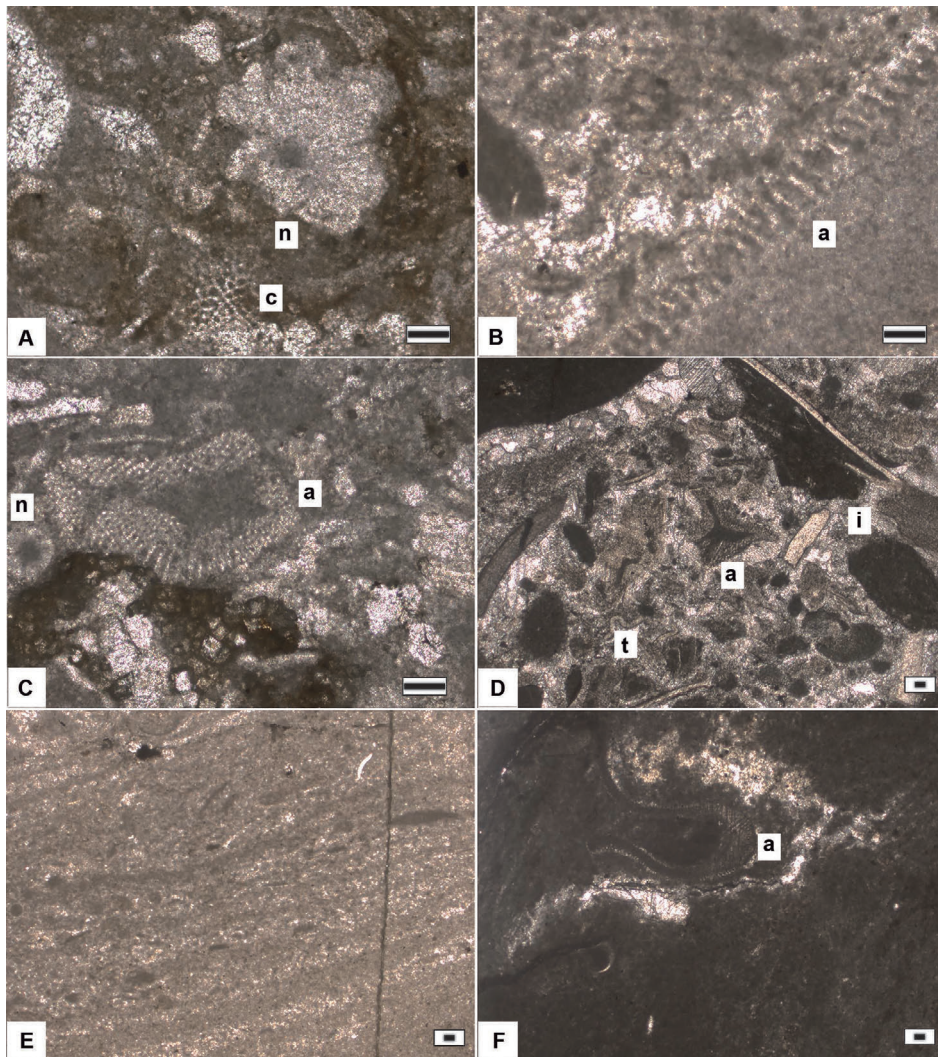


FIG. 3. Photomicrographs of the thin sections from the Los Baños de Talacasto section, the bar scale represents 100 µm. A. BT3 sample, bioclastic wackestone-packstone, *Nuia sibirica* (n), cyanobacteria (c). B-C. BT5 sample, calcareous algae (a). D. BT3 sample, calcareous algae (a) and trilobite (t). E. BT8 sample, microbialite undulatory dark and white laminae. F. BT9 sample, calcareous algae (a).

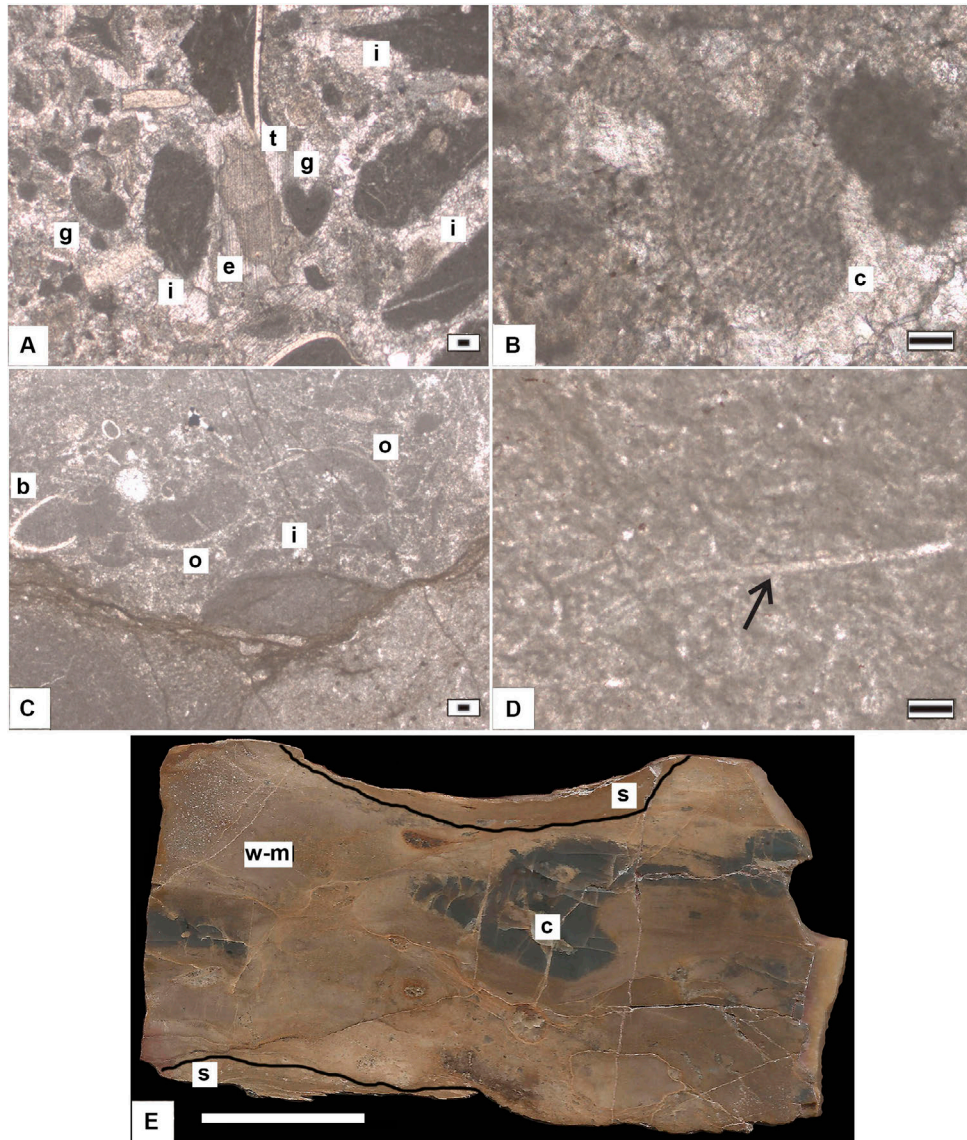


FIG. 4. Photomicrographs of thin and polished sections from the Los Baños de Talacasto section, A-D the bar scale represents 100 μm and in E represents 2 cm. **A.** BT5 sample, Intrabioclastic grainstone microfacies. pelmatozoan ossicles (e), trilobites (t), gastropods (g), angular to subangular intraclasts (i), cemented by blocky sparite. **B.** BT5 sample, cyanobacteria (c). **C.** BT8 sample, bioclastic concentration, ostracods (o), brachiopods (b), intraclasts (i). **D.** BT10 sample, isolated and badly preserved *Girvanella* tubes. **E.** BT13 sample, wackestone-mudstone (w-m) interbedding with thin levels of greenish shale (s) and small nodule of chert (c).

fine microbial cortex. The intraclasts are angular to subangular and show chaotic arrangement suggesting a short transport and reworking, they are cemented by blocky sparite (Fig. 4A).

**Bioclastic packstone-wackestone (BT6-BT9 samples):** This microfacies contains abundant large-

sized sponges on the bedding surface and shell debris of echinoderm, brachiopods, ostracods, gastropods, scarce calcareous algae and intraclasts (Fig. 3F) that are either embedded in a micritic matrix or are nearby cemented by sparite (Fig. 4C). Locally, it is observed a possible microbialite represented

by alternating types of micritic laminae, one with darker dense micritic, and another with lighter micritic and scattered intraclast, giving rise to an alternating simple lamination (Fig. 3E) (Monty, 1976). The bioturbation is intense along of this facies and there are several colored firmground/hardground on the beds surface.

**Bioclastic wackestone-mudstone** (BT10-BT13 samples): This microfacies displays a micritic matrix with flasery texture due to the incipient recrystallization of the micrite. There are few ostracod valves, trilobites, echinoderm fragments, and thin brachiopod shells which are embedded in the silty micrite. Locally is observed isolated and badly preserved *Girvanella* tubes (Fig. 4D). The bioclastic wackestone-mudstone are interbedding with thin levels of greenish shale of 2 to 5 cm of thickness, which increases the thickness to the top, exhibiting a style-nodular to wavy bedding. In the stratigraphically youngest 50 cm of the section is rich in small chert nodules (Fig. 4E).

Based on the presence of fine-grained siliciclastic sediment, intense bioturbation, and the diverse faunal assemblage with robust fossil morphologies, which in some case, they are in live position (especially sponges and brachiopods), we interpret that this facies succession was deposited in a normal shallow subtidal environment below wave action with occasional high-energy episodes (Mamet *et al.*, 1984; Holland, 1993; Mángano and Droser, 2004). The presence of *Nuia sibirica*, as well as cyanobacteria, calcareous algae, and possible microbialite characterizes a warm-water shallow subtidal environment in the photic zone (Riding and Fan, 2001; Liu *et al.*, 2017; Yu *et al.*, 2019) and supports inferences of an equatorial to a subequatorial climate in a low-latitude region (Vachard *et al.*, 2017).

## 5. Conodont biostratigraphy and global correlation

The conodont biostratigraphy studies from the top of the San Juan Formation in the Talacasto range are limited. Lozano and Hünicken (1990) recognized the *P. serra* Zone for the uppermost beds of the San Juan Formation, but these authors did not offer details of the section sampled. Then, those conodont association was reinterpreting by Lehnert (1995), who proposed the *E. suecicus* Zone for these levels based on the presence of the conodont *Histiodela kristinae* Stouge. On the other hand, the *L. variabilis* Zone

was mentioned for the top of San Juan Formation in the Ancha creek (Albanesi *et al.*, 2006).

