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 darrilianos 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 ostrácono. La asociación de conodontes identificados permite reconocer las zonas *Lenodus crassus* y *L. pseudoplanus*, que confirman la edad darriliana 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 Tibet, 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 experienced 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 lumnensis* 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 Aluvión 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 Baños 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 Microscopía Electrónica y Análisis de Rayos X) laboratory at the Universidad Nacional de Córdoba, 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 Lantset 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; Cañas, 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).
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
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 intraclast 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,

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

<table>
<thead>
<tr>
<th>Conodonts</th>
<th>Samples</th>
<th>L. crassus Zone</th>
<th>L. pseud Z.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BT1</td>
<td>BT2</td>
<td>BT3</td>
</tr>
<tr>
<td>Ansella jemtlandica</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Aurilobodus leptosomatus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cornuodus longibasis</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drepanoistodus bariovalis</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drepanoistodus costadus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Erraticodon hexianensis</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fahraeusodous sp.</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Histiodella holodentata</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Histiodella cf. holodentata</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Histiodella serrata</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Histiodella sinuosa</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lenodus cf. pseudoplanus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lenodus crassus</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lenodus variabilis</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parakalloidos simplicissimus</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Paroistodus horridus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Periodon macrodentatus</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Protopanderodus gradatus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Protopanderodus rectus</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pteracontiodus cryptodens</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rossodus barnesi</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scolopodus oldstockensis</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Semiacontiodus potrerillensis</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>23</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Ostracods**

| Pilla nodospinosa | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 2    | 7    | 9    |
| gen. sp. ind. | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    |

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(Translated from Spanish to English)
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 geopetal infilling and others have

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**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).
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...
Darriwilian microfossils from the Los Baños de Talacasto section, San Juan Formation

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 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 Lehner (1995), who proposed the E. suecicus Zone for these levels based on the presence of the conodont Histiodella 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, Histiodella 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, Cornodus longibasis (Lindström), Drepanostodus basiovalis (Sergeeva), Drepanodus arcuatus Pander, Erraticodon hexianensis, Fahraeusodus sp., Histiodella 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 Semicontiodus potrerillensis Albanesi (Fig. 2).
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
Darriwilian microfossils from the Los Baños de Talacasto section, San Juan Formation

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 *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 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.
1998 *Juanognathus jaanussoni* Sepagli. Albanesi, part pl.4, figs. 6-7.
2008 *Juanognathus serpaglii* Stouge. Zhen and Pickett, pp. 72-73, fig. 9C-F.
2009 *Aurilobodus leptosomatus* An. Agematsu and Sashida, fig. 4.
2014 *Aurilobodus leptosomatus* An. Tolmacheva, pp. 132-133, pl. 16, figs. 1-5.
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.

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 Beyrichiopoda 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

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

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**FIG. 7.** Microphotographs of scanning electron microscope of the ostracod specimens. The bar indicates 100 µm. (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 Aluvión 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 Aguditas section and several sections in the Villicum range (Fig. 1), where the San Juan Formation is overlain by the Los Azules or Las Aguditas 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

![Stratigraphic correlation scheme](image.png)

**FIG. 8.** Stratigraphic correlation scheme of the top of the San Juan formation between the Darriwilian sections from Eastern and Central Precordillera, showing the diachronic boundary between the San Juan Formation and the Los Azules/Las Aguditas 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. Paleoeccological 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 (Gobal Ordovician Biodiversificiation Event) rise (Stigal et al., 2019). Regarding the paleoenvironmental preference of the *Histiodella* 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) (Alanesi 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...
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 Shihztzupu 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 rhynchonelliform 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 rhynchonelliform 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 (Astiní 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 Torviss and Cocks (2013, 2017) and Cocks and Torviss (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 Neuwexier (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 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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Darriwilian microfossils from the Los Baños de Talacasto section, San Juan Formation


