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Biostratigraphy and palaeoecology of Middle–Late Ordovician conodont and graptolite faunas of the Las Chacritas River section, Precordillera of San Juan, Argentina

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Abstract – A conodont-graptolite biostratigraphic study was carried out on the top strata of the San Juan, Las Chacritas and Las Aguaditas formations in the La Trampa Range, Precordillera of San Juan in western Argentina. Significant conodont records in the San Juan and Las Chacritas formations allow for the recognition of the *Yangtzeplacognathus crassus*, *Eoplacognathus pseudoplanus* (*Microzarkodina hagetiana* and *M. ozarkodella* subzones) and *Eoplacognathus suecicus* zones of Darriwilian age. Index species and co-occurrences of graptolites and conodonts were recorded in the Las Aguaditas Formation allowing the identification of the *Nemagraptus gracilis* and the *Pygodus anserinus* zones, which represent the Sandbian Stage. These data indicate a hiatus between the Las Chacritas and the Las Aguaditas formations, corresponding to the *Pygodus serra* Zone and the *Pterograptus elegans* and *Hustedograptus teretiusculus* zones (upper Darriwilian). A total of 7287 identifiable conodont elements were recorded from the study section. The species frequency registered for each zone shows that *Periodon* and *Paroistodus* are the most abundant taxa, which are indicative of open marine environments. The records of particular conodont taxa, such as *Histiodella*, *Periodon*, *Microzarkodina*, *Eoplacognathus* and *Baltoniodus*, allow a precise global correlation with other regions such as south-central China, Baltoscandia, North America, Great Britain, Southern Australia and New Zealand. The graptolite fauna identified here are recognized worldwide in equivalent strata in the Baltic region, Great Britain, North America, China, southern Australia and New Zealand. The presence of graptolites in the ribbon limestones of the Las Chacritas Formation is documented for the first time.

Keywords: conodonts, graptolites, biostratigraphy, palaeoecology, Middle–Upper Ordovician, Central Precordillera, Argentina.

1. Introduction

The Argentine Precordillera is interpreted as an extensive fold-and-thrust orogenic belt located to the east of the main Andes in the northwestern region of Argentina (Astini, 1998). This geological region is situated in the La Rioja, San Juan and Mendoza provinces with an extension of 450 km north–south and 110 km east–west (Furque & Cuerda, 1979). Based on its stratigraphical and structural characteristics, the Precordillera has been divided into three morphostructural units: the Eastern (Ortiz & Zambrano, 1981), Central (Baldis & Chebli, 1969) and Western Precordillera (Baldis *et al.* 1982). The Eastern and Central Precordillera are represented by a Lower Palaeozoic carbonate succession unique in South America, which was deposited in diverse platform environments ranging from shallow intertidal to marginal shelf or deep distal ramp settings (Cañas, 1999; Bordonaro, 2002).

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The marine deposition in the Precordillera underwent a dramatic change from limestone to black shale during early Darriwilian time (Carrera & Astini, 1998). This event is interpreted to be due to a rapid sea-level rise that led to the drowning of the platform to the east, hindering carbonate production (e.g. Los Azules and Gualcamayo formations); however, in some areas the carbonate sedimentation continued until late Darriwilian time (e.g. Las Aguaditas and Las Chacritas formations; Keller, Eberlein & Lehnert, 1993; Carrera & Astini, 1998). These unevenly distributed transitional environments prove the diachronic nature of the Precordilleran carbonate sedimentation (Carrera & Astini, 1998).

The La Trampa Range is part of the Central Precordillera in the San Juan Province (Fig. 1) where an important Middle Ordovician section is represented by a richness in micro and macrofossils. Upper Lower – lower Middle Ordovician rocks of the San Juan Formation conformably overlain by the Las Chacritas Formation of middle Darriwilian age are exposed here. The

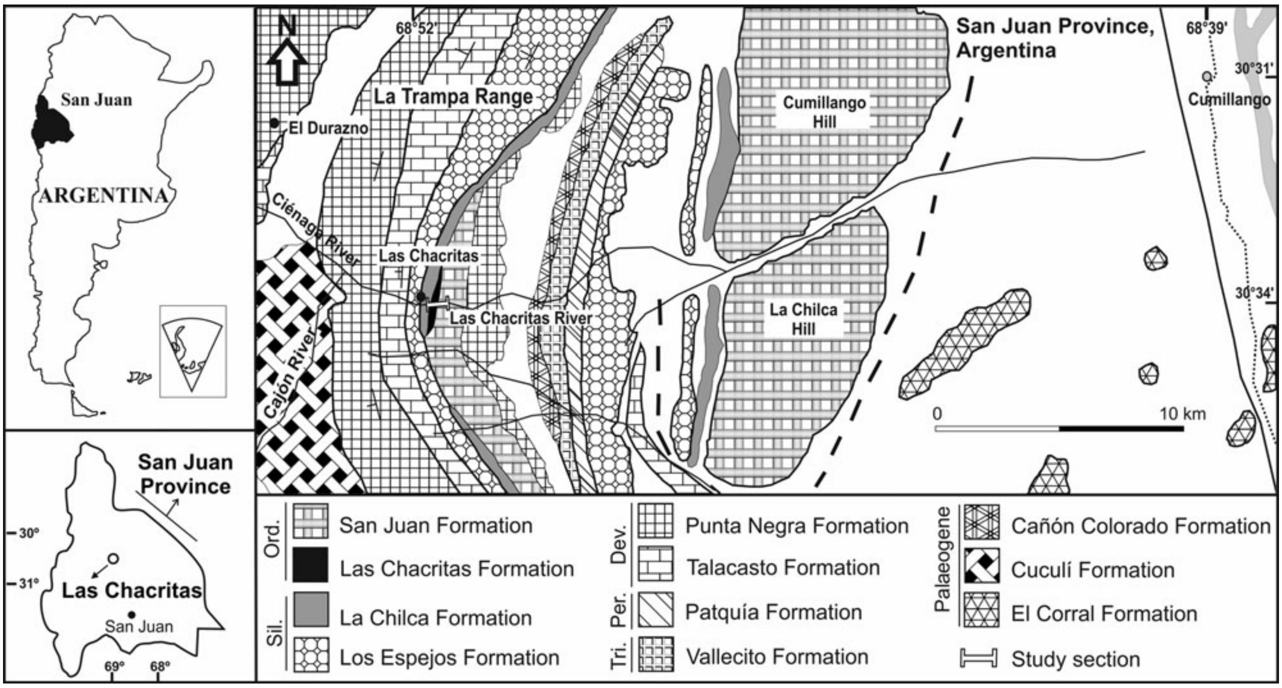

Figure 1. Location and geological map of the Las Chacritas River section in the La Trampa Range, Precordillera of San Juan, Argentina.

latter unit is paraconformably overlain by the lower Sandbian Las Aguaditas Formation at the Las Chacritas River section (Carrera & Astini, 1998), where part of the middle and upper Darriwilian section are missing. At other localities however, it is unconformably overlain by the La Chilca Formation which is a latest Ordovician – Silurian siliciclastic unit.

The conodont zones of the Argentine Precordillera are based on assemblages of species characteristic of the North American Midcontinent Province during Early Ordovician time, with an increase in Atlantic Province representatives of Middle Ordovician age (Bagnoli & Stouge, 1991). In the Middle Ordovician section there is a mixture of faunas in transitional environments, while characteristic cold-water forms dominate the late part of the period (Lehnert, 1995; Albanesi, Hünicken & Barnes, 1998; Lehnert *et al.* 1999). Traditionally, the Baltoscandian zone system has been considered as a reference for the Middle Ordovician conodont biostratigraphy of the Precordillera (Albanesi & Ortega, 2002). In previous Precordilleran studies the ranges of the index species *Lenodus variabilis* (Sergeeva), *Yangtzeplacognathus crassus* (Chen & Zhang), *Eoplacognathus pseudoplanus* (Viira), *Eoplacognathus suecicus* Bergström and *Pygodus serra* (Hadding), and the lower range of *Pygodus anserinus* Lamont & Lindström, have been recognized in the middle–upper Darriwilian (Heredia, 1982, 1998; Sarmiento, 1985; Hünicken & Ortega, 1987; Albanesi, Benedetto & Gagnier, 1995; Ortega, Albanesi & Hünicken, 1995; Albanesi, Hünicken & Barnes, 1998; Ottone *et al.* 1999; Albanesi *et al.* 2013; Feltes, Albanesi & Bergström, 2013; Mestre & Heredia, 2013*a*; Serra, Albanesi & Bergström, 2013). The upper range of *Pygodus anserinus* and the range of *Amorphognthus tvaerensis* Bergström in the Sandbian Stage have been established in several sections of the Precordillera (Heredia, 1982; Lehnert, 1995, Albanesi & Ortega, 1998; Ottone *et al.* 1999).

The first graptolite record in Argentina was a didymograptid specimen from the Ordovician Portezuelo Formation of Salta (Brackebush, 1883); since then, graptolite contributions have greatly increased, providing significant information for regional and global correlation and palaeobiogeographic studies. Floian – early Dapingian graptolite faunas from NW Argentina show Atlantic provincial affinity (Maletz & Ortega, 1995) and some particular associations include Pacific, Baltic and Chinese faunas (Toro, 1999). According to recent analysis, Floian graptolites from NW Argentina show strong similarity to graptolite faunas from Baltica, less affinity with Great Britain and weaker affinities with Laurentia and SW China (Vento, Toro & Maletz, 2012). Graptolite assemblages of the Precordillera are recorded from upper Tremadocian (Ortega *et al.* 2014) to Hirnantian rocks (Albanesi & Ortega, 2002). Important graptolite assemblages of Darriwilian and Sandbian age were identified in the Precordillera. The *Levisograptus austrodentatus* (Da1), *Levisograptus dentatus* (Da2), *Holmograptus lentus* (Da3), *Pterograptus elegans* (Da4a), *Hustedograptus teretiusculus* (Da4b) (Webby *et al.* 2004), *Nemagraptus gracilis* and *Climacograptus bicornis* (Sandbian) zones have been recognized (Albanesi & Ortega, 2002; Brussa, Toro & Benedetto, 2003, p. 76; Toro & Brussa, 2003, p. 452; Ortega, Albanesi & Frigerio, 2007).