Despite the low number of conodonts recovered from the carbonate beds of the San Juan Formation at Los Baños de Talacasto section (Table 1), the presence of Darriwilian key conodonts let to identify the following conodont biozones.

### 5.1. *Lenodus crassus* Zone

The record of the *L. crassus* Zone in the Los Baños de Talacasto section is based on the occurrence of the eponymous species at the base of the study section of the San Juan Formation, and the upper limit of this biozone is indicated by the first occurrence of *L. cf. pseudoplanus* (Viira) at 17 m above the base of the section (Fig. 2; Table 1).

In this study, the *L. crassus* (Fig. 5a) is contemporaneous with the occurrences of *L. variabilis* (Sergeeva) (Fig. 5h), *Erraticodon hexianensis* An and Ding, *Histiodela sinuosa* (Graves and Ellison) (Fig. 5b, j), *H. serrata* Harris (Fig. 5c), *H. cf. holodentata* (Fig. 5f), *H. holodentata* Ethington and Clark (Fig. 5g, i, k), and *Aurilobodus leptosomatus* An (Fig. 5d, e). The open nomenclature species *H. cf. holodentata* was proposed by Stouge (2012) as intermediate form between *H. holodentata* and *H. kristinae* (Stouge) and was defined as having a Pa element which cusp is high as the tallest anterior denticle (Jing *et al.*, 2016).

The occurrence of *L. crassus* in this section is significant for regional and intercontinental correlation because it is used as an index species for the zonal schemes in China, Baltoscandia and Precordillera (Zhang, 1998a, b; Löfgren, 2003; Löfgren and Zhang, 2003; Heredia *et al.*, 2017; Mestre, 2013, 2014; Mestre and Heredia, 2013a) (Fig. 6).

The *L. crassus* Zone associated conodont fauna in the study section includes: *Ansella jemtlandica* (Löfgren), *Aurilobodus leptosomatus*, *Cornuodus longibasis* (Lindström), *Drepanoistodus basiovalis* (Sergeeva), *Drepanodus arcuatus* Pander, *Erraticodon hexianensis*, *Fahraeusodus* sp., *Histiodela sinuosa*, *H. serrata*, *H. holodentata*, *H. cf. holodentata*, *L. crassus*, *L. variabilis*, *Parapaltodus simplicissimus* Stouge, *Periodon macrodentatus* (Graves and Ellison), *Protopanderodus gradatus* Serpagli, *P. rectus* (Lindström), *Rossodus barnesi* Albanesi, *Scolopodus oldstockensis* Stouge and *Semiacontiodus potrerillensis* Albanesi (Fig. 2).



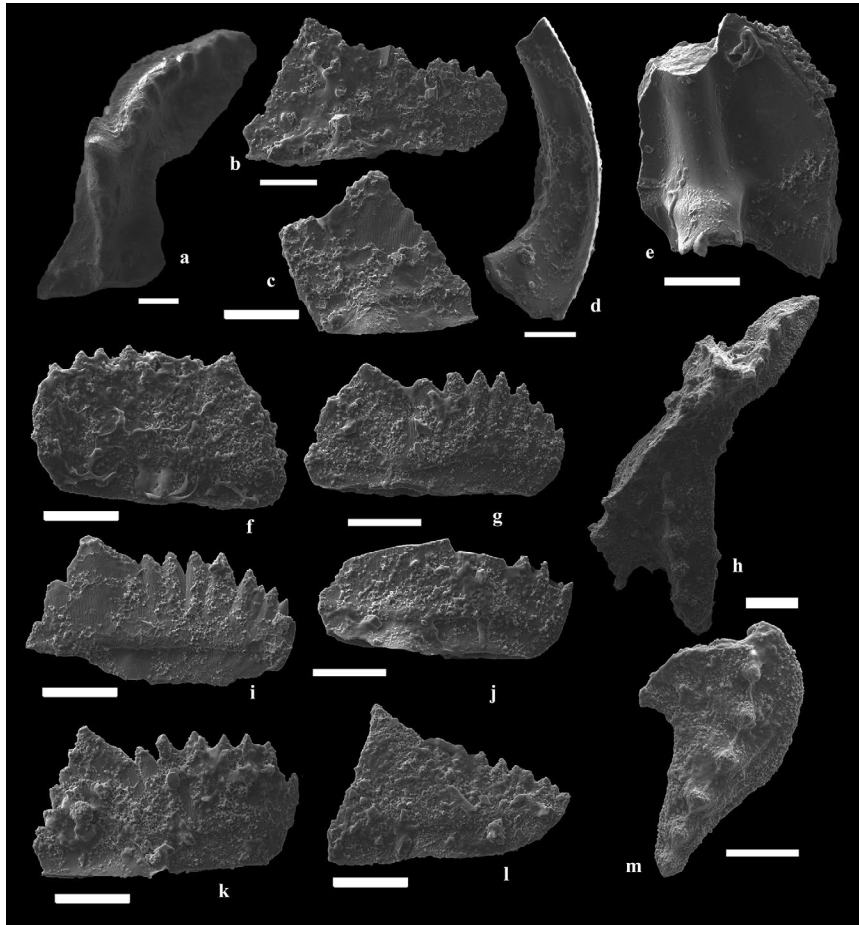


FIG. 5. Microphotographs of scanning electron microscope of the conodont elements. The bar indicates 100  $\mu\text{m}$ . (a-k) specimens from the *L. crassus* Zone and (l-m) specimens from the *L. pseudoplanus* Zone. (a) *Lenodus crassus* (Chen and Zhang), sinistral Pa element, BT1 sample, INGEO-MP-1992 (1); (b, j, l) *Histiodella sinuosa* (Harris), (b) Pa element, BT4 sample, INGEO-MP-2004 (1); (j) Pa element, BT6 sample, INGEO-MP-2020 (1); (l) Pa element, sample BT12, INGEO-MP-2028 (1); (c) *Histiodella serrata* Harris, Pa element, BT6 sample, INGEO-MP 2019 (1); (d-e) *Aurilobous leptosomatus* An, (d) Sb element, BT5 sample, INGEO-MP 2005 (1); (e) Sa element, BT5 sample, INGEO-MP 2005 (2); (f) *Histiodella* cf. *holodentata*, (f) Pa element, BT6 sample, INGEO-MP-2018 (1); (h) *Lenodus variabilis* (Sergeeva), sinistral Pa element, BT6 sample, INGEO-MP 2021 (1); (g, i, k) *Histiodella holodentata* (Etingthon and Clark), (g) Pa element, BT6 sample, INGEO-MP-2017 (4); (i) Pa element, BT6 sample, INGEO-MP 2017 (1); (k) Pa element, BT6 sample, INGEO-MP 2017 (2); (m) *Lenodus* cf. *pseudoplanus* (Viira), Pa element, BT12 sample, INGEO-MP 2034 (1).

The co-occurrence of *H. sinuosa*, *H. serrata*, *H. holodentata*, *H. cf. holodentata* and *A. leptosomatus* in the same stratigraphic level represents an uncommon association of Darriwilian species of *Histiodella*. However, the limestone beds from the top of the San Juan Formation in the study section were deposited predominantly in a carbonate shallow water environment in similar conditions to the Midcontinent early Darriwilian carbonate platform, this setting could have promoted the extension of the biostratigraphic range

of the early Darriwilian species of *Histiodella* into the middle Darriwilian in this area of the Precordillera.

The record of *H. cf. holodentata* and *H. holodentata* allow to correlate the top of San Juan Formation with the Darriwilian strata from Lévis Formation (Maletz, 2009; Stouge, 2012), the upper part of the Oil Creek Formation (Oklahoma) (Bauer, 2010), Thompson Creek (New Zealand) (Zhen *et al.*, 2009), lower part of the Dawangou Formation from the Tarim Basin (Du *et al.*, 2005; Zhen *et al.*, 2011), North

System	Series	Stages	Baltoscandia	South-Central China	Precordillera		
			Bergström (1971); Lofgren and Zhang (2003)	Zhang (1998a)	Heredia <i>et al.</i> (2017); Mestre and Heredia (2020)		
Ordovician	Upper	Sandb.	<i>A. tvaerensis</i>	<i>A. tvaerensis</i>	<i>A. tvaerensis</i>		
			<i>Pygodus anserinus</i>	<i>Y. jianyeensis</i> - <i>P. anserinus</i>	<i>Pygodus anserinus</i>		
	Middle	Darrivillian	<i>P. serra</i>	<i>li.</i>	<i>Y. protoramosus</i>	<i>P. serra</i>	<i>E. lind.</i>
				<i>ro.</i>			<i>E. rob.</i>
				<i>re.</i>	<i>Y. foliaceus</i>		
				<i>fo.</i>			
	<i>E. suecicus</i>	<i>P. anitae</i>	<i>E. suecicus</i>	<i>L. suecicus</i>	<i>P. anitae</i>		
		<i>P. lunnensis</i>			<i>P. lunnensis</i>		
	<i>E. pseudoplanus</i>	<i>M. ozarkodella</i>	<i>M. ozarkodella</i>	<i>Dzikodus tablepointensis</i>	<i>M. ozarkodella</i>	<i>L. pseudoplanus</i>	
							<i>M. hagetiana</i>
	<i>Y. crassus</i>	<i>Y. crassus</i>	<i>Y. crassus</i>		<i>Y. crassus</i>	<i>L. crassus</i>	
	<i>L. variabilis</i>	<i>L. variabilis</i>	<i>L. variabilis</i>		<i>L. variabilis</i>	<i>L. variabilis</i>	
	Daping.	<i>B. norrlandicus</i>	<i>L. antivariabilis</i>		<i>L. antivariabilis</i>	<i>L. antivariabilis</i>	
			<i>Trapezognathus quadrangulum</i>			?	

FIG. 6. Darrivillian conodont biostratigraphical chart from the Precordillera. The shadow area represents the conodont zones recorded in the study section.

China Slope successions (Myrow *et al.*, 2015; Jing *et al.*, 2016, 2020) and Jiangnan Slope successions (Wang *et al.*, 2019). *A. leptosomatus* in association with *H. holodentata* allow a close correlation with the carbonate bed from the Thong Pha Phum section (Agematsu *et al.*, 2008), the Beianzhuang Formation (North China Platform) (Wang *et al.*, 2014), carbonate-mixed shallow water platform from the Kazakhstan in the western part of the Central Asian Fold Belt (Tolmacheva, 2014), the lower and middle part of the Goldwyer Formation (Caning basin) (Zhen *et al.*, 2020; Zhen, 2020), the warm-water carbonates of the Alai Formation in southern Xizang (Tibet) (Yu *et al.*, 2019) and the Lower Formation (Chiatsun

Group) from the Nyalam region, southern Tibet (Stouge *et al.*, 2021).

