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New Early Ordovician conodont data from the San Juan Formation, Central Precordillera (Argentina): Biostratigraphic and paleogeographic significance

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Abstract

The Early Ordovician conodont faunas from the Cerro La Chilca and Las Chacritas river sections (Central Precordillera) have been studied and compared to those of the well-known Talacasto section. The vertical distribution of the recovered upper Floian conodonts from Cerro La Chilca and Las Chacritas river sections is presented for the first time, recording the *Oepikodus evae* and *O. intermedius* zones, this distribution has been compared to the Talacasto section. The conodonts *Bergstroemognathus hubeiensis* An, and *Microzarcodina* n. sp. (sensu Pyle and Barnes) are recorded for the first time in the Precordillera, and these two species are described and illustrated herein. The occurrence of the *B. hubeiensis* and *Microzarkodina* n. sp. in the early Ordovician strata of the San Juan Formation, provides significant data related to the ties between Precordillera to Gondwana, peri-Gondwana, and Northwestern of the Midcontinent regions for this time interval, increasing the knowledge about the paleogeographic reconstruction of the western margin of Gondwana. The evidence of biogeographic connections between these regions let to suggest that those were in closer position than previous assumptions or at least that marine currents connected them during the late Lower Ordovician.

Keywords: Floian; Conodont; Precordillera; Argentina

1. Introduction

The Paleozoic deposits of the Precordillera are developed along a length of 400 km N-S with a width of 150 km E-W in western Argentina. The carbonate Ordovician succession begins with the uppermost part of La Silla Formation (Upper Cambrian-Lower Ordovician), transitionally covered by the Lower-Middle Ordovician San Juan Formation, this last composed mainly of fossiliferous limestone and marly limestone. The San Juan Formation is conformably overlain by grey and black shale, thin- to medium-bedded marly limestone, and black shale of the Los Azules-Las Aguaditas formations of Middle to Late Ordovician age (Mestre, 2010; Heredia et al., 2011; Mestre and Heredia, 2013a, b; Mestre, 2014). The San Juan Formation outcrops that appear in several classical localities at the Central and Eastern Precordillera were well studied (synthesis in Benedetto et al. 2007).

The San Juan Formation exposed in the Cerro La Chilca and Las Chacritas river sections (Central Precordillera) has been fully measured but was poorly described, except the uppermost beds (Espisúa, 1968; Blasco and Ramos, 1976; Furque, 1979; Astini, 1991, Astini, 1994; Lenhert, 1995; Peralta and Baldis, 1995; Carrera, 1997; Carrera and Astini, 1998; Keller, 1999; Peralta et al., 1999a, b). Similarly, the conodont data have been obtained from the Darriwilian beds from the top or few meters from the top of the San Juan Formation (Heredia et al., 2005 a, b, 2011; Mestre, 2010, 2012; Mestre and Heredia, 2013a, b, 2019, 2020). However, the study on the conodont content of Floian and Dapingian strata from these both sections are scarce, only Heredia et al. (2011) mentioned Floian beds in the base of the San Juan Formation in the Las Chacritas river section, after recovered representative conodonts of the *Oepikodus evae* Zone.

The Floian conodont biostratigraphy was previously studied in several sections to northward of the Central Precordillera, such as La Silla section (Lenhert, 1995), Cerro Potrerillo (Albanesi, 1998), Huaco (Mango and Albanesi, 2018a), where has been recorded the *P. proteus (A. deltatus* subzone)*, P. elegans, O. evae,* and *O. intermedius* zones. However, the most extended record of the upper Floian conodont biozones in the Central Precordillera is present southward, such as the Talacasto, Villicum, and San Juan river sections (Serpagli, 1974, Sarmiento, 1987, Soria et al. 2013). Thus, the Floian conodont biostratigraphy and the conodont fauna of many of the San Juan Formation outcrops remain unknown.

In the present contribution, the upper Floian conodont faunas from the Cerro La Chilca and Las Chacritas river sections are studied and compared with the well-known Talacasto conodont fauna, adding two Floian species for the Precordilleran conodont list that are described for the first time. The biostratigraphic and paleogeographic significance of these new findings in the regional and global context are discussed.

2. Geological setting

The Lower Paleozoic outcrops in Argentina are well exposed in the geological province of Precordillera. The Lower-Middle Ordovician carbonate succession of the Precordillera is represented by the San Juan Formation. This unit is composed mainly of fossiliferous limestone and marly limestone. The San Juan Formation is conformably overlain by grey and black shale and thin- to medium-bedded marly limestone and black shale of the Los Azules or Las Aguaditas Formations of Middle to Late Ordovician age (Heredia et al., 2011; Mestre and Heredia, 2013a, b; Mestre, 2014; Mestre and Heredia, 2019, 2020). The San Juan Formation exposures in the Las Chacritas river, Cerro La Chilca, and Talacasto represent classic sections from the Central Precordillera (Fig. 1a).

Lower-Middle Darriwilian index conodonts were mostly recorded from the upper beds of the Las Chacritas river, and Cerro La Chilca sections (Heredia et al., 2011; Mestre and Heredia, 2013 b), but few contributions describing the complete San Juan Formation outcrops from these sections can be mentioned (Keller, 1999).

The upper levels of the San Juan Formation at the Las Chacritas river section are Darriwilian in age by the recovering of conodonts that allowed recording the *Lenodus variabilis*, *L. crassus* and *L. pseudoplanus* zones (Lehnert, 1995; Mestre and Heredia, 2019 and references mentioned there). The Darriwilian outcrops of the San Juan Formation in Las Chacritas area are recognized in two sections, one on the Las Chacritas river and the other on a secondary creek named La Brecha creek where was partially described and measured by Mestre (2010) and Mestre and Heredia (2013 b).

The Ordovician of the Cerro La Chilca section was completely surveyed by Keller (1999), including the San Juan Formation and recording that lowermost beds of this unit were in contact with the La Silla Formation (Fig. 1b). Several paleontological studies were developed just in the last 20 or 30 meters, such as Sánchez *et al.* (1996), Benedetto (2015), among others. Lehnert (1995) recorded the first Darriwilian conodonts, followed by Mestre (2012) and Mestre and Heredia (2019, 2020).

In the Talacasto section (Fig. 1c), the San Juan Formation has been dated as Floian-Darriwilian in age (Sánchez et al., 1996; Soria et al., 2013). The *O. evae* and *O. intermedius* zones were recorded for the first time in the San Juan Formation strata at the Talacasto section by Soria et al. (2013). The conodont fauna of the Talacasto section was included in the present contribution to be compared with those of the Las Chacritas river section and the Cerro La Chilca section.

The San Juan Formation lower-middle beds from the Las Chacritas river and Cerro La Chilca sections have been studied for the present contribution (Fig. 1b). The *ca*. 25 m of the stratigraphic range studied of the San Juan Formation in the Cerro La Chilca section begins with 8 m of light grey wackestone-packstone succession (CH1), followed by 6 m of the grey nodular limestone with abundant gastropods in contact to bentonite bed of 0.20 m thick (CH2 and CH3). These levels are followed by 3 m of grey nodular limestone with well-preserved crinoids and brachiopod shells constituting middle grey bioclastic wackestone-packstone (CH4). The section continues with 8 m of the alternating wackestone and grainstone beds, interbedded with fine layers of bentonite (0.05 m thick) with big gastropods, trilobites and brachiopods, these deposits present oxide-Fe mineral on the surface that may be interpreted as firmgrounds (CH5, CH6 y CH7) (Fig. 2).