Despite the many studies of conodonts in the Precordillera, their published records in the Las Chacritas River section at the La Trampa Range are contradictory. Moreover, the knowledge of graptolites from these

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units is poor, only a few specimens having been documented from the Las Aguaditas Formation by Peralta & Baldis (1995). The present contribution reports new data on the conodont biostratigraphy of the San Juan, Las Chacritas and Las Aguaditas formations and reports graptolites from the Las Chacritas and Las Aguaditas formations. The local and regional chronostratigraphic relationships are revised, providing a more accurate and detailed biostratigraphic scheme for the Middle and Upper Ordovician of the Argentine Precordillera. Based on the analysed collections, new information on the composition of conodont and graptolite associations through the stratigraphic column is presented, including the first records of graptolites from the Las Chacritas Formation.

2. Las Chacritas Formation

The mostly calcareous Las Chacritas Formation crops out in the northern La Trampa Range. This unit was first described by Espisúa (1968), and was then subject of many studies such as those by Astini (1994), Peralta & Baldis (1995), Carrera & Astini (1998), Heredia, Beresi & Peralta (2005, 2011), Mestre & Heredia (2012), Albanesi *et al.* (2013), Heredia *et al.* (2013), Serra & Albanesi (2013) and Serra, Albanesi & Bergström, (2013).

Peralta, Heredia & Beresi (1999) defined the Las Chacritas Formation as a 55-m-thick sequence made up of fine-grained siliciclastic and carbonate sediments deposited in a continental shelf setting (Carrera, 1997). The former authors described two members. The lower member is a 38-m-thick succession with a layer of K-bentonite at the contact with the San Juan Formation, composed of tabular, thin- to medium-bedded fossiliferous dark mudstones, nodular wackestone and packstones. Synsedimentarily deformed beds occur in the middle and upper part of the unit, indicating a deepening slope transport towards the north. The upper member is 17 m thick, and consists of thin-bedded wackestone, bioclastic grainstone, mudstone and spiculitic mudstone. It is very fossiliferous with increasing bioclastic content towards the top of the unit (Carrera & Astini, 1998; Peralta, Heredia & Beresi, 1999).

A deeper-water limestone sequence overlies the Las Chacritas Formation, and is referred to the Las Aguaditas Formation by Peralta, Heredia & Beresi (1999). The Las Aguaditas Formation was formally defined by Baldis *et al.* (1982) at its type section, Las Aguaditas Creek in the Los Blanquitos Range. It consists of platy limestone intercalating slumped horizons and breccias (Baldis *et al.* 1982) which, according to Keller, Eberlein & Lehnert (1993) were developed during times of a rapidly falling sea level. Astini (1995, 1997) suggested that it was deposited on structural hights (horsts) within the basin, which served as a reservoir of carbonate remnants.

3. Previous biostratigraphic studies

Graptolites have been poorly studied previously in this outcrop, probably because of the lack of records in the calcareous sequence. Peralta & Baldis (1995) have documented a graptolite and trilobite fauna from the Las Aguaditas Formation in the Las Chacritas Creek outcrop, including the following taxa: *Dicellograptus divaricatus* var. *salopiensis* Elles & Wood, *Hustedograptus* aff. *H. teretiusculus* (Hisinger), *Glossograptus* aff. *G. hincksii* (Hopkinson), *Climacograptus* cf. *antiquus* Lapworth and *Amplexograptus* sp. These authors suggested a Darriwilian age for the unit based on the presence of *Hustedograptus* aff. *H. teretiusculus*, and correlated this unit with the Las Aguaditas Formation in the Los Blanquitos Creek section on the basis of its lithostratigraphic and palaeontologic composition (Peralta & Baldis, 1995).

The Las Chacritas Creek section has also been the subject of several studies involving the conodont fauna. In the lower strata of the Las Chacritas Formation the *L. variabilis* Zone was first mentioned by Peralta, Heredia & Beresi (1999) and later verified by Albanesi & Ortega (2002). Albanesi & Astini (2000) recorded the *E. pseudoplanus* Zone based on the appearance of *Eoplacognathus pseudoplanus* in the middle part of this unit, and the presence of species of *Microzarkodina* enabled these authors to divide the zone into the *M. hagetiana* and *M. ozarkodella* subzones following the Baltoscandian and Chinese conodont zonal schemes. Heredia, Beresi & Peralta (2011) recognized the *E. pseudoplanus* Zone spanning the upper metre of the San Juan Formation and the basal part of the Las Chacritas Formation and the *E. suecicus* Zone in the middle part of the latter formation, suggesting a hiatus between these zones based on the absence of early or intermediate forms of *E. suecicus* in their collections. Recent studies by Mestre & Heredia (2013*b*) have recognized the *Y. crassus* Zone near the top of the San Juan Formation below the *E. pseudoplanus* Zone. These zones were also described in the study unit by Albanesi *et al.* (2013) and Serra, Albanesi & Bergström (2013). The *E. pseudoplanus* Zone in the Las Chacritas Formation correlates with the lower Sierra de La Invernada Formation (Albanesi, Bejerman & Astini, 2009), the upper Lower Member of the Los Azules Formation (Ortega, Albanesi & Frigerio, 2007) and the upper Lower Member of the Las Aguaditas Formation (Feltes, Albanesi & Bergström, 2013).

4. Materials and methods

Our study is based on completely new conodont records throughout the Las Chacritas section, which allow us to revise previous interpretations. Thirty-eight carbonate samples were collected along the section from the top of the San Juan through Las Chacritas and Las Aguaditas formations. Four samples collected from the Las Aguaditas Formation were barren of conodonts and excluded from Table S1 (in the online Supplementary

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Material available at http://journals.cambridge.org/geo). Samples of 2 kg were processed and produced a total of 7287 identifiable conodont elements (Table S1, available at http://journals.cambridge.org/geo). These specimens are well preserved with a colour alteration index (CAI) of 2.5, indicating overburden palaeotemperatures ranging from 90 °C to 110 °C (Epstein, Epstein & Harris, 1977). Conodont elements recorded from the uppermost San Juan Formation, the upper strata of the Las Chacritas Formation and the basal part of the Las Aguaditas Formation are abundant and taxonomically diverse, whereas the specimens recovered from the basal and middle parts of the Las Chacritas Formation, as well as from the middle and upper intervals of the Las Aguaditas Formation, are scarce (Fig. 2).

A thorough sampling for graptolites was accomplished in the Las Chacritas and the Las Aguaditas formations. The taxa recorded in the former formation are few and the preservation of the tubarium is rather poor, while in the latter formation graptolites are more abundant and better preserved (Fig. 3).

The fossil collection is housed in the Museo de Paleontología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, under the repository codes CORD-MP (conodonts) and CORD-PZ (graptolites).

5. Conodont biostratigraphy and correlation

Conodont species recorded in the study section represent the *Yangtzeplacognathus crassus*, *Eoplacognathus pseudoplanus* with its *M. hagetiana* and *M. ozarkodella* subzones, *Eoplacognathus suecicus* and *Pygodus anserinus* zones (Fig. 4). In the entire thickness of the Las Aguaditas Formation, specimens of *P. anserinus* were recorded as isolated elements as well as on bedding plane surfaces of calcareous shales where they are associated with the index graptolite species *Nemagraptus gracilis* (Hall).

5.a. *Yangtzeplacognathus crassus* Zone

The recognition of the lower limit of the *Y. crassus* Zone is based on the first occurrence of the eponymous species at 3.75 m from the top on the uppermost San Juan Formation, and the upper limit of the zone is defined by the first appearance datum (FAD) of *Eoplacognathus pseudoplanus* in the Las Chacritas Formation at 36 m above the base. This zone occupies the upper part of the *Paroistodus horridus* Subzone of the *Lenodus variabilis* Zone proposed by Albanesi & Ortega (2002) for the biostratigraphic scheme of the Precordillera.

In this study, the first appearance of *Y. crassus* is contemporaneous with the occurrences (although not first appearances) of *L. variabilis*, *P. horridus*, *Histiodella sinuosa* (Graves & Ellison) and *H. holodentata* Ethington & Clark. The ranges of these species straddling the contact between the San Juan and the Las Chacritas formations support the recognition of the *Y. crassus* Zone through the interval that spans a significant change of lithofacies.

The occurrence of *Yangtzeplacognathus crassus* in this section is significant for intercontinental correlation, because it is used as an index species for the zonal schemes in China and Baltoscandia (Zhang, 1998*a*, *b*; Löfgren, 2003; Löfgren & Zhang, 2003; Stouge & Nielsen, 2003). Stouge (2012) indicates that the *P. macrodentatus* Zone (*H. sinuosa*, *H. holodentata* and *H.* cf. *holodentata* subzones) as defined in western Newfoundland corresponds to the upper part of the *Y. crassus* Zone. Bradshaw (1969) documented the presence of *Histiodella sinuosa* in association with *Oistodella pulchra* Bradshaw in the lower and middle members of the Fort Peña Formation exposed in the Marathon Basin in Texas. In the Las Chacritas River section, both species were also found in the top strata of the San Juan Formation allowing a correlation with that part of the Fort Peña Formation. In Baltoscandia and south-central China the *Y. crassus* Zone is defined by the stratigraphic range of the eponymous species (Zhang, 1998*a*, *b*). Löfgren & Zhang (2003) reported that *Y. crassus* first appears in association with *L. variabilis*, similar to our records, and disappears in the basal part of the interval bearing few specimens of *E. pseudoplanus*.

The associated conodont fauna of this zone includes *Ansella jemtlandica* (Löfgren), *Baltoniodus medius* (Dzik), *Baltoniodus clavatus* Stouge & Bagnoli, '*Bryantodina*' aff. *typicalis* (Stauffer), *Coelocerodontus bicostatus*, *C. trigonius*, *Cornuodus longibasis* (Lindström), *Decoriconus* sp., *Drepanoistodus tablepointensis* Stouge, *Drepanoistodus forceps* (Lindström), *Drepanodus arcuatus* Pander, *Erraticodon alternans* (Hadding), *Fahraeusodus marathonensis* (Bradshaw), *Histiodella sinuosa*, *H. holodentata*, *Juanognathus jaanussoni* Serpagli, *Lenodus variabilis*, *Microzarkodina hagetiana*, *Parapaltodus simplicissimus* Stouge, *Paroistodus horridus*, *P. originalis* (Sergeeva), *Paltodus jemtlandicus* Löfgren, *Periodon macrodentatus* (Graves & Ellison), *Protopanderodus gradatus* Serpagli, *Rossodus barnesi* Albanesi, *Scolopodus striatus* (Lindström) and *Semiacontiodus potrerillensis* Albanesi.

