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Conodont biostratigraphy from the upper San Juan Formation (Middle Ordovician) at Niquivil, Argentine Precordillera

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A B S T R A C T

The present work deals with the conodont biostratigraphy from the upper San Juan Formation in the section of Niquivil, Central Precodillera of San Juan, Argentina. We study the upper 129.45 m of the San Juan Formation, starting from the upper strata of the second reef horizon up to the top of the formation. Digested limestone samples yielded 20 conodont species. The presence of *Tripodus laevis* Bradshaw not associated to *Baltoniodus navis* (Lindström) allows the recognition of the *Baltoniodus triangularis-Tripodus laevis* Zone, which is interpreted as correlative with the *"Parapanderodus" nogamii/Parapanderodus gracilis/Ansella jemtlandica* Association of Lehnert (1993, 1995; Lehnert and Keller, 1993), conversely to previous interpretations that suggested the latter as correlative to the *Baltoniodus navis* Zone. The zonal identification is supported by the associated conodonts *Protopanderodus rectus* (Lindström), *Juanognathus jaanussoni* Serpagli, *Juanognathus* n. sp., *Protopanderodus gradatus* (Serpagli), *Rossodus barnesi* Albanesi, *Paltodus subaequalis* Pander, *Drepanodus arcuatus* (Pander), *Cornuodus longibasis* (Lindström), *Protopanderodus elongatus* Serpagli, *Oistodus lanceolatus* Pander, *Periodon flabellum* (Lindström), *Semiacontiodus potrerillensis* Albanesi, *Triangulodus brevibasis* (Sergeeva), *Paroistodus originalis* (Sergeeva), *Drepanoistodus forceps* (Lindström), *Oistodus multicorrugatus* Harris, *Parapanderodus paracornuformis* (Ethington and Clark), *Anodontus longus* Stouge and Bagnoli, and *Pteracontiodus cryptodens* Mound. The petrographic microscope analysis of carbonate rocks thin sections refer to proximal middle ramp deposits.

1. Introduction

The Precordillera is located in the central-western sector of the Argentine territory, bounded to the west by the Cordillera Frontal and to the east by the Sierras Pampeanas. It is located between 28° 30′ and 33° south latitude and 68° 15′ and 69° 45′ west longitude, covers part of the provinces of La Rioja, San Juan and Mendoza (Ramos, 1999).

The Precordillera is divided into three morpho-structural units based on its stratigraphic characteristics and structural style. These units are known to as the Eastern (Ortiz and Zambrano, 1981), Central (Baldis and Chebli, 1969) and Western Precordillera (Baldis et al., 1982).

The Central Precordillera is composed mainly of carbonate platform deposits developing about 2500 m thick, in apparent continuous cycle under warm to temperate environmental conditions, whose sedimentation began in the Cambrian and continued up to the Middle Ordovician (Baldis and Bordonaro, 1982).

The San Juan Formation was studied with different approaches and through different fossil groups; however, with respect to the conodont biostratigraphy particular intervals of the formation are still not well understood.

The conodont biostratigraphy of the San Juan Formation exposed at Niquivil was formerly studied by Lehnert (1993, 1995) and Lehnert and Keller (1993). The lower and middle sections were later adjusted to the current biostratigraphic scheme by Albanesi et al. (2003, 2006). Additionally, Soria et al. (2017) analyzed the microfacies of the middle section. However, the conodont biostratigraphy from the upper San Juan Formation, overlying the upper reef horizon, was not revised according to the current scheme, tough it was estimated that the study interval correlates with the *Baltoniodus navis* Zone on the record of the species *Histiodella altifrons* Harris. Nevertheless, the lack of detailed

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studies of the microfacies of this section, the scarcity of conodonts, in particular the absence of the index species *Baltoniodus navis*, promoted the analysis of microfacies and the conodont faunas of this section.

The San Juan Formation is exposed at Niquivil, neighbouring the National Route 40, 22 km south of Jáchal city in the Central Precordillera of the San Juan Province (Figs. 1 and 2). At this locality, the upper part of the outcrop is analyzed, with the purpose of reviewing the conodont biostratigraphy of the section, supported by new microfacies analysis.

2. The San Juan Formation

The carbonate sequence of the San Juan Formation, *ca.* 330 m thick, consists of skeletal micritical limestone deposited from the late Tremadocian on a ramp topography (Keller et al., 1994), recording two or three regressive-transgressive cycles depending on the depocenter of the basin (Cañas, 1995; Carrera et al., 2013). The boundary between the La Silla Formation and the overlying San Juan Formation marks a major change in the configuration of the carbonate platform, with facies change from subtidal environment to open platform facies and carbonate ramp geometry (Pratt et al., 2012).