In the Las Chacritas river section, the 20 m of the stratigraphic range studied of the San Juan Formation begins with dark grey massive wackestone-packstone beds (LCE1), the beds of 0.3 m interbedded with k-bentonite layers of 0.2 m thick appear in the firsts 2 m, followed by 4 m of massive wackestone-packstone beds. The section continues to dark grey bioclastic wackestone-packstone beds of 7 m thick, where the bioclasts are fragmented and small (LCE2). The next strata group of 5 m of thickness (LCE 3) is composed of nodular bioclastic wackestone-packstone with abundant gastropods from 5 to 10 cm average in size (*Maclurites* sp.). The surveyed section ends with 2 m of nodular dark grey packstone beds (LCE4) where the content of bioclast decrease (Fig. 2).

The first 25 m of the San Juan Formation that outcrops in the Talacasto section were studied in this report. This stratigraphic range is mainly composed of wackestone interbedded with K-bentonite (from TR0 to TR5 and from T5 to T8), and few packstone-grainstone beds (from TR6 from TR7 and T9) (Fig. 2).

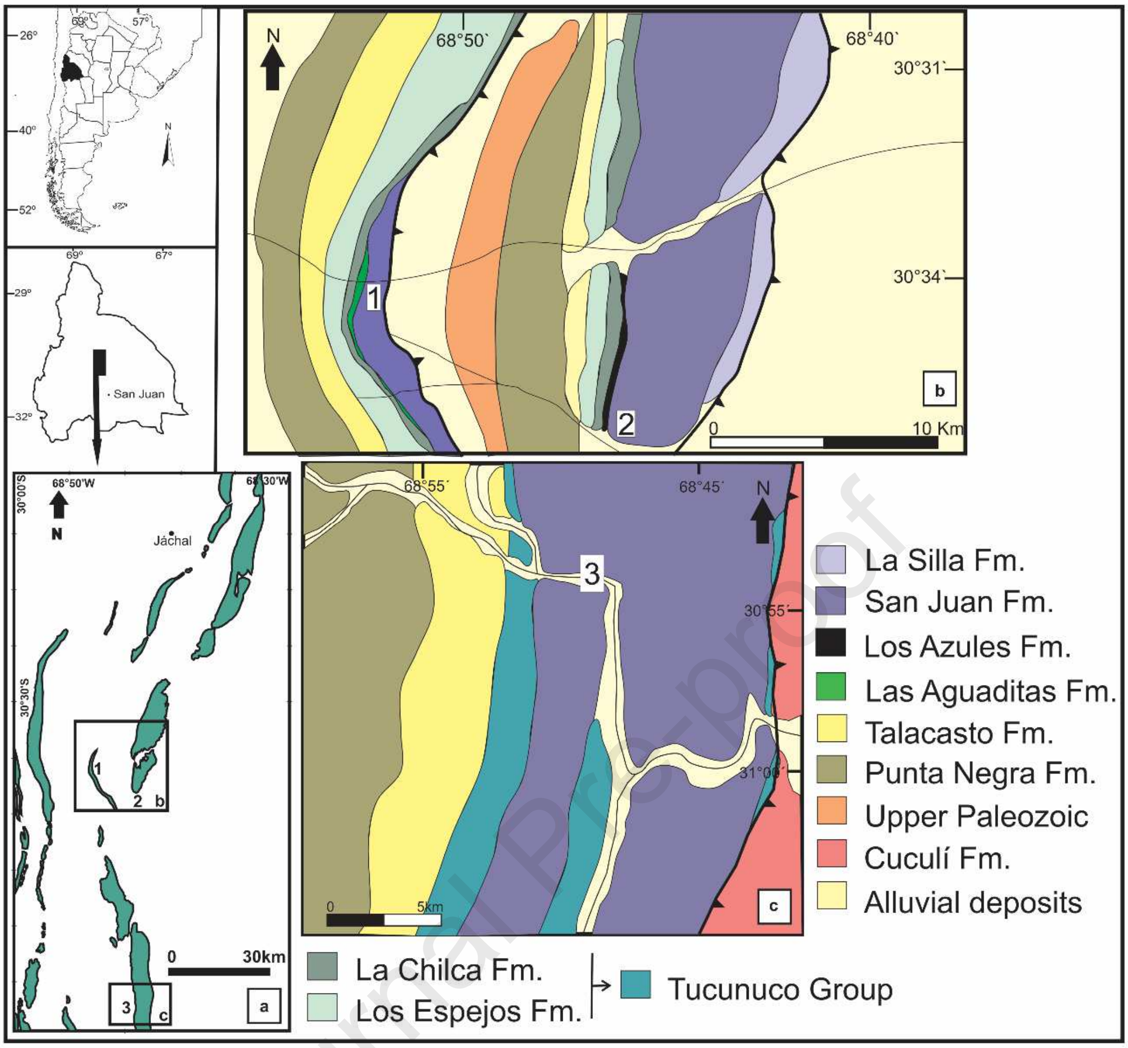

Figure 1: a- The Central Precordillera map shows the location of the study sections; **b-** Detail geologic map from the (1) Las Chacritas river and (2) Cerro La Chilca sections, **c-** Detail geologic map from the (3) Talacasto section.

3. Materials and Methods

Nine hundred elements of conodonts were recovered between complete, identified fragments and unidentified parts after processing 40 kg of limestone. The samples were treated following conventional laboratory methods, using 10% formic acid, to isolate the elements contained in the rocks (Stone,1987). The insoluble residue of the samples was