5.b. *Eoplacognathus pseudoplanus* Zone

In the Las Chacritas Formation samples CHA11 to CHA18 yielded abundant Pa and Pb elements of *E. pseudoplanus* allowing the recognition of the eponymous zone. The *E. pseudoplanus* Zone ranges from 36 m above the base of the Las Chacritas Formation up to the first appearance of *E. suecicus* at 58 m from the base of the unit.

This interval also includes the following species: *A. jemtlandica*, *C. bicostatus*, *C. trigonius*, *Costiconus costatus* Dzik, *C. longibasis*, *Decoriconus* sp., *Drepanoistodus basiovalis* (Sergeeva), *D. tablepointensis*, *F. marathonensis*, *H. holodentata*, *H. kristinae* Stouge, *M. hagetiana*, *M. ozarkodella* Lindström, *P. simplicissimus*, *P. horridus*, *P. macrodentatus*, *Polonodus*

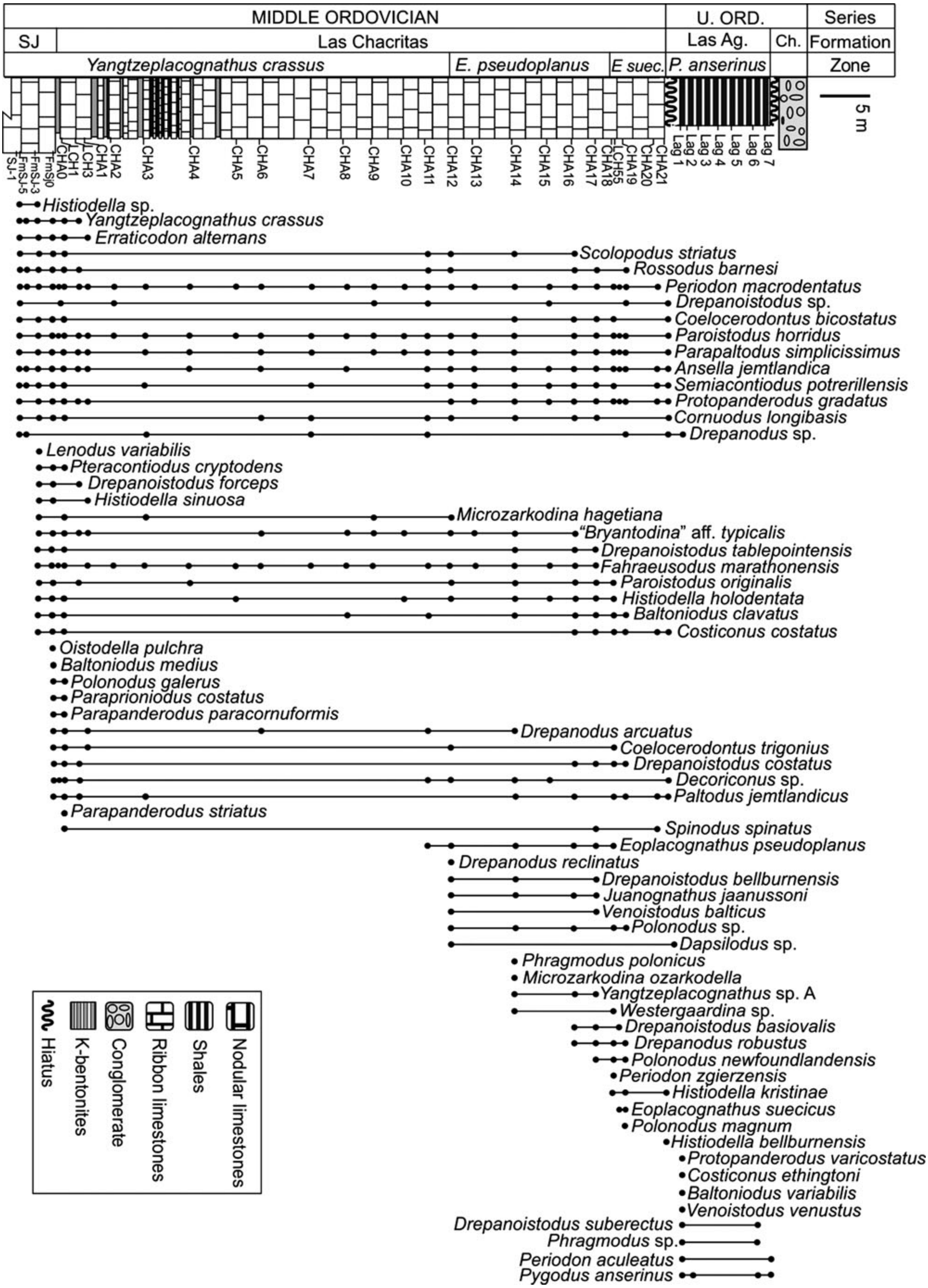

Figure 2. Stratigraphic column showing conodont species ranges and zones. Abbreviations: U. ORD. – Upper Ordovician; Las Ag. – Las Aguaditas; Ch. – La Chilca; SJ – San Juan; *E. suec*. – *E. suecicus*.

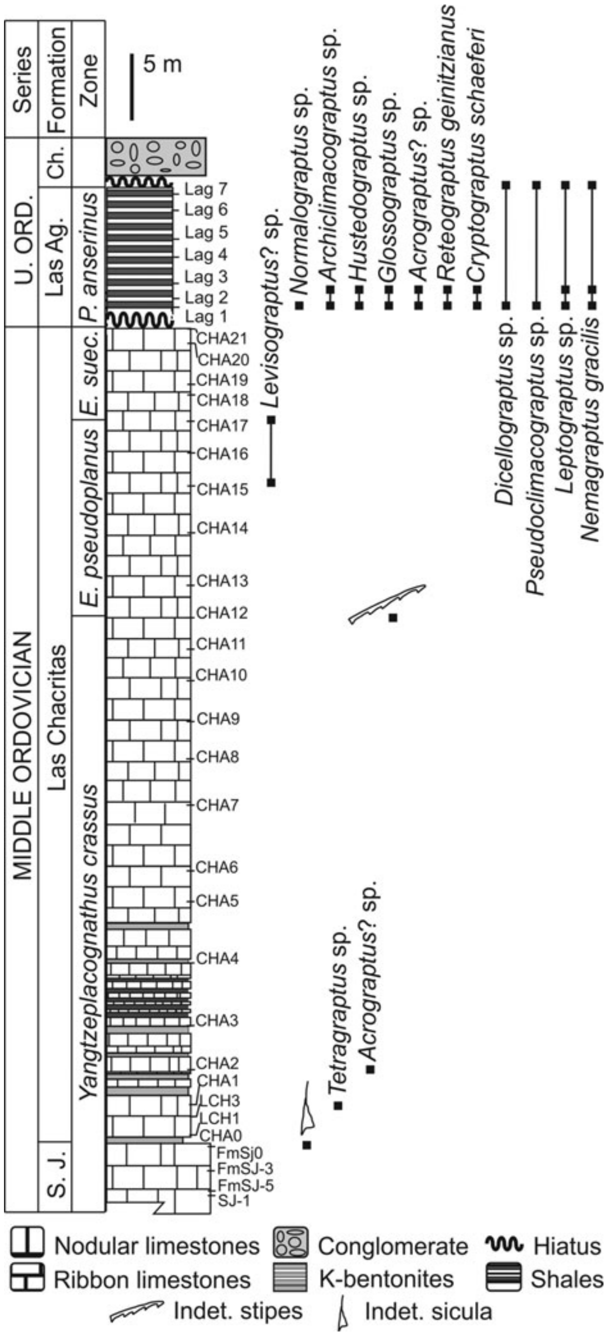

Figure 3. Stratigraphic column showing graptolite species ranges and conodont zones. Abbreviations as for Figure 2.

newfoundlandensis Stouge, *Polonodus* sp., *P. gradatus*, *S. potrerillensis* and *Westergaardodina* sp.

In the studied section, stratigraphically late forms of *E. pseudoplanus* were recorded at 53.5 m above the base of the Las Chacritas Formation (sample CHA17) and *E. pseudoplanus* and *E. suecicus* coexist in the same sample (CHA18) at 55.6 m from the base, where late forms of *E. pseudoplanus* exhibit great similarity to early forms of *E. suecicus*. A direct evolutionary relationship between these species was suggested by Zhang (1999) based on similar records in her collections.

The first appearance of *Microzarkodina ozarkodella* defines the base of the upper subzone of the *E. pseudoplanus* Zone (Zhang, 1998*b*; Löfgren, 2004). The occurrence of this species in the Las Chacritas Formation supports a correlation with the *E. pseudoplanus* Zone as defined in Baltoscandia. A number of typical taxa of this zone, such as *Ansella jemtlandica*, *Costiconus costatus*, *Drepanodus arcuatus*, *Drepanoistodus* spp., *Histiodella holodentata*, *Parapaltodus simplicissimus*, *Protopanderodus gradatus* and *Semiacontiodus potrerillensis*, frequently occur in this interval, which is a similar conodont association of the correlative interval in Baltoscandia as described by Löfgren (2004).

At Las Chacritas, *H. kristinae* first appears at the top part of the *E. pseudoplanus* Zone. This is in agreement with Zhang (1998*a*) who documents the replacement of *H. holodentata* by *H. kristinae* in her study area. Löfgren (2004) recorded *H. holodentata* and *H. kristinae* as co-occurring in the upper part of the *E. pseudoplanus* Zone in Sweden as well. These data allow for a correlation not only with China and Baltoscandia but also with the uppermost part of the Table Point Formation of the Table Head Group in western Newfoundland, where Stouge (1984) demonstrated the same evolutionary succession in this interval. Based on Stouge (2012) data, the first appearance of *P. macrodentatus*, *H. holodentata* and then *H. kristinae* in successively younger strata are useful for a precise correlation with the succession in Newfoundland.