The lower-middle San Juan Formation corresponds, in general, to shallow subtidal environments with frequent intercalation of storm layers. The upper section corresponds to deposits that accumulated below the basal level of storm waves, in external ramp environments (Sorrentino et al., 2009). Several authors recognize an abundant and diverse open marine fauna in the formation (Serpagli, 1974; Herrera and Benedetto, 1991; Vaccari, 1994; Lehnert, 1995; Carrera, 1997), which contains communities of sponges, brachiopods, bryozoans, trilobites, gastropods, nautiloids, conodonts and ostracods, among others.

K-bentonite strata were deposited from the Middle Ordovician, being the first layers found towards the uppermost San Juan Formation. Huff et al. (1998) estimate that they could have come from the explosive volcanism of the Famatina Range, given that their age and composition is similar. In Baltica and Laurentia, K-bentonites are almost restricted to the Upper Ordovician.

As a result of a relative rise in sea level, which led to the drowning of the carbonate platform below the photic zone, a suffocation of carbonate production occurs in the Darriwilian. The culmination of the carbonate cycle was followed by the deposition of calcareous-black shale facies and subsequent black shales beds (Baldis and Beresi, 1981), which are known as the Gualcamayo and Los Azules formations at different locations of the Precordillera.

Between the San Juan Formation and the overlying Los Azules Formation a hardground type surface is documented, interpreted as a paraconformity (Astini, 1994). This surface seems to represents a brief hiatus, since Ortega et al. (1996) were not able to constrain it by index fossils.

It should be noted that the San Juan Formation has two reef levels; the first one is made up mainly of calcimicrobes and sponges, and is close to the base of the formation; the second reef horizon is formed by microbialites, receptaculitids (*Calathium*) and frequent stromatoporoids (*Zondarella*), developed near the base of the Middle Ordovician (Cañas and Carrera, 2003).

3. Framework of the conodont biostratigraphy in the study area

Lehnert (1993, 1995) and Lehnert and Keller (1993) study the conodont biostratigraphy of the Niquivil section, proposing six association zones; the *Prioniodus elegans* Zone for the 26.5 m basal, the *Oepikodus evae* Zone between 26.5 and 65.5 m, the *Oepikodus evae/Oepikodus intermedius* Zone between 65.5 and 94.75 m, the *Oepikodus intermedius* Zone between 94.75 and 106.15 m, the *Juanognathus jaanussoni/Oistodus* aff. *O. lanceolatus* between 106.15 and 130.65 m, and the *"Parapanderodus" nogamii/Parapanderodus gracilis/Ansella jemtlandica* Zone between 130.65 and 264.70 m. In the latter zone, Lehnert (1993, 1995) verifies a reduction in the amount of conodonts in relation to previous zones, recording *"Parapanderodus" nogamii* (Lee), *Ansella jemtlandica* (Löfgren), *Parapanderodus gracilis* (Ethington and Clark), *Periodon flabellum* (Lindström), *Oistodus* aff. *O. lanceolatus*, *Triangulodus brevibasis* (Sergeeva), *Juanognathus jaanussoni* Serpagli, *Paroistodus originalis* (Sergeeva), *Drepanoistodus forceps* (Lindström), *"Oistodus" striolatus* Serpagli, *Paroistodus* cf. *P. parallelus* (Pander), *Cornuodus longibasis* (Lindström), *"Scandodus"* cf. *"S." furnishi* Lindström, *Jumudontus gananda* (Cooper) and, towards the top, the record of *Histiodella altifrons*.

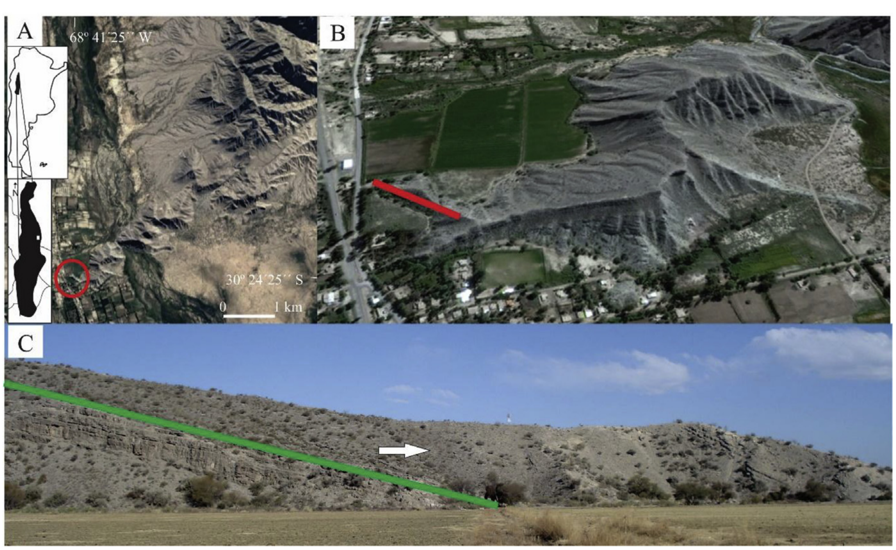

Fig. 1. **A:** geographical location of the Niquivil section (red circle indicates position of study area). **B:** detail of the area, view to the north (the red line marks the study profile). **C:** image of the Niquivil section, view to the west (the arrow indicates the start of the study profile). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