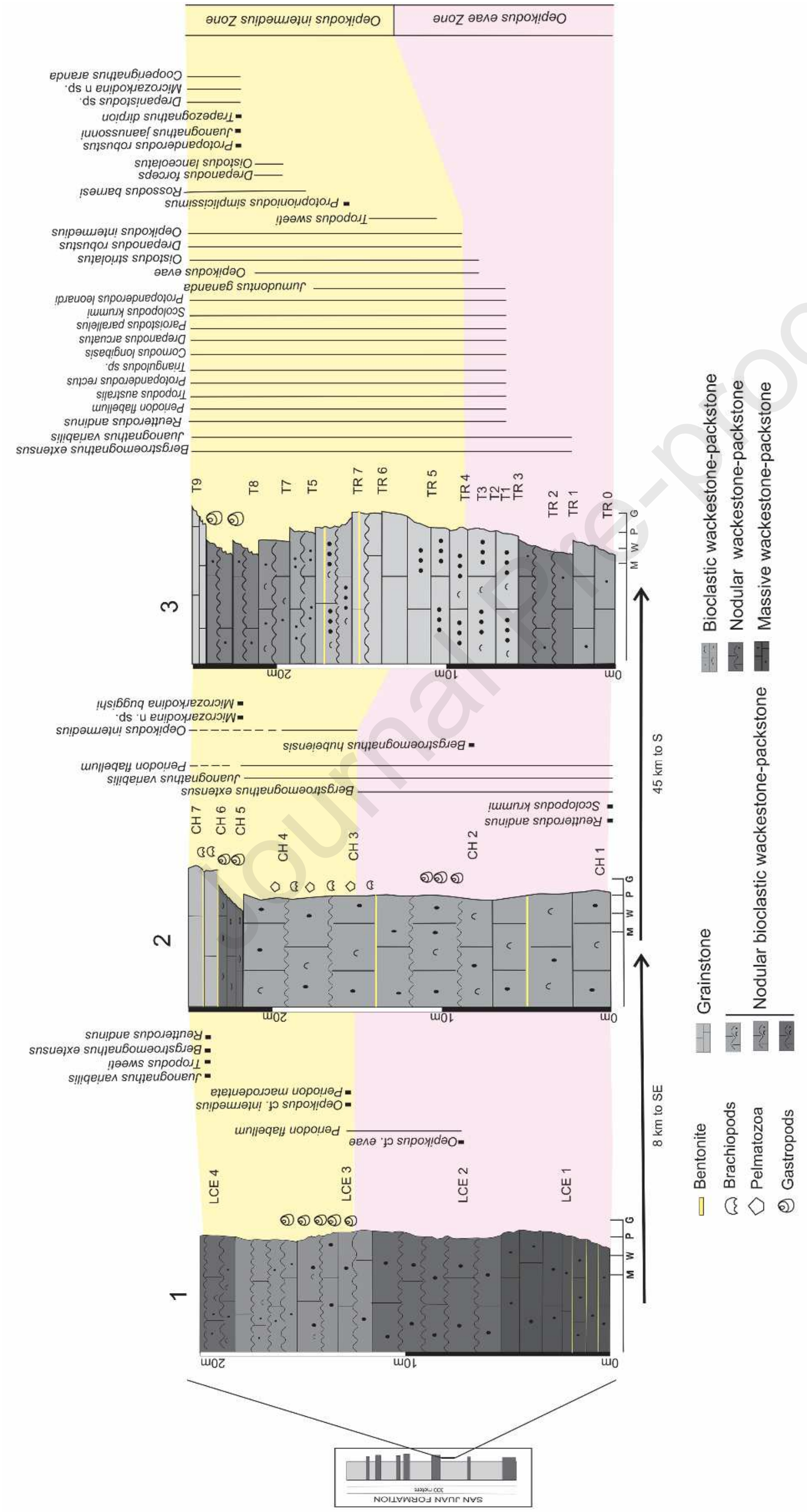

Figure 2: Stratigraphic column of the study section showing the sampled levels and conodont vertical distribution, 1- Las Chacritas river section, 2- Cerro La Chilca section and 3- Talacasto section.

recovered by sieves No. 40, 80, and 120 (IRAM), and then the conodonts were separated under a binocular microscope. Microphotographs were obtained with the Scanning Electron Microscope of the Instituto de Investigaciones Mineras (IIM), Facultad de Ingeniería, Universidad Nacional de San Juan. The conodont collections are housed in the Instituto de Geología P. E. Aparicio (INGEO), Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan; under the code INGEO-MP.

4. Conodonts

The conodont fauna recovered from the Cerro La Chilca section is composed as follows: *Bergstroemognathus hubeiensis* An, *Bergstroemognathus extensus* (Graves and Ellison), *Juanognathus variabilis* Serpagli, *Microzarkodina* n. sp. (*sensu* Pyle and Barnes, 2002), *"M." buggischi* Lenhert, *Oepikodus intermedius* Serpagli, *Periodon flabellum* (Lindström), *Reutterodus andinus* Serpagli, and *Scolopodus krummi* Lenhert (Figs. 2, 3, Table 1). The Las Chacritas river section conodonts fauna is composed of *Bergstroemognathus extensus*, *Juanognathus variabilis*, *Oepikodus* cf. *intermedius*, *Oepikodus* cf. *evae*, *Periodon flabellum*, *Periodon macrodentata* (Graves and Ellison), and *Tropodus sweeti* Serpagli (Figs. 2, 4, Table 1). In this report several levels from the

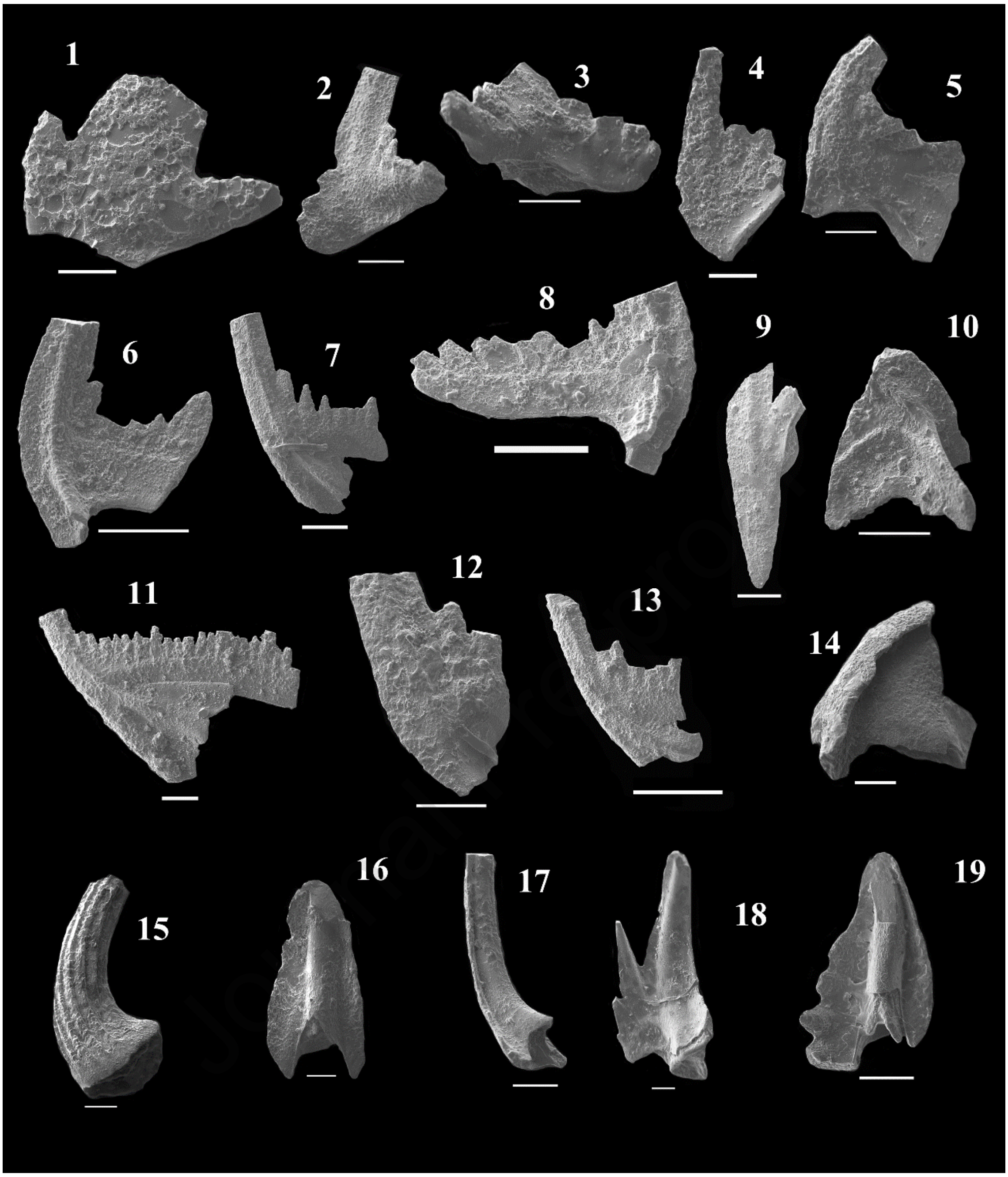

Figure 3: Microphotographs of scanning electron microscope. The bar indicates 0.1 mm. Specimens from Cerro La Chilca section, 1-5- CH 5 sample, 6-13- CH4 sample, 14-19- CH 1 sample. 1-*Microzarkodina* n. sp., P element, INGEO-MP 9019 (1); 2-3, 5- *Periodon flabellum* (Lindström), 2-3, Pb element, INGEO-MP 9021 (1-2); 5- Sc element, INGEO-MP 9021 (3); 4- *"Microzarkodina" buggischi* Lenhert, P element, INGEO-MP 9020 (1); 6-13- *Oepikodus intermedius* Serpagli, 6, Pa element, INGEO-MP 9016 (1); 7, 13, Sc element, INGEO-MP 9016 (2-3); 8, Pb element, INGEO-MP

9016 (4); 9, M element, INGEO-MP 9016 (5); 11, Sd element, INGEO-MP 9016 (6); 12, Sb element, INGEO-MP 9016 (7); 14, 19-*Reutterodus andinus* Serpagli, 14, P element, INGEO-MP 9004 (1); 19, Sb element, INGEO-MP 9004 (2); 15-*Scolopodus krummi* (Lenhert), a element, INGEO-MP 9005 (1); 16-17- *Juanognathus variabilis* Serpagli, Sa element, INGEO-MP 9005 (1-2); 18- *Bergstroemognathus extensus* (Graves and Ellison), Sb element, INGEO-MP 9000 (1).