5.c. *Eoplacognathus suecicus* Zone

The base of this zone is located in the upper Las Chacritas Formation, at 55.6 m above the base in the study section (Sample CHA19) where early forms of this species are associated with late forms of *E. pseudoplanus*. Zhang (1998*c*) subdivided the *E. suecicus* Zone into the *Pygodus lunnensis* and *P. anitae* subzones; the record of *Polonodus magnus* Albanesi, 1998 (senior synonym of *Pygodus lunnensis* Zhang 1998*c*) allows the identification of the lower *E. suecicus* subzone for the interval in our section. The *E. suecicus* Zone was initially recognized in the Argentine Precordillera by Hünicken & Ortega (1987) in the Los Azules Formation at Cerro Viejo of Huaco.

The key species *E. suecicus* and *H. kristinae* recorded here allow for correlation with the *E. suecicus* Zone from Baltoscandia, and with the *H. kristinae* Zone as defined by Stouge (1984) for western Newfoundland. The presence of *H. bellburnensis* Stouge in the top strata of the Las Chacritas Formation supports correlation with the *Periodon zgierzensis* Zone of the Table Point Group in western Newfoundland, as this zone was recently defined by Stouge (2012).

The index species *E. suecicus* has been shown to be biostratigraphically useful since its first description by Bergström (1971). It displays a wide geographic distribution having been documented in Baltoscandia (Viira, 1967, 1974; Bergström, 1971; Löfgren, 1978), North America (Harris *et al.* 1979), and north China (An &

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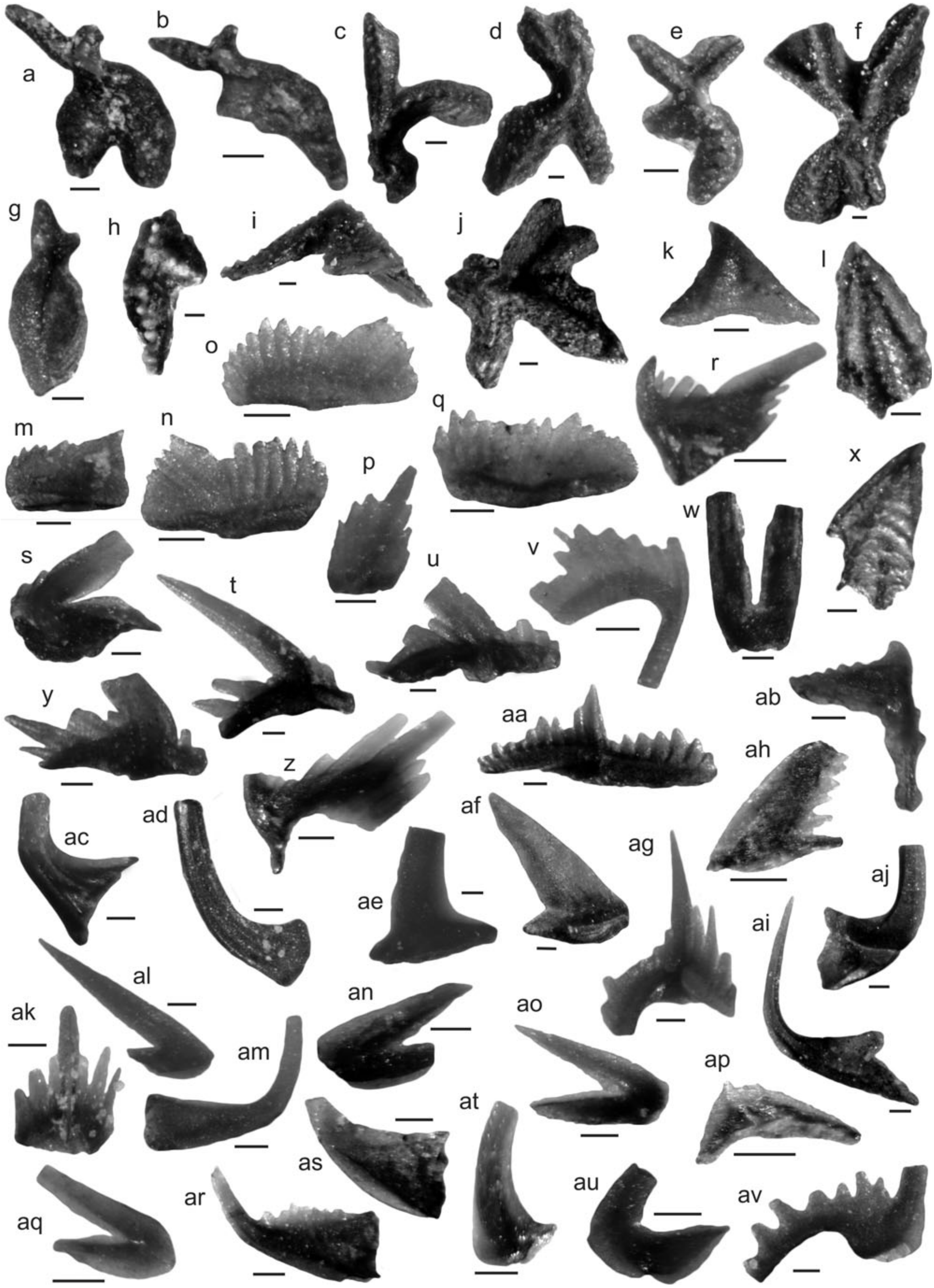

Figure 4. Darriwilian and Sandbian conodont elements from the Las Chacritas River section. Scale: 0.1 mm. (a–c) *Yangtzeplacognathus crassus* (Chen & Zhang), San Juan Formation; (a, b) Pa elements, oral view; (a) sample FmSJ-3, ×50, CORD-MP 18218; (b) sample SJ-1, ×80, CORD- MP 29332. (c) Pb element, sample SJ-1, ×50, CORD- MP 29333. (d, i) *Polonodus magnus* Albanesi, Las Chacritas Formation, sample CHA19, ×40, CORD-MP 29334; (d) oral view; (i) lateral view. (e) Late forms of *Eoplacognathus pseudoplanus*

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Zheng, 1990). The species taxonomy was thoroughly reviewed by Zhang (1999).

This zone has also been identified in diverse strata of the Precordillera, such as the Gualcamayo Formation in the Villicum Range (Sarmiento, 1991) and the Cerro Potrerillo (Albanesi, Hünicken & Barnes, 1998), the lower part of the Sierra de La Invernada Formation (Ortega *et al.* 2008), and the Yerba Loca Formation (Albanesi, Benedetto & Gagnier, 1995). Although E.D. Brussa (unpub. thesis, Universidad Nacional de Córdoba, 1994) reported the *E. suecicus* Zone from the Las Aguaditas Formation, recent studies by Albanesi *et al.* (2013) and Feltes, Albanesi & Bergström (2013) indicate the presence of a hiatus that probably covers the interval from the top part of the *E. pseudoplanus* through the *E. suecicus* and the *Pygodus serra* zones up to the lower *P. anserinus* Zone in the Las Aguaditas Formation as its type locality.

In our study collections, the *E. suecicus* Zone yields a conodont association including *A. jemtlandica*, *B. clavatus*, *C. longibasis*, *Drepanoistodus basiovalis*, *D. costatus*, *F. marathonensis*, *H. kristinae*, *H. bellburnensis*, *P. simplicissimus*, *P. horridus*, *P. originalis*, *P. macrodentatus*, *P. zgierzensis*, *P. gradatus*, *Polonodus* sp., *P. magnus* and Gen. nov. sp. nov. A.

5.d. *Pygodus anserinus* Zone

The *P. anserinus* Zone is identified in the Las Aguaditas Formation at the Las Chacritas River section by the record of the homonymous species and associated forms. The lowest productive sample is from the base of the formation, where elements of *P. anserinus* were found on bedding plane surfaces of shales associated with *Nemagraptus gracilis*, and isolated elements were recovered from all samples of this zone. The uppermost sample was taken 10 m above the base, just at the top of the Las Aguaditas Formation, where the specimens were found either isolated from mudstone or on bedding planes. The occurrence of *P. anserinus* and *N. gracilis* clearly demonstrates that these strata correspond to the upper part of the *P. anserinus* Zone of early Sandbian age. The associated conodont fauna includes *Baltoniodus variabilis* (Bergström), *Costiconus ethingtoni* (Fåhraeus), *Drepanoistodus suberectus* (Branson & Mehl), *Drepanodus* sp., *Phragmodus* sp., *Protopanderodus varicostatus* (Sweet & Bergström), *Periodon aculeatus* Hadding and *Venoistodus venustus* (Stauffer).

P. anserinus has been documented from several localities of the Argentine Precordillera; for example,

(Viira), Las Chacritas Formation, Pa element, oral view, sample CHA18, ×80, CORD-MP 29337. (f) *Eoplacognathus pseudoplanus* (Viira), Las Chacritas Formation, Pa element, oral view, sample CHA14, ×30, CORD-MP 29335. (g) *Yangtzeplacognathus* sp. A Stouge, Las Chacritas Formation, oral view, sample CHA16, ×60, CORD-MP 29336. (h) *Eoplacognathus suecicus* Bergström, Las Chacritas Formation, Pa element, oral view, sample LCH55, ×50, CORD-MP 18216. (j) *Polonodus newfoundlandensis* (Stouge), Las Chacritas Formation, Pa element, oral view, sample CHA19, ×40, CORD-MP 29338. (k) *Polonodus* sp. Las Chacritas Formation, lateral view, sample CHA12, ×100, CORD-MP 29348. (l, x) *Pygodus anserinus* Lamont & Lindström, Las Aguaditas Formation, Pa elements, oral view, sample Lag6, ×80, CORD-MP 29339, 29340. (m) *Histiodella sinuosa* (Graves & Ellison), San Juan Formation, Pa element, lateral view, sample FmSJ0, ×100, CORD-MP 18278. (n, p) *Histiodella holodentata* Ethington & Clark, Las Chacritas Formation; (n) Pa element, lateral view, sample CHA17, ×100, CORD-MP 29342; (p) Sc element, lateral view, sample CHA16, ×100, CORD-MP 29355. (o) *Histiodella kristinae* Stouge, Las Chacritas Formation, Pa element, lateral view, sample CHA18, ×100, CORD-MP 29341. (q) *Histiodella bellburnensis* Stouge, Las Chacritas Formation, Pa element, lateral view, sample QN3, ×90, CORD-MP 18327. (r) *Phragmodus* sp., Las Aguaditas Formation, lateral view, sample Lag1, ×60, CORD-MP 56. (s, y) *Periodon aculeatus* Hadding, Las Aguaditas Formation, sample Lag1; (s) M element, lateral view, ×80, CORD-MP 29344; (y) Pa element, lateral view, ×80, CORD-MP 29345. (t, z) *Periodon macrodentatus* (Graves & Ellison), Las Chacritas Formation; (t) Pa element, lateral view, sample CHA12, ×50, CORD-MP 29347; (z) Sd element, sample CHA17, ×60, CORD-MP 29357. (u) *Periodon zgierzensis* Dzik, Las Chacritas Formation, Pa element, lateral view, sample CHA18, ×80, CORD-MP 29346. (v) *Fahraeusodus marathonensis* Bradshaw, Las Chacritas Formation, lateral view, sample CHA16, ×60, CORD-MP 29358. (w) *Westergaardodina* sp., Las Chacritas Formation, lateral view, sample CHA18, ×100, CORD-MP 29343. (aa) '*Bryantodina*' aff. *typicalis* Stauffer, Las Chacritas Formation, P element, lateral view, sample CHA14, ×50, CORD-MP 29353. (ab) *Baltoniodus clavatus* Stouge & Bagnoli, Las Chacritas Formation, Pa element, lateral view, sample CHA17, ×60, CORD-MP 29359. (ac) *Costiconus costatus* Dzik, Las Chacritas Formation, lateral view, sample CHA19, ×30, CORD-MP 29360. (ad) *Scolopodus striatus* Pander, Las Chacritas Formation, lateral view, sample CHA14, ×35, CORD-MP 29365. (ae, af) *Drepanoistodus bellburnensis* Stouge, Las Chacritas Formation, lateral view; (ae) Sa element, sample CHA14, ×40, CORD-MP 29363; (af) M element, sample CHA17, ×50, CORD-MP 29364. (ag) *Microzarkodina hagetiana* Stouge & Bagnoli, Las Chacritas Formation, Sa element, anterior view, sample CHA14, CORD-MP 29372. (ah) *Oistodella pulchra* Bradshaw, San Juan Formation, M element, lateral view, sample FmSJ0, ×50, CORD-MP 19464. (ai, aj) *Protopanderodus gradatus* Serpagli, Las Chacritas Formation, lateral view; (ai) sample CHA14, ×25, CORD-MP 29352; (aj) sample CHA14, ×40, CORD-MP 29351. (ak) *Microzarkodina ozarkodella* Lindström, Las Chacritas Formation, Sa element, posterior view, sample CHA14, ×45, CORD-MP 29350. (al) *Drepanoistodus tablepointensis* Stouge, Las Chacritas Formation, M element, lateral view, sample CHA14, ×40, CORD-MP 29361. (am) *Cornuodus longibasis* (Lindström), Las Chacritas Formation, lateral view, sample CHA16, ×60, CORD-MP 29362. (an, at) *Drepanoistodus costatus* Abaimova, Las Chacritas Formation, lateral view, sample CHA17, ×100; (an) M element, CORD-MP 29366; (at) P element, CORD-MP 29367. (ao) *Venoistodus balticus* Löfgren, Las Chacritas Formation, M element, lateral view, sample CHA15, ×100, CORD-MP 29368. (ap) Gen nov. sp. nov. A, Las Chacritas Formation, P element, lateral view, sample QN2, ×50, CORD-MP 19462. (aq) *Venoistodus venustus* (Stauffer), Las Aguaditas Formation, lateral view, sample Lag1, ×80, CORD-MP 29373. (ar, as) *Ansella jemtlandica* Löfgren, Las Chacritas Formation, lateral view, sample CHA 14, ×80; (ar) Sa element, CORD-MP 29369; (as) P element, CORD-MP 29370. (au) *Paroistodus originalis* (Sergeeva), Las Chacritas Formation, lateral view, sample CHA16, ×100, CORD-MP 29371. (av) *Paroistodus horridus* (Barnes & Poplawski), Las Chacritas Formation, lateral view, sample CHA17, ×60, CORD-MP 29354.

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Heredia (1982) published the first report of this species form the San Rafael Block, where the lower boundary of the zone was determined by Lehnert *et al.* (1999). The upper boundary was recorded in the Las Aguaditas Formation, Precordillera of San Juan, by the FAD of *Amorphognathus tvaerensis* (Lehnert, 1995; Albanesi & Ortega, 1998). In the latter formation, the *P. anserinus* Zone was recently described by Albanesi *et al.* (2013) and Feltes, Albanesi & Bergström (2013) at the Las Aguaditas section.

5.e. Comments on previous conodont studies

Previous conodont studies of the San Juan and Las Chacritas formations have shown that these units are middle Darriwilian in age. In our study area, Albanesi & Astini (2000) recorded the *E. pseudoplanus* Zone in the uppermost part of the San Juan Formation up to 49.5 m above the base of the Las Chacritas Formation. Subsequently, Heredia (2012) found the basal part of the Las Chacritas Formation to be barren and recovered the first conodont specimens 2 m above the base, including the index species *E. pseudoplanus*. The *E. pseudoplanus* Zone (Heredia, 2012) and the *E. pseudoplanus*/*D. tablepointensis* Zone (Heredia, Beresi & Peralta, 2005) were recorded at the contact between the San Juan and Las Chacritas formations, and alternative schemes for this section were published (Heredia, Beresi & Peralta, 2005, 2011).

Based on this new data, the contact between the San Juan and Las Chacritas formations corresponds to the *Y. crassus* Zone. This species is well documented from the upper part of the San Juan Formation, but it decreases in abundance and disappears in the basal part of the Las Chacritas Formation. We also recorded a diverse conodont fauna from the lower part of the formation. Supporting our findings, the brief report by Feltes *et al.* (2014) verifies the occurrence of *Y. crassus* as documented by various authors from the upper San Juan Formation and overlying strata at diverse localities of the Central Precordillera including La Chilca, Las Chacritas, Las Aguaditas, Oculta creek and the Viejo de Huaco Mountain.

Heredia (2012) documented the appearance of late forms of *E. suecicus* at 7 m above the base of the Las Chacritas Formation and suggested a possible hiatus in the first metres of the formation due to the absence of early or intermediate forms of *E. suecicus*. In our study, the *E. pseudoplanus* Zone with the *M. hagetiana* and *M. ozarkodella* subzones are defined in the middle part of the Las Chacritas Formation, followed by the *E. suecicus* Zone at the top strata of the formation. According to our analysis, in the transition between the *E. pseudoplanus* and *E. suecicus* zones early forms of *E. suecicus* are recorded; any lithological discontinuity is not verified to support the hiatus suggested by Heredia (2012) and Heredia, Beresi & Peralta (2011).

6. Graptolite biostratigraphy and correlation

The sampled interval for graptolites included the Las Chacritas and the Las Aguaditas formations spanning the upper Darriwilian – lower Sandbian stages. The ranges of species recorded through these units are shown in Figure 3.

The base of the *Nemagraptus gracilis* Zone is recognized by the appearance of the *N. gracilis* fauna including the eponymous species, which marks the beginning of the Sandbian Stage. Index graptolite species from the topmost Darriwilian strata were not found; nevertheless, a Darriwilian biostratigraphy could be established by conodont studies. The graptolites from the Las Chacritas Formation are rare and the preservation of the tubaria is poor; however, they provide significant palaeontological data for this group in outer ramp deposits of this formation. Conversely, in the Las Aguaditas Formation the graptolites are abundant, diverse and useful fossils for biostratigraphy.

Fragments of stipes and siculas were recovered from K-bentonite layers at the base of the Las Chacritas Formation (*Y. crassus* Zone). Specimens of *Tetragraptus* sp. are present in the lower and middle parts of the unit (Figs 5j, 6e), although only mature colonies were recovered. Poorly preserved stipes that do not show much detail were found a few metres above, some of which could be identified as *Acrograptus*? sp., but no proximal ends were found to permit identification at the species level (Figs 5g, 6i). In the middle and upper part of this formation scandent tubaria of *Levisograptus*? sp. were recorded (Figs 5e, 6d, g). Although the graptolite fauna is scarce, the association of this species with *E. pseudoplanus* suggests an age equivalent to the *Holmograptus lentus* Zone of the Argentine Precordillera (Ortega, Albanesi & Frigerio, 2007).

6.a. *Nemagraptus gracilis* Zone

Specimens of *N. gracilis* (Fig. 5d, f) were recorded in the basal and top strata of the Las Aguaditas Formation. The graptolite fauna that accompanies this species consists of *Glossograptus ciliatus* Emmons, *Cryptograptus schaeferi* Lapworth (Fig. 6a), *Pseudoclimacograptus* sp. (Fig. 5a), *Normalograptus* sp. (Figs 5b, 6b), *Dicellograptus* sp. (Fig. 5c), *Leptograptus* sp. (Fig. 5h), *Archiclimacograptus*? sp. (Figs 5i, 6c), *Reteograptus geinitzianus* Hall (Fig. 6h) and *Hustedograptus* sp. (Fig. 6f). This association indicates the *N. gracilis* Zone, and the common presence of *P. anserinus* enables us to conclude that these strata belong to the basal part of the zone which is early Sandbian in age.

This zone is reported from several localities in the Argentine Precordillera. In Central Precordillera it is identified in the Los Blanquitos section (Las Aguaditas Formation; Brussa, 1996), Sierra de la Invernada (Sierra de la Invernada Formation; Ortega *et al.* 2008), Cerro La Chilca (Los Azules Formation; Blasco & Ramos, 1976) and El Tontal Range (Portezuelo del Tontal Formation; Cuerda, 1986; Peralta *et al.* 2003).

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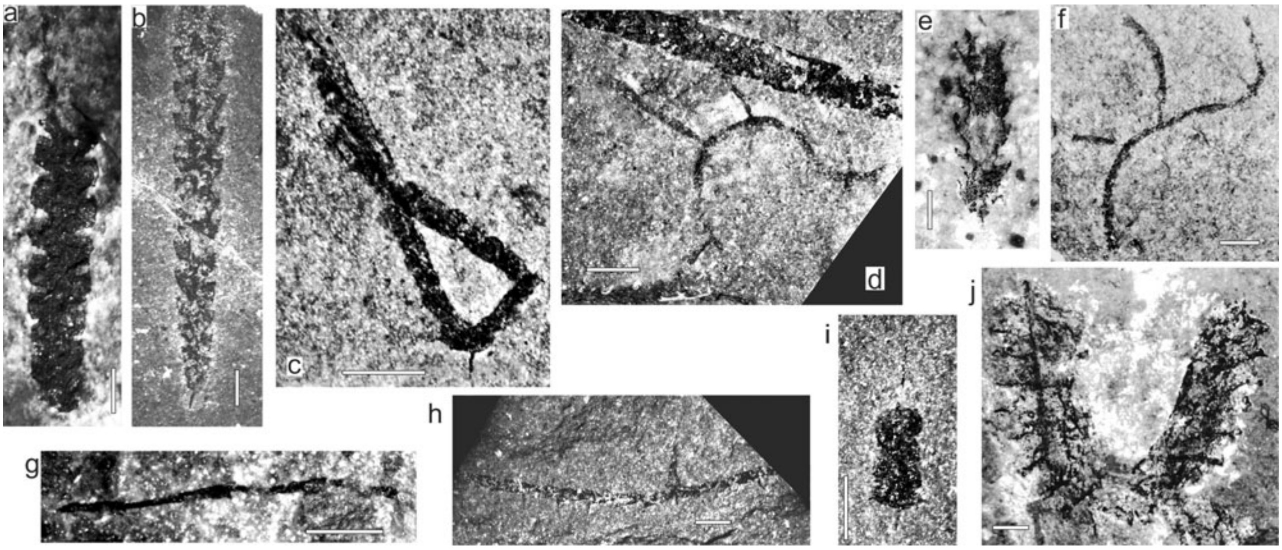

Figure 5. Darriwilian and Sandbian graptolites from the Las Chacritas River section. Scale: 1 mm. (a) *Pseudoclimacograptus* sp., Las Aguaditas Formation, sample Lag7, CORD-PZ 33552. (b) *Normalograptus* sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33580. (c) *Dicellograptus* sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33563. (d, f) *Nemagraptus gracilis* Hall, Las Aguaditas Formation; (d) sample Lag1, CORD-PZ 33581; (f) sample Lag2, CORD-PZ 33550. (e) *Levisograptus*? sp., Las Chacritas Formation, sample CHA17, CORD-PZ 33576. (g) *Acrograptus*? sp., Las Chacritas Formation, sample CHA2, CORD-PZ 33575. (h) *Leptograptus* sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33582. (i) *Archiclimacograptus*? sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33569. (j) *Tetragraptus* sp., Las Chacritas Formation, sample LCH4, CORD-PZ 33574.

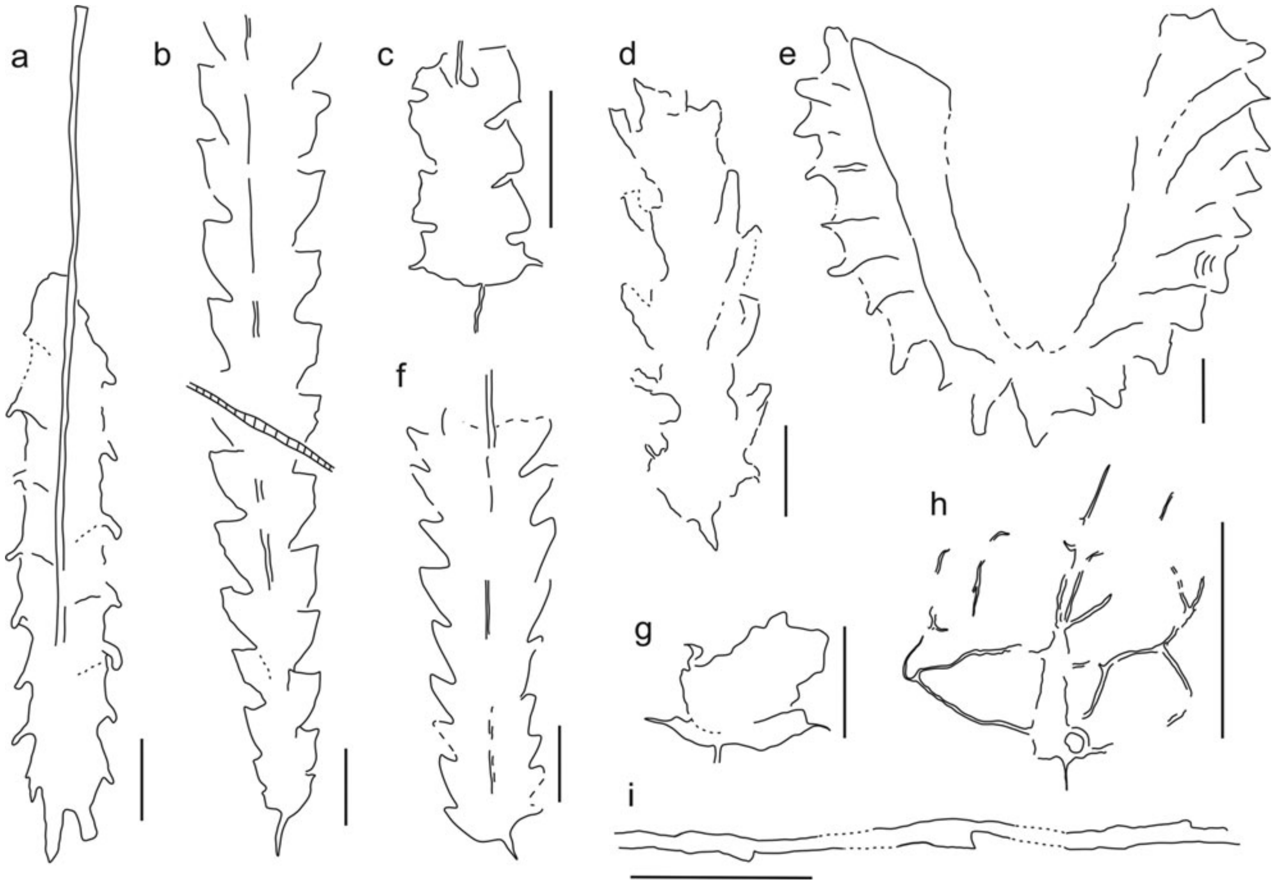

Figure 6. *Camera lucida* drawings of Darriwilian and Sandbian graptolites from the Las Chacritas River section. (a) *Cryptograptus schaeferi* Lapworth, Las Aguaditas Formation, sample Lag2, CORD-PZ 33561. (b) *Normalograptus* sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33580. (c) *Archiclimacograptus*? sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33569. (d) *Levisograptus*? sp., Las Chacritas Formation, sample CHA17, CORD-PZ 33576. (e) *Tetragraptus* sp., Las Chacritas Formation, sample LCH4, CORD-PZ 33574. (f) *Hustedograptus* sp., Las Aguaditas Formation, sample Lag1, CORD-PZ 33544. (g) *Levisograptus*? sp., Las Chacritas Formation, sample CHA15, CORD-PZ 33583. (h) *Reteograptus geinitzianus* Hall, Las Aguaditas Formation, sample Lag1, CORD-PZ 33511. (i) *Acrograptus*? sp. Las Chacritas Formation, sample CHA2, CORD-PZ 33575.

It was also documented in the Western Precordillera in the Yerba Loca Formation, in the Jáchal River section (Blasco & Ramos, 1976) and in the Eastern Precordillera in the La Cantera Formation, Villicum Range (Peralta, 1993).

This graptolite fauna has a worldwide distribution (Baltic region, Great Britain, North America, Australasia, China, South America) (Finney, 1986; Finney & Bergström, 1986). Its presence in the Argentine Precordillera was discussed by Ortega & Brussa (1990) and Ortega & Albanesi (1998). New information about the *N. gracilis* Zone in Peru, Bolivia and Venezuela extends its record to other parts of South America (Brussa *et al*. 2007; Gutiérrez-Marco *et al*. 2011).

7. Conodont palaeoecology

Conodonts are abundant and of high diversity through the contact interval between the San Juan and the Las Chacritas formations, as is the case for the middle–upper part of the Las Chacritas Formation. A decline in the relative abundance of most taxa is observed near the base of the Las Chacritas Formation and the presence of some prominent forms, such as *Paroistodus horridus*, *Periodon macrodentatus*, *Ansella jemtlandica* and *Fahraeusodus marathonensis*, indicates a change in the environmental conditions. The major part of the carbonate sequence is dominated by *P. macrodentatus* and *P. horridus*.

A total of 2179 conodont elements were counted from the *Y. crassus* Zone. The proportion of *Y. crassus* ranges between 0.32 and 2.80 % per sample, with a maximum in the upper 1 m of the San Juan Formation and the first 2 m of the Las Chacritas Formation. *Periodon macrodentatus* and *Paroistodus horridus* are by far the most abundant taxa in the *Y. crassus* Zone, at 37.90 % and 37.67 % respectively. At the top of the San Juan Formation, the species *P. horridus* is more abundant (40 %) than *P. macrodentatus* (29 %); in the lower 30 m of the Las Chacritas Formation however, the latter species contributes the highest percentage (30–67 %) in all samples. Other taxa, such as *A. jemtlandica* (7.57 %), *P. gradatus* (6.96 %) and *F. marathonensis* (6.35 %), are less common but appear in all the samples of this zone (Fig. 7). *Periodon* and *Paroistodus* are both considered indicators of high sea levels or cold-water environments (Rasmussen & Stouge, 1995). The presence of *Ansella* and *Protopanderodus* further supports an outer shelf-slope setting, which characterizes the deep-water *Protopanderodus*–*Periodon* Biofacies as defined by Rasmussen & Stouge (1995).

From the conodont collection with 4092 specimens recorded in the *E. pseudoplanus* Zone, *Paroistodus horridus* and *Periodon macrodentatus* are the most abundant species representing 40 % and 23 %, respectively (Fig. 8). The next most abundant taxa are *Protopanderodus gradatus* (10 %), *Parapaltodus simplicissimus* (4.40 %), *Drepanoistodus* spp. (4 %), *Ansella jemtlandica* (3 %) and *Polonodus* sp.(0.9 %) that are common in

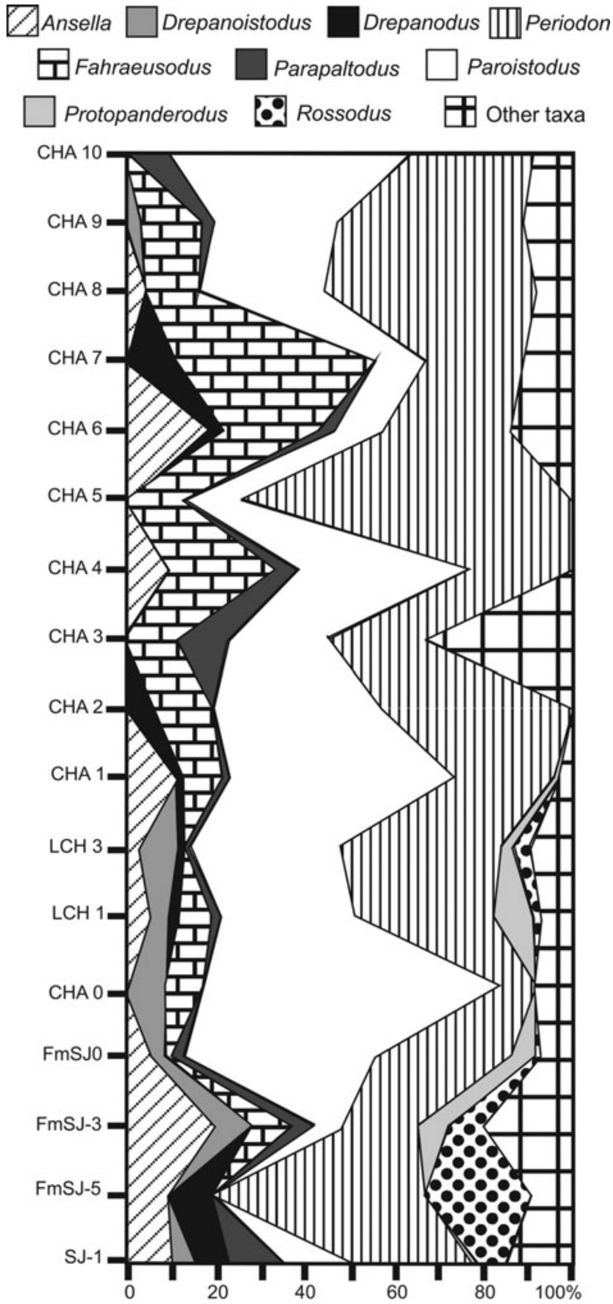

Figure 7. Sampled levels and relative abundance of conodont taxa in the *Y. crassus* Zone.

western Newfoundland (Stouge, 1984) and in south-central China (Zhang, 1998*a*) from deeper sea environments. The presence of *Histiodella* spp. (2.80 % in abundance) reflects North American affinities, suggesting similar environmental conditions. According to Löfgren (2004), the occurrence of *Histiodella* is related to transgressions; this is in accordance with the associated conodonts of our *E. pseudoplanus* Zone, which can be interpreted as indicative of deep-water environments.

Among the 837 conodont elements recovered from the *E. suecicus* Zone the most abundant species is *Protopanderodus gradatus*, which represents the 24.4 % of the total taxa. *P. macrodentatus* (21.9 %),

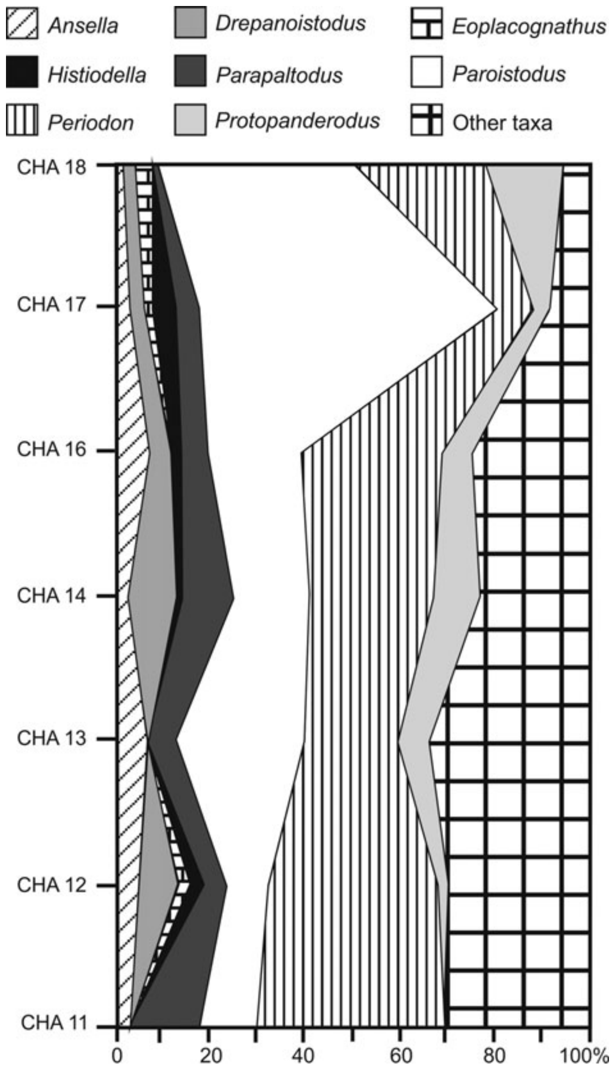

Figure 8. Sampled levels and relative abundance of conodont taxa in the *E. pseudoplanus* Zone.

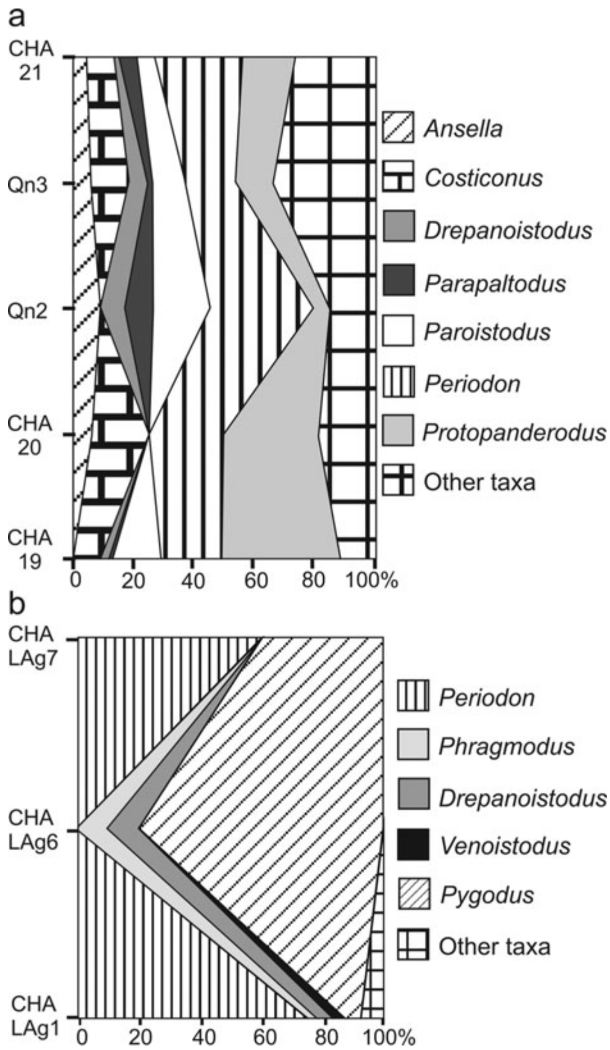

Figure 9. Sampled levels and relative abundance of conodont taxa: (a) *E. suecicus* Zone; (b) *P. anserinus* Zone.

P. horridus (13.6 %) and *Costiconus costatus* (6.9 %) follow in abundance (Fig. 9a). The presence of these taxa is related to transgressive events (Pohler, 1994), and they were recognized by Stouge (1984) as characteristic taxa of the *Periodon–Cordylodus* (=*Paroistodus*) Biofacies which represents shelf edge to slope environments.

A collection of 179 conodont specimens was recovered from the *P. anserinus* Zone. The most abundant species is *Periodon aculeatus*, which represents 70.4 % of the total conodont fauna. *P. anserinus* (10.06 %), *D. suberectus* (5.03 %) and *V. venustus* (3.91 %) follow in abundance (Fig. 9b). In comparison to the previous zones, the conodont fauna of the *P. anserinus* Zone is less diverse and abundant and graptolites become the dominant fossils. The lithology consists of grainstones–packstones interbedded with mudstones and black shales. These facts suggest a significant environmental change caused by different water depth conditions, being a deeper facies compared to that of the Las Chacritas Formation.

7.a. Relative abundance of principal genera

The relative abundance logs displayed here are based on the relative abundance of the major conodont genera for each zone. In the *Y. crassus* Zone, *Periodon* shows four major peaks while *Paroistodus* shows up to three; in both cases these are spread over several samples (Fig. 10a). *Periodon* represents the most abundant taxon in the uppermost strata of the San Juan Formation (samples SJ-1, FmSJ-5 and FmSJ-3) and in the middle and top parts of this zone (samples CHA2 and CHA5–CHA9). However, this trend changes upwards in the succession where *Paroistodus* becomes more abundant at the base of the Las Chacritas Formation (samples LCH3-CHA1 and CHA4) and at the top of the first zone (sample CHA10). An antithetical relationship is determined by the increase of one species and the concomitant decrease of the other although both taxa are typical of deep, proximal to distal slope environments. *Paroistodus* represents a biotope constrained to lower temperatures or deeper conditions compared to *Periodon*, which indicates pulses of depth change to deeper environments. The lithofacies in these strata are

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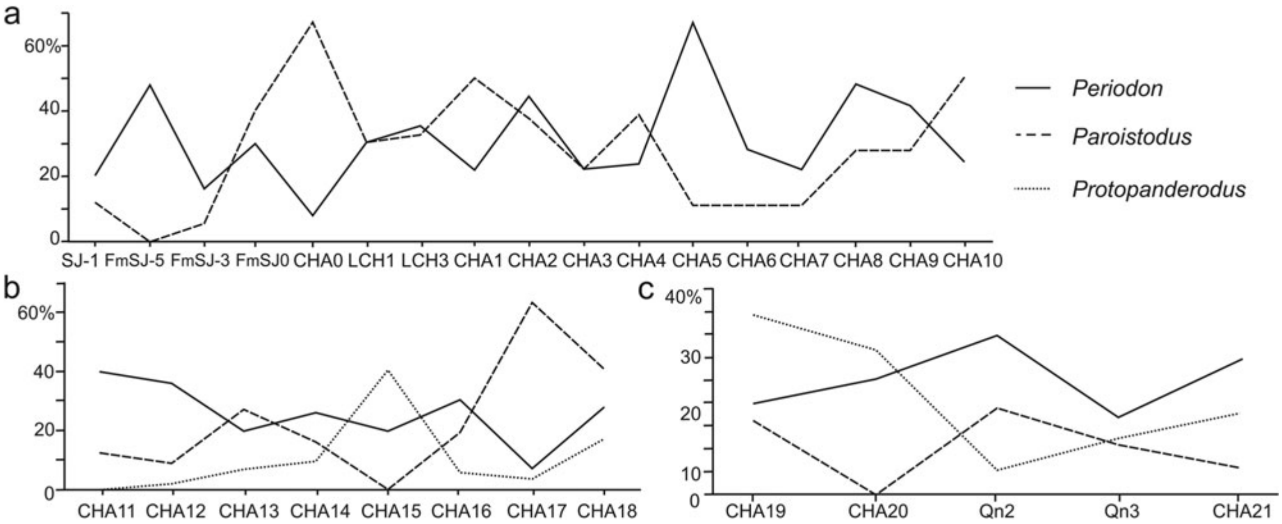

Figure 10. Relative abundance logs based on the relative abundance of the major conodont genera in each zone, *Periodon*, *Paroistodus* and *Protopanderodus*, from the *Y. crassus*, *E. pseudoplanus* and *E. suecicus* zones.

made up of nodular limestones in the upper San Juan Formation and ribbon limestone interbedded with black shales in the basal part of the Las Chacritas Formation, indicating a change of environments that is interpreted as a transition to deeper-water facies.

Periodon is the dominant genus through most of the *E. pseudoplanus* Zone, although *Paroistodus* becomes more common than *Periodon* in abundance and remains the dominant taxon (Fig. 10b) at the top of the zone (sample CHA17). *Protopanderodus* is the next most common taxon and shows a main increase phase in the middle part of the zone (sample CHA15). At this level *Periodon* decreases, whereas *Paroistodus* disappears for the only time in the zone. These genera are representative of deep facies, although the lithology indicates a shallower setting compared to that of the previous zone.

At the base of the *E. suecicus* Zone the *Paroistodus–Periodon* association is replaced by *Protopanderodus* as the most abundant (Fig. 10c). This relation is reversed in sample Qn2 where *Periodon* and *Paroistodus* reappear with peaks of high abundance, the former being the highest. Samples Qn3 and CHA 21 were taken from the top part of the Las Chacritas Formation in different outcrops of the formation. The lithology and conodont fauna composition of this zone are similar to that of the *E. pseudoplanus* Zone, suggesting similar environmental conditions.

8. Conclusions

Based on this study a new conodont–graptolite biostratrigraphic scheme is compiled for the Middle–Late Ordovician Las Chacritas River section in the Central Precordillera (Fig. 11).

The four Middle–Upper Ordovician conodont zones identified in the study area are (in ascending order): the *Yangtzeplacognathus crassus*, *Eoplacognathus pseudoplanus*, *Eoplacognathus suecicus* and *Pygodus anserinus* zones. A detailed conodont biostratigraphic scheme is based on the records of not only the index species but also other significant chronostratigraphic markers such as *Microzarkodina hagetiana*, *M. ozarkodella*, *P. magnus*, *P. newfoundlandensis*, *Histiodella sinuosa*, *H. holodentata*, *H. kristinae*, *H. bellburnensis*, *Periodon macrodentatus*, *P. zgierensis* and *P. aculeatus*.

The conodont fauna from the Las Chacritas River section shows both Baltic and Laurentian provincial affinity. *Yangtzeplacognathus* and *Eoplacognathus* species are less frequently represented in the studied units, while the *Histiodella* and *Periodon* evolutionary stages proved to be additional aids for correlation. *Yangtzeplacognathus* sp. A, identified by Stouge (2012) from the Cow Head Group, was found in association with *H. holodentata* and *P. macrodentatus* in the Las Chacritas Formation. The faunal similarity between the Las Chacritas River section and the Cow Head Group further suggests that the *Periodon* zones and their *Histiodella* subzones defined by Stouge (2012) may offer potential for intercontinental biostratigraphic correlation, and should be considered for conodont biostratigraphy and palaeobiogeographic analysis of the Middle Ordovician Precordillera.

The *Nemagraptus gracilis* Zone is identified through the Las Aguaditas Formation in the Las Chacritas River section. According to our records, this formation is Sandbian in age and correlates with the middle member of the Las Aguaditas Formation in its type section at the Las Aguaditas Creek in the Los Blanquitos Range.

Based on the conodont and graptolite faunas, the interval from the top part of the San Juan Formation and through the Las Chacritas Formation corresponds to the Darriwilian Stage. The Las Aguaditas Formation in the Las Chacritas River section belongs to the Sandbian Stage. The new biozonation allows for a precise global correlation with other regions, for example China, Baltoscandia, North America, Great

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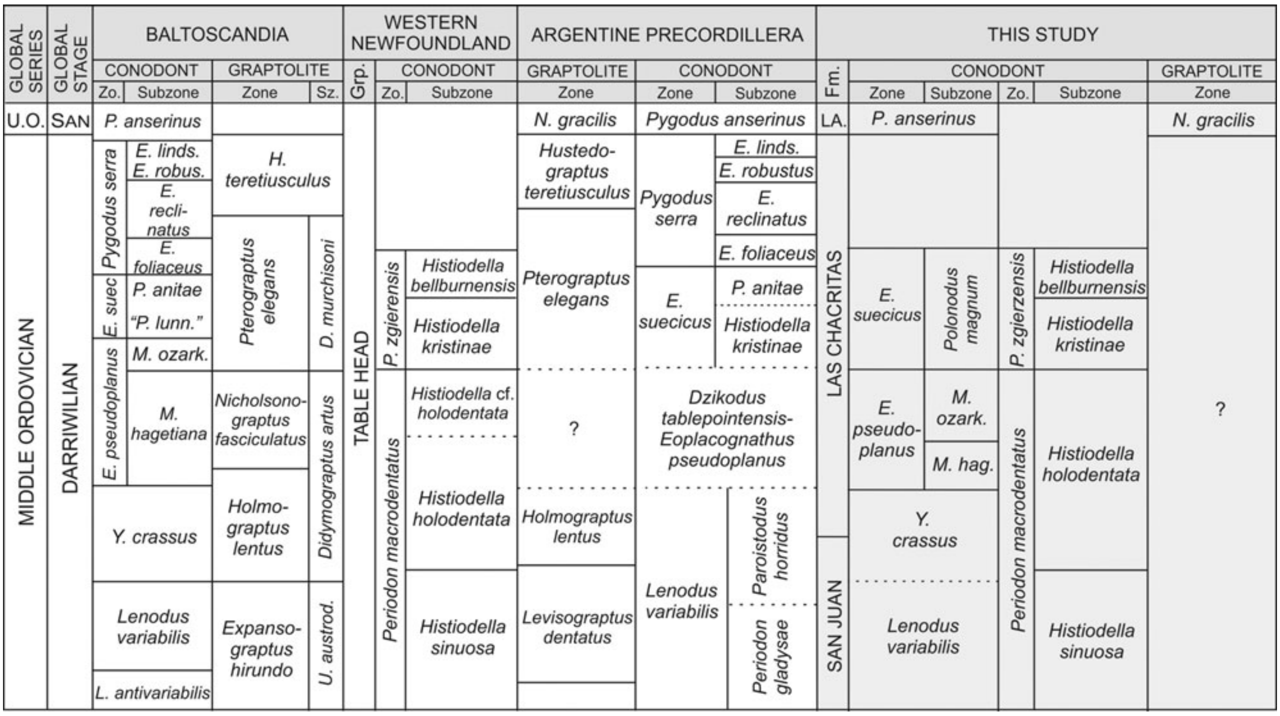

Figure 11. Stratigraphic chart of the Middle Ordovician section showing correlations between the main graptolite and conodont zonal schemes. After Zhang (1998*c*), Löfgren & Zhang (2003) and Stouge (1984, 2012) for reference zonations, Albanesi & Ortega (2002), Heredia *et al*. (2005) and present work for the Argentine Precordillera. Abbreviations: LA – Las Aguaditas; UO – Upper Ordovician; SAN – Sandbian; Zo. – Zone; Sz. – Subzone; Grp – Group; Fm. – Formation.

Britain, Southern Australia and New Zealand. Moreover, the presence of a hiatus between the Las Chacritas and the Las Aguaditas formations, spanning the upper Darriwilian interval (involving the *P. serra* conodont Zone and the *P. elegans* and *H. teretiusculus* graptolite zones), is indicated by the records of *E. suecicus* at the top part of the Las Chacritas Formation and of *P. anserinus* and *N. gracilis* at the base of the Las Aguaditas Formation.

Environmental depositional settings are interpreted based on analysis of the lithology and relative abundance logs of conodont genera for each zone. *Periodon*, *Paroistodus* and *Protopanderodus* are the major components of the faunas from the San Juan and Las Chacritas formations, whereas *Periodon* and *Paroistodus* maintain an antithetical relationship throughout most of the unit. The main taxa indicate deep-water settings for all of the zones. The lithofacies in the top part of the San Juan Formation is of nodular limestones, whereas ribbon limestone interbedded with black shales are characteristic of the basal part of the Las Chacritas Formation, suggesting a change in environmental conditions to deeper-water facies. Black-shale deposits are absent in the middle and upper portions of this formation, which represent a slightly less deep environment. We document graptolite taxa for the first time from the shallow, outer ramp deposits of the Las Chacritas Formation. Conodont elements from the Las Aguaditas Formation are less frequent with *Periodon aculeatus* as the most abundant species, while graptolites tend to be abundant in the whole unit with *Dicellograptus*, *Leptograptus* and *Nemagraptus* as the dominant genera. Carbonate siltstones with a high percentage of organic matter, graptolitic facies and the presence of *Periodon* in high abundance suggest a further deepening of the basin after the hiatus that separates the upper part from the underlying sequence.

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Supplementary material

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