**5.2. *Lenodus pseudoplanus* Zone**

The sample BT12 yielded a fragmented Pa element of *L. cf. pseudoplanus* (Fig. 5m), allowing the recognition of the eponymous biozone. This sample also includes the following species: *A. jemtlandica*, *D. basiovalis*, *Fahraeusodus* sp., *Paroistodus horridus* (Barnes and Poplawski), *P. macrodentatus*, *H. sinuosa* (Fig. 5l), and *Rossodus barnesi* (Fig. 2).

The record of *L. pseudoplanus* Zone in the Los Baños de Talacasto section represents the most

southern record for this conodont biozone in the Central Precordillera. It is also significant for the intercontinental correlation since it is used as an index species for the zonal schemes in China, Baltoscandia, Australia and Precordillera (Zhang, 1998a, b; Löfgren, 2003; Löfgren and Zhang, 2003; Heredia et al., 2017; Mestre, 2012; Mestre and Heredia, 2012, 2013b; Zhen, 2020) (Fig. 6).

The extension of the *H. sinuosa* range up to the *L. pseudoplanus* Zone may be related to relative shallow water environment of these stratigraphic levels, owing to the *H. sinuosa* is characteristic of early Darriwilian carbonate shallow water settings from the Midcontinent (Bauer, 2010). Based on the absence of *H. kristinae* and the presence of *H. sinuosa* in the uppermost beds of San Juan Formation in the Los Baños de Talacasto section, we also interpret that in these levels could be registering the base of the *L. pseudoplanus* Zone.

The co-occurrence of the *H. kristinae* and *H. holodentata* was documented for the first time by the upper part of the *L. pseudoplanus* Zone in the Precordillera by Mestre and Heredia (2012). On the other hand, Feltes et al. (2016) and Serra et al. (2017a) recognize the co-occurrence of the *H. sinuosa*, *H. serrata*, and *H. holodentata* to the top of San Juan Formation and the overlapped range of the *H. kristinae*, *H. cf. holodentata* and *H. holodentata* in uppermost strata of the lower member of the Las Aguaditas Formation, correlative with the *L. crassus* and the upper part of the *L. pseudoplanus* zones, respectively.

## 6. Systematic Paleontology

Conodonts obtained from the studied samples were mainly described and illustrated in previous publications (Lehnert, 1995; Albanesi, 1998; Mestre and Heredia, 2013; Mestre, 2014). Hence, only one species is included in the following description in this report, since this represents the first mention for the Precordillera. A single species of ostracod was recovered from the study section, however, it represents the first ostracod record from the top of the San Juan Formation, for this reason, a brief description of it is also included.

### Class Conodonta Pander, 1856

#### Genus *Aurilobodus* Xiang and Zhang in An et al. 1983

**Type species** *Aurilobodus aurilobus* (Lee, 1975).  
*Aurilobodus leptosomatus* An et al. 1983

#### Fig. 5d-e

1983 *Aurilobodus leptosomatus* An in An et al. pp. 72-73, pl. 21, figs. 14-17, pl. 22, fig. 1, text-figs. 12.8-12.10.

1984 *Juanognathus serpaglii* Stouge, pp. 58-59, pl. 5, figs. 10-20.

1988 *Juanognathus leptosomatus* (A, p. 116, pl. 1, figs. 1-3, 6.

1995 *Juanognathus leptosomatus* (An). Lehnert, pp. 92-93, pl. 13, fig. 9.

1995 *Juanognathus* aff. *leptosomatus* (An). Lehnert, pl. 14, fig. 4.

1998 *Juanognathus jaanussoni* Sepagli. Albanesi, part pl.4, figs. 6-7.

2005 *Aurilobodus leptosomatus* An. Kuhn and Barnes, p. 319, figs. 2.1-2.2.

2008 *Juanognathus serpaglii* Stouge. Zhen and Pickett, pp. 72-73, fig. 9C-F.

2008 *Aurilobodus leptosomatus* An. Agematsu et al. p. 186, figs. 7.3-7.4.

2009 *Aurilobodus leptosomatus* An. Agematsu and Sashida, fig. 4.

2014 *Aurilobodus leptosomatus* An. Tolmacheva, pp. 132-133, pl. 16, figs. 1-5.

2016 *Aurilobodus leptosomatus* An. Jing et al. figs. 6.14-6.16.

2019 *Aurilobodus leptosomatus* An. Yu et al. fig. 4, C-D.

2020 *Aurilobodus leptosomatus* An. Zhen et al. fig. 7, F-I.

2020 *Aurilobodus leptosomatus* An. Zhen, fig. 4, B-H.

2020 *Aurilobodus leptosomatus* An. Jing et al. fig. 2, 9-10.

**Description:** In the Los Baños de Talacasto section were retrieved symmetrical Sa (Fig. 5e) and asymmetrical Sb (Fig. 5d) elements. The Sa shows a stronger carina on the anterior margin and a thicker prominent costa on the posterior margin of the cusp. Also, exhibit blade-like lateral edges on each side of the cusp. The Sb element shows a strongly extending downward lateral blade.

**Material:** Three elements, INGeo-MP 2006 (1-2); INGeo-MP 2009 (1).

**Remarks:** The present record represented the first mention of the genus *Aurilobodus* from Darriwilian strata of the Precordillera. Xiang and Zhang (in An et al., 1983) defined the genus *Aurilobodus* as

having a bimembrate apparatus including symmetrical and asymmetrical elements. Nevertheless, An *et al.* (1983) described six species of *Aurilobodus* from the Darriwilian from North China, which are composed of four morphotypes: geniculate M, symmetrical Sa, asymmetrical Sb, and strongly asymmetrical Sc elements (Zhen *et al.*, 2020). Lehnert (1995) proposed the genus *Aurilobodus* as a probably junior synonym of the genus *Juanognathus*, but the arguments to support this statement are not clear. However, Zhen *et al.* (2020) proposed both genera as valid, *Juanognathus* which typically dominated the Floian offshore faunas of the Open-Sea Realm, and *Aurilobodus*, which inhabited mainly from the Darriwilian shallow marine setting.

The species *Juanognathus serpaglii* Stouge, 1984, was reported from the Table Head Formation (Newfoundland) by Stouge (1984), in the present contribution is considered as a junior synonym of the species *A. leptosomatus*, following the proposal of Lehnert (1995) and Zhen *et al.* (2020).

**Class Ostracoda Latreille, 1802**

**Subclass Podocopa Sars, 1866**

**Order Beyrichiocopida Pokorný, 1954**

**Suborder Binodicopina Schallreuter, 1972**

**Superfamily Drepanelloidea Ulrich and Bassler, 1923**

**Family Drepanellidae Ulrich and Bassler, 1923**

**Subfamily Pillinae Schallreuter, 1996**

**Genus *Pilla* Schallreuter and Siveter, 1988**

**Type species. *Pilla piformis* Schallreuter and Siveter, 1988**

***Pilla nodospinosa* Salas, 2002a**

**Fig. 7**

**2001 *Pilla nodospinosa* n. sp. Salas; Salas, pp. 51-53, pl. III, figs. 5-10.**

**2002a *Pilla nodospinosa* sp. nov. Salas; Salas, pp. 50-51, pl. 6, figs. J-M, pl. 7, figs. A-B.**

**2003 *Pilla nodospinosa* Salas; Salas in: Benedetto, pp. 414, pl. 2, figs. 15-18.**

**Remarks:** The recorded material bears two dorsal nodes, which protrude beyond the dorsal margin. The posterior one is spine-like and slightly smaller than the anterior one; nodes are separated by a wide sulcus. The valves show a well-developed and ridge-like pseudovelum extended from the anterior cardinal angle to the postero-ventral sector of valve. While the recorded material is scarce and constituted only by internal molds, this can be assigned without doubt to *Pilla nodospinosa* Salas, 2002a, species recorded until now from the Darriwilian levels of the Las Aguaditas and Las Chacritas formations (Salas, 2002a) in the Precordillera Argentina. The studied material has all the diagnostic features of *P. nodospinosa*, species, nodes separated from each other, both protruding beyond the dorsal margin, with the posterior one spine like. These features differentiate this species from the remaining species of the genus, where the nodes are rounded and the sulcus narrow. The more similar species is *P. reedi* (Wolfart, 2001a), from Darriwilian-early Sandbian western Thailand, by its broad sulcus and its smaller posterior node, however, in *P. nodospinosa* the posterior node is spine-like. Moreover, in this species the valves show a well-developed and ridge-like pseudovelum extended from the anterior cardinal angle to the postero-ventral sector of valve, while the remaining species show a rounded and wide pseudovelum. Some specimens of the recorded

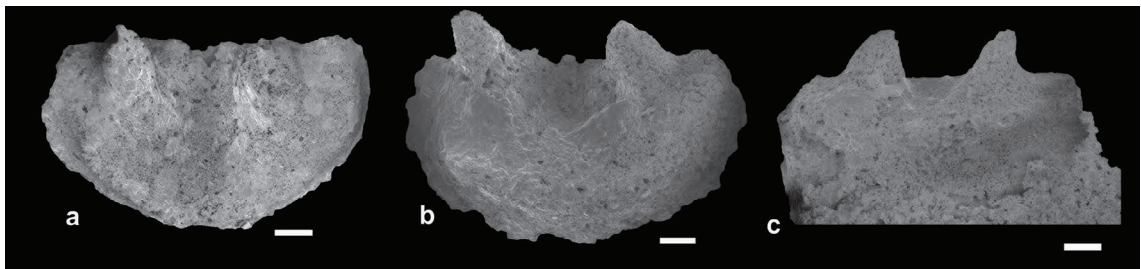


FIG. 7. Microphotographs of scanning electron microscope of the ostracod specimens. The bar indicates 100  $\mu\text{m}$ . (a-c) *Pilla nodospinosa* Salas, (a) right valve, lateral view of internal mold, BT12 sample, INGEO-MP-2039 (1); (b) right valve, lateral view of internal mold, BT12 sample, INGEO-MP-2039 (2); (c) left valve, ventral view of internal mold, BT12 sample, INGEO-MP-2039 (3).

material show the anterior node developed like a spine, feature also observed in the juveniles of *P. nodospinosa*, this would agree with the maximum size observed in this exemplar (L=0,88mm) while the adults could reach 1,16 mm in length.