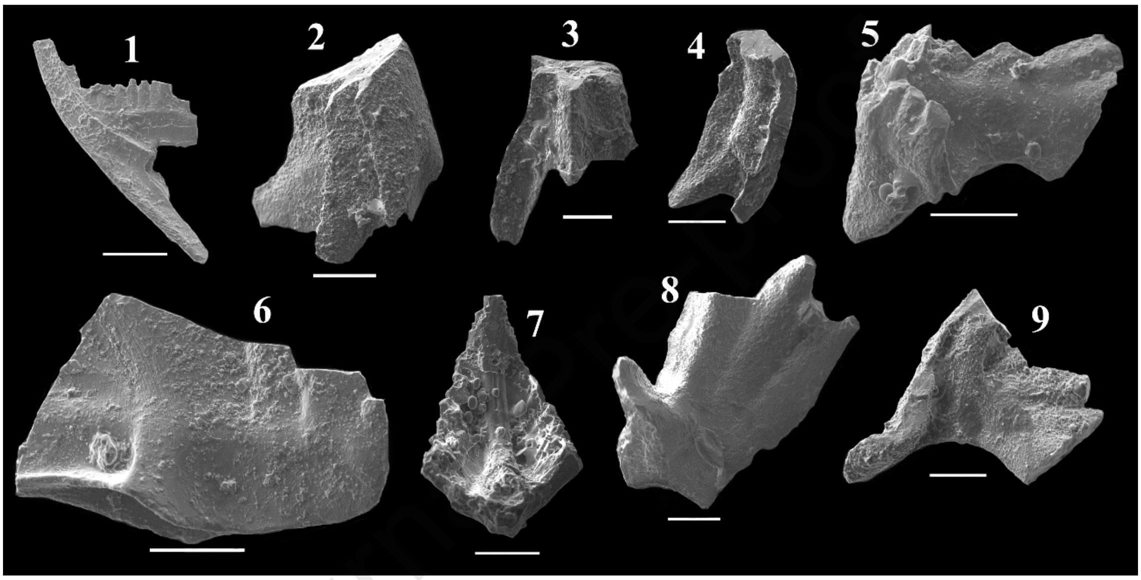

Figure 4: Microphotographs of scanning electron microscope. The bar indicates 0.1 mm. Specimens from Las Chacritas river section, 1, 5-6- LCE 2 sample, 2-4, 7-8- LCE 4 sample, 9- LCE 3 sample. 1- *Oepikodus* cf. *evae*, Sc element, INGEO-MP 9500 (1); 2-3-*Tropodus sweeti* Serpagli, Sd element, INGEO-MP 9508 (1-2); 4- *Juanognathus variabilis* Serpagli, Sa element, INGEO-MP 9506 (1); 5- *Periodon flabellum* (Lindström), Sd element, INGEO-MP 9501 (1); 6- *Periodon macrodentata* (Graves and Ellison), Pa element, INGEO-MP 9504 (1); 7- *Reutterodus andinus* Serpagli, Sa element, INGEO-MP 9507 (1); 8- *Bergstroemognathus extensus* (Graves and Ellison), Sd element, INGEO-MP 9505 (1); 9- *Periodon flabellum* (Lindström), Sb element, INGEO-MP 9503 (1).

the Talacasto section was resampled and the resulted conodont collection was studied including the previous conodont assemblage considered by Soria et al. (2013). The new data provide the following conodont association: *Bergstroemognathus extensus*, *Cornuodus longibasis* (Lindström), *Cooperignathus aranda* Cooper, *Drepanodus arcuatus* Pander, *Drepanodus forceps* (Lindström), *Drepanodus robustus* Hadding, *Juanognathus jaanussonni* Serpagli, *Juanognathus variabilis*, *Jumudontus gananda* Cooper, *Microzarkodina* n. sp., *Oepikodus evae* (Lindström), *Oepikodus intermedius* Serpagli, *Oistodus striolatus* Serpagli, *Paroistodus parallelus* (Pander), *Periodon flabellum*, *Protopanderodus leonardii* Serpagli, *Protopanderodus rectus* (Linström), *Protopanderodus robustus* Hadding, *Protoprioniodus simplicissimus* Cooper, *Rossodus barnesi* Albanesi, *Reutterodus andinus*, *Scolopodus krummi*, *Scolopodus rex* Lindström, *Trapezognathus diprion* Lindström, *Triangulodus* sp., *Tropodus australis* (Serpagli) and *Tropodus sweeti* (Figs. 2, 6, Table 1).

5. Systematic Paleontology

Conodonts retrieved from the studied samples were mainly described and illustrated in previous publications (Serpagli, 1974; Lehnert, 1995; Albanesi, 1998; Mestre, 2008; Soria et al., 2013). Hence, only two species are described, due to those represent the first mention of them in the Precordillera.

Family RHIPIDOGNATHIDAE Lindström, 1970

Genus *BERGSTROEMOGNATHUS* Serpagli, 1974

Remarks: The genus *Bergstroemognathus* was defined by Serpagli (1974) conformed by 3 morphotypes: falodiform, prioniodiform, and trichonodelliform, after having studied the Lower Ordovician conodont fauna from the San Juan Formation of the Precordillera (Argentina). Cooper (1981) and Stouge and Bagnoli (1988) considered the falodiform as the M element, the prioniodiform as the S elements, and the trichonodelliform as the Sa element. On the other hand, Sweet (1988) included a group of genera with three or seven elements in the apparatuses into the Rhipidognathidae family, such as *Appalachignathus*, *Bergstroemognathus*, and *Rhipidognathus*. This author proposed that *Bergstroemognathus* is composed of alate Sa element, bipennate M element, and bipennate P or S elements. Nevertheless, Albanesi (1998) proposed a quinquimembrate apparatus for the genus *Bergstroemognathus*, constituted by segminate M and P elements, alate Sa element, tertiopedate Sb element, and dolobrate Sc element. This apparatus reconstruction is incongruent to the genera apparatuses composition included in the *Rhipidognathidae* family as that proposed by Sweet (1981), however, Albanesi (1998) retains the family assignation.

The septimembrate apparatus reconstruction was proposed by Zhen *et al.* (2001) for the genus *Bergstroemognathus*, including angulate Pa and Pb elements, makellate M element, alate Sa element, and digyrate or bipennate Sb, Sc, and Sd elements, following Sweet (1981) Rhipidognathidae family configuration. The apparatus architecture proposed by Zhen et al. (2001) is followed in this contribution.

The genus *Bergstroemognathus* include only four species: *B. extensus* (Graves and Ellison), *B. hubeiensis* An, *B. kirki* Stait and Druce, and *B. pectiniformis* Yang and Zhang.

Bergstroemognathus hubeiensis An, 1981

Fig. 5, 1-4.

1981 *Bergstroemognathus hubeiensis* AN; AN et al., pl. 1, fig. 15.

1983 *Bergstroemognathus hubeiensis* AN, 1981; AN et al., p. 80, pl. 17, figs. 9, 10.

1984 *Bergstroemognathus hubeiensis* AN, 1981; AN and XU, Pl. 2, fig. 11.

1985 *Bergstroemognathus hubeiensis* AN, 1981; AN, DU and GAO, p. 37, pl. 7, figs. 8-12, text-fig. 5-1, 5-2, 5-5.