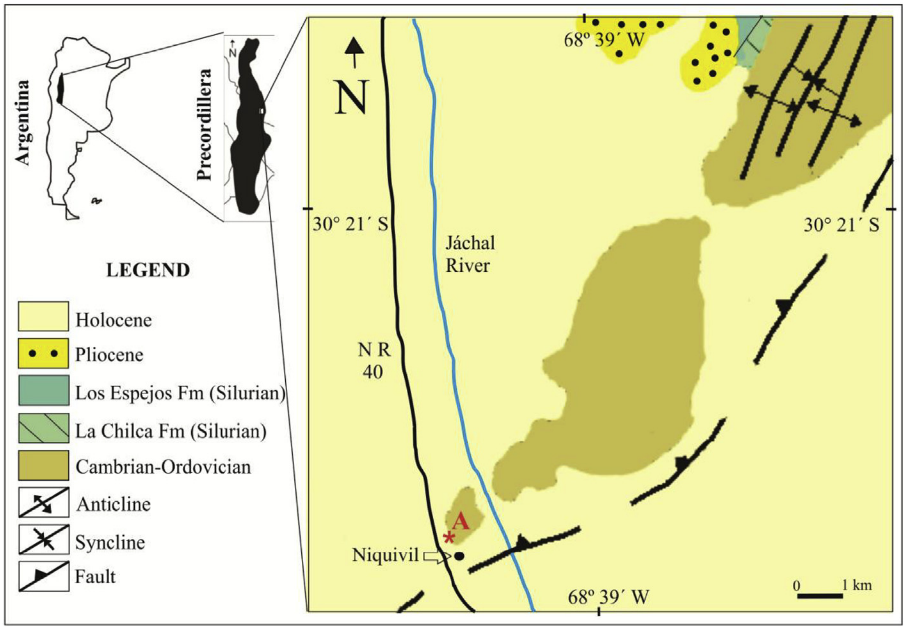

Fig. 2. Geological map of the study area and location of the analyzed stratigraphic section at Niquivil: *A.

Subsequently, Albanesi et al. (2003, 2006) modify the biostratigraphic scheme proposed by Lehnert (1993) by adjusting it to the biozonation of Albanesi et al. (1998), when studying the 170 lower most meters of the San Juan Formation in the Niquivil section. The authors define the *Paroistodus proteus*, *Prioniodus elegans*, *Oepikodus evae*, *Oepikodus intermedius*, *Tripodus laevis*, and *Baltoniodus navis* zones. The latter biozone would be equivalent to the "*Parapanderodus*" *nogamii/Parapanderodus gracilis/Ansella jemtlandica* Zone of Lehnert (1993, 1995), where Albanesi et al. (2003, 2006) recorded *Triangulodus brevibasis*, *Tripodus laevis* Bradshaw, *Oistodus multicorrugatus* Harris, *Juanognathus jaanussoni*, *Protopanderodus nogamii* (Lee), *Mikrozarkodina* sp. A, *Protopanderodus elongatus* Serpagli, *Jumudontus gananda*, and *Oistodus lanceolatus* Pander; likewise, Albanesi et al. (2003, 2006) propose the use of *Cooperignathus aranda* (Cooper) as the index fossil for the Lower/Middle Ordovician boundary, and the Niquivil section as GSSP candidate.

For the stratigraphic interval between the *Oepikodus evae* and *Oepikodus intermedius* zones of this section, Soria et al. (2017) describe and interpret the carbonate microfacies, recognizing five microfacies that, from base to roof, are: M1 bioclastic mudstone-wackestone; M2 bioclastic-peloidal wackestone; M3 intrabioclassic wackestone; M4 intra-bioclastic packstone; M5 peloidal grainstone. The authors interpret a trend towards shallowing, which would correspond to a low energy middle ramp environment without wave effect evolving to a middle-inner ramp environment, with higher energy by wave action and the development of tempestites.