**Material:** Four internal molds of left valves and three internal molds of right valves, INGEO-MP-2038 (1); INGEO-MP-2039 (1-3).

**7. Regional correlations**

The presence of the index taxon *L. crassus* was first recorded in the Precordillera from the uppermost level of the San Juan Formation in Del Aluvi3n section (Fig. 1) (Mestre, 2010; Mestre and Heredia,

2013a) and subsequently, it was found at numerous localities from Central and Eastern Precordillera (Heredia and Mestre, 2011; 2013; Mestre and Heredia, 2013a, b, 2020a, b; Mestre, 2014; Heredia et al., 2017). This biozone is also recorded from the uppermost level of the San Juan Formation in the Los Amarillitos section, Las Aguaditas section and several sections in the Villicum range (Fig. 1), where the San Juan Formation is overlain by the Los Azules or Las Aguaditas formations (Mestre and Heredia, 2013a, 2020a, b; Mestre, 2014) (Fig. 8). Moreover, the *L. crassus* Zone is registered in the upper levels of the San Juan Formation at the Cerro La Chilca and Las Chacritas River sections, where the *L. pseudoplanus* Zone is recorded from the

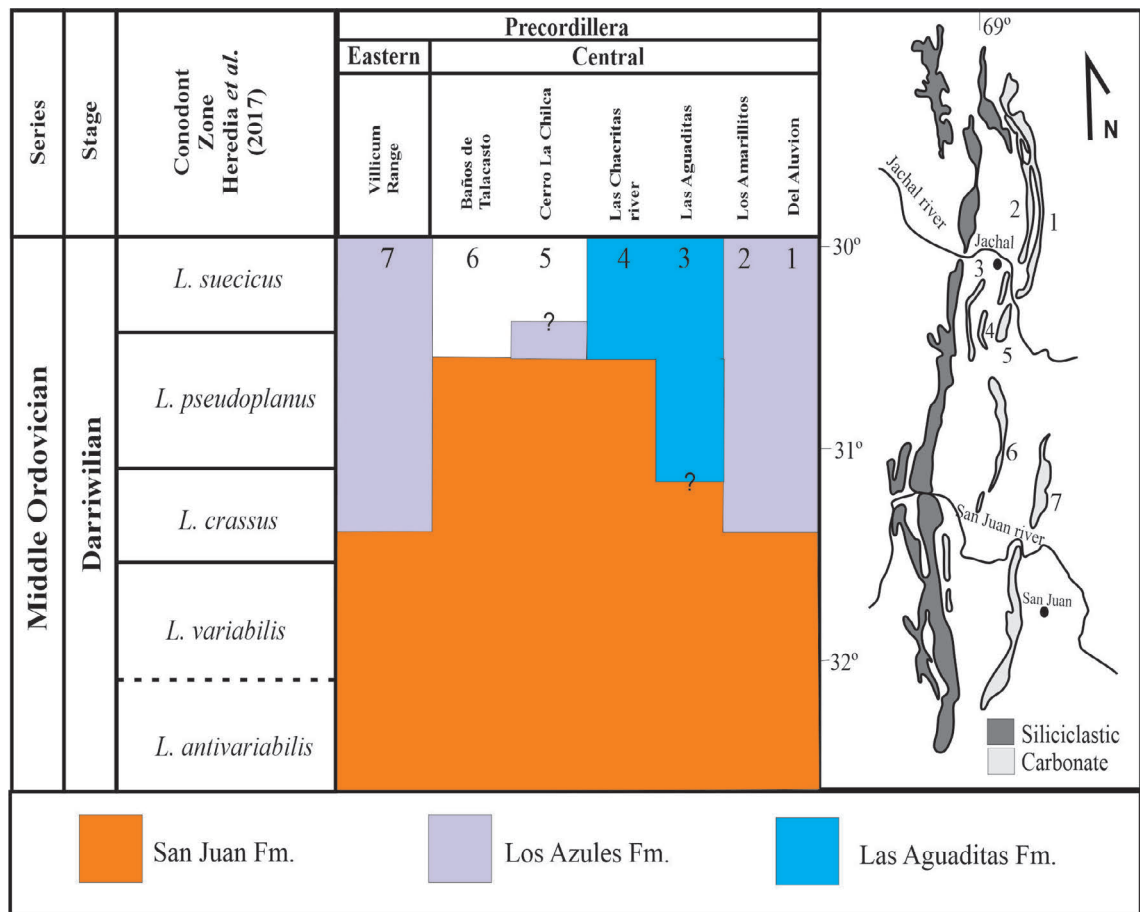


FIG. 8. Stratigraphic correlation scheme of the top of the San Juan formation between the Darrivilian sections from Eastern and Central Precordillera, showing the diachronic boundary between the San Juan Formation and the Los Azules/Las Aguaditas formations (modified from Mestre, 2014).

uppermost strata of the San Juan Formation and lower levels of the Los Azules and Las Aguaditas formations (Heredia, 2012; Mestre, 2012; Mestre and Heredia, 2013a, b, 2020b) (Fig. 8).

Regarding the presence of the ostracod *P. nodospinosa* in the Los Baños de Talacasto section, it represents the first record of the genus in the top of the San Juan Formation. The previous record of the species corresponds to the lower-middle levels of the Las Aguaditas Formation (*sensu* Heredia *et al.*, 2011), assigned to the *L. pseudoplanus* and *L. suecicus* zones indicating a Darriwilian age (Heredia, 2012; Feltes *et al.*, 2016; Mestre and Heredia, 2013b, 2020a, b). Although the ostracods are not good biostratigraphic markers, the presence of this species in Los Baños de Talacasto section would agree to the age and correlation documented by conodonts.

### 8. Paleocological remarks of the conodont association

The Darriwilian conodont fauna from the Precordillera is characterized by high diversity and abundance perhaps as response to the GOBE (Global Ordovician Biodiversification Event) rise (Stigal *et al.*, 2019). Regarding the paleoenvironmental preference of the *Histiodellella* species, they show a wide distribution on all marine environments, from shallow to deep water and from carbonate to siliciclastic settings, having pelagic behavior (Ethington and Clark, 1981; Stouge, 1984; Zhang, 1998a; Löfgren, 2004; Tolmacheva, 2014; Jing *et al.*, 2016).

*P. horridus* and *P. macrodentatus* are the most abundant species in the Darriwilian conodont fauna in the Precordillera, representing about the 50% of the population in the *L. crassus* and *L. pseudoplanus* zones, especially in western sections from the Central Precordillera, such as Las Chacritas river and Cerro La Chilca sections (Mestre, 2010; Serra *et al.*, 2017b; Mestre and Heredia, 2020b). In other regions of the world, the genera *Periodon* and *Paroistodus* characterized deep and open-sea biotopes, occupying upper to lower slope environments (Stouge, 1984; Zhang, 1998a; Wu *et al.*, 2014; among others). However, low number of specimens recovered of *P. horridus* and *P. macrodentatus* from the top of San Juan Formation in the Los Baños de Talacasto section and the presence of the *A. leptosomatus*, may be related to shallow environment recognized for those beds (Table 1). Nevertheless, the regional study for recognizing the distribution of these shallow

water settings and its conodont faunas in the Central and Eastern Precordillera should be developed in the future for corroborating this hypothesis.

### 9. Affinities of the recorded microfauna and its paleobiogeographic implications

The genus *Aurilobodus* has affinities to the warm water fauna of the North China Platform (An *et al.*, 1983; Wang *et al.*, 2014) and it inhabited the shallow waters on the shelf with normal temperatures and salinities of the Australasian Superprovince (Agematsu *et al.*, 2006, 2008; Agematsu and Sashida, 2009; Zhen and Percival, 2017; Kuhn and Barnes, 2005; Yu *et al.*, 2019). The *A. leptosomatus* occurrence in the Precordillera indicates a probable paleobiogeographic tie between North China, South Tibet, Central Asia, western Thailand, Australia, Newfoundland and the Precordillera during the early-middle Darriwilian (Fig. 9).

The previous studies on Ordovician conodont paleobiogeography interpreted a temperate domain for the Ordovician from the Precordillera (Zhen and Percival, 2004) or suggested that the Precordillera was closer links to North America (Marathon basin, Newfoundland, and the Antelope Valley) (Albanesi and Bergström, 2010). On the other hand, the Darriwilian conodont biostratigraphy chart is based on Baltoscandian and South-Central China biostratigraphy schemes evidencing ties with those areas (Heredia and Mestre, 2011, 2013; Heredia *et al.*, 2017) (Fig. 4).

The probable paleobiogeographic links between North China, South Tibet, Central Asia, western Thailand, Australia, Newfoundland, and the Precordillera during the Darriwilian, show the necessity to re-evaluate the significance of the spectrum of the conodont biofacies, from shallow to deep water, in the conodont provincialism or paleobiogeography affinities. As first noted by Sweet *et al.* (1959) and Sweet and Bergström (1962), the correlation of shallow- and deep-water facies is difficult by the conodont provincialism in the Ordovician. In several regions were defined different conodont biostratigraphic chart for the platform and the slope environment, *e.g.*, North and South China (Wang *et al.*, 2019; Jing *et al.*, 2017) or British Columbia (Pyle and Barnes, 2002), showing the strong biofacial control on the provincialism.