1987 *Bergstroemognathus hubeiensis* AN, 1981; AN, p. 132, pl. 23, figs. 3-7, 12, pl. 26, fig. 22.

1990 *Bergstroemognathus hubeiensis* AN, 1981; AN and ZHENG, pl. 8, fig. 10.

1993 *Bergstroemognathus hubeiensis* AN, 1981; DING and others, in WANG, p. 166, pl. 20, fig. 15.

1995 *Bergstroemognathus hubeiensis* AN, 1981; CHEN, PENG and JIN, pl. 2, figs. 7, 8.

Description: In our collection, we only recovered Pb, Sa, Sb, and Sc elements. The Pb element has a long anterior process with many erected denticles. The strongly recurved cusp has its posterior margin parallel to the upper margin of the posterior process. The Sa element: alate, each process carries nineteen fused and lateral compressed denticles. The cusp is taller and slender than denticles with a well-marked rib. The basal cavity extended like a groove under each process. The bipennate Sb element shows an anterior process with one denticle and an adenticulate posterior one. The cusp is proclined with lateral carina and sharp anterior and posterior processes. The bipennate Sc element has an erect to recline cusp, anterior process with three denticles, and a posterior process with one denticle or adenticulate.

Material: four elements, one Pb, one Sa, one Sb, one Sc, INGEO-MP 9007 (1-4).

Remarks: Zhen et al. (2001) and Zhen and Percival (2003) mentioned that *B. hubeiensis* is only retrieved from North China, South China, and Iran from middle-late Early Ordovician, being recovered from the *Prioniodus elegans* to *Oepikodus evae* zones (Wang et al., 1996). It was also recorded from classical sections and formations, like the Honghuayuan (An et al., 1981) and the overlying Dawan (An, 1987), Lower Meitan Formation (South China) (An, 1987) and Liangjiashan Formation (North China) (An et al., 1983). It is also pointed out that this species was recorded from the lower part of Katkoyeh Formation of the Kerman region in east-central Iran (Zhen et al., 2001). Ghaderi et al. (2008) recovered from the Shirgesht Formation in Central Iran a fragment element assigned to *Bergstroemognathus* sp. into the *P. proteus* assemblage Zone. The present record of *B. hubeiensis* represents the first mention of this species in the Precordillera and lets to infer the *O. evae* Zone for the sampled lower beds of the San Juan Formation in the La Chilca section (LCH 1 and LCH 2) (Fig. 2).

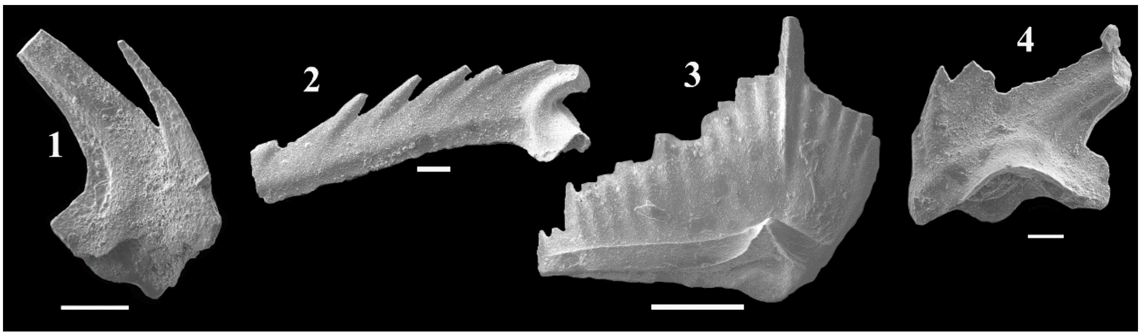

Figure 5: Microphotographs of scanning electron microscope. The bar indicates 0.1 mm. Specimens from Cerro La Chilca section, 1-4 CH 2 sample. *Bergstroemognathus*

hubeiensis An, 1- Sb element, INGEO-MP 9007 (1); 2- Pb element, INGEO-MP 9007 (2); 3- Sa element, INGEO-MP 9007 (3); 4- Sc element, INGEO-MP 9007 (4).

Family PERIODONTIDAE Lindström, 1970

Genus *Microzarkodina* Lindström, 1971

Microzarkodina n. sp. Pyle and Barnes

Fig. 3, 1; Fig. 6, 1-4.

2002 *Microzarkodina* n. sp. PYLE and BARNES, p. 107, pl. 24, fig. 12-14.

Description: P elements are different from the *Microzarkodina* species previously described for this genus, due that the *Microzarkodina* n. sp. bears a large anterior denticle and small posterior denticles on the thin posterior process. The cusp is wide and strongly proclined. As just only five P elements were recovered, the specific assignment is not attempted.

Material: one specimen, INGEO-MP 9019 (1) from Cerro La Chilca section and four specimens, INGEO-MP 1910 (1-2), INGEO-MP 1901 (1-2), Talacasto section.

Remarks: Pyle and Barnes (2002) recovered a new conodont from the *Jumudontus gananda* Zone beds in the Skoki Formation (Northeastern British Columbia) that was assigned to the genus *Microzarkodina* as new species no identified, which apparatus is composed by P and M elements. The Precordilleran specimens that were retrieved from beds of the *O. intermedius* Zone in the La Chilca section (CH5 sample) and the Talacasto section (T8 and T9 samples) are only conformed by P elements. The present finding represents the first mention of this conodont species outside Canada.

Six species are established themselves successfully for the genus *Microzarkodina*, mainly recovered from the Baltoscandia region, they are: *M. russica* Löfgren and Tomalcheva, *M. flabellum* (Lindström), *M. parva* Lindström, *M. bella* Löfgren, *M. hagetiana* Stouge and Bagnoli, *M. ozarkodella* Lindström; the succession of these species ranges from the upper part of the Early Ordovician (*M. russica*) to upper part of the Middle Darriwilian (*M. ozarkodella*) (Löfgren and Tomalcheva, 2008) and are used for their biostratigraphic value.

The *Microzarkodina* n. sp. probably has the same biostratigraphic range to the *M. russica* but a comparison of these two species shows the most significant morphological differences between them, the *Microzarkodina* n. sp. has a larger anterior denticle and smaller posterior process than *M. russica*.

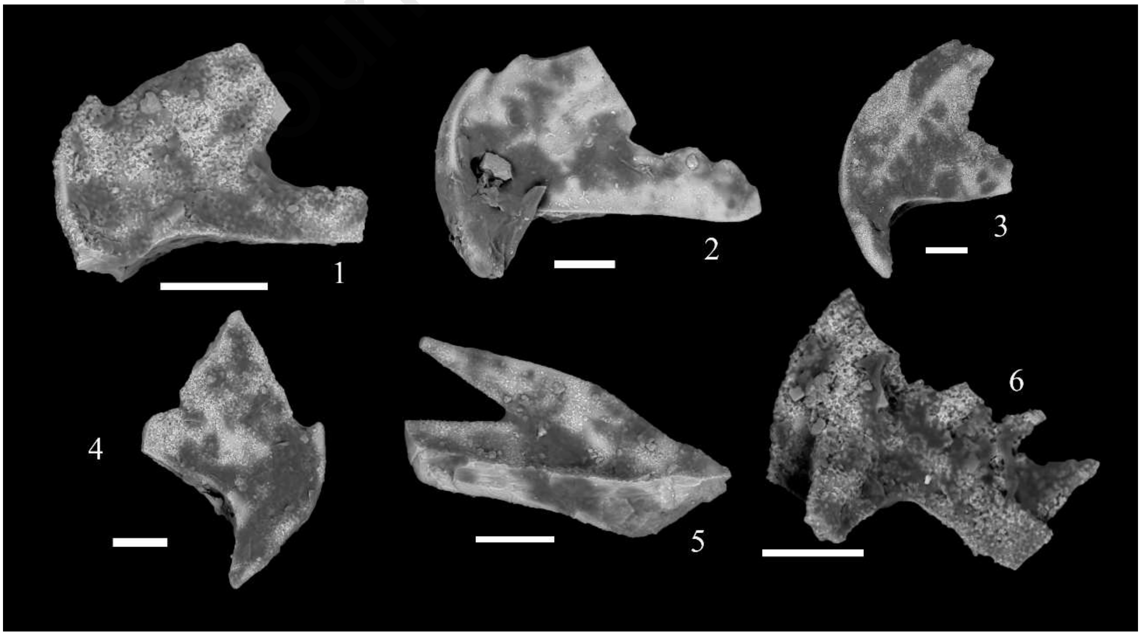

Figure 6: Microphotographs of scanning electron microscope. The bar indicates 0.1 mm. specimens from Talacasto section, 1-2, T9 sample and 3-6, T8 sample. 1-4-

