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Darriwilian Conodont Biostratigraphy of the Las Chacritas Formation, Central Precordillera (San Juan Province, Argentina)

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ABSTRACT

The Las Chacritas Fm in the type section in the Sierra de La Trampa, Central Precordillera (San Juan Province) was deposited in an outer carbonate ramp setting that evolved from relatively deep to shallow water. Samples from this well-exposed Middle Ordovician section yielded collections of low-diversity conodont faunas stratigraphically significant. The top of the underlying San Juan Fm and the lower and middle parts of the Las Chacritas Fm contain conodonts representative of the *Lenodus variabilis* Zone, and the upper part of the Las Chacritas Fm yields conodonts that correlate with the *Paroistodus horridus* subzone of the upper part of the *Lenodus variabilis* Zone. The occurrence of *Dzikodus tablepointensis* and *Eoplacognathus pseudoplanus* in the upper part of the *Paroistodus horridus* subzone is especially significant. The occurrence of *Histiodella kristinae* in the highest levels indicates that the top of the Las Chacritas Fm correlates with the *Eoplacognathus suecicus* Zone. Conodont biofacies are analyzed trough the entire section, supporting an outer platform or open sea conditions. Baltic and Sino-Pacific affinities are stated.

KEYWORDS **Ordovician. Conodonts. Biostratigraphy. Central Precordillera. Argentina.**

INTRODUCTION

The Ordovician succession of the Las Chacritas river section (Fig. 1) in the La Trampa range, Central Precordillera of San Juan Province (Baldis and Chebli, 1969), Argentina, was first studied by Espizúa (1968). Since then, this section has been reviewed by Peralta and Baldis (1995). Astini (1994a) and Carrera and Astini (1998) examined sedimentologically this section, analyzing paleoenvironmental changes and faunal turnover. Peralta et al. (1999a) defined the Las Chacritas Fm, and Beresi et al. (2000) analyzed its carbonate microfacies.

Albanesi and Astini (1994) reported conodonts of the *Eoplacognathus suecicus* Zone at the top of the San Juan Fm in the Las Chacritas section, and Lehnert (1995a) reported the *E. suecicus* and *Pygodus serra* Zones from the uppermost levels top of the San Juan Fm and the "Transfacies" ("transfacies calcáreo-peliticas" in the sense of Baldis and Beresi, 1981). The occurrence of the

Lenodus variabilis Zone in the Las Chacritas Fm was first mentioned by Peralta et al. (1999a) and was documented in Peralta et al. (1999b). Later, Albanesi and Astini (2000) reported the occurrence of the *Eoplacognathus pseudoplanus* Biozone in the Rio de Las Chacritas section, and Albanesi and Ortega (2002) mention the occurrence of the *Lenodus variabilis* Zone.

In contrast to these earlier reconnaissance studies, in this paper we document the distribution of the conodont taxa in the Las Chacritas Fm on the basis of an extensive and systematic sampling. In addition, we consider the applicable conodont zonation and boundaries between the zones, and we analyze the relationship between lithostratigraphy and biostratigraphy within the Las Chacritas section.

GEOLOGIC SETTING

The thick, upper Lower to lower Upper Ordovician stratigraphic succession exposed in the Las Chacritas River section is composed of dark gray carbonates, marls and mixed carbonate/siliciclastic sediments deposited in a continental shelf setting (Espizúa, 1968; Carrera, 1997; Peralta et al., 1999a, b; Peralta and Baldis, 1995; Baldis et al., 1995). The section begins in the upper Lower to lower Middle Ordovician San Juan Fm, which is composed mainly of fossiliferous limestone and dolomite with conspicuous chert nodules. Its base is not exposed because of faulting, and the upper part that is preserved is 120 m thick. The San Juan Fm is conformably overlain by 55 m of thin- to medium-bedded marly limestone and black shale of the Las Chacritas Fm, which correlates with the lower Darriwilian Stage (middle Middle Ordovician). The Las Chacritas Fm, in turn, is overlain by the lower Upper Ordovician Las Aguaditas Fm, which is composed of 50 m of mixed calcareous/siliciclastic deposits (Peralta and Baldis, 1995) (Fig. 2). The contact between the Las Chacritas and Las Aguaditas formations is an unconformity with the hiatus corresponding to the middle to upper Darriwilian Stage (upper Middle Ordovician Series). The top of the Las Aguaditas Fm is an erosional unconformity.

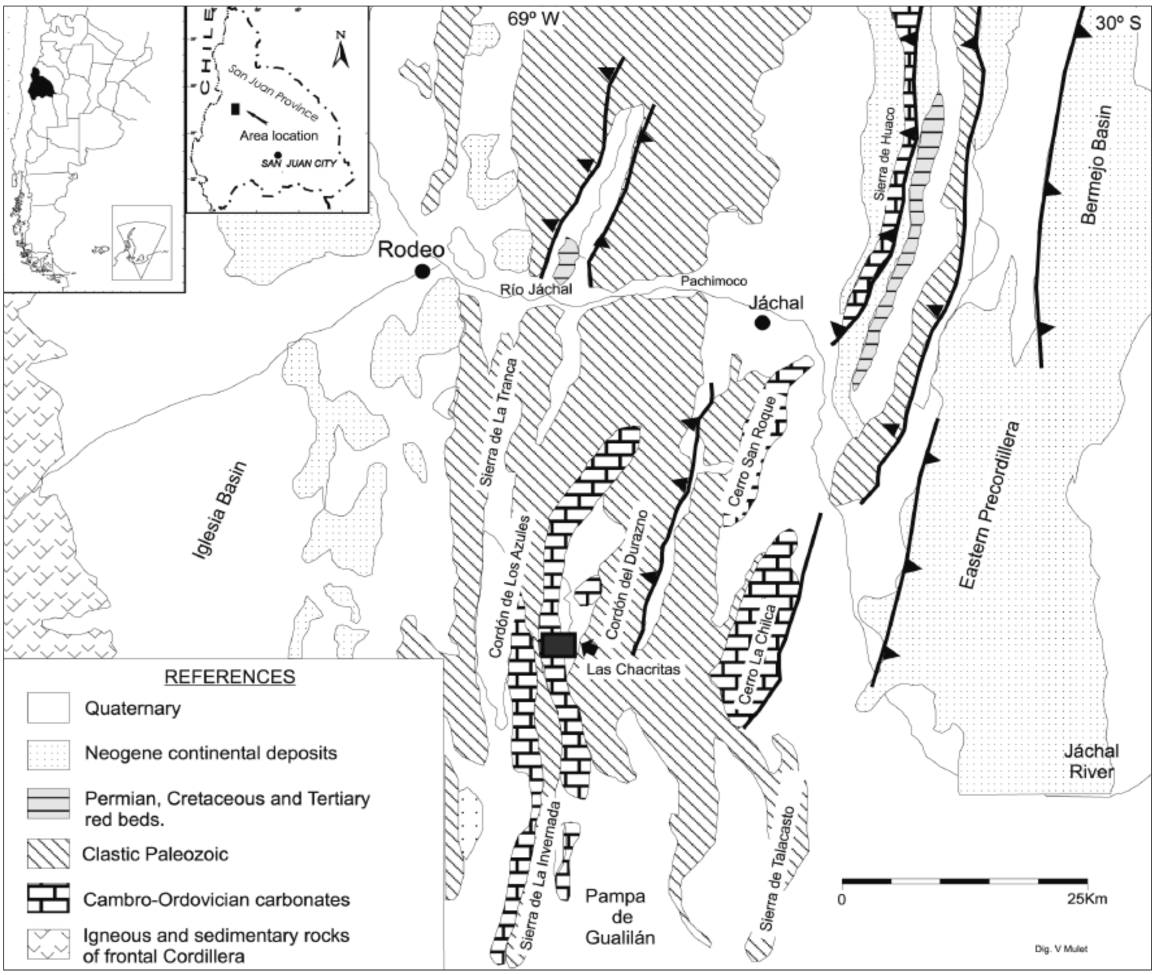

FIGURE 1 **Location map of the Las Chacritas River section at Central Precordillera, San Juan, Argentina.**

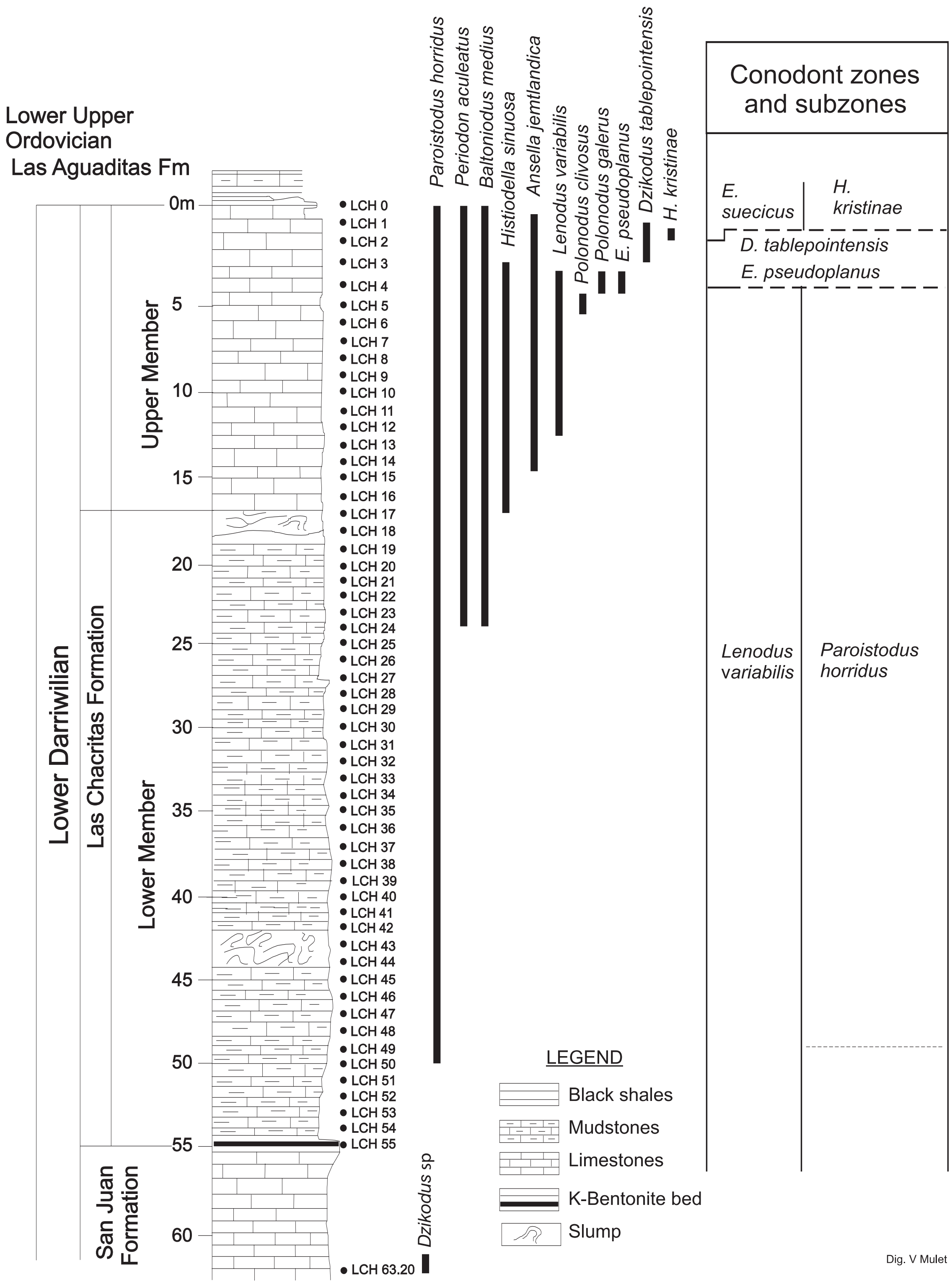

FIGURE 2 **Stratigraphic log at Las Chacritas Creek showing lithology, sampled levels and range of selected conodont species.**

It is overlain by a conspicuous basal chert conglomerate and then, in turn, by the fine-grained siliciclastic La Chilca Fm, which correlates with uppermost Upper Ordovician to lower Wenlock strata elsewhere in the Central Precordillera, according to Kerlleñevich and Cuerda (1986) and Cuerda et al. (1988).

Stratigraphy of the Las Chacritas Formation

The 55 m thick succession of generally fine-grained siliciclastic/carbonate strata between the San Juan and Las Aguaditas formations at Las Chacritas Creek was named the Las Chacritas Fm by Peralta et al. (1999a) (Fig. 2). It is recognized to the north in the Las Tunas Creek section, where Carrera (1997, p. 313) previously referred to the strata by the informal name Unidad Calcárea Las Tunas and considered it a correlative facies of the Gualcamayo Aloformation (*sensu* Astini, 1994a, 1994b). However, it is best studied in the Las Chacritas River section, where both lower and upper contacts are well exposed and two members can be recognized.

The Lower Member of the Las Chacritas Fm is 38 m thick and it is composed of interbeds of tabular**,** thin- to medium-bedded, fossiliferous, dark mudstone, nodular wackestone to packstone, black shale, and rare thin beds of bentonite (Fig. 2). Sinsedimentary slumps occur in the middle and upper part of the Lower Member and were the basis for the interpretation of a northward deepening slope in the depositional environment (Carrera and Astini, 1998). The calcareous algae *Nuia* is common in the mudstone beds in the upper part of the Lower Member. Although conformably overlying the San Juan Fm, the partly siliciclastic lime mudstone of the Lower Member contrasts markedly with richly fossiliferous limestone of the San Juan Fm, and a K-bentonite bed separates the two formations at the contact.

The Upper Member of the Las Chacritas Fm overlies the Lower Member gradationally, is 17 m thick and is composed of very fossiliferous, thin-bedded wackestone, intrabioclastic grainstone, mudstone, and spiculitic mudstone. The upper part of the Upper Member is dominantly calcareous and richly fossiliferous. Fossil diversity is high with abundant trilobites (at least four species of *Annamitella*) and several genera of brachiopods, sponges, gastropods, bryozoans and crinoids, among other forms (Carrera, 1997). The sponge fauna has been analyzed by Carrera (1997) who concluded that this fauna represents the *Archaeoscyphia* Biofacies and indicates a shallow subtidal depositional environment below fair-weather base and periodically affected by storm wave base. The top of the Upper Member is an erosional unconformity and its fossiliferous limestone is overlain abruptly by calcareous black shale and interbedded black marly mudstone of the Las Aguaditas Fm, which contains graptolites of the *Nemagraptus gracilis* Zone and trilobites of the *Incaia* Fauna (Peralta and Baldis, 1995).

CONODONT DISTRIBUTION

Conodont samples were collected at 1 m intervals from limestone beds from the upper part of San Juan Fm to the top of the Las Chacritas Fm in Las Chacritas Creek section (Fig. 2). Initially, 300 to 500 g of each sample was processed with additional material processed if needed. A collection of *ca*. 8000 identifiable conodont elements was recovered. All conodont elements have a color alteration index of 2–3 (Epstein et al., 1977). The conodonts are registered and housed in the collection of the Institute of Geology (INGEO) at Universidad Nacional de San Juan under the code INGEO-MP.

Distribution of conodonts recovered from the Las Chacritas Fm is summarized in Figure 2. Conodonts are abundant, but their diversity is low. Only one species, *Paroistodus horridus* (Barnes and Poplawski), occurs through most of the Lower Member, but at 30 m above the base of the Lower Member (sample LCH 24), diversity increases with the appearance of *Periodon aculeatus zgierzensis* Dzik and *Baltoniodus medius* (Dizk) (Fig. 2) suggesting a change on the environment condition. Then in the Upper Member, several other species appear successively such that species diversity is greatest with as many as 21 species (11 species are showed in Fig. 2) in the upper few meters of the Upper Member. Samples LCH 2, 3, 4, at the top of the section, yielded great quantities of conodont elements (e.g. LCH 3 with 18.300 conodonts per kg). In terms of abundance, two species - *Paroistodus horridus* and *Periodon aculeatus zgierzensis* – are the most common. All other species are uncommon, but several of these are of great value for biostratigraphic correlation. These include *Lenodus variabilis* (Sergeeva), *Eoplacognathus pseudoplanus* (Viira), *Dzikodus tablepointensis* (Stouge), *Dzikodus sp*., *Baltoniodus medius, Polonodus clivosus* (Viira) and *Histiodella kristinae* Stouge (Figures 2 and 3). Certain specimens are still under study (*e.g. Eoplacognathus*? sp.) (Fig. 3).

Several species representative of the Atlantic Faunal Region (Bergström, 1990) dominate the conodont fauna. They include *Lenodus variabilis, Eoplacognathus pseudoplanus, Periodon aculeatus zgierzensis*, *Baltoniodus medius, Polonodus clivosus* and *Ansella jemtlandica* (Löfgren). The species *Paroistodus horridus, Polonodus clivosus, Dzikodus tablepointensis* are pandemic and are representative of a cold-water oceanic fauna (Zhang, 1998).

On the basis of lithologic and sedimentologic evidence, Peralta et al. (1999a) concluded that the depositional environment of the Upper Member of the Las

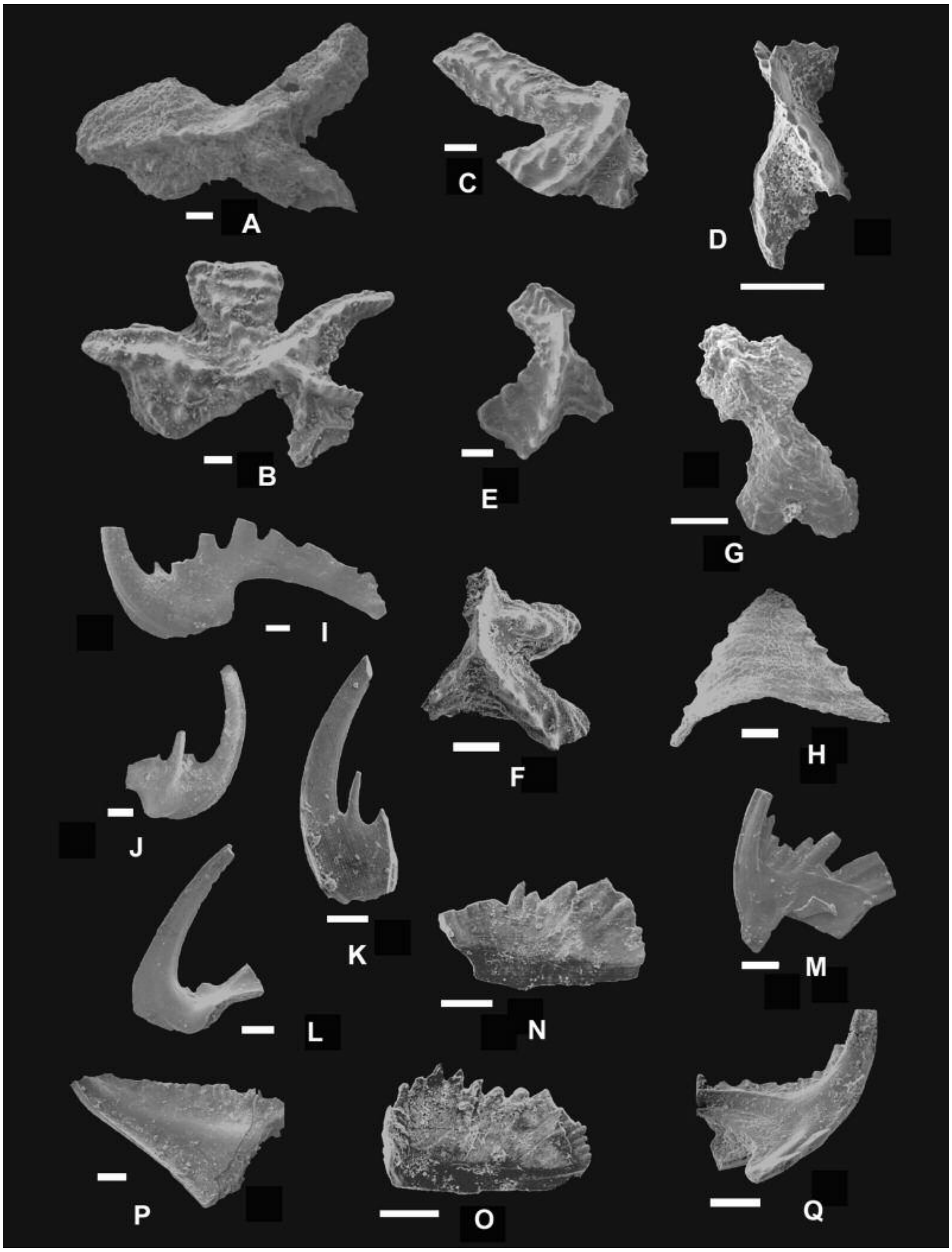

FIGURE 3 | **Darriwilian conodonts from Las Chacritas Creek section, Central Precordillera, San Juan. A) *Lenodus variabilis* (Sergeeva). Upper view. P element (sinistral). Las Chacritas Fm, LCH12. INGEO-MP -100/1. From the *Lenodus variabilis* Zone, *Paroistodus horridus* subzone. B) *Eoplacognathus* ? sp. Upper view. P element (dextral). Las Chacritas Fm, LCH14. INGEO-MP-101/1. From the *Lenodus variabilis* Zone, *Paroistodus horridus* subzone. C) *Dzikodus tablepointensis* (Stouge). Upper view. Pa element (dextral). Las Chacritas Fm, LCH1. INGEO–MP-102/10. From the *Eoplacognathus suecicus* Zone, *Histiodella kristinae* subzone. D) *Eoplacognathus pseudoplanus* (Viira). Upper view. P element (sinistral). Las Chacritas Fm, LCH4. INGEO-MP-103/1. From the *Eoplacognathus pseudoplanus* Zone. E) *Polonodus clivosus* (Viira). Upper view. P element (sinistral). Las Chacritas Fm, LCH5. INGEO-MP-104/1. From the *Lenodus variabilis* Zone/ *Paroistodus horridus* subzone. F) *Polonodus clivosus* (Viira). Upper view. P element (dextral). Las Chacritas Fm, LCH4. INGEO-MP-105/2. From the *Eoplacognathus pseudoplanus* Zone. G) *Dzikodus* sp. Upper view. P element (dextral). San Juan Fm, LCH63,20. INGEO-MP-106/1. From the *Lenodus variabilis* Zone. H) *Polonodus galerus* Albanesi. Lateral view. Pa element. Las Chacritas Fm, LCH4. INGEO-MP-107/1. From the *Eoplacognathus pseudoplanus* Zone. I to N) *Paroistodus horridus* (Barnes and Poplawski). Lateral views. Sc, P, Sb and Sa elements respectively. Las Chacritas Fm, LCH3. INGEO-MP-108/1, 108/2, 108/3, 108/4. From the *Eoplacognathus pseudoplanus* Zone. O) *Periodon aculeatus zgierzensis* Dzik. Lateral view. Sb element. Las Chacritas Fm, LCH3. INGEO-MP-109/1. From the *Dzikodus tablepointensis* Zone. P and Q) *Histiodella sinuosa* (Graves & Ellison). Inner lateral view. Pa element. Las Chacritas Fm, LCH4. INGEO-MP-110/1. From the *Eoplacognathus pseudoplanus* Zone. R) *Histiodella kristinae* Stouge. Inner lateral view. Pa element. Las Chacritas Fm, LCH2. INGEO-MP-111/1. From the *Eoplacognathus suecicus* Zone/ H. kristinae subzone. S) *Ansella jemtlandica* (Löfgren). Lateral view. Sb element. Las Chacritas Fm, LCH3. INGEO-MP-112/1. From the *Dzikodus tablepointensis* Zone. T) *Baltoniodus medius* (Dzik). Lateral view. Sd element. Las Chacritas Fm, LCH1. INGEO-MP-113/1. From the *Eoplacognathus suecicus* Zone/ *H. kristinae subzone*. Bar scale: 0,1 mm.**

Chacritas Fm was significantly shallower than that of the Lower Member. The application of conodont biofacies criteria (Barnes and Fåhræus, 1975; Stouge, 1984; Pohler and Barnes, 1990; Rasmussen and Stouge, 1995; Zhang, 1998) provides a more accurate interpretation. The Lower Member is dominated by *P. horridus (Costiconus,* formerly "*Walliserodus" , - Periodon* Biofacies), this biofacies characterizes the outer margin of the carbonate platform. Zhang (1998) indicates platform edge environment for this conodont association. The conodont assemblage in the Upper Member of the Las Chacritas Fm (see Fig. 2), in particular the presence of *P. horridus, Dzikodus, Ansella* and *Histiodella*, is representative of the *Costiconus* - *Periodon* Biofacies (*Periodon*/*Protopanderodus* Biofacies *sensu* Rasmussen and Stouge, 1995) with few components of the *Baltoniodus* Biofacies (Rasmussen and Stouge, 1995). Elements of *Baltoniodus medius* appear near the 25 m of the section, and increase to the top. The record of the *Baltoniodu*s Biofacies is typical of deep subtidal platform (Rasmussen and Stouge, 1995). It suggests that a shallowing event started at around the 25 m and continued to the top where the abundance of the *Baltoniodus* elements increases upward. A tiring of conodont genera is noticed toward the top showing increase on diversity (Fig 2). These both associations are typical of no restrictive and cool oceanic water and have a widespread geographic distribution.

Besides, the average frequency of conodonts in the upper most levels samples of LCHF is high (12000 to 18000 specimens per kilogram), suggesting slow carbonate deposition (Zhang, 1998).

According to Astini's model (1997), the Middle Ordovician Eastern Tectofacies (Astini, 1992), evolved as part of an extensional system in the Eastern and Western Precordillera. In this scenario the graben basin (Astini, 1998a) controlled deposition of siliciclastic and mixed deposits, meanwhile fine-grained carbonate and mixed deposits, among them the Las Chacritas Fm containing the Baltic conodont fauna, were accumulated on the horst. Conodont distribution in the Las Chacritas Fm shows the timing of the tectonic activity beginning, which developed horst-uplifting, that allows shallower carbonate deposition. The comparison between Las Chacritas section and the classical Don Braulio section (Villicum Range) reveals that a forced flooding took place at the Don Braulio section (Astini, 1998a) meantime a forced regression is recorded at Las Chacritas section.

CONODONT BIOSTRATIGRAPHY AND CORRELATION

The "Precordillera Province" (Bagnoli and Stouge, 1991) (Fig. 4) was a faunal province where a major change on the conodont record in the early Middle

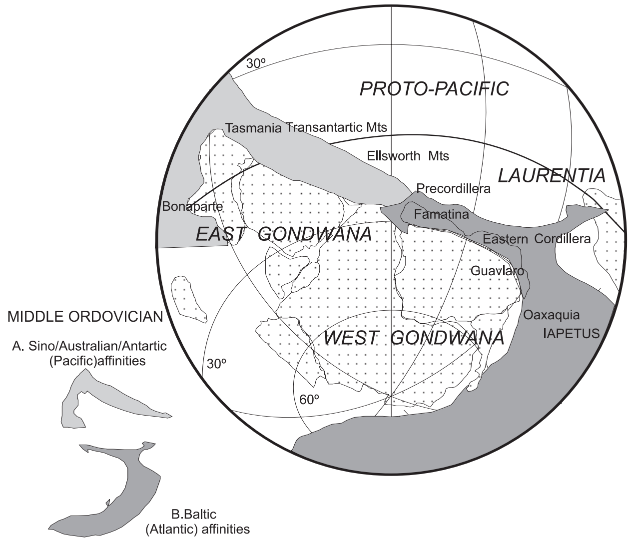

FIGURE 4 **Paleogeographic position of the Precordillera at Middle Ordovician times (modified from Aceñolaza et al., 2002)**

Ordovician is noted. Albanesi and Ortega (2002) pointed out a Midcontinent conodont record for the Lower Ordovician and a Baltic conodont record for the Middle and Upper Ordovician, both of them with a few components from the other faunal realm. The Darriwilian (or Middle Ordovician) conodont fauna from the Las Chacritas section is very similar at the species level to correlative faunas of the Baltic region (Sarmiento, 1985; Stouge and Bagnoli, 1990; Albanesi et al., 1998) (Fig. 5). Nevertheless, the Darriwilian conodont zonations for the Baltic region and the Precordillera are not the same (Bagnoli and Stouge, 1996; Albanesi and Ortega, 2002: fig. 1) because of differences in the distribution and record of certain index species. The middle Darriwilian of the Baltic conodont zonation includes four successive zones (Zhang, 1998; Löfgren, 2000, 2004)- *Lenodus variabilis, Yangtzeplacognathus crassus, Eoplacognathus pseudoplanus, and Eoplacognathus suecicus* - that are correlative with two zones and four subzones of the Precordillera zonation, which are the *L. variabilis* Zone composed of the lower *Periodon gladysi* and upper *Paroistodus horridus* subzones and the *E. suecicus* Zone composed of the lower *Histiodella kristinae* and upper *Pygodus anitae* subzones. Further complicating the zonation in the North Atlantic province is that Zhang (1998) has erected the *Dzikodus tablepointesis* Zone in South-central China (Fig. 5). This zone correlates with the interval from the upper part of the *L. variabilis* Zone to the lower part of the *E. suecicus* Zone, according to Löfgren (1978) and it takes the same interval of *E. pseudoplanus* Zone (Stouge and Bagnoli, 1990) in north Öland (Sweden).

Based on the range of first appearance of *Paroistodus horridus* (Fig. 2), and the presence of B. medius and *L.*

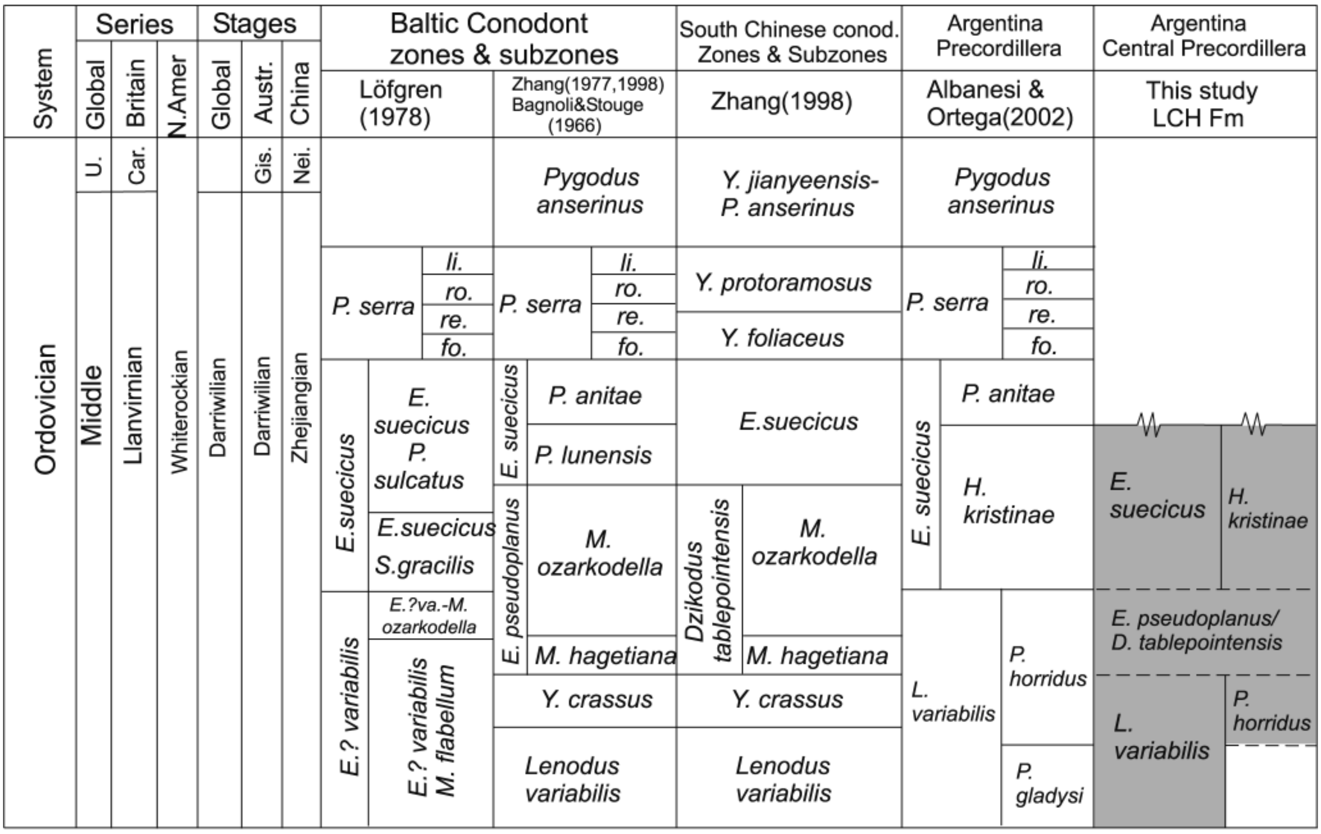

FIGURE 5 | **Comparison between conodont zones of Baltoscandia, South-central China and the Precordillera.**

variabilis the entire Las Chacritas Fm can be correlated with the *P. horridus* Subzone of the *L. variabilis* Zone (Albanesi *et al*., 1998). In addition, our discovery of *Dzikodus* sp at the top of the underlying San Juan Fm suggests that the upper San Juan Fm also correlates with the *L. variabilis* Zone (Zhang, 1998). However, the marked increase in diversity in the Upper Member and the appearance of several biostratigraphically important species provide for a more refined biostratigraphic subdivision and correlation of the Upper Member. Samples LCH 12 to LCH 5 include a conodont assemblage of *P. horridus, B. medius* and *Lenodus variabilis*. Although these species range to the top of the Upper Member, the species assemblage changes markedly in composition with the appearance of *Eoplacognathus pseudoplanus, Dzikodus tablepointensis* and *Polonodus clivosus* between samples LCH 4 and LCH 3. The presence of *D. tablepointensis* with *E. pseudoplanus* in LCH 3 is also found in the Baltic conodont succession (Bagnoli and Stouge, 1996; Löfgren, 2004).

In Baltoscandia, *D. tablepointensis* is approximately equivalent to the *E. pseudoplanus* Zone Zhang (1998). Latter, Löfgren (2004) reported that the base of *E. pseudoplanus* Zone is slightly lower than the base of the *Dzikodus tablepointensis* Zone in South-Central China.

For this reason, we are taking in consideration the recognition of the *D. tablepointensis* Zone in the Central Precordillera conodont zonation, detailed studies on these samples will be done to get an accurate response about the timing appearance of *D. tablepointensis* in the Las Chacritas section.

On the other hand, it is also possible to recognize the Baltic Zone of *E. pseudoplanus* based on the first appearance of the homonymous species. An alternative zonal subdivision of the Las Chacritas Fm would be to recognize the *H. kristinae* subzone (Stouge, 1984) of the *Eoplacognathus suecicus* Zone at the top of the Las Chacritas Fm. *H. kristinae* occurs in LCH 2, but it is rare. Further, additional detailed studies are necessary to determine whether or not demonstrate the presence of *Y. crassus* is present in the section.

The conodont biostratigraphy supports a correlation of the Lower and Upper Members of the Las Chacritas Fm with the lower and middle members of the Gualcamayo Fm, as proposed by Albanesi et al. (1998). Moreover, in the Don Braulio Creek section in the Villicum range (Sarmiento, 1985), and in the Rinconada section at Chica de Zonda range (Lehnert, 1995b), the *Lenodus variabilis* Biozone occurs in the so-called flagstone upper member of the San Juan Fm. Thus, the Las Chacritas Fm may be biostratigraphically correlative with the uppermost part of the San Juan Fm in those localities.

A significant facies change occurs in the lower Darriwilian from carbonate facies (San Juan Fm) to shale facies (Gualcamayo/ Los Azules Fm) throughout much of the Precordillera (Baldis and Beresi, 1981; Baldis et al., 1981). However, at the Las Chacritas section, the carbonate facies continues into the upper Darriwilian (*E. suecicus* Zone, *H. kristinae* subzone), and the shale facies is absent.

CONCLUSIONS

All of the Las Chacritas Fm, except for its very top, is characterized by conodonts of the *Paroistodus horridus* Subzone of the *Lenodus variabilis* Zone**,** which correlates with much of the lower Darriwilian Stage. The occurrence of *Eoplacognathus pseudoplanus* and *Dzikodus tablepointensis* in the upper part of the Upper Member of the Las Chacritas Fm indicates the homonymous biozones. The *Eoplacognathus suecicus* Zone can be recognized at the uppermost levels of the unit. So, 3 conodont zones are determined which include typical Baltic taxa. The present open sea conodont fauna could be also related with conodont faunas with Sino-Pacific affinities.

Lenodus variabilis, *Baltoniodus medius* and *Paroistodus horridu*s occur together defining a conodont association in the Lower Member and the lower Upper Member of the Las Chacritas Fm, but a very different association dominated by *Paroistodus horridus*, *Polonodus clivosus*, *Eoplacognathus pseudoplanus* and *Dzikodus tablepointensis* characterize**s** the upper part of the Upper Member.

The top of the underlying San Juan Fm is assigned to the *Lenodus variabilis* Zone and it is also of early Darriwilian age.

The comparison of these Early Darriwilian conodont faunas to those from Baltoscandia and South- Central China allow us to reconsidering a better and accurate biostratigraphic scheme for the Precordillera Province which is presented here.

The present conodont biofacies recorded strongly support open sea conditions for Las Chacritas Fm. Besides, the conodont distribution on the section is showing the timing when the tectonic activity started in this part of the basin, uplifting the horst and allowing shallower deposits toward the top.

The lower Darriwilian strata of the Las Chacritas river section include conodont faunas similar to those of the upper part of the San Juan Fm and the lower part of the Gualcamayo Fm, indicating a correlation of the Las Chacritas Fm with the uppermost San Juan and lower Gualcamayo formations.

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