Respect to the ostracods, the genus *Pilla* Schallreuter and Siveter, 1988 has so far six known species from

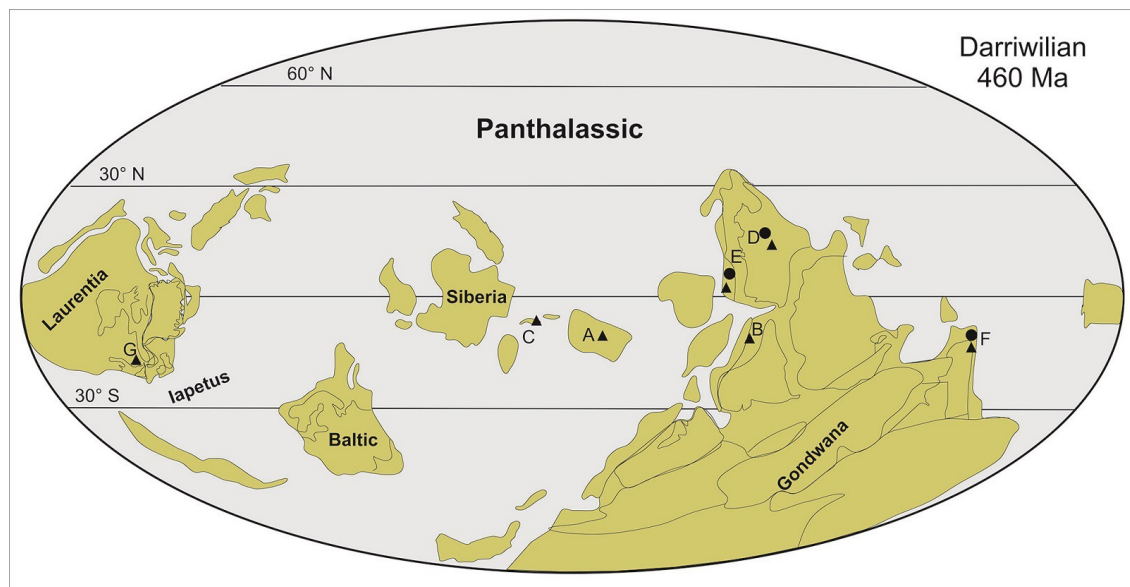


FIG. 9. Paleogeographical reconstruction for the Middle Ordovician (Torsvik and Cocks, 2013) showing geographical distribution of the *Aurilobodus leptosomatus* (triangle) and ostracod genus *Pilla* (circle). (A) North China, (B) South Tibet, (C) Central Asia, (D) Australia, (E) Thailand, (F) Precordillera and (G) Newfoundland.

Australia, western Thailand (Sibumasu), southwestern China and northern India, in addition to the two of Precordillera. The recorded species *P. nodospinosa*, was defined for material from other localities of the Precordillera Argentina, so their only previous record corresponds to the Darriwilian of the lower-middle levels of the Las Aguaditas Formation (*sensu* Heredia *et al.*, 2011); meanwhile, *P. austramericana* Schallreuter, 1996 comes from the middle-upper levels of this formation (lower Sandbian). The oldest species of the genus is *P. latolobata* Jones and Schallreuter from Floian-Dapingian levels of the Amadeus Basin (Jones and Schallreuter, 1990). *P. piformis* Schallreuter and Siveter (type species of the genus), also from Australia, comes from Sandbian-Katian levels of New South Wales (Schallreuter and Siveter, 1988). Moreover, *P. reedi* (Wolfart, 2001a) from western Thailand in Sibumasu, is also recorded during the Darriwilian, in younger levels than of the Precordillera. The species is known from late Darriwilian to early Sandbian Thong Pha Phum Silt-Mudstone Formation (Wolfart, 2001a, b). Recently, *P. reedi* was also recorded in the late Darriwilian to early Sandbian Shihtzupu Formation of South China (Zhang, 2020). Finally, the youngest species of the genus, *P. pinensis* Schallreuter, occurs in the Pin Formation (late Katian), northern India,

northwestern Himalaya (Schallreuter *et al.*, 2008). The paleogeographical distribution of the genus was discussed by Zhang (2020) who suggest that the temporal and spatial distribution of *Pilla* might have originated in low-latitude areas and then migrated to peri-Gondwana terranes during the Middle Ordovician.

In this context, the presence of the genus *Pilla* suggests, at least since the Darriwilian, a paleobiogeographic relationship between the Precordillera Argentina with Eastern Gondwana and Peri-Gonwana terranes. This paleobiogeographic affinities are also suggested by other genera of ostracods like *Eodominina* Schallreuter and *Velapezoides* McGill recorded both in Precordillera (Salas, 2002a, b) and Australia (Schallreuter and Siveter, 1988); while with South China, in addition to *Pilla*, genera like *Aechmina* and *Longiscula* are also common (Salas, 2003, 2007; Yichi Zhang, 2020). This connection between the Precordillera and Australia begins during the Darriwilian with the record of the Pillinae (Salas, 2002a), even though the remaining fauna exhibit a high percentage of endemic genera, and a mixture of genera with several affinities, Baltic and peri-Gondwanan (Salas, 2007).

Other groups like trilobites show similar behaviour, with genera that suggest biogeographic relationships

with several localities around Gondwana since the Darriwilian, such as North and South China, Australia, Tasmania, Himalaya, Turkey and Armorica (Edgecombe *et al.*, 1999; Waisfeld *et al.*, 2001). The same occurs with the rostroconch *Tolmachovia*, that also suggest affinities with Australia and Tasmania since Darriwilian (Sánchez, 1998).

Regarding rhyntonelliform brachiopods, they display a significant percentage of genera with Baltic and Celtic affinities (Benedetto, 2003). Nevertheless, during the Darriwilian the Precordillera is thought to have been situated relatively close to the Gondwana margin but not too far from Laurentia (Benedetto, 2004). Moreover, based on Darriwilian Baltic signature of a number of linguliform and rhyntonelliform brachiopods from the Precordillera, Lavié and Benedetto (2016) infer that it was located in low-temperate latitudes like to Baltica. On the other hand, the acrotretids and other lingulid microbrachiopods from the San Juan Formation in the La Chilca section and La Brecha creek section display major similarities with those inhabiting low-latitude paleocontinents (Holmer *et al.*, 2016; Lavié *et al.*, 2021). Accordingly, the paleobiogeographic affinities shown by the Darriwilian conodont assemblage in the Los Baños de Talacasto section are in agreement with those observed in ostracods and other fauna.

The discovery of the shallower water marine environment at the Baños de Talacasto section and the conodont association retrieved from these beds provided substantial information on the biofacial control on the paleobiogeography affinities in the Ordovician conodonts from the Precordillera and denoting the strong control of the biofacies on the provincialism. In a similar way the analysis of Ordovician ostracod palaeobiogeography has also shown that geography and environment appear to be an important control on the distribution of the fauna. Thus, the composition of ostracods, at least at an upper taxonomic group level (suborder and family), displays an important palaeobiogeographic component, which can be observed since the Middle to Late Ordovician (*e.g.*, Vannier *et al.*, 1989; Williams *et al.*, 2003; Salas, 2011).

In the light of this new data, is evident the necessity of future studies for understanding the distribution of the shallow water carbonate environment and the microfossil faunas that inhabit these biotopes in the Precordillera basin, as well as the paleogeographic location of the Precordillera and surface currents configuration in the Iapetus during the Middle Ordovician.

## 10. Darriwilian *Nuia* record

The genus *Nuia* was recognized in the Early Ordovician carbonate beds of the San Juan Formation in several sections from Eastern and Central Precordillera (Beresi, 1986; Cañas, 1999; Keller, 1999) and the siliciclastic Volcancito Formation in Famatina (Astini, 2001). This microfossil was considering as algae, cyanobacteria, or microproblematic organism that was common and widespread in the Late Cambrian-Middle Ordovician shallow water deposits (Riding and Fan, 2001). Recently, Vachard *et al.* (2017) proposed that the *Nuia* is probable a rivulariacean cyanobacteria exclusively from the Early Ordovician, dismissing the Late Cambrian and Middle Ordovician records, also these authors defined the *Nuia* paleogeographic province that characterizes a tropical to subtropical low-latitude settings. This paleogeographic province would include the Laurentia, Siberia, Tarim, Kazakhstan, North China, South China, and Precordillera during the Early Ordovician.

The paleolatitudinal position of Precordillera was probably tropical to subtropical (low-latitude) until the latest Dapingian-earliest Darriwilian, due to the presence of the *Zondarella*-dominated reefs in the upper part of the San Juan Formation at the Eastern Precordillera (Lehnert and Keller, 1993; Mestre *et al.*, 2020). However, the youngest strata over this reef facies most likely were deposited on a carbonate and mixed platform in middle latitude as result of the collision of the Precordillera (Cuyania terrane) against to the western margin of Gondwana (Astini *et al.*, 1995; Thomas and Astini, 1996; Thomas *et al.*, 2000).

The finding of *Nuia* in the studied strata would allow to place the Precordillera in a low-latitude position during the *L. crassus* Zone, extending up to this time interval the tropical to subtropical condition for the south-western margin of Gondwana, as is proposed by Torvisk and Cocks (2013, 2017) and Cocks and Torsvik (2020). On the other hand, we confirmed the record of *Nuia* up to the Middle Ordovician, as have already been verified by Guildbault *et al.* (1976), Riding and Fan (2001) and Shen and Neuweiler (2016) in Canada and Tarim basin (North China).

## 11. Conclusion

A new conodont and ostracod fauna, as well as carbonate component across the upper part of the



San Juan Formation, have been analyzed based on material from the Los Baños the Talacasto stratigraphic section. The main conclusions are as follows:

- Darriwilian conodont and ostracod association is documented for the first time from the top of San Juan Formation at Los Baños de Talacasto section.
- The *L. crassus* and *L. pseudoplanus* zones are recorded, providing a substantial improvement in the knowledge on the distribution of these biozones in the Central Precordillera.
- A shallow warm-water subtidal environment in equatorial to subequatorial climate in low latitudes was recognized in the last meters of the San Juan Formation in this section.
- The *A. leptosomatus* occurrence in the Precordillera Darriwilian strata shows a probable paleobiogeographic link with equivalent beds from North China, South Tibet, Central Asia, western Thailand, Newfoundland, and Australia during the Darriwilian.
- The presence of *P. nodospinosa* is recorded for the first time in San Juan Formation, its record would be in agreement with the biostratigraphic and paleobiogeographic analysis based on conodont associations.

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### References

Agematsu, S.; Sashida, K. 2009. Ordovician sea-level change and paleogeography of the Sibumasu terrane based on the conodont biostratigraphy. *Paleontological Research* 13: 327-336.

Agematsu, S.; Sashida, K.; Salyapongse, S.; Sardud, A. 2006. Lower and Middle Ordovician conodonts from the Thung Song and Thung Wa areas, southern peninsular Thailand. *Paleontological Research* 10: 215-231.

Agematsu, S.; Sashida, K.; Sardud, A. 2008. Reinterpretation of Early and Middle Ordovician conodonts from the Thong Pha Phum area, western Thailand, in the context of new material from western and northern Thailand. *Paleontological Research* 12: 181-194.

Albanesi, G.L. 1998. Taxonomía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas de la Academia Nacional de Ciencias* 12: 102-253.

Albanesi, G.L.; Bergström, S.M. 2010. Early-Middle Ordovician conodont paleobiogeography with special regard to the geographic origin of the Argentine Precordillera: A multivariate data analysis. *In* The Ordovician Earth System (Finney, S.C.; Berry, W.B.N.; editors). Geological Society of America, Special Paper 466: 119-139. Colorado.