Microzarkodina n. sp., P element, INGEO-MP 1910 (1-2), INGEO-MP 1901 (1-2); 5- *Cooperignathus aranda* (Cooper), M element, INGEO-MP 1898 (1); 6- *Oepikodus intermedius* (Serpagli), Pa element, INGEO-MP 1902 (1).

6. Conodont Biostratigraphy

The conodont associations recovered from the San Juan Formation lower-middle beds in each section let to record the *O. evae* and *O. intermedius* zones, indicating the upper Lower Ordovician. These conodont zones have an extensive record in the Precordillera carbonate Ordovician basin representing the *Evae* highstand cycle with a wide record in other regions, while the *O. intermedius* Zone (and equivalents conodont zones elsewhere) represents a worldwide regressive cycle (Nielsen, 2003, 2011; Haq and Schutter, 2008).

6.1. *Oepikodus evae* Zone

Sergeeva (1963) introduced the *O. evae* Zone in the Baltoscandian succession, after this biozone had been recorded in different regions from Baltoscandia (Lindström, 1955; Löfgren, 1978), Newfoundland (Stouge and Bagnoli, 1988; Polher, 1994), British Columbia (Pyle and Barnes, 2002); North America (Sweet and Bergström, 1986), South China (An, 1987), Australia (Zhen et al., 2003) and Russia (Tomalcheva, 2014) (Fig. 7). The conodont assemblage of the *O. evae* Zone is characterized as the Fauna B, defined by Serpagli (1974) in the San Juan River section (Central Precordillera). Later, the *O. evae* Zone was mentioned for several Precordilleran localities (Sarmiento, 1987; Beresi and Heredia, 1992; Albanesi, 1998; Mestre, 2008; Soria et al., 2013, 2017; Mango and

Albanesi, 2018a), and in allochthonous blocks in the Ponón Trehué Formation (San Rafael, Mendoza) (Lehnert et al., 1998).

The *O. evae* Zone is recorded from the CH1 to CH2 samples at the Cerro La Chilca section, that also provided *B. extensus, B. hubeiensis, J. variabilis, P. flabellum* and *R. andinus.* The conodont *B. hubeiensis* appears form the *P. elegans* to *O. evae* zones in the meager worldwide record, but for the precordilleran consortium conodont fauna is considered in this contribution as characteristic of the *O. evae* Zone. The first occurrence of the conodont *Oepikodus intermedius* is reported in the sample CH3 in the Cerro La Chilca section indicating the top of the *O. evae* Zone.

A poor conodont association composed by *Oepikodus* cf. *evae* and *P. flabellum* from Las Chacritas river section was recovered from the LCE2 sample, letting to suggest the *O. evae* Zone. The *O. evae* Zone in the Talacasto section ranging from the TR1 to TR4 sample where the first appearance of *O. intermedius* is recorded. The conodont fauna in this section is more abundant and diverse than the other two sections (Fig. 2).

Considering the vertical distribution of the genus *Bergstroemognathus* and the species present in the Precordillera, *B. extensus* and *B. hubeiensis,* results of interest that both remain in the Lower Ordovician. *B. hubeiensis* would be constrained to the *O. evae* Zone (this contribution) and *B. extensus* since *P. elegans* to *O. intermedius* zones as typical conodont stock that characterize the Lower Ordovician biostratigraphy (Albanesi et al., 1998; Zhen et al., 2001; Mango and Albanesi, 2018a). Lenhert (1993) extends the upper limit of the *B. extensus* biostratigraphic range to the *J. jaanussini* / *O.* aff. *O. lanceolatus* Association probably equivalent to the *B. triangularis/B. navis* Zone. However, Mango and Albanesi (2018b) interpreted that the subsequently conodont association *"P." nogamii/P. gracilis/A. jemtlandica* Association proposed by Lenhert

(1993) is correlative with the *T. leavis/B. triangularis* Zone, thus restricting the *B. extensus* biostratigraphic range to the Early Ordovician like the worldwide record.

6.2. *Oepikodus intermedius* Zone

The conodont species *Oepikodus intermedius* was defined by Serpagli (1974) with Precordilleran specimens and it was considered as descendant of *O. evae*. Serpagli (1974) proposed that the first occurrence of *O. intermedius* as the boundary between both biozones, besides recorded that the *O. intermedius* replacing to *O. evae* during the Fauna C (Serpagli, 1974, Tab.1). This conodont zone has also been recorded in several sections from the San Juan Formation by Sarmiento (1990), Lehnert (1993, 1995), Albanesi *et al.* (1998), Soria *et al.* (2013, 2017) and Soria (2017). Soria et al. (2017) studied the beds that represent the *O. evae* and *O. intermedius* zones from the Niquivil section, and recording *Cooperignathus aranda* (Cooper) in association with *O. evae, O. intermedius, B. extensus* and *R. andinus*, among others, that represent the typical late Lower Ordovician conodont fauna from the Precordillera.

Outside Argentina, the conodont *O. intermedius* was recorded in the Huanghuachang section (Wang et al., 2009), South China (Li et al., 2010), Rusia (Dubinina and Ryazantsev, 2008) and Spitsbergen or the Svalbard Islands (Lenhert et al., 2013) (Fig. 7).

The *O. intermedius* Zone is recorded from the CH3 to CH7 samples (Fig. 2) at the Cerro La Chilca section. These samples provided the eponymous key conodont in association to *B. extensus, J. variabilis, P. flabellum, Microzarkodina* n. sp. and *"M." buggischi.* The *Microzarkodina* n. sp. only appears in the upper *Jumudontus gananda* Zone from Canada (Pyle and Barnes, 2002).

The conodont association composed by *B. extensus, O.* cf. *intermedius, P. flabellum, P. macrodentata, J. variabilis* and *T. sweeti* from Las Chacritas river section was recovered from the LC3 and LC4 samples (Fig. 2.2). Most of this conodont fauna is interpreted as typical of the *O. intermedius* zone (Löfgren, 1978; Lehnert, 1995; Mestre, 2008).

In the Talacasto section, the *O. intermedius* Zone contain a most abundant and diverse conodont fauna than the Cerro La Chilca and Las Chacritas river sections, this zone ranging from the TR4 sample to T9 sample, but its record continued until the sample T18 according to Soria et al. (2013) data. The last occurrence of the *J. gananda, P. simplicissimus, O. evae, T. sweeti, T. diprion* and *Microzarkodina* n. sp. are recorded in this time interval. Soria et al. (2013) and Heredia et al. (2013) mentioned and illustrated the Gondwanan conodont *Erraticodon patu* Cooper for the first time in the Lower Ordovician deposits of the Talacasto section. In this contribution, like Soria et al. (2013, 2017), the *Oepikodus intermedius* Zone is considered as an interval zone with a lower boundary pointed out by the first occurrence of the index conodont; indeed *O. evae* and *O. intermedius* cooccur during the lower interval of the *O. intermedius* Zone.