In this work, the biostratigraphic scheme updated by Albanesi and Ortega (2016) is followed, where the lower boundary of the *Baltoniodus triangularis-Tripodus laevis* Zone is given by the first appearance data of the nominal species, and the upper limit by the first occurrence of *Baltoniodus navis* (Lindström), which demarks base of the *Baltoniodus navis* Zone. The upper boundary of the latter zone is given by the first record of *Microzarkodina parva* Lindström (Fig. 3).

SYSTEM	SERIES	STAGE	STAGE SLICE	CONODONT ZONES			
				NORTH AMERICA	BALTOSCANDIA	ARGENTINE PRECORDILLERA	NORTHWEST ARGENTINA
ORDOVICIAN	MIDDLE	DAPINGIAN	Dp3	*H. altifrons*	*B. norrlan./M. parva*	*M. parva*	
					P. originalis	*B. navis*	"*B. navis*"
			Dp2	*P. flabellum/ T. laevis*	*B. navis*		
			Dp1		*B. triangularis*	*B. triangularis/ T. laevis*	*B. triang.*

Fig. 3. Chrono-stratigraphic scheme of the Dapingian (Middle Ordovician), with conodont zones of North America and Baltoscandia, and biozones of the Precordillera and Northwestern Argentina (modified from Albanesi and Ortega, 2016).

4. Materials and methods

Field work included the geological study of the area and survey of the stratigraphic section that involves the upper San Juan Formation at Niquivil section (129.45 m thick). For the recovery of conodonts, eight limestone samples (2 kg each one) plus one limestone block of 500 g were taken, at regular intervals (20 m of apparent thickness).

Nine limestone samples (NIQ 0.1 to NIQ 8, Fig. 4) were processed for the recovery of the microfossils following traditional acid etching techniques (10% glacial acetic acid) (Stone, 1987). Each sample provided 20 g–150 g of insoluble residue, depending on the composition of the limestone, which yielded a total of 133 conodont elements that correspond to 20 species. Additionally, six petrographic cuts of carbonate rocks were prepared. The fossils were deposited in the Museo de Paleontología, Universidad Nacional de Córdoba (CORD-MP 61218 to CORD-MP 61350; CORD-MP 73514 to CORD-MP 73515). Selected conodont specimens were illustrated by conventional optical photomicrography, with a LEICA DM 4500 P LED instrument (see Fig. 5).

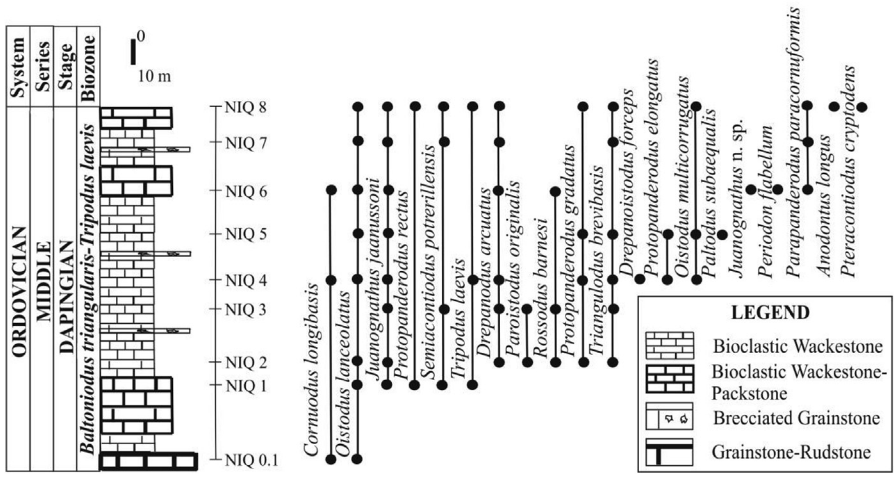

Fig. 4. Stratigraphic column of the upper San Juan Formation in the Niquivil section, with vertical distribution of conodont records.

5. Sedimentary paleoenvironment

The study section begins with tabular strata of grainstones-rudstones, orange-reddish alteration color and dark gray in fresh cut, with abundant casts and hard parts of nautiloids. Other casts correspond to gastropods, crinoid, spicules of sponges, trilobites and brachiopods, from the top of the second reef horizon present in the San Juan Formation, developed in a carbonate inner ramp.

The study section consists mostly of bioclastic wackestones, bioclastic wackestones-packstones, bio-peloid packstones, and isolated bioclastic packstones of 1 cm thick. For lithologic determinations petrographic sections were made from 6 samples: NIQ 1, 2, 3, 5, 6, 8. The sampled strata for petrographic analysis are 10–40 cm thick, with weathering colors that vary from dark gray to ocher, and dark gray in fresh surface, including some levels with nodular pseudostratification. These levels contain *Halysis* sp., *Nuia* sp., sponge spicules, bryozoans, casts and hard parts of nautiloids, crinoids, chitinozoos, casts of gastropods, trilobites, brachiopods, internal, external and secondary casts of ostracods, foraminifera and scolecodonts, which are present in the upper section. Frequent wackestones indicates a dominant low energy environment, with intervals of increasing energy as indicated by packstones, or even storm episodes inferred by the presence of thin strata of brecciated grainstones, which are interpreted as tempestites. The presence of abundant specimens of *Nuia* and *Halysis* algae in the whole interval, and of isolated oncoids, indicates the photic zone (Astini, 2001). Accordingly, this interval is interpreted as deposits of a proximal middle ramp with intercalations of thin storm layers.

6. Conodont biostratigraphy

Samples taken from the top of the second reef horizon (NIQ 0.1 to NIQ 8, Fig. 4) contain the conodont species *Protopanderodus rectus* (Lindström), *Juanognathus jaanussoni*, *Juanognathus* n. sp., *Protopanderodus gradatus* (Serpagli), *Rossodus barnesi* Albanesi, *Paltodus subaequalis* Pander, *Drepanodus arcuatus* (Pander), *Cornuodus longibasis*, *Protopanderodus elongatus*, *Oistodus lanceolatus*, *Tripodus laevis*, *Periodon flabellum*, *Semiacontiodus potrerillensis* Albanesi, *Triangulodus brevibasis*, *Paroistodus originalis*, *Drepanoistodus forceps*, *Oistodus multicorrugatus*, *Parapanderodus paracornuformis* (Ethington and Clark), *Anodontus longus* Stouge and Bagnoli, and *Pteracontiodus cryptodens* Mound (Table 1). The record of *Tripodus laevis* (Fig. 6) not associated with *Baltoniodus navis* indicates that these strata correspond to the *Baltoniodus triangularis-Tripodus laevis* Zone. Throughout the study section, the conodont abundance is lower than that of the underlying zones, as previously recorded by Lehnert (1993, 1995) and Albanesi et al. (2006), probably due to a facies control.

7. Correlation

The *Baltoniodus triangularis-Tripodus laevis* Zone can be correlated regionally with the Fauna D recorded in the San Juan Formation at Pachaco, on the margin of the San Juan river, in the Central Precordillera (Serpagli, 1974). Both, at the latter locality and at the Portezuelo Yanso in the Cerro Potrerillo (Albanesi et al., 1998), the record of conodonts elements is scarce. It also correlates with the *Baltoniodus triangularis* Zone as defined by Carlorosi (2013) for the mudstone-sandstone succession of the Alto del Cóndor Formation in the Los Colorados area, western flank of the Cordillera Oriental of Jujuy, northwestern Argentina.

The *Baltoniodus triangularis-Tripodus laevis* Zone correlates with the *Baltoniodus? triangularis* and *Microzarkodina flabellum* zones of Bagnoli and Stouge (1997), and the *Baltoniodus triangularis* Zone originally defined by Lindström (1971) and Löfgren (1978), and also recognized by Tolmacheva (2001) for the Baltoscandinavian biostratigraphic schemes. In the GSSP of Huanghuachang, China, the *Baltoniodus triangularis* Zone was described by Wang et al. (2003).

Ji and Barnes (1994) define the *Parapanderodus retractus* Zone, for shallow-water environments, and the *Pteracontiodus cryptodens* Zone, for deep water environments in the Aguathuna Formation, Saint George Group, Newfoundland, which correlates with the *Baltoniodus triangularis-Tripodus laevis* Zone as recognized in this study. Originally, the *Tripodus laevis* Zone was defined by Ross et al. (1997) for the Wah Wah and Juab formations from central-west Utah, United States, which correlates with the *Baltoniodus triangularis-Tripodus laevis* Zone.

Likewise, what can be correlated with the *Tripodus laevis* Zone recognized in part of the Green Point Formation, Cow Head Group, in the St. Pauls Inlet section, and Martin Point, Western Newfoundland, Canada (Johnston and Barnes, 1999). Pyle et al. (2003) identify the *Tripodus laevis* Zone in the Skoki Formation, Southern Canadian Cordillera. The discussed biozone also corresponds to the *Periodon hankensis* Zone that Stouge (2012) defined for part of the Shallow Bay Formation, and the Green Point Formation of the Cow Head Group, west of Newfoundland, Canada.

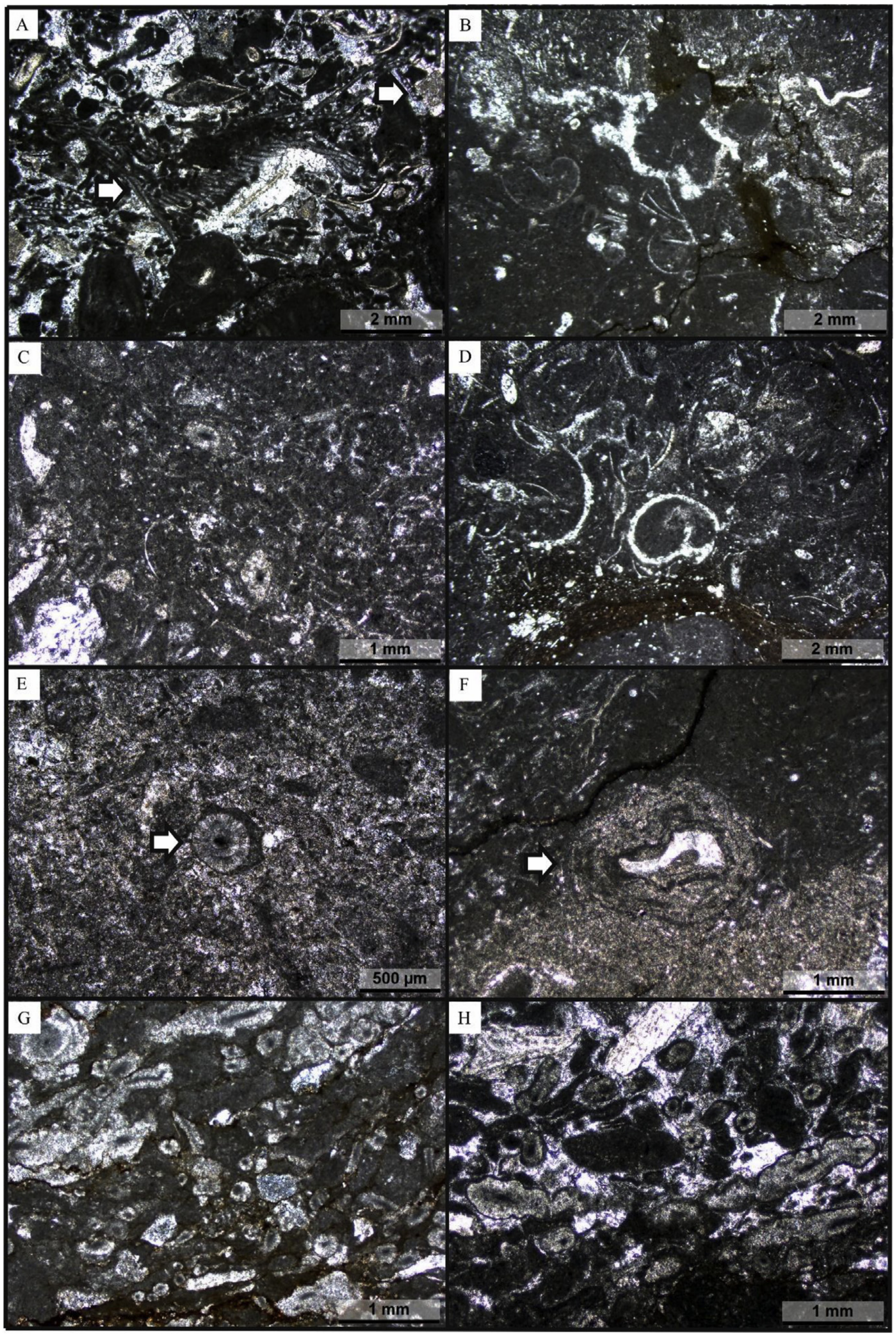

Fig. 5. Photomicrographs of thin sections from carbonate samples at Niquivil section**. A: NIQ 1**; pel-bioclastic packstone with *Halysis* sp. in cross section (upper right arrow) and oblique section (lower left arrow). **B: NIQ 2**; bioclastic wackestone featuring stylolites with iron oxide. **C: NIQ 3**; bioclastic wackestone with isolated *Nuia* sp. (lower and upper center). **D: NIQ 5**; bioclastic wackestone featuring stylolites with iron oxide; in the center a gatropod in cross section. **E-F: NIQ 6**; **E:** bioclastic wackestone-packstone with *Nuia* sp. (center); **F:** bioclastic wackestone-packstone with oncoid presenting a trilobite pleura as the core (arrow); a stylolite with iron oxide is above. **G-H: NIQ 8**; **G:** bioclastic wackestone-packstone with abundant *Nuia* sp. and stylolites with iron oxide; **H:** bioclastic packstone with abundant *Nuia* sp.

8. Discussion

The *Baltoniodus triangularis-Tripodus laevis* and *Baltoniodus navis* conodont biozones are biostratigraphic intervals of low conodont diversity in the Argentine Precordillera (Lehnert, 1993, 1995; Albanesi et al., 1998, 2006; Mango and Albanesi, In press).

The published stratigraphic distributions as well as currently records of conodont species through the Floian-Dapingian boundary up to the upper boundary of the *Baltoniodus navis* Zone, such as those of *Ansella jemtlandica*, *Periodon flabellum*, *Juanognathus jaanussoni*, *Paroistodus originalis*, *Drepanoistodus forceps*, *Oistodus lanceolatus*, *Oistodus striolatus*, *Oistodus multicorrugatus*, *Cornuodus longibasis*, *Protopanderodus rectus*, *Protopanderodus gradatus*, *Rossodus barnesi*, *Drepanodus arcuatus* and *Semiacontiodus potrerillensis* (*Parapanderodus gracilis* sensu Lehnert, 1993, 1995) have biostratigraphic ranges that extend from levels below the *Baltoniodus triangularis-Tripodus laevis* Zone and above the upper limit of the *Baltoniodus navis* Zone (Serpagli, 1974; Löfgren, 1997; Stouge and Bagnoli, 1988, 1990; Albanesi, 1998; Löfgren and Tolmacheva, 2003; Mellgren and Eriksson, 2006; Zhen et al., 2007; Lehnert,

Table 1
Absolute frequency of conodont species determined in the study section of the upper San Juan Formation at Niquivil.

Species/Samples	NIQ 0.1	NIQ 1	NIQ 2	NIQ 3	NIQ 4	NIQ 5	NIQ 6	NIQ 7	NIQ 8	Total
Anodontus longus								1		1
Cornuodus longibasis	1				2		1			4
Drepanodus arcuatus			1	1	1		1	4	1	9
Drepanoistodus forceps					2					2
Juanognathus jannussoni		2	1	1	2	1	2	4	2	15
Juanognathus n. sp.							2			2
Oistodus lanceolatus	1	4	3		4	10	2	5	8	37
Oistodus multicorrugatus					2	3			1	6
Paltodus subaequalis						1				1
Parapanderodus paracornuformis							5	6	2	13
Paroistodus originalis			1							1
Periodon flabellum		1					1	1		3
Protopanderodus elongatus						1				1
Protopanderodus gradatus			1	1	2	4			1	9
Protopanderodus rectus									1	1
Pteracontiodus cryptodens									2	2
Rossodus barnesi			1				1			2
Semiacontiodus potrerillensis		1		1	1			1	1	5
Triangulodus brevibasis		1	1	5	1	1		2	4	15
Tripodus laevis		1		1	1				1	4
Total conodont elements per sample	2	10	9	10	18	21	15	25	24	133
Amount of processed material (g)	500	2000	2240	1920	2510	2160	2135	2005	1990	17460
Unsoluble material (g)	0	0	20	0	10	10	100	50	20	210
Soluble material (g)	500	2000	2220	1920	2500	2150	2035	1955	1970	17250

1993, 1995; Albanesi et al., 2003, 2006). The species *Pteracontiodus cryptodens* and *Parapanderodus paracornuformis* (*"Parapanderodus" nogamii* sensu Lehnert, 1993, 1995, or *Protopanderodus nogamii* in Albanesi et al., 2003) have their first occurrence in the *Baltoniodus triangularis-Tripodus laevis* Zone and their last occurrence in younger zones than that of the *Baltoniodus navis* Zone (Repetski, 1982; Stouge and Bagnoli, 1990; Albanesi, 1998).

Albanesi and Ortega (2016) mention that the species *Triangulodus brevibasis* and *Histiodella altifrons* is indicative of the *Baltoniodus navis* Zone according to their acme in this biozone; however, their first appearance data occur in the *Baltoniodus triangularis-Tripodus laevis* Zone, though with isolated records (Ethington and Clark, 1981; Ross et al., 1997; Mango and Albanesi, In press).

The species described by Albanesi et al. (2003, 2006) as *Mikrozarkodina* sp. A was reported until now only by these authors, so the actual extension of its biochron can not be evaluated. Nevertheless, the genus *Mikrozarkodina* includes species that appears in the biozones under discussion in other regions (e.g., *Mikrozarkodina flabellum* (Lindström), Bagnoli and Stouge, 1997).

The latest elements of *Paroistodus parallelus* are recorded in the *Oepikodus evae* Zone, with some elements that are assigned to *Paroistodus* cf. *P. parallelus* up to the *Baltoniodus triangularis-Tripodus laevis* Zone. The species *Protopanderodus elongatus*, *Scandodus furnishi* have their last record in the latter unit (Stouge and Bagnoli, 1988; Löfgren, 1997; Bagnoli and Stouge, 1997; Albanesi et al., 1998), and *Jumudontus gananda* in the *B. navis* Zone (Nicoll, 1992; Albanesi and Vaccari, 1994).

The species *Anodontus longus* and *Paltodus subaequalis* are usually recorded up to the *Oepikodus evae* Zone (Stouge and Bagnoli, 1988; Albanesi et al., 1998), but scarce isolated elements can be recovered from the *Baltoniodus triangularis-Tripodus laevis* Zone.

Regarding the index species *Tripodus laevis*, its first record coincides with the base of the *Baltoniodus triangularis-Tripodus laevis* Zone and its last record occurs in the lower part of the *Baltoniodus navis* Zone (Albanesi, 1998). At the present work, we record the presence of *T. laevis* above the second reef level in the Niquivil section, being recovered throughout the study section of the San Juan Formation.

Thus, the exposed upper 129.45 m of the San Juan Formation, above the second reef structure, covers the *Baltoniodus triangularis-Tripodus laevis* Zone, with the top level close to the base of the *Baltoniodus navis* Zone considering the presence of *Histiodella altifrons*, as recorded by Lehnert (1995); though revoking previous interpretations that suggested the *"Parapanderodus" nogamii/Parapanderodus gracilis/Ansella jemtlandica* Association of Lehnert (1993, 1995) (Lehnert and Keller, 1993) as correlative with the *Baltoniodus navis* Zone (Albanesi et al., 2003, 2006). Accordingly, at the study locality, the San Juan Formation reveals a high sedimentation rate for the discussed biostratigraphic interval, compared to other areas of the Precordillera (*cf.* Albanesi et al., 1998).

9. Conclusions

The occurrence of *Tripodus laevis* through the upper San Juan Formation (upper 129.45 m studied in this work) in the Niquivil section, not associated with *Baltoniodus navis* indicates that the bearer strata correspond to the *Baltoniodus triangularis-Tripodus laevis* Zone, verifying the actual extension of the outcrops in the study area.

We determine the *Baltoniodus triangularis-Tripodus laevis* Zone as correlative with the *"Parapanderodus" nogamii/Parapanderodus gracilis/Ansella jemtlandica* Association of Lehnert (1993, 1995; Lehnert and Keller, 1993), opposite to previous interpretations that assumed the latter as correlative with the *Baltoniodus navis* Zone.

Fig. 6. Conodonts of the ***Baltoniodus triangularis-Tripodus laevis*** **Zone** of the upper San Juan Formation at the Niquivil section**: 1:** ***Anodontus longus*** Stouge and Bagnoli, NIQ 7, CORD-MP 61321.**2:** ***Cornuodus longibasis*** (Lindström), e element, NIQ 4, CORD-MP 61258.**3-4:** ***Drepanoistodus forceps*** (Lindström); **3:** Pa element, NIQ 4, CORD-MP 61262; **4:** Pb element, NIQ 4, CORD-MP 61251.**5-7:** ***Oistodus lanceolatus*** Pander; **5:** M element, NIQ 7, CORD-MP 61317**; 6:** Sc element, NIQ 5, CORD-MP 61276, **7:** P element, NIQ 8, CORD-MP 61332.**8-9:** ***Oistodus multicorrugatus*** Harris; **8:** M element, NIQ 5, CORD-MP 61285; **9:** Sb element, NIQ 8, CORD-MP 61341.**10-12:** ***Pteracontiodus cryptodens*** Mound; **10-11:** Sa element, NIQ 8, CORD-MP 61339; **12:** Sc element, NIQ 8, CORD-MP 61340.**13:** ***Protopanderodus elongatus*** Serpagli, e element, NIQ 5, CORD-MP 61281.**14-18:** ***Triangulodus brevibasis*** (Sergeeva); **14:** M element, NIQ 8, CORD-MP 61344; **15:** Sa element, NIQ 3, CORD-MP 61239; **16:** Sb element, NIQ 5, CORD-MP 61282; **17:** Sc element, NIQ 3, CORD-MP 61245; **18:** P element, NIQ 2, CORD-MP 61235.**19-20:** ***Tripodus laevis*** Bradshaw; **19:** M element, NIQ 3, CORD-MP 61242; **20:** Pa element, NIQ 1, CORD-MP 61225. Graphic scale: 200 μm.

The petrographic analysis of the exposed upper strata of the San Juan Formation in the Niquivil section is interpreted as a carbonate ramp environment; corresponding to an inner ramp sub-environment for the reefal interval, and to a proximal middle ramp with interbedded storm layers for the upper 129.45 m.

The presence of abundant specimens of *Nuia* and *Halysis* in the study interval, as well as isolated oncoids, indicate the photic zone. The *Baltoniodus triangularis-Tripodus laevis* Zone at Niquivil is a bioestratigraphic interval of low conodont diversity, which is probably related to a particular facies control.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jsames.2018.03.008.

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