Albanesi, L.; Ortega, G.; Hünicken, M. 2006. Bioestratigrafía de conodontes y graptolitos silúricos en la sierra de Talacasto, Precordillera de San Juan, Argentina. *Ameghiniana* 43 (1): 93-112.

An, T.X.; Zhang, F.; Xiang, W.D.; Zhang, Y.Q.; Xu, W.H.; Zhang, H.J.; Jiang, D.B.; Yang, C.S.; Lin, L.D.; Cui, Z.T.; Yang, X.C. 1983. The Conodonts of North China and the Adjacent Regions. Beijing Science Press: 223 p. (Chinese with English abstract).

Astini, R.A. 2001. Las algas calcáreas *Niua-Girvanella* a través de la transición cambro-ordovícica (Formación Volcancito) en el Famatina: significado paleoambiental y paleogeográfico. *Ameghiniana* 38 (2):2 43-255.

Astini, R.A.; Piovano, E. 1992. Facies de plataforma terrígenas del Silúrico de la Plataforma sanjuanina. *Revista de la Asociación Argentina* 47 (1): 99-110.

Astini, R.A.; Benedetto, J.L.; Vaccari, N.E. 1995. The early Paleozoic evolution of the Argentina Precordillera as a Laurentian rifted, drifted, and collided terrane: a geodynamic model. *Geological Society of American Bulletin, Special Paper* 107: 253-273.

Asurmendi, E.; Sánchez, M.L.; Heredia, S. 2020. Stratigraphy and facies analysis of the La Chilca Formation, Central Precordillera: Insights on the postglacial Ordovician-Silurian boundary and Early Silurian deposits from Argentina. *Geological Journal* 55 (1): 54-76.

Baldis, B.; Beresi, M.; Bordonaro, O.; Vaca, A. 1982. Síntesis evolutiva de la Precordillera Argentina. *In* Congreso Latinoamericano de Geología, No. 5, Actas 4: 399-445. Buenos Aires.

Bauer, J.A. 2010. Conodonts and Conodont Biostratigraphy of the Joins and Oil Creek Formations, Arbuckle Mountains, South-central Oklahoma. *Oklahoma Geological Survey Bulletin* 150: 1-41.

- Benedetto, J.L. 2003. Early Ordovician (Arenig) brachiopods from volcanoclastic rocks of the Famatina Range, northwestern Argentina. *Journal of Paleontology* 77: 212-242.
- Benedetto, J.L. 2004. The allochthony of the Precordillera ten years later (1993-2003): A new paleobiogeographic test of the microcontinental model. *Gondwana Research* 7: 1027-1039.
- Benedetto, J.L.; Vaccari, N.E.; Waisfeld, B.G.; Sánchez, T.M.; Foglia, R.D. 2009. Cambrian and Ordovician paleobiogeography of Andean margin of Gondwana and accreted terranes. In *Early Palaeozoic Peri-Gondwana Terranes: New Insights from Tectonics and Biogeography* (Bassett, M.G.; editor). The Geological Society London, Special Publications 325: 199-230. London.
- Beresi, M.S. 1986. Paleocología y biofacies de la Formación San Juan al sur del paralelo de 30° sur, Precordillera de San Juan. Ph.D. Thesis (Unpublished), Universidad Nacional de San Juan: 400 p.
- Cañas, F.L. 1999. Facies and sequences of the Late Cambrian-Early Ordovician carbonates of the Argentine Precordillera: a stratigraphic comparison with Laurentian platforms. In *Laurentia-Gondwana connections before Pangea* (Ramos, V.A.; Keppie, J.D.; editors). Geological Society of America, Special Paper 336: 43-62. Colorado.
- Carrera, M.G. 1997. Análisis paleoecológico de la fauna de poríferos del Llanvirniano tardío de la Precordillera Argentina. *Ameghiniana* 34: 309-316.
- Carrera, M.G.; Astini, R.A. 1998. Valoración de las restricciones ambientales durante la transición Arenigiano-Llanvirniano, Ordovío de la Precordillera. *Revista Asociación Geológica Argentina* 53: 41-56.
- Carrera, M.G.; Ernst, A. 2010. Darriwilian Bryozoans from the San Juan Formación (Ordovician), Argentine Precordillera. *Ameghiniana* 47 (3): 343-354.
- Cocks, L.R.M.; Torsvik, T.H. 2020. Ordovician palaeogeography and climate change. *Gondwana Research* 100: 53-72. doi: 10.1016/j.gr.2020.09.008.
- Du, P.D.; Zhao, Z.X.; Huang, Z.B.; Tan, Z.J.; Wang, C.; Yang, Z.L.; Zhang, G.Z.; Xiao, J.N. 2005. Discussion on four conodont species of *Histiodela* from Tarim Basin and their stratigraphic implication. *Acta Microbiologica Sinica* 22: 357-369.
- Edgecombe, G.; Chatterton, B.D.; Waisfeld, B.; Vaccari, N.E. 1999. Ordovician pliomereid and prosopiscid trilobites from the Argentina. *Journal of Paleontology* 73 (6): 1144-1154.
- Ethington, R.L.; Clark, D.L. 1981. Lower and Middle Ordovician Conodonts from the Ibex Area Western Millard County, Utah. *Brigham Young University Geology Studies* 28 (2): 1-159.
- Feltes, N.A.; Albanesi, G.L.; Bergström, S.M. 2016. Conodont biostratigraphy and global correlation of the middle Darriwilian-lower Sandbian Las Aguaditas Formation, Precordillera of San Juan, Argentina. *Andean Geology* 43 (1): 60-85. doi: 10.5027/andgeoV43n1-a04.
- Furque, G.; Cuerda, A. 1979. Precordillera de La Rioja, San Juan y Mendoza. In *Simposio de Geología Regional Argentina*, No. 2, Boletín de la Academia Nacional de Ciencias 1: 455-522. Córdoba.
- Gallardo, M. 2018. Bioestratigrafía de conodontes y microfácies carbonáticas del tramo superior de la Formación San Juan, Baños de Talacasto, Precordillera Central. Ph.D. Thesis (Unpublished), Universidad Nacional de San Juan, Departamento de Geología: 141 p.
- Guildbault, J.P.; Hubert, C.; Mamet, B. 1976. *Nuia* et *Halysis*, deux algues ordovicienes énigmatiques des Basses-Terres du Saint-Laurent. *Naturaliste Canadien*, 103 (2): 119-132.
- Harper, D.A.T.; Owen, A.W.; Bruton, D.L. 2009. Ordovician life around the Celtic fringes: diversifications, extinctions and migrations of the brachiopod and trilobite faunas at middle latitudes. In *Early Palaeozoic Peri-Gondwana Terranes: New Insights from Tectonics and Biogeography* (Bassett M.G.; editor). The Geological Society, Special Publications 325: 157-170. London.
- Henningsmoen, G. 1953. Classification of Paleozoic straight-hinge ostracods. *Norske Geologiske Tidsskrift* 31: 185-288.
- Heredia, S. 2012. Bioestratigrafía de conodontes del Darriwiliano medio (Ordovícico) de Argentina: la Formación Las Aguaditas, Precordillera Central. *Revista Mexicana de Geología* 29: 76-86.
- Heredia, S.; Mestre, A. 2011. Middle Darriwilian Conodont Biostratigraphy in the Argentine Precordillera. In *Ordovician of the World* (Gutiérrez Marco, J.C.; Rábano, I.; García Bellido, D.; editors). Cuadernos del Museo Geominero 14: 229-234. Madrid.
- Heredia, S.; Mestre, A. 2013. Advances in the middle Darriwilian conodont biostratigraphy of the Argentine Precordillera. In *Conodonts from the Andes* (Albanesi G.; Ortega, G.; editors). Proceedings of the 3<sup>rd</sup> International Conodont Symposium and Regional Field Meeting of the IGCP project 591. *Publicación Especial de la Asociación Paleontológica Argentina* 13: 45-47. Buenos Aires.
- Heredia, S.; Beresi, M.; Mestre, A. 2011. La estratigrafía del Ordovícico Medio del Río Las Chacritas, Precordillera Central de San Juan. *Serie Correlación Geológica* 27: 18-26.