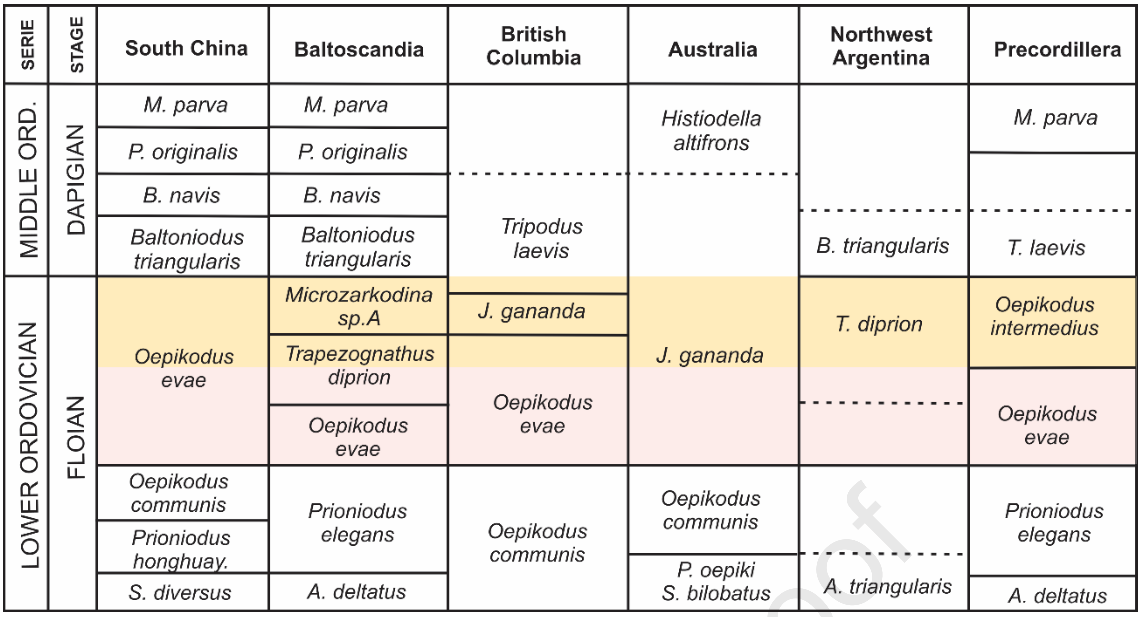

Figure 7: Correlation of the Floian (Lower Ordovician) conodont zonation of the Cerro La Chilca, Las Chacritas river and Talacasto sections (Albanesi and Ortega, 2002; Soria et al., 2013, this study) with those of the South China (Wang et al., 2018), Baltoscandia (Bagnoli and Stouge, 1997), British Columbia (Pyle and Barnes, 2002), Australia (Normore et al., 2018), and Northwest Argentina (Carlorosi and Heredia, 2017).

7. The late Floian biogeography and paleogeography of the Precordillera

The Precordillera was considered as an allochthonous terrane that docking to the western margin of Gondwana during Middle Ordovician (Benedetto, 1993; Astini *et al.*, 1995; Thomas *et al.*, 2002). The allochthonous model is supported, between other arguments, by a progressive change in biogeographic affinities of the Precordilleran fauna through the late Cambrian to Ordovician times, from entirely Laurentian fauna to mainly Gondwanan fauna. Based on variations in the proportion of Laurentian to Gondwanan elements, four biogeographic evolution stages were proposed for the Precordillera terrane (Benedetto et al., 1999), they are Laurentian stage (Cambrian-

Tremadocian), isolation stage (Floian-Dapingian), pre-accretion stage (Darriwilian-Katian), and finally the Gondwanan stage (Hirnantian-Silurian). The position of the Precordillera in the Early Ordovician and the mechanism of transfer from Laurentia to Gondwana have been the subjects of considerable controversy. However, the most accepted propose is that the Precordillera was probably located in the Iapetus ocean between the Laurentia, and Gondwana during the Lower Ordovician (Mac Niocaill et al., 1997; Christiansen and Stouge, 1999).

The previous biogeographic hypothesis is not clearly supported by the conodont records in the Lower to Middle Ordovician from the Precordillera. The similarity of the Precordillera to southern Laurentian faunas is significant until the Tremadocian, during the Floian it is not evident and the similarity between these two regions remains about the same through the early Middle Ordovician (Albanesi and Bergström, 2010).

The correlation of shallow- and deep-water facies is complicated by the conodont provincialism in the Ordovician, as first noted by Sweet et al. (1959) and Sweet and Bergström (1962). The two faunal realms, the North Atlantic and Midcontinent realms, necessitate two separate biozonations. Provincialism within each Realm is controlled by ecologic factors in which conodont faunas are adapted to warmer, more saline waters (Midcontinent), or cooler waters of normal salinity (Atlantic) (Pohler and Barnes, 1990).

In the Ordovician conodont biogeography reconsideration proposed by Zhen and Percival (2003), the South China and Precordillera provinces might be situated within the Temperate Domain during the Early Ordovician, but the former had closer biogeographic links to the Australian and North China provinces, whereas the Precordillera would exhibit closer ties with the Laurentian Province.

The finding of the conodonts *B. hubeiensis* and *Microzarkodina* n. sp. in the Lower Ordovician strata of the San Juan Formation provides significant information related to the links of the Precordillera to Gondwana (Iran), peri-Gondwana (South and North China), and Northwestern of Midcontinent (British Columbia) regions (Fig. 8). However, the biogeographic connection during the late Floian times between Gondwana and Precordillera had already been pointed out by Heredia et al. (2013) after the first record of the Gondwanan conodont *Erraticodon patu* (Cooper) in the San Juan Formation (Fig. 8).

The conodont *B. hubeiensis* exhibit a bounded paleogeographic distribution, at the moment it only occurs in peri-Gondwana and Gondwana regions such as Central Iran, North China, and South China (Zhen et al., 2001, Zhen and Percival, 2003), the record of this conodont species in the Lower Ordovician carbonate succession of the Precordillera represents the first record out to the eastern margin of Gondwana.

The conodont biostratigraphy of British Columbia region that is located in the northwestern of the Midcontinent presents different biogeographic affinities between the shallow- and deep-water facies (Pyle and Barnes, 2002), the species *Microzarkodina* n. sp. was recovered from the conodont assemblage interpreted as included in the