- Heredia, S.; Mestre, A.; Kaufmann, C. 2017. The Darriwilian conodont biostratigraphy from the Argentine Precordillera. *In* Progress on Conodont Investigation (Liao, J.-C.; Valenzuela-Ríos, J.I.; editors). International Conodont Symposium, No. 4, Cuadernos del Museo Geominero 22: 65-69.
- Holland, S.M. 1993. Sequence stratigraphy of a carbonate-clastic ramp: The Cincinnati Series (Upper Ordovician) in its type area. *Geological Society of America Bulletin* 105: 306-322.
- Holmer, L.E.; Popov, L.E.; Lehnert, O.; Ghobadi Pour, M. 2016. Ordovician (Darriwilian-Sandbian) linguliform brachiopods from the southern Cuyania Terrane of west-central Argentina. *Memoirs of the Association of Australasian Palaeontologists* 49: 31-50.
- Jing, X.C.; Zhou, H.R.; Wang, X.L. 2016. Biostratigraphy and biofacies of the Middle Darriwilian (Ordovician) conodonts from the Laoshidan section in the western margin of the North China Craton. *Marine Micropaleontology* 125: 51-65.
- Jing, X.C.; Stouge, S.; Ding, L.; Wang, X.L.; Zhou, H.R. 2017. Upper Ordovician conodont biostratigraphy and biofacies from the Sigang section, Neixiang, Henan, central China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 480: 18-32.
- Jing X.C.; Zhou, H.; Wang, X.; Yang, Z.; Fang, Q.; Wang, Z.; Fan, J. 2020. A review on Ordovician conodont biostratigraphy in North China Plate and new advances in its northwestern margin. *Earth Science Frontiers* 27 (6): 57-70.
- Jones, P.J.; Schallreuter, R.E.L. 1990. On *Pilla latolobata* Jones and Schallreuter sp.nov. *Stereo-Atlas of Ostracod Shells* 17: 93-96.
- Keller, M. 1999. Argentine Precordillera: Sedimentary and Plate Tectonic History of a Laurentian Crustal Fragment in South America. *Geological Society of America, Special Paper* 341: 1-131.
- Keller, M.; Cañas, F.; Lehnert, O.; Vaccari, N.E. 1994. The Upper Cambrian and Lower Ordovician of the Precordillera (Western Argentina): Some stratigraphic reconsiderations. *Newsletters in Stratigraphy* 31: 115-132.
- Kuhn, T.; Barnes, C. 2005. Ordovician conodonts from the Mithaka Formation (Georgina Basin, Australia). Regional and paleobiogeographical implications. *Geologica Acta* 3: 317-337.
- Latreille, P.A. 1802, *Histoire Naturelle, Générale et Particulière des Crustacés et des Insectes* Vol.1. De L' Imprimerie de F. Dufart: 382 p. Paris.
- Lavié, F.; Benedetto, J.L. 2016. Middle Ordovician (Darriwilian) Linguliform and Craniiform Brachiopods from the Precordillera (Cuyania Terrane) of West-Central Argentina. *Journal of Paleontology* 90: 1068-1080.
- Lavié, F.J.; Mestre, A.; Carrera, M. 2021. Middle Ordovician linguliformean microbrachiopods from western Argentina: new data and biogeographic implications. *Journal of Paleontology*. doi: 10.1017/jpa.2021.19.
- Lee, H.Y. 1975. Conodonten aus dem unteren und mittleren Ordovizium von Nordkorea. *Paleontographica, Abteilung A* 150: 161-186.
- Lehnert, O. 1995. Ordovizische Conodonten aus der Präkordillere Westargentiniens: Ihre Bedeutung für Stratigraphie und Paläogeografie. *Erlangen geologische Abhandlungen* 125: 1-193.
- Lehnert, O.; Keller, M. 1993. Posición estratigráfica de los arrecifes arenigianos en la Precordillera Argentina. *Travaux et Documents des Laboratoires de Géologie de Lyon* 125: 263-275.
- Liu, L.; Wu, Y.; Jiang, H.; Wu, N.; Jia, L. 2017. Paleoenvironmental distribution of ordovician calcimicrobial associations in the tarim basin, Northwest China. *Society for Sedimentary Geology, Palaios* 32 (7): 462-489.
- Löfgren, A. 2003. Conodont faunas with *Lenodus variabilis* in the upper Arenigian to lower Llanvirnian of Sweden. *Acta Palaeontologica Polonica* 48 (3): 417-436.
- Löfgren, A. 2004. The conodont fauna in the Middle Ordovician *Eoplacognathus pseudoplanus* Zone of Baltoscandia. *Geological Magazine* 141: 505-524.
- Löfgren, A.; Zhang, J. 2003. Element association and morphology in some Middle Ordovician platform-equipped conodonts. *Journal of Paleontology* 77: 723-739.
- Lozano, B.; Hünicken, M. 1990. Conodonts and biostratigraphy of the San Juan Formation (Arenigian-Llanvirnian) in the Quebrada of Talacasto, Ullum Department, San Juan Province, Argentina. *In* 1<sup>st</sup> Latin American Conodonts Symposium, LACOM I (Hünicken, M.; editor). *Academia Nacional de Ciencias*: 101-102.
- Maletz, J. 2009. *Holmograptus spinosus* and the middle Ordovician (Darriwilian) graptolite biostratigraphy at Les Méchins (Quebec), Canada. *Canadian Journal of Earth Sciences* 46 (10): 739-755.
- Mamet, B.; Roux, A.; Shalabi, H. 1984. Role des algues calcaires dans la sédimentation ordovicienne de la Plate-Forme du Saint-Laurent. *Geobios* 8: 261-269.
- Mángano, M.G.; Droser, M. 2004. The ichnologic record of the Ordovician radiation. *In* The Great Ordovician Biodiversification Event (Webby, B.; Droser, M.; Paris, F.; Percival, I.; editors). *Columbia University Press*: 369-379. New York.

- Mango, M.; Ortega, G.; Albanesi, G. 2019. Conodont and graptolite biostratigraphy of the lower-middle Darriwilian (Middle Ordovician), Cerro Viejo of Huaco, Argentine Precordillera. *Geological Journal* 54: 3349-3361.
- Maslov, V.P. 1954. O nizhnem silure Vostochnoy Sibiri. 495-531. *In* Voprosy geologii Azii I. USSR Academy of Sciences Publishing House, Moscow.
- Mestre, A. 2010. Estratigrafía y bioestratigrafía de Conodontes de la “Transición Cuspidal” de la Formación San Juan al sur del paralelo 30°, Precordillera de San Juan. Ph.D. Thesis (Unpublished), Universidad Nacional de San Juan: 330 p.
- Mestre, A. 2012. Bioestratigrafía de conodontes del techo de la Formación San Juan y el miembro inferior de la Formación Los Azules, Cerro La Chilca, Precordillera Central. *Ameghiniana* 49: 185-197.
- Mestre, A. 2013. Middle Darriwilian conodont biostratigraphy of the Villicum Range, Eastern Precordillera, Argentina. *In* Conodonts from the Andes (Albanesi, G.; Ortega, G.; editors). *In* Proceedings of the 3rd International Conodont Symposium and Regional Field Meeting of the IGCP project 591. Publicación Especial de la Asociación Paleontológica Argentina 13: 69-72.
- Mestre, A. 2014. Bioestratigrafía de conodontes del Darriwilense medio (Ordovícico) en el borde oriental de la Sierra de Villicum (Precordillera Oriental, Argentina). *Boletín Geológico y Minero* 125: 65-76.
- Mestre, A.; Heredia, S. 2012. Darriwilian species of the genus *Histiodela* (Conodonta) in the Argentina Precordillera. *Alcheringa* 36: 141-150.
- Mestre, A.; Heredia, S. 2013a. La Zona de *Yangtzeplacognathus crassus* (Conodonta), Darriwiliano de la Precordillera Central de San Juan, Argentina. *Ameghiniana* 50 (4): 407-417.
- Mestre, A.; Heredia, S. 2013b. Biostratigraphic significance of Darriwilian conodonts from Sierra de La Trampa (Central Precordillera, San Juan, Argentina). *Geosciences Journal* 17 (1): 43-53.
- Mestre, A.; Heredia, S. 2020a. The conodont *Paroistodus horridus* (Barnes and Poplawski) as a new biostratigraphical tool for the middle Darriwilian (Ordovician). *Palaeogeography, Palaeoclimatology, Palaeoecology* 549. doi: 10.1016/j.palaeo.2019.03.015.
- Mestre, A.; Heredia, S. 2020b. Lower-middle Darriwilian index conodonts from the Precordillera: New taxonomical approaches. *Palaeobiodiversity and Palaeoenvironment* 100: 737-756.
- Mestre, A.; Heredia, S.; Moreno, F.; Benegas, L.; Morfil, A.; Soria, T. 2020. New insights on Lower Ordovician pulchrlaminid reefs from the Argentine Precordillera: sedimentology and palaeogeographical implications. *Journal of South American Earth Sciences* 103. doi: 10.1016/j.jsames.2020.102801.
- Monty, C.L. 1976. The origin and development of cryptalgal fabrics. *In* Developments in Sedimentology (Walter, M.R.; editor). Elsevier 20: 193-249. Amsterdam.
- Myrow, P.M.; Chen, J.; Snyder, Z.; Leslie, S.; Fike, D.; Fanning, M.; Yuan, J.; Tang, P. 2015. Depositional history, tectonics, and provenance of the Cambrian-Ordovician succession in the western margin of the North China block. *Geological Society of America Bulletin* 127: 1174-1193.
- Ortiz, A.; Zambrano, J. 1981. La provincia geológica Precordillera Oriental. *In* Congreso Geológico Argentino, No. 8, Acta 3: 9-74. San Luis.
- Pander, C.H. 1856. Monographic der fossilen Fische des silurischen Systems der Russisch-Baltischen Gouvernements. *Akademie der Wissenschaften*: 1-91.
- Peralta, S.H. 1990. Silúrico de la Precordillera de San Juan-Argentina. *In* Congreso Geológico Argentino, No 9, Relatorio: 48-65. San Juan.
- Pokorný, V. 1954. A contribution to the taxonomy of the Paleozoic ostracods. *Sbornik ústředního ústavu geologickeho (oddíl paleontologický)*, 20 (for 1953): 213-232.
- Pyle, L.J.; Barnes, C.R. 2002. Taxonomy, evolution, and biostratigraphy of conodonts from the Kechika Formation, Skoki Formation, and Road River Group (Upper Cambrian to Lower Silurian), Northeastern British Columbia. NRC Research Press: 227 p. Ontario.
- Riding, R.; Fan, J. 2001. Ordovician calcified algae and cyanobacteria, Northern Tarim Basin Subsurface, China. *Palaeontology* 44: 783-810.
- Salas, M.J. 2001. “Taxonomía y paleobiogeografía de los ostrácodos ordovícicos de la Precordillera Argentina”. Tesis Doctoral de la carrera del Doctorado en Ciencias Geológicas (Inédito), Facultad de Ciencias Exactas, Físicas y Naturales de la Universidad Nacional de Córdoba.
- Salas, M.J. 2002a. Ostrácodos binodicopas del Ordovícico de la Precordillera de San Juan, Argentina. *Ameghiniana* 39 (1): 41-58.
- Salas, M.J. 2002b. Ostrácodos podocopas del Ordovícico de la Precordillera de San Juan, Argentina. *Ameghiniana* 39 (2): 129-149.
- Salas, M.J. 2003. Ostracods. *In* Ordovician fossils of Argentina (Benedetto, J.L.; editor). Secretaría de Ciencia y Tecnología, Universidad Nacional de Córdoba: 411-440. Córdoba.

- Salas, M.J. 2007. Assessing the biodiversity of Ordovician ostracods from the Argentine Precordillera. *Journal of Paleontology* 81 (6): 1442-1453.
- Salas, M.J. 2011. Biodiversity and composition of the Early Ordovician Ostracods from the Cordillera Oriental, Northwest Argentina. *Geological Journal* 46: 637-650.
- Sanchez, T.M. 1998. Rostroconchia (Mollusca, Diasoma) en la Formación San Juan (Ordovícico temprano), Precordillera Argentina. *Ameghiniana* 35: 345-347.
- Sánchez, T.; Carrera, M.G.; Benedetto, J.L. 1996. Variaciones faunísticas en el techo de la Formación San Juan (Ordovícico temprano, Precordillera Argentina): significado paleoambiental. *Ameghiniana* 33 (2): 185-200.
- Sars, G.O.I. 1866. Oversigt af Norges marine Ostracoder. *Forhandlinger i Videnskabs-Selskabet i Christiania* 1865: 1-130.
- Schallreuter, R. 1972. Drepanellacea (Ostracoda, Beyrichioida) aus Mittelordovizischen backsteinkalkgeschieben IV. Laterophores hystrix sp. n., Pedomphalella germanica sp. n. und Easchmidella fragosa (Neckaja). *Berichte der Deutschen Gesellschaft für Geologische Wissenschaften. Reihe A.*, 17: 139-145.
- Schallreuter, R.E. 1995a. On *Harpabollia argentina* Schallreuter sp. nov. *Stereo-Atlas of Ostracod Shells* 22: 82-85.
- Schallreuter, R.E. 1995b. On *Spinodiphores praepletus* Schallreuter gen. et sp. nov. *Stereo-Atlas of Ostracod Shells* 22: 74-77.
- Schallreuter, R.E. 1995c. On *Ansipe anseripediculus* Schallreuter gen. et sp. nov. *Stereo-Atlas of Ostracod Shells* 22: 78-81.
- Schallreuter, R.E. 1996. Ordovizische Ostracoden Argentinens II. *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* 79: 139-169.
- Schallreuter, R.E.; Siveter, D.J. 1988. On *Pilla piformis* Schallreuter y Siveter gen. et sp. nov. *Stereo-Atlas of Ostracod Shells* 15 (7): 25-28.
- Schallreuter R.E.; Hinz-Schallreuter I. 1999. Altpaläozoische Ostrakoden mit Stoppern. [Lower Palaeozoic Ostracodes with Stop-pegs]. *Neues Jahrbuch für Geologie und Paläontologie* 4: 227-242.
- Schallreuter, R.E.L.; Hinz-Schallreuter, I.; Suttner, T. 2008. New Ordovician ostracodes from Himalaya and their palaeobiological and palaeogeographical implications. *Revue de Micropaléontologie* 51: 191-204.
- Serra, F.; Feltes, N.; Ortega, G.; Albanesi G.L. 2017a. Lower middle Darriwilian (Ordovician) graptolites and index conodonts from the Central Precordillera of San Juan Province, Argentina. *Geological Journal* 53: 2161-2177.
- Serra, F.; Feltes, N.; Henderson, M.; Albanesi, G.L. 2017b. Darriwilian (Middle Ordovician) conodont biofacies from the Central Precordillera of Argentina. *Marine Micropaleontology* 130: 15-28.
- Shen, Y.; Neuweiler, F. 2016. Taphocoenoses and diversification patterns of calcimicrobes and calcareous algae, Ordovician, Tarim Basin, China. *Canadian Journal of Earth Sciences* 53: 702-711.
- Stigall, A.L.; Cole, T.E.; Freeman, R.; Rasmussen, M.O. 2019. Coordinated biotic and abiotic change during the Great Ordovician Biodiversification Event: Darriwilian assembly of early Paleozoic building blocks. *Palaeogeography, Palaeoclimatology, Palaeoecology* 530: 249-270.
- Stone, J. 1987. Review of investigative techniques used in the study of conodonts. *In* *Conodonts: Investigative Techniques and Applications* (Austin, R.; editor). Ellis Horwood Limited: 17-34. Chichester.
- Stouge, S. 1984. Conodonts of the Middle Ordovician Table Head Formation, Western Newfoundland. *Fossils and Strata* 16: 1-145.
- Stouge, S. 2012. Middle Ordovician (late Dapingian-Darriwilian) conodonts from the Cow Head Group and Lower Head Formation, western Newfoundland, Canada. *Canadian Journal of Earth Sciences* 49 (1): 59-90.
- Stouge, S.; Harper, D.; Zhan, R.; Liu, J.; Stemmerik, L. 2021. Middle Ordovician (Darriwilian) conodonts from southern Tibet, the Indian passive margin: Implications for the age and correlation of the roof of the world. *Geological Magazine* 158 (6): 1010-1034.
- Sweet, W.C.; Bergström, S.M. 1962. Conodonts from the Pratt Ferry Formation (Middle Ordovician) of Alabama. *Journal of Paleontology* 36: 1214-1252.
- Sweet, W.C.; Turco, A.C.; Warner, E.J.; Wilkie, L.C. 1959. The American Upper Ordovician Standaer I, Eden conodonts from the Cincinnati region of Ohio and Kentucky. *Journal of Paleontology* 33: 1029-1068.
- Thomas, W.A.; Astini, R.A. 1996. The Argentine Precordillera: A traveler from the Ouachita embayment of North American Laurentia. *Science* 273: 752-757.
- Thomas, W.A.; Tucker, R.D.; Astini, R.A. 2000. Rifting of the Argentine Precordillera from southern Laurentia: palimpsestic restoration of basement provinces. *Geological Society of America, Abstracts with Programs* 32: A-505.
- Tolmacheva, T. 2014. Biostratigraphy and biogeography of the Ordovician conodonts from the western part of Central Asian Fold Belt. *Proceedings of VSEGEI, New Series* 356 (in Russian).

- Torsvik, T.H.; Cocks, L.R. 2013. New global palaeogeographical reconstructions for the Lower Palaeozoic and their generation. *In* Early Palaeozoic Biogeography and Geograph (Harper, D.A.T.; Servais, T.; editors). Geological Society of London, Memoir 38: 5-24. London.
- Torsvik, T.H.; Cocks, L.R.M. 2017. Earth History and Palaeogeography. Cambridge University Press: 317 p. Cambridge.
- Ulrich, E.O.; Bassler, R.S. 1923. Paleozoic Ostracoda: Their Morphology, Classification and Occurrence. *In* Silurian (Maryland Geological Survey; editor). The Johns Hopkins press: 271-391. Baltimore.
- Vachard, D.; Clausen, S.; Palafox, J.; Buitrón, B. 2017. Lower Ordovician microfacies and microfossils from Cerro San Pedro (San Pedro de la Cueva, Sonora, Mexico), as a westernmost outcrop of the newly defined *Nuia* Province. *Facies* 63: 1-37.
- Vannier, J.M.C.; Siveter, D.; Schallreuter, R.E.L. 1989. The composition and palaeogeographical significance of the Ordovician ostracode faunas of southern Britain, Baltoscandia and Ibero-Armorica. *Palaeontology* 32: 163-222.
- Waisfeld, B.G.; Vaccari, N.E.; Chatterton, B.D.; Edgcombe, G. 2001. Systematics of Shumardiidae (Trilobita), with new species from the Ordovician of Argentina. *Journal of Paleontology* 75: 827-859.
- Wang, Z.H.; Bergström, S.M.; Zhen, Y.Y.; Zhang, Y.D.; Wu, R.C. 2014. A revision of the Darriwilian biostratigraphic conodont zonation in Tangshan, Hebei Province based on new conodont collections. *Acta Palaeontologica Sinica* 53: 1-15.
- Wang, Z.H.; Zhen, Y.Y.; Bergström, S.M.; Wu, R.C.; Zhang, Y.D.; Ma, X. 2019. A new conodont biozone classification of the Ordovician System in South China. *Palaeoworld* 28 (1-2): 173-186.
- Watson, S.T. 1988. Ordovician conodonts from the Canning Basin (W. Australia). *Palaeontographica* 203A: 91-147.
- Williams, M.; Floyd, J.D.; Salas, M.J.; Siveter, D.J.; Stone, P.; Vannier, J.M.C. 2003. Patterns of ostracod migration for the 'North Atlantic' region during the Ordovician. *Palaeogeography, Palaeoclimatology, Palaeoecology* 195: 193-228.
- Wolfart, R. 2001a. Ostracoda from Thong Pha Phum and Bo Noi regions, West Thailand. *Geologisches Jahrbuch B* 94: 119-179.
- Wolfart, R. 2001b. West Thailand in the Ordovician world. *Geologisches Jahrbuch B* 94: 5-34.
- Wu, R.C.; Stouge, S.; Percival, I.G.; Zhan, R.B. 2014. Early-Middle Ordovician conodont biofacies on the Yangtze Platform margin, South China: Applications to palaeoenvironment and sea-level changes. *Journal of Asian Earth Sciences* 96: 194-204.
- Yu, S.; Fang, X.; Munnecke, A.; Li, W.; Zhen, Y.; Li, Y.; Wang, Z.; Zhang, Y. 2019. First documentation of Middle Ordovician warm-water carbonates in the Mount Jolmo Lungma (Mount Everest) area, southern Xizang (Tibet), China, and its paleogeographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 530: 136-151. doi: 10.1016/j.palaeo.2019.05.030.
- Zhang, J.H. 1998a. Conodonts from the Guniutan Formation (Llanvirnian) in Hubei and Hunan Provinces, south-central China. *Stockholm Contributions in Geology* 46: 161 p.
- Zhang, J.H. 1998b. Four evolutionary lineages of the Middle Ordovician conodont family Polyplacognathidae. *Meddelanden från Stockholms Universitets Institution för Geologi och Geokemi* 298: 35 p.
- Zhang, Y. 2020. Middle to Late Ordovician (late Darriwilian to early Sandbian) ostracods from the Meitan area of northern Guizhou, SW China. *Alcheringa: An Australasian Journal of Palaeontology*. doi: 10.1080/03115518.2020.1829043.
- Zhen, Y.Y. 2020. Revision of the Darriwilian (Middle Ordovician) conodonts documented by Watson (1988) from subsurface Canning Basin, Western Australia. *Alcheringa* 44 (2): 217-252.
- Zhen, Y.; Percival, I. 2004. Ordovician conodont biogeography reconsidered. *Lethaia* 36: 357-370.
- Zhen, Y.Y.; Pickett, J.W. 2008. Ordovician (Early Darriwilian) conodonts and sponges from west of Parkes, central New South Wales. *Proceedings of the Linnean Society of New South Wales* 129: 57-82.
- Zhen Y.Y.; Percival, I.G. 2017. Late Ordovician conodont biozonation of Australia-current status and regional biostratigraphic correlations. *Alcheringa* 41 (3): 285-305.
- Zhen, Y.Y.; Percival, I.G.; Cooper, R.A.; Simes, J.E.; Wright, A.J. 2009. Darriwilian (Middle Ordovician) conodonts from Thompson Creek, Nelson Province, New Zealand. *Memoirs of the Association of Australasian Palaeontologists* 37: 25-53.
- Zhen, Y.Y.; Wang, Z.H.; Zhang, Y.D.; Bergström, S.M.; Percival, I.G.; Chen, J.F. 2011. Middle to Late Ordovician (Darriwilian-Sandbian) conodonts from the Dawangou Section, Kalpin area of the Tarim Basin, northwestern China. *Records of the Australian Museum* 63: 203-266.
- Zhen, Y.Y.; Normore, L.S.; Dent, L.M.; Percival, I.G. 2020. Middle Ordovician (Darriwilian) conodonts from the Goldwyer Formation of the Canning Basin, Western Australia. *Alcheringa* 44 (1): 25-55.