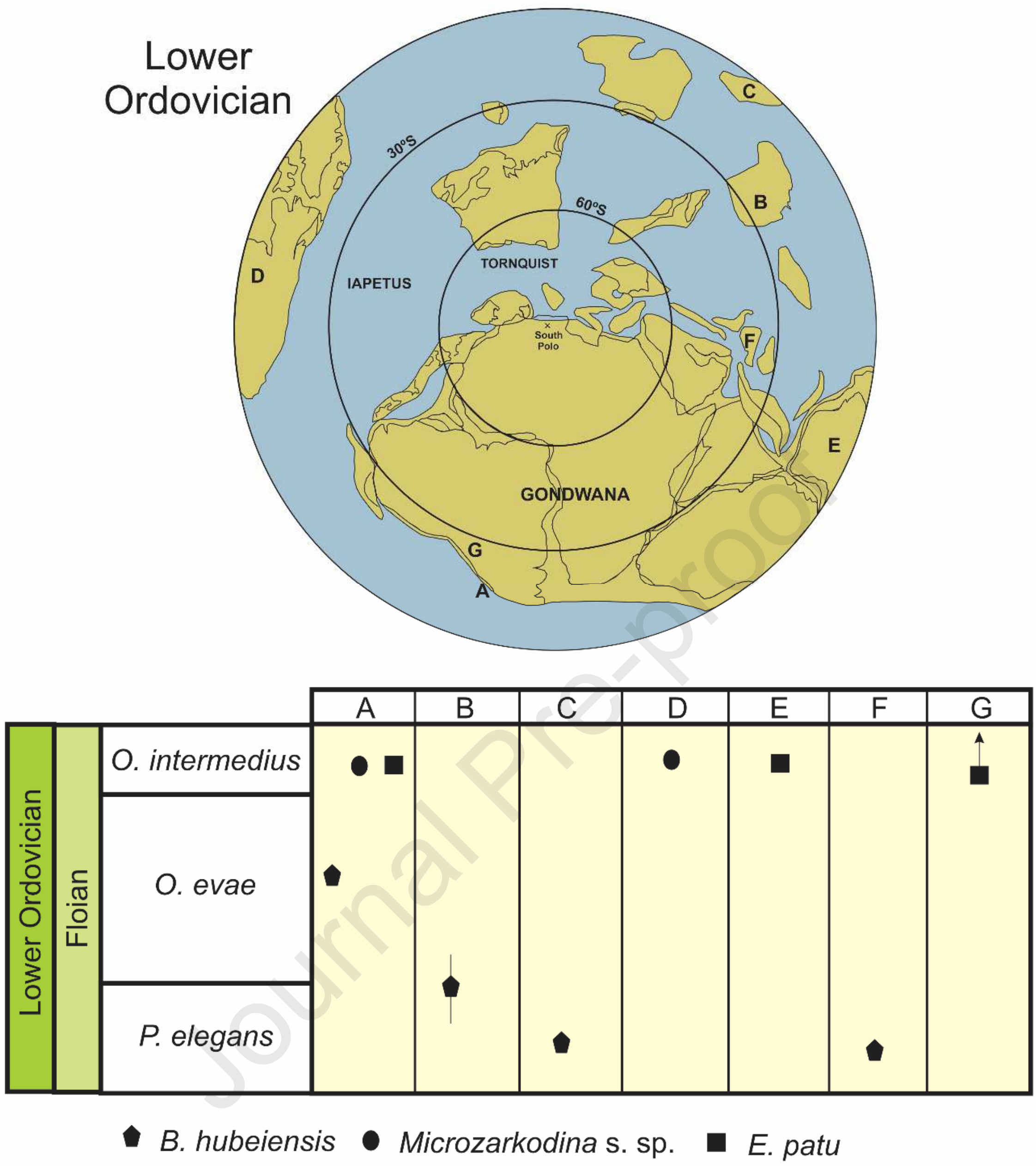

Figure 8: Global distribution and stratigraphic occurrences of the conodonts *Bergstroemognathus hubeiensis*, *Microzarkodina* n. sp. and *Erraticodon patu*. **A-** Precordillera (this study, Heredia et al. 2013); **B-** South China (Wang et al., 1996); **C-** North China (Wang et al., 1996); **D-** British Columbia (Pyle and Barnes, 2002); **E-** Australia (Cooper, 1981); **F-** Iran (Zhen et al., 2001); **G-** Northwest Argentina (Heredia et al., 2013).

Midcontinent realm (Pyle and Barnes, 2002), in this way the record of *Microzarkodina* n. sp. in the upper Floian strata from the San Juan Formation extends its paleogeographic distribution beyond the British Columbia region.

The increasing conodont biogeographic evidence of the connections between the Precordillera, Gondwana, and peri-Gondwana regions allows us to suggest that these regions exhibited a closer position between them than previous assumptions or at least there were marine currents that connected these regions during the late Lower Ordovician. A surface water currents reconstruction for the Lower-Middle Ordovician boundary was proposed by Servais *et al.* (2014), evidence that the precise number and location of the different gyres are highly speculative. These new conodont biogeographic data could provide crucial information about early Ordovician paleogeography and paleoceanography reconstruction of the west margin of Gondwana, as well as concerning possible directions of the surface currents around the Iapetus Ocean.

8. **Conclusion**

New conodont fauna across the middle part of the San Juan Formation has been analyzed on the basis of material from the Cerro La Chilca, Las Chacritas river and Talacasto sections. The major results are as follows:

- Two conodont zones have been recorded: the *Oepikodus evae* and *O. intermedius* that occur in the middle part of the San Juan Formation.
- The conodonts *Bergstroemognathus hubeiensis* and *Microzarkodina* n. sp. were retrieved for the first time from the *O. evae* and *O. intermedius* zones respectively.

- The occurrence of the conodonts *B. hubeiensis* and *Microzarkodina* n. sp. in the Lower Ordovician strata of the San Juan Formation, provide significant information related to the links of the Precordillera to Gondwana, peri-Gondwana, and Northwestern of the Midcontinent regions for this time interval, increasing the knowledge about the paleogeographic reconstruction of the western margin of Gondwana.
- The evidence of biogeographic connections between the Precordillera, Gondwana, and peri-Gondwana regions let to suggest that these regions were in closer position than previous assumptions or at least that marine currents connected these regions during the late Lower Ordovician.

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Conodonts	1	2	3
Bergstroemognathus extensus	X	X	X
Bergstroemognathus hubeiensis		X	
Cornodus longibasis			X
Cooperignathus aranda			X
Drepanodus arcuatus			X
Drepanodus forceps			X
Drepanodus robustus			X
Juanognathus jaanussonni			X
Juanognathus variabilis	X	X	X
Microzarkodina n. *sp.*		X	X
“Microzarkodina” buggischi		X	
Oepikodus evae			X

Oepikodus intermedius		X	X
Oepikodus cf. *evae*	X		
Oepikodus cf. *intermedius*	X		
Oistodus striolatus			X
Paroistodus parallelus			X
Periodon flabellum	X	X	X
Periodon macrodentata	X		
Protopanderodus leonardii			X
Protopanderodus rectus			X
Protopanderodus robustus			X
Protoprionodus simplicissimus			X
Rossodus barnesi			X
Reutterodus andinus	X	X	
Scolopodus krummi		X	
Scolopodus rex			X
Trapezognathus diprion			X
Triangulodus sp.			X
Tropodus australis			X
Tropodus sweeti	X		X

Table 1: Conodont distribution in the 1- Las Chacritas river section, 2- Cerro La Chilca section and 3- Talacasto section.

New Early Ordovician conodont data from the San Juan Formation, Central Precordillera (Argentina): Biostratigraphic and paleogeographic significance

Moreno, Florencia[1], Mestre, Ana[1] and Heredia, Susana[1]

Highlights

- Upper Floian conodonts from three sections in Central Precordillera are reported.
- The *Oepikodus evae* and *O. intermedius* zones are recorded.
- We documented the Early Ordovician conodont *B. hubeiensis* for the first time.
- The *Microzarcodina* n. sp. is reported in the Precordillera.
- We provide significant data related to the Precordillera palaeobiogeographic ties.

Author Statement

“**New Early Ordovician conodont data from the San Juan Formation, Central Precordillera (Argentina): Biostratigraphic and paleogeographic significance**” by Moreno, Florencia, Mestre, Ana and Heredia, Susana.

Dear editor:

A detailed description of the diverse contributions to the work is shown.

Lic. Moreno, Florencia: Conceptualization, methodology, conodont analysis, writing - review and editing.

Dr. Ana Mestre: Conceptualization, methodology, conodont analysis, writing - review and editing. Funding acquisition and project administration.

Dr. Susana Heredia: Conceptualization, methodology, conodont analysis, writing - review and supervision.

16 May 2020

Dear Editor of the Journal of South American Earth Sciences:

We declare that we have no conflict of interest.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: