

RESEARCH ARTICLE

Lower middle Darriwilian (Ordovician) graptolites and index conodonts from the Central Precordillera of San Juan Province, Argentina

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This study includes 3 localities from the Jáchal area in the Central Precordillera of San Juan Province, from north to south: the Oculita creek, Las Aguaditas creek, and Cerro La Chilca sections. We deal with the graptolite faunas and conodont index species recorded from units that overlie the carbonate San Juan Formation, spanning the lower part of the Los Azules, Las Aguaditas, and Gualcamayo formations in their respective areas. The index graptolites and associated species are reported, which enable the recognition of the *Levisograptus dentatus* Zone in the Central Precordillera. The presence of graptolites in the limestones from the top of the San Juan Formation at the Cerro La Chilca section is documented for the first time. The record of representatives of the *Lenodus variabilis*, *Yangtzeplacognathus crassus*, *Eoplacognathus pseudoplanus*, *Histiodella*, and *Periodon* lineages recognized in these units, linked with respective graptolite zones, provide precise information for global correlation purposes. The use of conodont and graptolite zones from different areas of the Central Precordillera enables the verification of the diachronous contact between the San Juan Formation and overlying units, which spans the lower to middle Darriwilian, in our investigated sections and classical localities previously documented.

KEYWORDS

Argentina, biostratigraphy, Central Precordillera, conodont, Darriwilian, graptolite

1 | INTRODUCTION

The geological province of the Precordillera is located in western Argentina and covers the La Rioja, San Juan and Mendoza provinces (Figure 1). It includes extensive Paleozoic outcrops that have been studied in many years. Conspicuous carbonate successions of shelf environments developed during the Cambrian until the middle Ordovician. The topmost unit of the carbonate platform is represented by the San Juan Formation, which is followed by a diachronous succession that is transitional to deep-ramp settings. This transitional succession consists of nodular marlstones, parted limestones interbedded with black shales through the lower middle Ordovician (Astini, 2003; Baldi, Beresi, Borbonaro, & Vaca, 1982; Furque & Cuerda, 1979; Kayser, 1876; Keller, 1999; Stelzner, 1873). The relative dating of these stratigraphic units indicate that the carbonate demise occurred diachronously from north to south in the Precordillera, commencing in the earliest Dapingian until the middle Darriwilian in the discussed sections (Albanesi, Hünicken, & Barnes, 1998; Hünicken, 1985). The drowning began in the northern part of the basin (Guandacol and Gualcamayo rivers) where assemblages of the

Isograptus victoriae maximus graptolite Zone and the *Baltoniodus triangularis*–*Tripodus laevis* conodont assemblage Zone confirm an Early Dapingian age (Albanesi & Ortega, 2016; Albanesi, Ortega, Barnes, & Hünicken, 1999; Ortega & Albanesi, 1999). In the Cerro Potrerillo and Yanso sections, ca. 40 km to the south, the facies transition occurs in the *Periodon gladysae* Subzone of the *Lenodus variabilis* conodont Zone and in the *Levisograptus austrodentatus* graptolite Zone (Albanesi, 1998; Albanesi et al., 1998; Ortega & Albanesi, 2000). In the central areas (Cerro Viejo, Cerro La Chilca, Las Aguaditas Creek, Las Chacritas River, and Villicum Range) the transgressive event begins in the *Yangtzeplacognathus crassus* conodont Zone and in the *Levisograptus dentatus* graptolite Zone (Carrera, Fenoglio, Albanesi, & Voldman, 2013; Feltes, Serra, Albanesi, & Voldman, 2014; Mestre, 2013; Ortega, Albanesi, & Frigerio, 2007; Serra, Albanesi, Ortega, & Bergström, 2015).

The study localities from the Central Precordillera of San Juan Province, from north east to the south west of Jáchal City, involve the Oculita Creek, Las Aguaditas Creek, and Cerro La Chilca sections (Figure 1). In the Jáchal area, the Ordovician System is extensively represented and has been the subject of many paleontological and

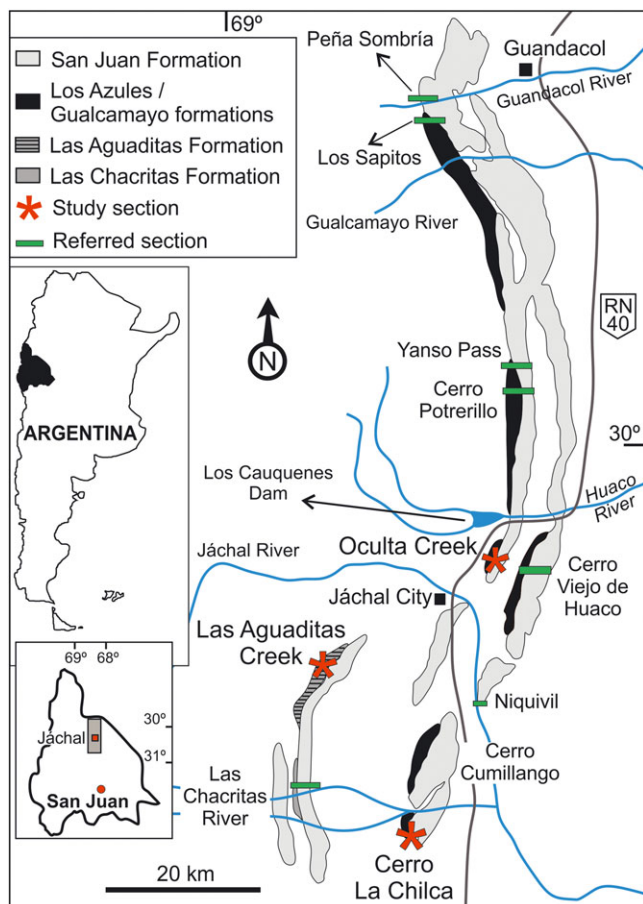


FIGURE 1 Location map of the study areas, from north to south of the Central Precordillera: Oculta Creek, Las Aguaditas Creek and Cerro La Chilca sections. Reference areas from the Precordillera of San Juan Province are also shown in the figure [Colour figure can be viewed at wileyonlinelibrary.com]

geological monographs. The Las Aguaditas Formation is one of the scarce remnants of carbonate deposits laid down after the Cambro-Ordovician carbonate cycle in the entire Precordillera (Astini, 1995). The Gualcamayo and Los Azules formations overlie the limestones of the San Juan Formation, with the hardground surface at the contact, which is interpreted as a paraconformity (Astini, 1995). An alternation of black shales and carbonate strata characterize the basal part of the Gualcamayo and Las Aguaditas formations but they are not present in the Los Azules Formation (Astini, 1993; Ortega et al., 2007). In the Cerro La Chilca, the Gualcamayo Formation is composed of an alternation of black, tabular marly limestone, dark-coloured black shale and K-bentonites that bear abundant shelly faunas and graptolites (Astini & Benedetto, 1992; Mestre, 2012; Ortega, Albanesi, & Zeballo, 2013; Tortello & Peralta, 2004). The lower member of the Los Azules Formation, at the Oculta Creek, consists of dark-brown argillites with yellowish alteration and conchoidal fracture. In these sections, abundant K-bentonite beds are recorded from the upper part of the San Juan Formation to the base of the Gualcamayo, Los Azules, and Las Aguaditas formations. These show explosive volcanism activity in a region close to the Precordillera terrane, providing the ash-fall deposits (Astini, 2003; Bergström et al., 1996; Brussa & Astini, 1998; Huff et al., 1997; Huff, Bergström, Kolata, Cingolani, & Astini, 1998). The diachronic drowning of the carbonate platform and the variable thickness of the black shales

across and along the platform suggest that facies changes are caused by local subsidence rather than eustacy (Astini, 2003).

The Ordovician black shales of the Precordillera are rich in graptolites, whereas the limestones yield abundant conodonts, trilobites, brachiopods, and poriferans, among other common fossils. Graptolites are present from the upper Tremadocian (Ortega et al., 2014) to the Hirnantian (Albanesi & Ortega, 2002; Albanesi & Ortega, 2016), and important Darrivilian assemblages have been identified in diverse localities characterizing the *Levisograptus austrodentatus*, *Levisograptus dentatus*, *Holmograptus lentus*, *Holmograptus spinosus*, *Pterograptus elegans*, and *Hustedograptus teretiusculus* zones (Albanesi & Ortega, 2002; Albanesi & Ortega, 2016; Brussa, Mitchell, Ortega, Maletz, & Astini, 2003; Kaufmann & Ortega, 2016; Ortega & Rickards, 2003; Ortega, Albanesi, & Hünicken, 1995; Ortega et al., 2007). The *L. austrodentatus* Zone with the *Arienigraptus zhejiangensis* and *Levisograptus sinicus* subzones are present in the Los Sapitos and Potrerillos creeks, and in the Cerro Potrerillo from the northern sector of the Precordillera (Albanesi & Ortega, 2002, 2016; Ortega & Albanesi, 1999; Ortega & Albanesi, 2000). Previous studies have assigned some graptolite assemblages to the *Paraglossograptus tentaculatus* Zone (e.g., Brussa, 1996; Ortega et al., 1995), which currently correspond to the *L. austrodentatus*, *L. dentatus*, or *H. lentus* zones (e.g., Brussa et al., 2003; Mitchell, Brussa, & Astini, 1998; Ortega et al., 2007). The *L. dentatus* Zone was identified for the first time in the lower member of the Los Azules Formation at the Cerro Viejo section (Mitchell et al., 1998). Two different graptolite associations were recorded for the *L. dentatus* Zone: a lower assemblage that includes *Tetragraptus acanthonotus* Gurley, *Pseudobryograptus parallelus* Mu, and *Zygograptus* cf. *Z. abnormis* (Hall) as distinctive elements (Gualcamayo River, Corridita Creek, Las Plantas Creek, and Cerro Potrerillo sections) and an upper assemblage characterized by *Arienigraptus angulatus* (Mu) and *Levisograptus primus* (Legg) in the Cerro Viejo section (Frigerio, 2004; Máspero Castro, Ortega, & Albanesi, 2003; Ortega et al., 2007; Ortega & Albanesi, 1999).

The present contribution deals with the graptolite faunas recorded from units that overlie the carbonate San Juan Formation (upper Tremadocian-lower Darrivilian), spanning the lower part of the Los Azules, Las Aguaditas, and Gualcamayo formations in their respective areas. Index graptolite and conodont species are reported and provided new information regarding the *Levisograptus dentatus* Zone and the *Periodon macrodentatus* and *Yangtzeplacognathus crassus* zones of the Central Precordillera.

2 | MATERIALS AND METHODS

A detailed search for graptolites was carried out in Darrivilian sequences from three study areas of the Precordillera: Oculta Creek, Las Aguaditas Creek, and Cerro La Chilca. At the same time, conodont samples were obtained (ca. 2 kg each), which were processed in a 10% acetic acid solution following Stone (1987). Graptolites were recorded from 24 samples; the material is abundant and well preserved in most cases enabling a taxonomic diagnosis for biostratigraphical purposes. Conodont index species herein identified allow for adjusting the graptolite biostratigraphy. The studied specimens are housed under the

repository code CORD-MP for conodonts and CORD-PZ for graptolites in the Museo de Paleontología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Argentina.

3 | STUDY AREAS

3.1 | Oculita Creek

The Oculita Creek section was recently described by Voldman, Ortega, and Albanesi (2013); it is located on the western flank of the Los Cauquenes Range, west of the Cerro Viejo de Huaco thrust (Figure 1). At this locality, the Ordovician is well exposed; the San Juan Formation is roofed by a hardground surface at the contact with the Los Azules Formation (226 m in thickness), which is in turn unconformably overlain by Holocene alluvial fan deposits. In the type area of Cerro Viejo de Huaco, Ortega (1987) recognized three members in the Los Azules Formation, from the lower Darriwilian to the upper Sandbian. The lower member of the Los Azules Formation is characterized by dark-brown argillites with yellowish alteration and conchoidal fracture interbedded with K-bentonites. The stratigraphic contact between the lower and middle member is partially covered. The latter member consists of black-grey shales, and the upper member of carbonate siltstones of dark colour and yellow alterations, with scarce mudstone strata intercalated (Voldman et al., 2013).

These authors documented the *L. dentatus* Zone for the lower member of the Los Azules Formation (lower middle Darriwilian *sensu* Bergström, Chen, Gutiérrez-Marco, & Dronov, 2009), the *Pterograptus elegans* and *Hustedograptus teretiusculus* zones for the middle member (upper Darriwilian) and the *Climacograptus bicornis* Zone (upper Sandbian) for the upper member of the formation.

The study interval is represented by the lower member of the Los Azules Formation that crops out in this area, where a total of 11 graptolite samples were taken. A diverse graptolite association composed of *Acrograptus* sp., *Holmograptus bovis* Williams and Stevens, *Xiphograptus lofuensis* Lee, *Pseudobryograptus parallelus* Mu, *Pseudotrigraptus ensiformis* (Hall), *Tetragraptus reclinatus* Elles and Wood, *T. serra* (Brongniart), *T. quadribrachiatus* (Hall), *T. bigsbyi* (Hall), *T. acanthonotus*, *Arienigraptus zhejiangensis* Yu and Fang, *A. cf. A. geniculatus* (Skevington), *Isograptus divergens* Harris, *Parisograptus caduceus* (Salter), *Glossograptus* sp., *Paraglossograptus tentaculatus* (Hall), *Levisograptus sinicus* (Mu and Lee), *L. cf. L. austrodentatus* (Harris and Keble), *L. dentatus* (Brongniart), and *L. cf. L. dentatus* was recorded from this unit (Figure 2). The graptolite composition is similar throughout the sampled interval, with colonies that tend to cover the bedding plane surfaces, although they are better preserved in the upper part of the lower member.

The most abundant species belong to *Tetragraptus*, *Arienigraptus*, and *Levisograptus*. The absence of *Arienigraptus angulatus* Mu, and the abundant stipes belonging to *T. acanthonotus* and some colonies of *Pseudobryograptus parallelus* allow for recognizing the lower *L. dentatus* Subzone in the lower member of the Los Azules Formation.

Typical conodonts of the *Yangtzeplacognathus crassus* Zone, as defined in South China (Zhang, 1998) and Scandinavian sections (Löfgren & Zhang, 2003), and the *Periodon macrodentatus* Zone-H.

holodentata Subzone, following the biozonal scheme for Tarim (Du et al., 2005; Stouge, Du, & Zhao, 2011) and Newfoundland (Stouge, 2012), were recorded at the top of the San Juan Formation, immediately underlying the Los Azules Formation (Voldman et al., 2013). Accordingly, we suggest that the *L. dentatus* Zone begins in the San Juan Formation and continues through the base of the Los Azules Formation. In this study, few conodonts were recorded from the latter unit; some ramiform elements of *P. macrodentatus* (Graves and Ellison) and one Pa element of *H. holodentata* Ethington and Clark were found on bedding plane surfaces from the upper strata of the lower member of the Los Azules Formation in association with the rich graptolite fauna mentioned above.

3.2 | Las Aguaditas Creek

The Las Aguaditas Formation crops out in the eastern flank of the Los Blanquitos Range, in the Central Precordillera of San Juan Province, and extends to the west of the La Trampa Range (Figure 1). The type section is located at the Las Aguaditas Creek, 10 km to the southwest of Jáchal City, as defined by Baldis et al. (1982). At this locality, the Las Aguaditas Formation is ca. 280 m thick and overlies paraconformably the San Juan Formation, with the contact marked by a regional hardground surface (Astini, 1995). The La Chilca Formation, latest Ordovician–early Silurian in age (Baldis & Blasco, 1974), unconformably overlies the upper member of the Las Aguaditas Formation. Baldis and Blasco (1974) described four members in the Las Aguaditas Formation; namely, a 54-m-thick lower member, a 110-m-thick platy member, a 40-m-thick middle member, and an 80-m-thick upper member. Later, Astini (1995) distinguished three transgressive and regressive cycles and described two types of facies associations that replace each other through the formation, a distal ramp to slope–basin facies transition, and an upper to middle slope facies. The top part of the San Juan Formation represents a distal ramp environment with minor storm influence. The basal part of the lower member of the Las Aguaditas Formation comprises carbonate-pelitic deposits, reflecting the change of depositional regime interpreted as caused by a flooding event over the platform (Astini, 1995; Carrera & Astini, 1998; Keller, Eberlein, & Lehnert, 1993).

There are many studies on fossils from the Las Aguaditas Formation such as, bryozoans, brachiopods, nautiloids (Carrera, 1997; Carrera & Ernst, 2010), trilobites (Waisfeld, Vaccari, Edgecombe, & Chatterton, 2011), and ostracods (Salas, 2007). The first graptolites recorded from this unit were *Dicellograptus divaricatus salopiensis* Elles and Wood in association with *Dicranograptus nicholsoni* Hopkinson (Blasco & Ramos, 1976). Later, *Hustedograptus teretiusculus* (Hisinger) and *Nemagraptus gracilis* (Hall) were reported (Baldis & Beresi, 1981) from unspecified stratigraphic levels. The first graptolite fauna documented from the lower member (Baldis, Shergold, & Peralta, 1994) consists of *P. tentaculatus*, “*Oelandograptus*” *austrodentatus americanus* (Bulman), *Eoglyptograptus cf. E. dentatus* (Brongniart), *Azygograptus* sp., *Pseudotrigraptus* sp., and *Ptilograptus* sp. Brussa (1996, 1997) provided new information for the Las Aguaditas Formation, identifying the upper part of the *Paraglossograptus tentaculatus* Zone for the lower member, and the

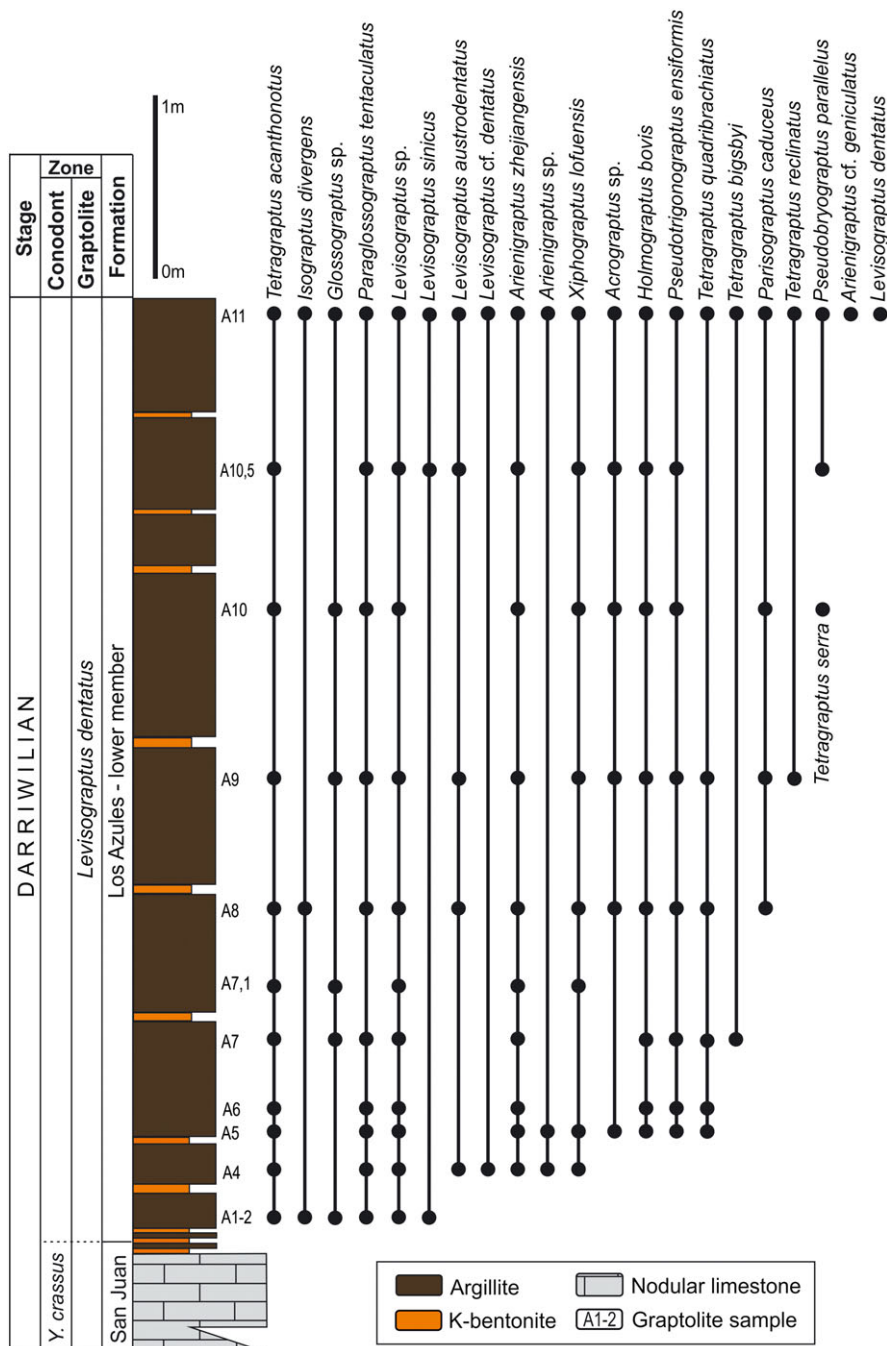


FIGURE 2 Stratigraphic column showing graptolite species ranges of the lower member of the Los Azules Formation in the Oculta Creek section [Colour figure can be viewed at wileyonlinelibrary.com]

Nemagraptus gracilis Zone for the rest of the unit. Several studies on conodonts were carried out in the section (Albanesi et al., 2013; Eberlein, 1990; Keller et al., 1993; Lehnert, 1995). Albanesi and Ortega (2002) proposed a lower middle Darriwilian age for the top of the San Juan Formation at the Las Aguaditas Creek section based on the identification of the *Lenodus variabilis* Zone. Recently, this record was updated to the *Yangtzeplacognathus crassus* Zone in the contact interval between the San Juan and the Las Aguaditas formations (Albanesi & Ortega, 2016; Feltes, Albanesi, & Bergström, 2016; Feltes et al., 2013).

In this study, graptolites were recorded from the basal 10 m of the lower member of the Las Aguaditas Formation (ca. 43 m; Figure 3). In the lower part of the formation, incomplete preserved tubaria

belonging to *Levisograptus* sp. and *Xiphograptus?* sp., together with fragmented stipes of *Acrograptus* sp. and *Holmograptus* sp. were found in a K-bentonite bed. A few meters above these levels, at 6 and 8 m from the base of the formation, the diversity in the record increases with a graptolite association that includes *Acrograptus* sp., *H. bovis*, *Holmograptus* sp., *Jiangshanites?* sp., *Xiphograptus* sp., *Tetragraptus bigsbyi* (Hall), *T. cf. serra*, *T. quadribrachiatius*, *Pseudophyllograptus* sp., *Cryptograptus antennarius* (Hall), *P. tentaculatus*, *Parisograptus caduceus*, *Arienigraptus zhejiangensis*, *Arienigraptus* sp., and *Levisograptus* sp. (Figure 3). The genera *Paraglossograptus* and *Tetragraptus* dominate the graptolite fauna in all samples from the lower member of the Las Aguaditas Formation.

Although the guide species *Levisograptus dentatus* cannot be recognized, some taxa such as *A. zhejiangensis* suggest that this assemblage precedes the *H. lentus* Zone. Also, conodonts from the *Periodon macrodentatus* Zone—*H. sinuosa* Subzone and from the *Lenodus variabilis* Zone (San Juan Formation) and from the *P. macrodentatus* Zone—*H. holodentata* Subzone and *Yangtzeplacognathus crassus* Zone (contact between the San Juan and Las Aguaditas formations and lower part of the latter unit), including the eponymous species were recorded. Species of the *Histiodela* lineage are well documented, with abundant specimens recovered (400 Pa elements). Therefore, it is now evident that the base of the Las Aguaditas Formation, previously referred to the *P. tentaculatus* Zone, and probably the top of the San Juan Formation, correspond to the *L. dentatus* Zone (lower middle Darriwilian) following the scheme by Maletz (1997) for Lévis, Quebec (see also Maletz, 2011).

Although Brussa (1996) identified a few taxa ("*Undulograptus austrodentatus*", *Isograptus* sp., and *P. ensiformis*) in the upper part of the lower member of the Las Aguaditas Formation, we have not recovered graptolites at these levels. Recently, Feltes et al. (2016) studied conodonts from this interval and determined the *Periodon zgierzensis* Zone (*sensu* Stouge, 2012) and the *Eoplacognathus pseudoplanus* Zone (*sensu* Löfgren & Zhang, 2003), with the first appearance datum of the significant taxon *Histiodela kristinae*. This suggests the presence of the *H. lentus* Zone or a younger graptolite biozone (e.g., *Holmograptus spinosus* Zone).

3.3 | Cerro La Chilca

The Cerro La Chilca section is located 18 km west of Tucunuco in the San Juan Province (Figure 1). The Ordovician succession exposed in this area consists of the San Juan (Tremadocian-Lower Darriwilian), Gualcamayo (Darriwilian), Los Azules (lower Sandbian), and Don Braulio (Hirnantian) formations (Peralta, 2003). The succession of shales and siltstones overlying the San Juan Formation was referred to the Gualcamayo Formation and interpreted as a transgressive event by Astini and Benedetto (1992). In its type area of Guandacol and Gualcamayo rivers, the Gualcamayo Formation was divided into three members (Astini, 1994b), which span the lower Dapingian to the upper Darriwilian.

Above this unit, black shales with thin mudstones strata, bearing the *Nemagraptus gracilis* fauna, were referred to the Los Azules Formation by Cuerda and Furque (1985). In subsequent contributions, Peralta (1998) and Tortello and Peralta (2004) interpreted the Gualcamayo Formation as a 4.5-m succession characterized by an alternation of black, tabular marly limestones and dark laminated shales. Strata of K-bentonites, usually a few centimetres thick, are present in the upper part of the San Juan Formation and in the Gualcamayo Formation (Ortega et al., 2013).

Mestre (2012) recognized the presence of *Eoplacognathus pseudoplanus* (Viira), *Histiodela kristinae* Stouge, and *Microzarkodina* sp. cf. *M. ozarkodella* Lindström, suggesting the presence of the upper part of the *E. pseudoplanus* Zone in the upper 4 m of the San Juan Formation and the overlying Gualcamayo Formation. This was later revised by Ortega et al. (2013), who verified an older age and reported the upper subzone of the *Lenodus variabilis* Zone in the uppermost strata of the San Juan Formation. The overlying Gualcamayo Formation bears a rich graptolite fauna assigned to the *Levisograptus austrodentatus*-*L. dentatus* Zone (lower middle Darriwilian; Cuerda,

1986; Peralta, 2003). Many other paleontological studies have been carried out in this section; for example, regarding brachiopods (Astini & Benedetto, 1992), sponges, bryozoans (Carrera, 1997), trilobites (Tortello & Peralta, 2004), and machaeridians (Benedetto, 2010; Ortega, 2010; Ortega et al., 2013).

Abundant graptolites were recovered from the Gualcamayo Formation. Pendent tubaria belonging to *P. parallelus* is the principal component of the graptolite fauna in the lower part of the unit and decreases to the top, where *Levisograptus* becomes the dominant genus. The graptolite assemblage consists of *Acrograptus* sp., *H. bovis*, *Holmograptus* sp., *P. parallelus*, *X. lofuensis*, *Xiphograptus* sp., *Thamnograptus?* sp., *Jiangshanites?* sp., *Pseudophyllograptus* sp., *T. bigsbyi*, *T. quadribrachiatus*, *A. zhejiangensis*, *Arienigraptus* sp., *P. caduceus*, *P. tentaculatus*, *L. austrodentatus*, *L. dentatus*, *L. cf. dentatus*, *L. primus*, *L. sinicus*, and *Levisograptus* sp. (Figure 4).

Graptolites are documented for the first time in the uppermost part of the San Juan Formation, ca. 1 m below its contact with the Gualcamayo Formation. Some specimens that belong to *L. primus* were identified, as well as fragmented stipes of sinograptids (Figures 5 and 6). Some specimens are poorly preserved and could not be defined taxonomically.

An abundant conodont fauna was recovered from this section; among the index species, *Y. crassus* (Chen and Zhang), *P. macrodentatus* (Graves and Ellison), and *H. sinuosa* (Graves and Ellison) were documented for the top stratum of the San Juan Formation and *P. macrodentatus* and *H. holodentata* in the Gualcamayo Formation. The recorded conodont fauna allows the identification of the *Y. crassus* Zone and the *P. macrodentatus* Zone, *H. sinuosa* Subzone, for the San Juan Formation and the *P. macrodentatus* Zone, *H. holodentata* Subzone for the Gualcamayo Formation (Figure 7).

The graptolite *L. primus* appears in the upper subzone of the *L. austrodentatus* Zone and ranges up to the *L. dentatus* Zone (Maletz, 1997); although, based on the co-occurrence of *L. primus* with *Y. crassus*, the graptolite association herein documented can be referred to the base of the *L. dentatus* Zone. The *L. dentatus* Zone is identified in the Gualcamayo Formation at the Cerro La Chilca section as well. The graptolite assemblage documented in the Gualcamayo Formation at this section could be referred to the lower assemblage of the *L. dentatus* Zone (*L. dentatus* Subzone; Figure 4).

4 | DISCUSSION ON CLASSICAL LOCALITIES FROM CENTRAL PRECORDILLERA

4.1 | Cerro Potrerillo

The study area is located in the northern sector of the Potrerillo-Perico Range, 40 km to the northeast of Jáchal City; where an important Ordovician succession crops out (Figure 1). The Gualcamayo Formation, ca. 76 m thick, paraconformably overlies the San Juan Formation and is unconformably covered by the pelites and calcipelites of the Las Plantas Formation. The record of graptolites of the *Pterograptus elegans* Zone in the upper part of the Gualcamayo Formation and assemblages of the *Climacograptus bicornis* Zone in the Las Plantas Formation indicates that a hiatus spanning the upper Darriwilian to the lower Sandbian interval is present in this section (Ortega & Albanesi, 2000).

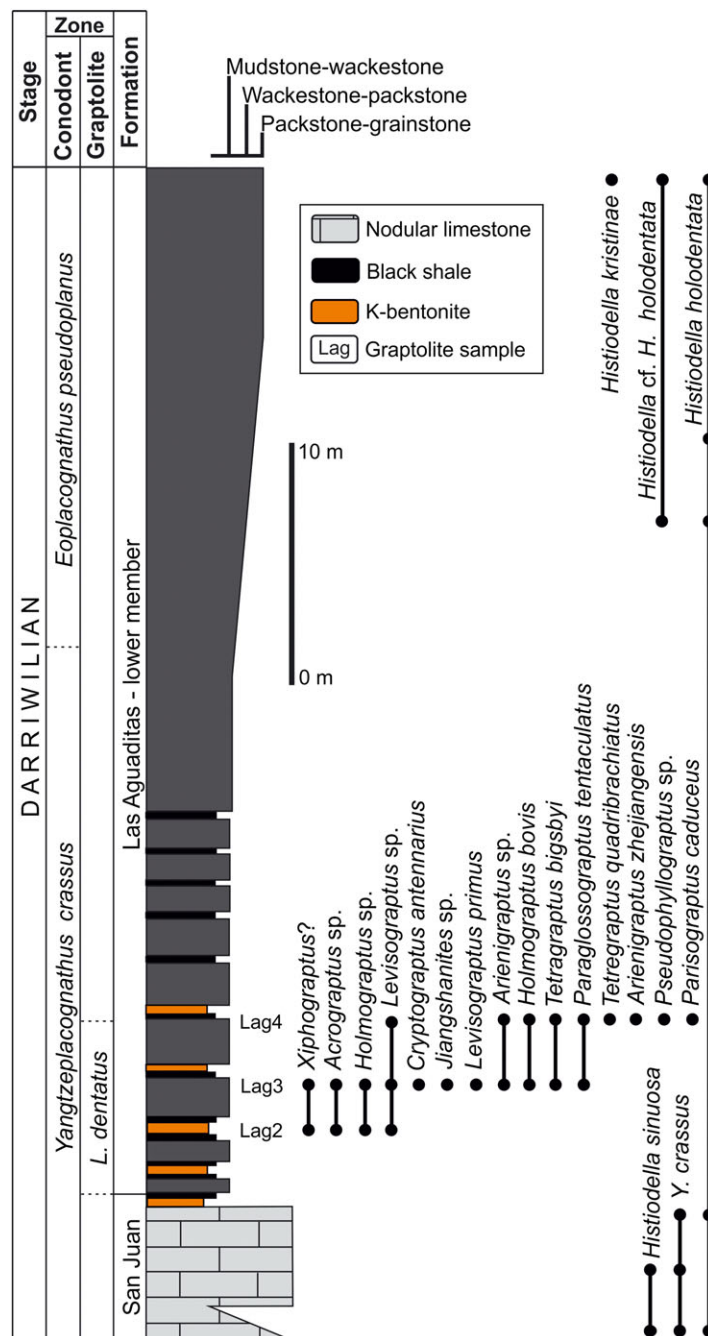


FIGURE 3 Stratigraphic column showing graptolite and key conodont species ranges of the lower member of the Las Aguaditas Formation in the Las Aguaditas Creek section [Colour figure can be viewed at wileyonlinelibrary.com]

The carbonate strata from the lower member of the Gualcamayo Formation, ca. 10 m thick, bear conodonts from the *Lenodus variabilis* Zone, *Periodon gladysae*, and *Parioistodus horridus* subzones (Albanesi et al., 1998), whereas the shelly sequence contains a graptolite association referred to the *L. austrodentatus* Zone (Ortega & Albanesi, 2000; Figure 8). This zone continues through the middle member of the Gualcamayo Formation, but the graptolite fauna increases in diversity and abundance with graptolites covering the stratigraphic plane surfaces. In the upper part of the unit, typical graptolites of the *Pterograptus elegans* Zone are documented (Ortega & Albanesi, 2000).

The graptolite association of the lower member consists of *P. tentaculatus*, *L. austrodentatus*, dichograptid stipes, and few tubaria of

Isograptus sp., with a rather poor preservation. The first 5 m of the middle member exhibits a richer graptolite fauna: *Acrograptus*? sp., *Etagraptus*? sp., *Zylograptus* sp., *P. parallelus*, *X. lofuensis*, *Tetragraptus serra*, *T. bigsbyi*, *T. headi* (Hall), *T. quadribrachiatus*, *P. ensiformis*, *C. antennarius*, *P. tentaculatus*, *P. tricornis* (Mu, Geh, and Yin), *I. divergens*, *P. caduceus*, *L. sinicus*, and *L. austrodentatus*.

Albanesi et al. (1998) described the conodont fauna from this interval and defined the *Lenodus variabilis* Zone. According to the co-occurrence of *L. variabilis* (Sergeeva) with *P. gladysae* Albanesi in the uppermost strata of the San Juan Formation and with *Parioistodus horridus* (Barnes and Poplawski) in the upper lower member of the Gualcamayo Formation, the *L. variabilis* and *Y. crassus* zones can be

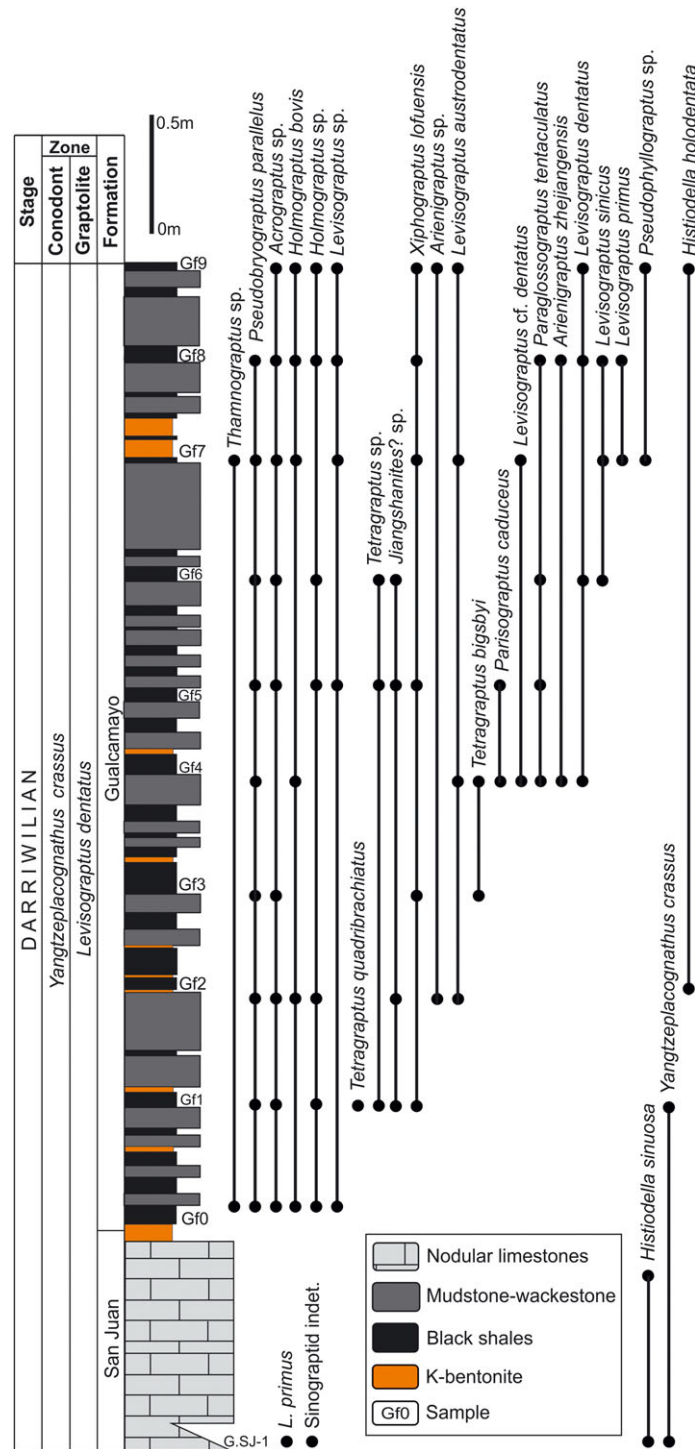


FIGURE 4 Stratigraphic column showing graptolite and key conodont species ranges of the base of the Gualcamayo Formation in the Cerro La Chilca section [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

identified, respectively (following Carrera et al., 2013). In the upper middle member of the Gualcamayo Formation, Ortega et al. (1995) and Albanesi et al. (1998) recognized the upper subzone of the *E. suecicus* Zone by the presence of *Pygodus anitae*.

4.2 | Cerro Viejo of Huaco

The Cerro Viejo is located west of Huaco Village, San Juan Province (Figure 1). On the western flank, the shaly succession of the Los Azules

Formation crops out (Furque, 1979), which paraconformably overlies the San Juan Formation through a hardground surface (Astini, 1994a). Graptolites are the most abundant fossils of the Los Azules Formation. The *Levisograptus dentatus* Zone, *Arienigraptus angulatus* Subzone, and *Holmograptus lentus* Zone were identified in the lower member (10.85 m thick) of the Los Azules Formation (Brussa et al., 2003; Ortega, 1995; Ortega et al., 2007; Ortega & Rickards, 2003), as well as the correlative *Lenodus variabilis* to the *Eoplacognathus suecicus* conodont zones (Ortega et al., 2007).



Considering the cited authors in the Cerro Viejo section, the graptolite assemblage of the *L. dentatus* Zone contains *Pseudobryograptus* sp., *Acrograptus* spp., *H. bovis*, *Holmograptus* sp., *Thamnograptus* sp., *Jiangshanites?* sp., *Loganograptus logani* (Hall), *X. lofuensis*, *P. ensiformis*, *T. serra*, *T. bigsbyi*, *T. quadribrachiatum*, *T. headi*, *Pseudophyllograptus* sp., *Brachiograptus etaformis* Harris and Keble, *I. divergens*, *P. caduceus*, *Glossograptus* sp., *P. tentaculatus*, *P. cf. tricornis*, *C. antennarius*, *A. zhejiangensis*, *A. angulatus*, *Arienigraptus* sp., *L. austrodentatus*, *L. dentatus*, *L. sinicus*, *L. primus*, *L. cf. dicellograptoides* Maletz, and *L. cf. cumbrensis* (Bulman). The co-occurrence of *A. angulatus* and *L. dentatus* allows the graptolite-bearing strata to be referred to the upper part of the *L. dentatus* Zone (Figure 8).

4.3 | Las Chacritas River

The Las Chacritas River section is located at La Trampa Range, 50 km southwest of Jáchal City (Figure 1). In this area, an important middle Ordovician section is exposed. Upper lower and lower middle Ordovician rocks of the San Juan Formation are paraconformably overlain by the Las Chacritas Formation of middle Darriwilian age. Peralta, Heredia, and 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 (Astini, 1994b; Carrera, 1997). The conodont fauna from the San Juan and Las Chacritas formations were studied by several authors (Albanesi et al., 2013; Albanesi & Astini, 1994, 2000; Heredia, Beresi, & Mestre, 2011; Heredia, Beresi, & Peralta, 2005; Mestre & Heredia, 2013; Serra, Albanesi, & Bergström, 2013). Recently, Serra et al. (2015) documented and described the biostratigraphy of this area based on the North American *P. macrodentatus*-*P. zgierzensis* zones and the Baltic *Y. crassus*, *E. pseudoplanus*, and *E. suecicus* zones, which are well represented along the unit.

In the Las Chacritas River section, elements of *L. variabilis* and *P. horridus* were recovered from the upper part of the San Juan Formation, and scarce graptolite remains were identified in the overlying

carbonate beds of Las Chacritas Formation (Serra et al., 2015). Incomplete stipes and siculae were recorded in the K-bentonite layers from the base of the latter formation. Mature colonies of *Tetragraptus* sp. and fragmented stipes probably belonging to *Acrograptus?* sp. together with *Y. crassus* are present in the lower and middle parts of the unit. In the middle and upper part of this formation, fragmented tubaria of *Levisograptus?* sp. were identified together with *E. pseudoplanus*.

In this section, index graptolites were not found for correlation; however, a well-represented and continuous record of conodonts from the *Histiodella* lineage is documented (130 elements). Specimens of *H. sinuosa* are recorded together with *P. macrodentatus* in the upper 24 m of the San Juan Formation. Abundant specimens of *H. holodentata* are documented from the top strata of the San Juan Formation up to the level 53.5 m from the base of the Las Chacritas Formation. At this level, *H. kristinae* Stouge appears (ranging from 53.5 to 56 m); in turn, the first appearance datum of *H. bellburnensis* Stouge occurs at the top strata of the latter unit.

According to the tie between *Histiodella* species and the graptolite zones provided by Maletz (2009) and Stouge (2012), a chronostratigraphic interval equivalent to the transition of the *L. austrodentatus*-*L. dentatus* zones is suggested for the top of the San Juan Formation and through the *L. dentatus*, *H. lentus*, *H. spinosus*, and *N. fasciculatus* zones for the complete Las Chacritas Formation (Figure 8).

5 | CORRELATION

The *L. austrodentatus* Zone was described in detail by Chen et al. (1995) and Mitchell and Maletz (1995), the first authors dividing this biozone into the *A. zhejiangensis* and *L. sinicus* subzones. The *L. austrodentatus* Zone was recognized in different sections of the central and northern Precordillera. Brussa, Mitchell, and Astini (1998) recorded the *A. zhejiangensis* and *U. sinicus* subzones in the Nazareno Creek, between Las Plantas and Potrerillos creeks, Brussa and Astini (1998) identified the *L. sinicus* assemblage in the lower part of the

FIGURE 5 Scale bar 1 mm. **A, J, T, W.** *Pseudobryograptus parallelus* mu: **A.** CORD-PZ 22202, 1 m above the base of the Gualcamayo Formation at Cerro La Chilca section; **J.** CORD-PZ 25779, 1.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section; **T.** CORD-PZ 22194, 0.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **W.** CORD-PZ 22179, 1 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **B, P.** *Levisograptus austrodentatus* (Harris and Keble); **B.** CORD-PZ 25728, top of the Gualcamayo Formation at the Cerro La Chilca section; **P.** CORD-PZ 25693, 3.2 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **C-D.** *Levisograptus primus* (Legg), 1 m below the top of the San Juan Formation at the Cerro La Chilca section; **C.** CORD-PZ 25727; **D.** CORD-PZ 25724. **E.** *Paraglossograptus tentaculatus* (Hall), CORD-PZ 34533, 7.5 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **F.** *Levisograptus dentatus* (Brongniart), CORD-PZ 25779, 1.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **G, R.** *Levisograptus cf. L. dentatus* (Brongniart): **G.** CORD-PZ 22350, 3.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section; **R.** CORD-PZ 22347, 3.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **H.** *Tetragraptus acanthonotus* (Gurley), CORD-PZ 36654, 3.2 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **I, M.** *Arienigraptus zhejiangensis* Yu and Fang: **I.** CORD-PZ 25502, 10 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section; **M.** CORD-PZ 25692, 3.2 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **K.** *Levisograptus sinicus* (Mu and Lee), CORD-PZ 25664, 0.5 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **L.** *Tetragraptus quadribrachiatum* (Hall), CORD-PZ 34526, 7.5 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **N.** *Parisograptus* sp. CORD-PZ 22316, 2.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **O.** *Isograptus divergens* Harris, 4 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **Q.** Sinograptid (gen. sp. indet.), CORD-PZ 25726, 1 m below the top of the San Juan Formation at the Cerro La Chilca section. **S.** *Holmograptus bovis* Williams and Stevens, CORD-PZ 25503, 10 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **U.** *Tetragraptus bigsbyi* (Hall), CORD-PZ 34533, 7.5 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **V.** *Xiphograptus lofuensis* Lee, CORD-PZ 25739, top of the lower member of the Los Azules Formation at the Oculita Creek section [Colour figure can be viewed at wileyonlinelibrary.com]

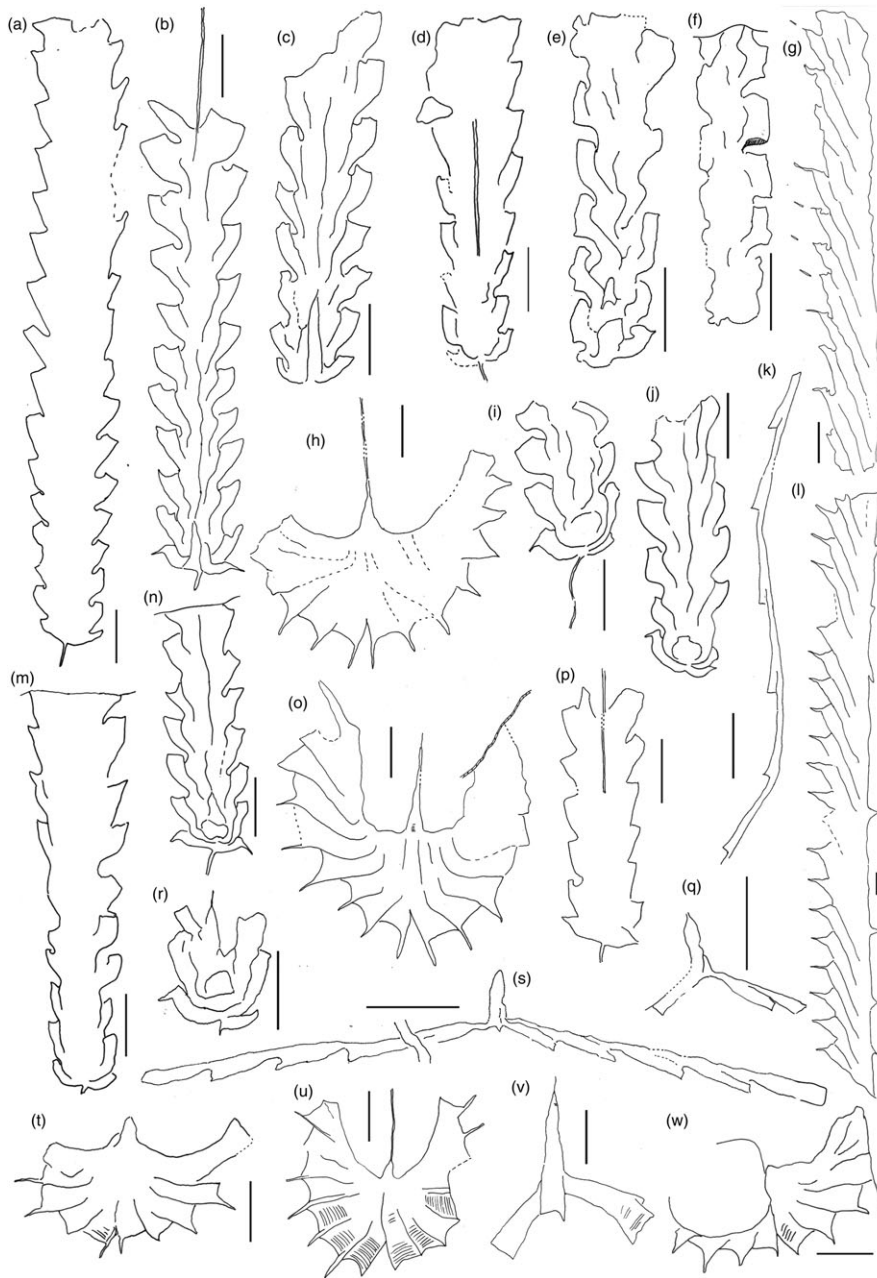


FIGURE 6 Important graptolite species from the study areas. **A, C–D.** *Levisograptus dentatus* (Brongniart): **A.** CORD-PZ 22354, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section; **C.** CORD-PZ 22443, 3 m above the base of the Gualcamayo Formation at the Cerro La Chilca section; **D.** CORD-PZ 36657, base of the lower member of the Los Azules Formation at the Oculita Creek section. **B, P.** *Levisograptus austrodentatus* (Harris and Keble): **B.** CORD-PZ 25728, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section; **P.** CORD-PZ 22216, 2 m above the base of the Gualcamayo Formation at the Cerro La Chilca section. **E–F.** *Levisograptus primus* (Legg), 1 m below the top of the San Juan Formation at the Cerro La Chilca section: **E.** CORD-PZ 25724; **F.** CORD-PZ 25725. **G.** Sinograptid (gen. et sp. indet.), CORD-PZ 25726, 1 m below the top of the San Juan Formation at the Cerro La Chilca section. **H.** *Arienigraptus* cf. *A. zhejiangensis* Yu and Fang, CORD-PZ 25729, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section. **I–J, N, R.** *Levisograptus* sp.: **I.** CORD-PZ 22415, 3.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section; **J.** CORD-PZ 25730, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section; **N.** CORD-PZ 22410, 3 m above the base of the Gualcamayo Formation at the Cerro La Chilca section; **R.** CORD-PZ 25732, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section. **K.** *Acrograptus* sp. CORD-PZ 25731, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section. **L.** *Tetragraptus acanthonotus* (Gurley), CORD-PZ 25737, 4.5 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **M.** *Levisograptus* cf. *L. dentatus* (Brongniart), CORD-PZ 36664, base of the lower member of the Los Azules Formation at the Oculita Creek section. **O.** *Arienigraptus zhejiangensis* Yu and Fang, CORD-PZ 25738, top of the lower member of the Los Azules Formation at the Oculita Creek section. **Q.** *Acrograptus*? sp. CORD-PZ 36523, 4.5 m above the base of the lower member of the Los Azules Formation at the Oculita Creek section. **S.** *Holmograptus bovis* Williams and Stevens, CORD-PZ 25733, uppermost strata of the Gualcamayo Formation at the Cerro La Chilca section. **T, W.** *Arienigraptus* sp. CORD-PZ 36506, top of the lower member of the Los Azules Formation at the Oculita Creek section. **U.** *Parisograptus caduceus* (Salter), CORD-PZ 36502, top of the lower member of the Los Azules Formation at the Oculita Creek section. **V.** *Pseudobryograptus parallelus* Mu, CORD-PZ 22185, 0.5 m above the base of the Gualcamayo Formation at the Cerro La Chilca section

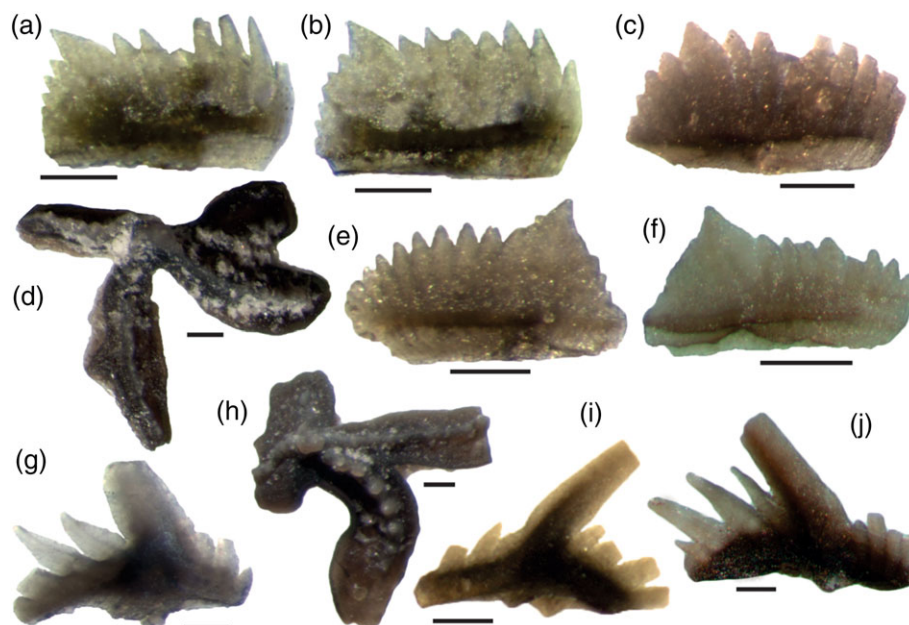


FIGURE 7 Scale bar 0.1 mm. **A.** *Histiodella kristinae* Stouge, CORD-MP 35194, recovered at 43 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **B.** *Histiodella* cf. *H. holodentata* CORD-MP 35190, recovered at 43 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section. **C.** *Histiodella holodentata* Ethington and Clark; **C.** CORD-MP 35150, recovered at 43 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section; **E.** CORD-MP 35078, recovered at 11.3 m below the top of the San Juan Formation at the Las Aguaditas Creek section. **D.** *Yangtzeplacognathus crassus* (Chen et Zhang), recovered at 1 m below the top of the San Juan Formation at the Cerro La Chilca section, **D.** CORD-MP 44002, Pa element; **H.** CORD-MP 44003 Pb element. **F.** *Histiodella sinuosa* (Graves and Ellison), CORD-MP 44001, recovered at 1 m below the top of the San Juan Formation at the Cerro La Chilca section. **G.** *Periodon macrodentatus* (Graves and Ellison); **G.** CORD-MP 36741, recovered at 0.7 m below the top of the San Juan Formation at the Las Aguaditas Creek section; **I.** CORD-MP 18518, recovered from the top stratum of the San Juan Formation at Las Chacritas River section. **J.** *Periodon zgierzensis* Dzik, CORD-MP 38934, recovered at 43 m above the base of the Las Aguaditas Formation at the Las Aguaditas Creek section [Colour figure can be viewed at wileyonlinelibrary.com]

Gualcamayo Formation exposed at Gualcamayo River section. The occurrence of *L. sinicus* with conodonts of the *L. variabilis* Zone (*P. gladysae* and *Paroistodus horridus* subzones) in the lower member of the Gualcamayo Formation at Cerro Potrerillo suggests the presence of the *L. sinicus* Subzone and the records of *H. sinuosa* in the same strata confirms an early Darriwilian age for these levels (Albanesi et al., 1998). The lower *A. zhejiangensis* Subzone and upper *L. sinicus* Subzone are present in the lower and middle member of the Gualcamayo Formation at the Los Sapitos Creek, Guandacol River (Ortega & Albanesi, 1999). These graptolite assemblages enable the recognition of an early Darriwilian age for the bearer strata. To the south, at the La Corridita Creek, Gualcamayo River area, Brussa and Astini (2001) assigned graptolites collected from the lower part of the Gualcamayo Formation to the *A. zhejiangensis* Subzone. Caballé, Alfaro, and Uriz (2005) described a graptolite fauna of the *L. sinicus* subzone from a section near the Los Celestitos Creek, Los Piojos River.

The *L. austrodentatus* Zone from northern Precordillera can be correlated with the *L. austrodentatus* Zone (Da1) of Australasia, and equivalent strata from China, Baltoscandia, Britain, and Russia (e.g., Bulman, 1963; Chen et al., 1995; Erdtmann, Maslov, Maletz, & Paalits, 1998; Fortey & Owens, 1987; Maletz, 1997; Mitchell et al., 1997; Mitchell & Maletz, 1995; VandenBerg & Cooper, 1992).

The *L. dentatus* Zone was introduced by Maletz (1997) who recognized its lower and upper subzones in the Lévis area, Quebec. The lower subzone is marked by the entrance of *L. dentatus* and the upper

subzone by the appearance of *A. angulatus*, two key species that were used later to designate both subzones (Maletz, 2011).

A diverse fauna from the *L. dentatus* Zone, including the lower and upper associations, was reported in the Precordillera by Ortega et al. (2007). These authors identified a lower association represented in the northern sections (e.g., Corridita Creek, Gualcamayo River, Las Plantas Creek, and Cerro Potrerillo), which comprise some characteristic taxa, such as *T. acanthonotus*, *P. parallelus*, and *Z. cf. abnormis*. The upper association, recorded at the La Corridita Creek (Gualcamayo Formation) and the Cerro Viejo (Los Azules Formation), is distinguished by *A. angulatus* and *L. primus*. The *H. lentus* Zone is identified by the appearance of the nominal taxon in the La Corridita Creek (Máspero Castro et al., 2003) and by the entrance of *Archiclimacograptus* and a conspicuous change in the graptolite fauna from the lower member of the Los Azules Formation at Cerro Viejo (Ortega et al., 2007).

In the Cerro Potrerillo succession, the *L. dentatus* Subzone is recorded in the lowermost middle member of the Gualcamayo Formation, above graptolite records of the *L. sinicus* Subzone (*L. austrodentatus* Zone) and conodonts referable to the *H. sinuosa* Subzone.

In the Cerro Viejo section, the lower member of the Los Azules Formation contains a rich graptolite fauna corresponding to the upper *L. dentatus* Zone (*A. angulatus* Subzone) including the presence of both guide taxa. Conodonts of the *L. variabilis* Zone in the upper part of the

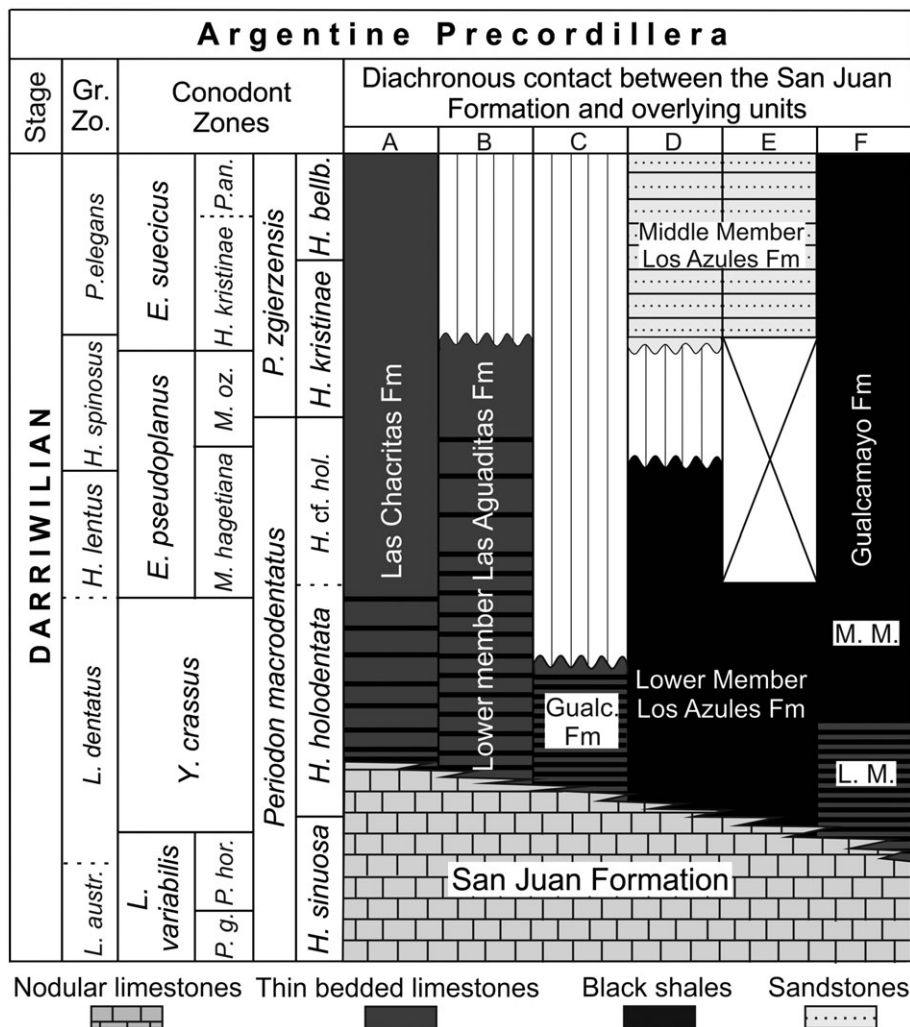


FIGURE 8 Darriwilian stratigraphic chart showing correlations between graptolite and conodont zones (adapted from Serra *et al.*, 2015; Feltes *et al.*, 2016; Albanesi & Ortega, 2016; and this study). A scheme for the interpretation of the diachronism in the Precordillera is included (right). Letters indicate the study sections: A. Las Chacritas River section; B. Las Aguaditas Creek section; C. Cerro La Chilca section; D. Cerro Viejo de Huaco section; E. Oculta Creek section; F. Cerro Potrerillo section. The diagonal lines represent covered strata. Abbreviations: Grapt. Zones: Graptolite Zones; *L. austr.*: *L. austrodentatus*; *P. g.*: *Periodon gladysae*; *P. hor.*: *Paroistodus horridus*; *M. oz.*: *Microzarkodina ozarkodella*; *P. an.*: *Pygodus anitae*; *H. cf. hol.*: *Histiodella cf. H. holodentata*; Gualc. Fm: Gualcamayo Formation; L. M.: Lower member; M. M.: Middle member

underlying San Juan Formation range throughout the lower part of the lower member of Los Azules Formation (Ortega *et al.*, 2007).

The *L. dentatus* Zone recognized in different areas of the Precordillera is comparable to the *L. dentatus* Zone as described at Lévis, Quebec, and Western Newfoundland, and the *D. hirundo* Zone from Scandinavia (Maletz, 1995; Maletz, 1997; Figure 9).

Histiodella species have great potential for global correlation; they are documented in middle Ordovician successions from New Zealand (e.g., Zhen, Percival, Cooper, Simes, & Wright, 2009), Western Newfoundland (e.g., Stouge, 2012), Argentine Precordillera (e.g., Feltes *et al.*, 2016; Mestre & Heredia, 2012; Serra *et al.*, 2015), North China (e.g., Jing, Zhou, & Wang, 2016), Tarim Basin (e.g., Du *et al.*, 2005; Stouge *et al.*, 2011; Zhen *et al.*, 2011), Yangtze Platform (e.g., Chen, Zhang, Bergström, & Xu, 2006), and Scandinavia (e.g., Löfgren & Zhang, 2003; Mellgren & Eriksson, 2010). Associated conodonts and graptolites occur at the same strata in the Lévis Formation, Quebec (Maletz, 2009; Stouge, 2012). The *H. sinuosa* Subzone correlates with the *L. austrodentatus* Zone, the *H. holodentata* Subzone is

equivalent to the *L. dentatus* and *H. lentus* zones, and the "*H. cf. holodentata*" Subzone to the *Holmograpus spinosus* Zone. The *H. kristinae* Subzone and lower part of *H. bellburnensis* Subzone of the *P. zgierzensis* Zone correspond to the *N. fasciculatus* Zone (Stouge, 2012), providing a high-resolution biozonal scheme for the correlation of a wide variety of environments.

Abundant specimens of the conodont genus *Histiodella* in the Precordillera provide a good tie with the Darriwilian graptolite zones as suggested by Maletz (2009). In the investigated sections, it is possible to correlate precisely the graptolite assemblages with the referred conodont zones. Several index species were documented from the top of the San Juan Formation, at the Cerro La Chilca section. Numerous specimens of *H. sinuosa* and *P. macrodentatus* were recovered allowing for the recognition of the *H. sinuosa* Subzone (*P. macrodentatus* Zone) as defined for Newfoundland (Stouge, 2012); whereas the record of *Y. crassus* enables a correlation with the Baltic scheme (Löfgren & Zhang, 2003). Furthermore, the presence of specimens of *L. primus* in the upper part of the San Juan Formation provide new information, and the co-occurrence with

GLOBAL SERIES	GLOBAL STAGE	BALTOSCANDIA				WESTERN NEWFOUNDLAND			ARGENTINE PRECORDILLERA										
		CONODONT		GRAPTOLITE		Grp.	CONODONT		Grp.	Fm	GRAPTOLITE		CONODONT						
		Zo.	Subzone	Zone	Sz.		Zo.	Subzone			Zone	Zone	Subzone	Zo.	Subzone				
						TABLE HEAD													
MIDDLE ORDOVICIAN	DARRIWILIAN	E. suec.	P. Anitae	Pterograptus elegans	D. murchisoni	P. zglierzensis	Histiodela bellburnensis	Nicholsonograptus fasciculatus	Overlying deep water units	Pterograptus elegans	E. suecicus	P. Anitae	P. zglierzensis	Histiodela bellburnensis					
			P. lunn.				Histiodela kristinae					H. kristinae		Histiodela kristinae					
		E. pseudoptermis	M. ozark.	Nicholsonograptus fasciculatus	D. murchisoni		Histiodela cf. holodentata	Holmograptus spinosus		Holmograptus spinosus	E. pseudoplanus	M. ozarkodella	M. hage-tiana	P. zglierzensis	Histiodela cf. holodentata				
			M. hagetiana				Holmograptus fasciculatus	Histiodela holodentata		Holmograptus lentus		Holmograptus lentus			Histiodela cf. holodentata				
		E. pseudoptermis	Y. crassus	Holmograptus lentus	Didymograptus artus		P. macrodentatus	Histiodela holodentata		Levisograptus dentatus	Y. crassus	Levisograptus dentatus	Levisograptus dentatus	Y. crassus	Histiodela holodentata				
	Lenodus variabilis					Expansograptus hirundo			U. austrodent.							Histiodela sinuosa	Levisograptus austrodentatus	P. horridus	Histiodela sinuosa

FIGURE 9 Biostratigraphic chart of the middle–upper Ordovician showing conodont and graptolite zones from Baltoscandia (modified from Löfgren & Zhang, 2003), Western Newfoundland (modified from Stouge, 2012; Maletz, 2009; Maletz, 2011), Argentine Precordillera (adapted from Serra et al., 2015; Feltes et al., 2016; Albanesi & Ortega, 2016) and the study area. Abbreviations: Zo.: Zone; Sz.: Subzone; Grp.: Group; E. suec.: *E. suecicus*; P. lunn.: *P. lunnensis*; L. austrodent.: *L. austrodentatus* [Colour figure can be viewed at wileyonlinelibrary.com]

H. sinuosa and *Y. crassus* suggests the base of the *L. dentatus* Zone for these strata. The calcipelitic succession of the Gualcamayo Formation at this study area contains a graptolite assemblage presumably referable to the lower part of the *L. dentatus* Zone, which is reinforced by the record of conodonts of the *H. holodentata* Subzone.

Graptolites of the lower member of the Las Aguaditas Formation, originally referred to the upper *P. tentaculatus* Zone (Brussa, 1996) indicate the *L. dentatus* Zone, which is supported by the presence of the index conodont *H. holodentata* in the same stratigraphic interval. The upper part of the lower member is characterized by scarce graptolites. In this part, late forms of *Histiodela holodentata* (with intermediate morphology between *H. holodentata* and *H. kristinae* as suggested by Stouge, 2001, 2012) and *Histiodela kristinae* were recorded, whose ranges correlate with the *Holmograptus spinosus* and *Nicholsonograptus fasciculatus* zones of the Newfoundland and Quebec schemes (Maletz, 2009).

The graptolite fauna studied in the Oculta Creek shares taxa, such as *T. acanthonotus* and *P. parallelus* with the *L. dentatus* Zone, as described by Ortega and Albanesi (2000) for the Cerro Potrerillo. This assemblage can be assigned to the lower part of the *L. dentatus* Zone, which develops above the carbonate strata of the top of the San Juan Formation. The latter formation, in its uppermost part, bears conodonts of the *H. holodentata* Subzone (*P. macrodentatus* Zone) and *Y. crassus* Zone (Voldman et al., 2013).

Similar records occur at the Las Chacritas River section, where the presence of *H. sinuosa* in the top levels of the San Juan Formation and of *H. holodentata*, *H. kristinae*, and *H. bellburnensis*, consecutively, throughout the Las Chacritas Formation allows the correlation of these units with the *L. austrodentatus*, *L. dentatus*, *H. lentus*, *Holmograptus spinosus*, and *Nicholsonograptus fasciculatus* zones from the mentioned schemes (Serra et al., 2015).

6 | CONCLUSIONS

A lower graptolite assemblage of the *Levisograptus dentatus* Zone is verified in the Las Aguaditas Formation (lower member) at the Los

Blanquitos Range, Los Azules Formation (lower member) at the Los Cauquenes Range, and Gualcamayo Formation (lower member) in the Cerro La Chilca, Central Precordillera. It is consistent with the occurrence of *L. dentatus* and the absence of *Arienigraptus angulatus* in our collections.

The presence of the *L. dentatus* Zone is also inferred for the lower part of the Las Chacritas Formation in correspondence with the record of typical conodonts from the *Yangtzeplacognathus crassus* Zone.

The record of graptolites (*Levisograptus primus* and sinograptid stipes) is documented for the first time from the uppermost San Juan Formation at Cerro La Chilca section, consistent with the presence of the conodont index species *Y. crassus* and *Histiodela sinuosa*, suggesting the lower part of the *L. dentatus* Zone.

Histiodela sinuosa and *H. holodentata* are documented in association with graptolites of the *L. dentatus* Zone in the Las Aguaditas Creek, Las Chacritas River, and Cerro La Chilca sections.

The use of conodont and graptolite zones enables the verification of the continuous diachronous contact between the San Juan Formation and overlying units, which spans the lower to middle Darrivilian, in the investigated sections of the central and northern regions of the Argentine Precordillera.

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REFERENCES

- Albanesi, G. L. (1998). Taxonomía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas de la Academia Nacional de Ciencias, Córdoba*, 12, 7–72.
- Albanesi, G. L., & Astini, R. A. (1994). Conodontofauna de los niveles cuspidales de la Formación San Juan (Llanvirniano) en el perfil de Las Chacritas, Provincia de San Juan. VI Congreso Argentino de Paleontología y Bioestratigrafía. *Resúmenes Paleoinvertebrados* 48–49.
- Albanesi, G. L., & Astini, R. A. (2000). Bioestratigrafía de conodontes de la Formación Las Chacritas, Precordillera de San Juan, Argentina. *Ameghiniana*, 37(4), 68–69R.
- Albanesi, G. L., Bergström, S. M., Schmitz, B., Serra, F., Feltes, N. A., Voldman, G. G., & Ortega, G. (2013). Darrivilian (middle Ordovician) $\delta^{13}\text{C}_{\text{carb}}$ chemostratigraphy in the Precordillera of Argentina: Documentation of the middle Darrivilian isotope carbon excursion (MDICE) and its use for intercontinental correlation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 389, 48–63.
- Albanesi, G. L., Hünicken, M., & Barnes, C. (1998). Bioestratigrafía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas de la Academia Nacional de Ciencias, Córdoba*, 12, 7–72.
- Albanesi, G. L., & Ortega, G. (2002). Advances on conodont-graptolite biostratigraphy of the Ordovician System of Argentina. In F. G. Aceñolaza (Ed.), *Aspects of the Ordovician System in Argentina: Instituto Superior de Correlación Geológica, Serie Correlación Geológica* (vol. 16) (pp. 143–165). San Miguel de Tucumán: Instituto Superior de Correlación Geológica (INSUGEO-CONICET).
- Albanesi, G. L., & Ortega, G. (2016). Conodont and Graptolite Biostratigraphy of the Ordovician System of Argentina. In M. Montenari (Ed.), *Stratigraphy & Timescales* (pp. 61–121) Elsevier (vol. 1).
- Albanesi, G. L., Ortega, G., Barnes, C. R., & Hünicken, M. A. (1999). Conodont-graptolite biostratigraphy of the Gualcamayo Formation (Middle Ordovician) in the Gualcamayo-Guandacol rivers area, Argentine Precordillera. In P. Kraft, & O. Fatka (Eds.), *Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System* (pp. 45–48). Prague, 43(1-2): Acta Universitatis Carolinae Geologica.
- Astini, R. A. (1993). Secuencias deposicionales y niveles del mar en el Sistema Ordovícico de la Precordillera Argentina. *Boletín de la Real Sociedad Española de Historia Natural*, 88(1–4), 113–126.
- Astini, R. A. (1994a). Geología e interpretación de la Formación Gualcamayo en su localidad clásica (suroeste de Guandacol y cordón de Perico-Potrerillo), Precordillera septentrional. *Revista de la Asociación Geológica Argentina*, 49(1–2), 55–70.
- Astini, R. A. (1994b). Significado estratigráfico del Miembro Superior de la Formación San Juan, cordón de Las Chacritas, Ordovícico medio de la Precordillera de San Juan. *Revista de la Asociación Geológica Argentina*, 49(3–4), 365–367.
- Astini, R. A. (1995). Sedimentología de la Formación Las Aguaditas (talud carbonático) y evolución de la cuenca precordillerana durante el Ordovícico medio. *Revista de la Asociación Geológica Argentina*, 50(1–4), 143–164.
- Astini, R. A. (2003). The Ordovician basins along the Proto Andean margin. In J. L. Benedetto (Ed.), *Ordovician Fossils of Argentina* (pp. 1–74). Córdoba: Secretaría de Ciencia y Tecnología de la Universidad Nacional de Córdoba.
- Astini, R. A., & Benedetto, J. L. (1992). El Ashgilliano tardío (Hirnantiano) del cerro La Chilca, Precordillera de San Juan, Argentina. *Ameghiniana*, 29, 249–264.
- Baldis, B., Shergold, J., & Peralta, S. (1994). New Llanvirnian trilobites and graptolites from the Las Aguaditas formation, Argentine Precordillera. *Actas 4 Congreso Argentino de Paleontología y Bioestratigrafía*, p. 50.
- Baldis, B. A., & Beresi, M. (1981). Fauna y ambiente en los sedimentos carbonáticos arenigianos de Talacasto, San Juan, Argentina. In *Actas VIII Congreso Geológico Argentino*, 2, 399–417. San: Luis.
- Baldis, B. A., Beresi, M., Borbonaro, O., & Vaca, A. (1982). Síntesis evolutiva de la Precordillera Argentina. *Actas 5º Congreso Latinoamericano de Geología Buenos Aires*, 4, 399–445.
- Baldis, B. A., & Blasco, G. (1974). Trilobites ordovícicos de la comarca de Jáchal, Precordillera Argentina. I. Telephinae. *Ameghiniana*, 11, 71–87.
- Benedetto, J. L. (2010). Placas de macaeridias (Annelida) en pelitas negras del Ordovícico Medio de la Precordillera de San Juan, Argentina. *Resúmenes 10 Congreso Argentino de Paleontología y Bioestratigrafía y 7 Congreso Latinoamericano de Paleontología, La Plata*, 137 p.
- Bergström, S. M., Chen, X., Gutiérrez-Marco, J. C., & Dronov, A. (2009). The new chronostratigraphic classification of the Ordovician system and its relations to major regional series and stages and to $\delta^{13}\text{C}$ chemostratigraphy. *Lethaia*, 42, 97–107.
- Bergström, S. M., Huff, W. D., Kolata, D. R., Krekeler, M. P. S., Cingolani, C., & Astini, R. A. (1996). Lower and middle Ordovician K-bentonites in the Precordillera of Argentina: A progress report. *13 Congreso Geológico Argentino y 2 Congreso de Explotación de Hidrocarburos*, 5, 481–490.
- Blasco, G., & Ramos, V. (1976). Graptolitos caradocianos de la Formación Yerba Loca y del cerro La Chilca, Departamento Jáchal, Provincia de San Juan. *Ameghiniana*, 13(3–4), 312–329.
- Brussa, E. D. (1996). Las graptofaunas ordovícicas de la Formación Las Aguaditas, Precordillera de San Juan, Argentina. Parte I Familias Thamnograptidae, Dichograptidae, Abrograptidae y Glossograptidae. *Ameghiniana*, 33(4), 421–434.
- Brussa, E. D. (1997). Las graptofaunas ordovícicas de la Formación Las Aguaditas, Precordillera de San Juan, Argentina. Parte II Familias Cryptograptidae, Dicranograptidae, Diplograptidae y Orthograptidae. *Ameghiniana*, 34(1), 93–105.
- Brussa, E. D., & Astini, R. A. (1998). The Gualcamayo River section: a graptolite constrained K-bentonite succession in the Ordovician of the Argentine Precordillera. In G.-J. C. Marco, & I. Rábano (Eds.), *Proceedings of the Sixth International Graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting of the International Subcommission on Silurian Stratigraphy (ICS-IUGS)* (vol. 23) (pp. 154–157). Madrid: Instituto Tecnológico Geominero de España.
- Brussa, E. D., & Astini, R. A. (2001). La graptofauna de los niveles inferiores de la Formación Gualcamayo (Ordovícico Medio) en la quebrada Corridita, suroeste de Guandacol, Precordillera argentina. *Ameghiniana*, 38(4), 29R–30R.
- Brussa, E. D., Mitchell, C. E., & Astini, R. A. (1998). Late Yapeenian to early Darrivilian graptolite faunas from Nazareno Creek, Guandacol region, Precordillera, Argentina. In J. C. Gutiérrez-Marco, & I. Rábano (Eds.), *Proceedings of the Sixth International Graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting of the International Subcommission on Silurian Stratigraphy (ICS-IUGS)* (vol. 23) (pp. 158–160). Madrid: Instituto Tecnológico Geominero de España.
- Brussa, E. D., Mitchell, C. E., Ortega, G., Maletz, J., & Astini, R. A. (2003). Middle Ordovician graptolite biostratigraphy from the Los Azules Formation at Los Gatos Creek, central Precordillera, Argentina. In *Proceedings of the 7th International Graptolite Conference Serie Correlación Geológica*, 18, 21–26.
- Bulman, O. M. B. (1963). On *Glyptograptus dentatus* (Brongniart) and some allied species. *Palaeontology*, 6, 665–689.
- Caballé, M., Alfaro, M., & Uriz, N. (2005). *Subzona de Undulograptus sínicus (Graptolitina), Ordovícico, Formación Gualcamayo, Quebrada Oscar, Región de Guandacol, Precordillera, Argentina*. Buenos Aires, Argentina: XVI Congreso Geológico Argentino.
- Carrera, M. G. (1997). Evolución y recambio de las Faunas de Poríferos y Briozoos en el ordovícico de la Precordillera Argentina. *Ameghiniana*, 34(3), 295–308.
- Carrera, M. G., & Astini, R. A. (1998). Valoración de las restricciones ambientales durante la transición Arenigiano-Llanvirniano, Ordovícico de la Precordillera Argentina. *Revista de la Asociación Geológica Argentina*, 53(1), 41–56.

- Carrera, M. G., & Ernst, A. (2010). Darriwilian bryozoans from the San Juan Formation (Ordovician), Argentine Precordillera. *Ameghiniana*, 47(3), 343–354.
- Carrera, M. G., Fenoglio, F., Albanesi, G. L., & Voldman, G. (2013). Conodonts sequence stratigraphy and the drowning of the San Juan carbonate platform in the Ordovician of the Argentine Precordillera. In G. L. Albanesi, & G. Ortega (Eds.), *Conodonts from the Andes International Conodont Symposium* (vol. 3) (pp. 5–12). Buenos Aires: Asociación Paleontológica Argentina.
- Chen, X., Rong, J. Y., Wang, X. F., Wang, Z. H., Zhang, Y. D., & Zhan, R. B. (1995). Correlation of the Ordovician rocks of China: Charts and explanatory notes. *International Union of Geological Sciences*, 31, 1–104.
- Chen, X., Zhang, Y. D., Bergström, S. M., & Xu, H. G. (2006). Upper Darriwilian graptolite and conodont zonation in the global stratotype section of the Darriwilian stage (Ordovician) at Huangnitang, Changshan, Zhejiang, China. *Palaeoworld*, 15, 150–170.
- Cuerda, A., & Furque, G. (1985). Graptolitos del techo de la Formación San Juan, Precordillera de San Juan. 1° *Jornadas de Geología de la Precordillera de San Juan*, 1, 113–118.
- Cuerda, A. J. (1986). Graptolitos del techo de la Formación San Juan, Precordillera de San Juan. 48° *Congreso Argentino de Paleontología y Bioestratigrafía*, 1, 49–57.
- Du, P. D., Zhao, Z. X., Huang, Z. B., Tan, Z. J., Wang, C., Yang, Z. L., ... Xiao, J. N. (2005). Discussion on four conodont species of *Histiodella* from Tarim Basin and their stratigraphic implication. *Acta Microbiologica Sinica*, 22, 357–369.
- Eberlein, S. (1990). Conodontenstratigraphie und Fazies der Formation Las Aguaditas (Ordovizium/Argentinische Präkordillere). Friedrich Alexander Univ. Erlangen, Inst. f. Geol; Unveröfftl. Dipl. Arb.: 83 S.
- Erdtmann, B.-D., Maslov, A., Maletz, J., & Paalits, I. (1998). Late Arenig - Llanvirn graptolites from Kaga Village, Bashkiria, Southern Urals of Russia. In J. C. Gutiérrez-Marco, & I. Rábano (Eds.), *Proceedings of the Sixth International Graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting of the International Subcommission on Silurian Stratigraphy (ICS-IUGS)* (vol. 23) (pp. 180–182). Madrid: Instituto Tecnológico Geominero de España.
- Feltes, N. A., Albanesi, G. L., & Bergström, S. M. (2016). Conodont biostratigraphy and global correlation of the middle Darriwilian - lower Sandbian Las Aguaditas formation, Precordillera of San Juan, Argentina. *Andean Geology*, 43(1), 60–85.
- Feltes, N. A., Albanesi, G. L., & Bergström, S. M. (2013). Middle Darriwilian conodont zones in the uppermost San Juan limestone and the lower member of the Las Aguaditas Formation, central Precordillera of San Juan, Argentina. In G. L. Albanesi, & G. Ortega (Eds.), *Conodonts from the Andes International Conodont Symposium* (vol. 3) (pp. 25–31). Buenos Aires: Asociación Paleontológica Argentina.
- Feltes, N. A., Serra, F., Albanesi, G. L., & Voldman, G. G. (2014). Las zonas de conodontes en el intervalo de contacto entre la Formación San Juan y unidades suprayacentes (Ordovícico Medio), Precordillera del oeste argentino. *XIX Congreso Geológico Argentino*, 52, 11.
- Fortey, R. A., & Owens, R. M. (1987). The Arenig series in South Wales: Stratigraphy and Palaeontology. I. The Arenig series in South Wales. *Bulletin of the British Museum (Natural History), Geology*, 41, 67–307.
- Frigerio, S. E. (2004). *Graptofaunas del Darriwiliano temprano (Ordovícico Medio) de las secuencias aflorantes en el cerro Viejo de Huaco y cerro Potrerillo, Precordillera de San Juan* (pp. 85). Argentina: Universidad Nacional de Córdoba.
- Furque, G. (1979). Descripción geológica de la Hoja 18c, Jáchal. *Boletín Servicio Geológico Nacional*, 164, 1–79.
- Furque, G., & Cuerda, A. (1979). Ordovícico argentino. *Asociación Geológica Argentina, Publicación Especial*, 87, 1–56.
- Heredia, S., Beresi, M., & Mestre, A. (2011). Estratigrafía y bioestratigrafía del Ordovícico Medio del río Las Chacritas, Precordillera Central de San Juan. *Serie Correlación Geológica*, 27(1), 18–26.
- Heredia, S., Beresi, M., & Peralta, S. (2005). Darriwilian conodont biostratigraphy of the Las Chacritas Formation, Central Precordillera (San Juan Province, Argentina). *Geologica Acta*, 3(4), 385–394.
- Huff, W. D., Bergström, S. M., Kolata, D. R., Cingolani, C. A., & Astini, R. A. (1998). Ordovician K-Bentonites in the Argentine Precordillera: relations to Gondwana margin evolution. In R. J. Pankhurst, & C. W. Rapela (Eds.), *The Proto-Andean Margin of Gondwana* (vol. 142) (pp. 107–126). London: Geological Society.
- Huff, W. D., Davis, D., Bergström, S. M., Krekeler, M. P. S., Kolata, D. R., & Cingolani, C. (1997). A biostratigraphically well-constrained K-bentonite U-Pb zircon age of the lowermost Darriwilian stage (middle Ordovician) from the Argentine Precordillera. *Episodes*, 20, 29–33.
- Hunicken, M. A. (1985). Lower Ordovician conodont biostratigraphy in Argentina. *Boletín de la Academia Nacional de Ciencia*, 56(3–4), 309–349.
- Jing, X., Zhou, H., & Wang, X. (2016). Biostratigraphy and biofacies of the middle Darriwilian (Ordovician) conodonts from the Laoshidan section in the western margin of the North China craton. *Marine Micropaleontology*, 125(2016), 51–65.
- Kaufmann, C., & Ortega, G. (2016). La Zona de Holmograpthus spinosus (Darriwiliano Medio) en la sierra de Villicum, Precordillera Oriental, provincia de San Juan. *Acta geológica lilloana*, 28, 101–105.
- Kayser, E. (1876). Ueber Primordiale und Untersilurische Fossilien aus der Argentinischen Republik. Cassel. *Beiträge zur Geologie und Palaeontologie der Argentinischen Republik, 2-Palaeontologischer Theil, 1 Abteilung, Palaeontograph*, 3, 1–33.
- Keller, M. (1999). Argentine Precordillera sedimentary and plate tectonic history of Laurentian crustal fragments in South America. *Geological Society of America Special Paper*, 341, 1–131.
- Keller, M., Eberlein, S., & Lehnert, O. (1993). Sedimentology of middle Ordovician carbonates in the Argentine Precordillera: Evidence of regional relative sea-level changes. *Geologische Rundschau*, 82, 362–377.
- Lehnert, O. (1995). Ordovizische Conodonten aus der Präkordillere Westargentinens: Ihre Bedeutung für Stratigraphie und Paläogeographie. *Erlanger Geologische Abhandlungen*, 125, 1–193.
- Löfgren, A. M., & Zhang, J. (2003). Element association and morphology in some middle Ordovician platform-equipped conodonts. *Journal of Paleontology*, 77(4), 721–737.
- Maletz, J. (1995). The middle Ordovician (Llanvirn) graptolite succession of the Aljära core (Scania, Sweden) and its implication for revised biozonation. *Zeitschrift für Geologische Wissenschaften*, 23, 249–259.
- Maletz, J. (1997). Arenig biostratigraphy of the point-de-Lévy slice, Quebec Appalachians, Canada. *Canadian Journal of Earth Sciences*, 34, 733–752.
- Maletz, J. (2009). *Holmograpthus spinosus* and the middle Ordovician (Darriwilian) graptolite biostratigraphy at Les Méchins (Quebec), Canada. *Canadian Journal of Earth Sciences*, 46(10), 739–755.
- Maletz, J. (2011). The identity of the Ordovician (Darriwilian) graptolite *Fucoides dentatus* Brongniart, 1828. *Palaeontology*, 54(4), 851–865.
- Máspero Castro, B., Ortega, G., & Albanesi, G. L. (2003). Middle Ordovician graptolite faunas of the Gualcamayo Formation (Middle Member) in the Corridita creek section, northern Precordillera, Argentina. In G. Ortega, & F. G. Aceñolaza (Eds.), *Proceedings of the 7° International Graptolite Conference and Field Meeting of the International Subcommission on Silurian Stratigraphy, Serie Correlación Geológica* (vol. 18) (pp. 61–66). Tucumán: Instituto Superior de Correlación Geológica (INSUGEO-CONICET).
- Mellgren, J. I. S., & Eriksson, M. E. (2010). Untangling a Darriwilian (middle Ordovician) palaeoecological event in Baltoscandia: Conodont faunal changes across the 'Täljsten' interval. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 100, 353–370.
- Mestre, A. (2012). Bioestratigrafía de conodontes del techo de la Formación San Juan y el miembro inferior de la Formación Los Azules, cerro La Chilca, Precordillera Central. *Ameghiniana*, 49(2), 185–197.
- Mestre, A. (2013). Middle Darriwilian conodont biostratigraphy of the Villicum Range, Eastern Precordillera, Argentina. In G. L. Albanesi, &

- G. Ortega (Eds.), *Conodonts from the Andes International Conodont Symposium* (vol. 3) (pp. 69–72). Buenos Aires: Asociación Paleontológica Argentina.
- Mestre, A., & Heredia, S. (2012). Darriwilian species of *Histiodela* (Conodonts) in the Argentine Precordillera. *Alcheringa: An Australasian Journal of Palaeontology*, 36(2), 141–150.
- Mestre, A., & Heredia, S. (2013). Biostratigraphic significance of Darriwilian conodonts from Sierra de la Trampa (central Precordillera, San Juan, Argentina). *Geosciences Journal*, 17(1), 43–53.
- Mitchell, C. E., Brussa, E. D., & Astini, R. A. (1998). A diverse Da 2 fauna preserved within an altered volcanic ash fall, Eastern Precordillera, Argentina: implications for graptolite paleoecology. In J. C. Gutiérrez-Marco, & I. Rábano (Eds.), *Proceedings of the Sixth International Graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting of the International Subcommission on Silurian Stratigraphy (ICS-IUGS)* (vol. 23) (pp. 222–223). Madrid: Instituto Tecnológico Geominero de España.
- Mitchell, C. E., Chen, X., Bergström, S. M., Zhang, Y., Wang, Z., Webby, B. D., & Finney, S. C. (1997). Definition of a global boundary stratotype for the Darriwilian stage of the Ordovician system. *Episodes*, 20(3), 158–166.
- Mitchell, C. E., & Maletz, J. (1995). Proposal for adoption of the base of the *Undulograptus austrodentatus* biozone as a global Ordovician stage and series boundary level. *Lethaia*, 28, 317–331.
- Ortega, G. (1987). La graptofauna y conodontes de la Formación Los Azules, Cerro Viejo, Zona de Huaco, Departamento Jáchal, San Juan. Doctoral thesis. FCFyN, Universidad Nacional de Córdoba, 2T, 1–109.
- Ortega, G. (1995). Graptolite zones of the Los Azules Formation (Middle Ordovician) from Precordillera, western Argentina. In 5th International Conference, Graptolite Working Group, International Palaeontology Association, Long Beach, California, Graptolite News 8 (pp. 57–59).
- Ortega, G., & Albanesi, G. L. (1999). Graptolite biostratigraphy of the Gualcamayo Formation (Middle Ordovician) at the Los Sapitos creek section, Argentina Precordillera. In P. Kraft, & O. Fatka (Eds.), *Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System*, 43(1-2), 49–52. (*Acta Universitatis Carolinae Geologica*). Prague.
- Ortega, G., & Albanesi, G. L. (2000). Graptolitos de la Formación Gualcamayo (Ordovícico Medio) en el cerro Potrerillo, Precordillera Central de San Juan, Argentina. *Boletín de la Academia Nacional de Ciencias*, 64, 17–59.
- Ortega, G., Albanesi, G. L., & Frigerio, S. E. (2007). Graptolite-conodont biostratigraphy and biofacies of the middle Ordovician Cerro Viejo succession, San Juan Precordillera, Argentina. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 245, 245–263.
- Ortega, G., Albanesi, G. L., & Hünicken, M. A. (1995). Bioestratigrafía en base a conodontes y graptolitos de las Formaciones San Juan (techo) y Gualcamayo (Arenigiano-Llanvirniano) en el cerro Potrerillo, Precordillera de San Juan, Argentina. *Boletín de la Academia Nacional de Ciencias*, 60(3–4), 317–364.
- Ortega, G., Albanesi, G. L., & Zeballo, F. J. (2013). Machaeridians from the middle and upper Ordovician of the Argentine Precordillera. *Geological Journal*, 48, 212–221.
- Ortega, G., Banchig, A. L., Voldman, G. G., Albanesi, G. L., Alonso, J. L., Festa, A., & Cardó, R. (2014). Nuevos registros de graptolitos y conodontes en la Formación Los Sombreros (Ordovícico), Precordillera de San Juan, Argentina. *XIX Congreso Geológico Argentino, Córdoba*, 52, 16.
- Ortega, G., & Rickards, B. (2003). A Darriwilian (middle Ordovician) graptolite fauna of the lower member of the Los Azules formation, Cerro Viejo, San Juan Precordillera, Argentina. *Proceedings 7th International Graptolite Conference and Field Meeting sub-commission on Silurian Stratigraphy, Serie Correlación Geológica* 18, 87–92.
- Peralta, S., Heredia, S., & Beresi, M. (1999). Upper Arenig–Lower Llanvirn sequence of the Las Chacritas River, Central Precordillera, San Juan Province, Argentina. In P. Kraft, & O. Fatka (Eds.), *Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System* (*Acta Universitatis Carolinae Geologica*) (pp. 123–126). Prague, 43(1-2).
- Peralta, S. H. (1998). Graptolites of the *N. gracilis* Zone in the black shale sequences of the San Juan Precordillera, Argentina: its biostratigraphic and paleoenvironmental significance. In J. C. Gutiérrez-Marco, & I. Rábano (Eds.), *Proceedings of the Sixth International Graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting of the International Subcommission on Silurian Stratigraphy (ICS-IUGS)* (vol. 23) (pp. 244–247). Madrid: Instituto Tecnológico Geominero de España.
- Peralta, S. H. (2003). Ordovician and Silurian of the Precordillera, San Juan Province, Argentina. In S. H. Peralta, G. L. Albanesi, & G. Ortega (Eds.), *Field Trip Guide 9th International Symposium on the Ordovician System 7th International Graptolite Conference & Field Meeting of the Subcommission on Silurian Stratigraphy* (vol. 10) (*Serie Correlación Geológica*) (pp. 23–43). Tucumán: Instituto Superior de Correlación Geológica (INSUGEO-CONICET).
- Salas, M. J. (2007). Assessing the biodiversity of Ordovician ostracods from the Argentine Precordillera. *Journal of Paleontology*, 81(6), 1442–1453.
- Serra, F., Albanesi, G. L., & Bergström, S. M. (2013). Middle Darriwilian conodont biostratigraphy of the Las Chacritas Formation, Central Precordillera of San Juan, Argentina. In G. L. Albanesi, & G. Ortega (Eds.), *Conodonts from the Andes International Conodont Symposium* (vol. 3) (pp. 109–115). Buenos Aires: Asociación Paleontológica Argentina.
- Serra, F., Albanesi, G. L., Ortega, G., & Bergström, S. M. (2015). Biostratigraphy and palaeoecology of middle-late Ordovician conodont and graptolite faunas of the Las Chacritas River section, Precordillera of San Juan, Argentina. *Geological Magazine*, 152(5), 813–829.
- Stelzner, A. (1873). Mitteilungen an Professor H.B. Geinitz. Ubreseine Reise durch die Argentinischen Provinzen San Juan und Mendoza und die Cordillere zwischen dem 31° und 32° S. *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie*, 726–744.
- Stone, J. (1987). Review of investigative techniques used in the study of conodonts. In R. L. Austin (Ed.), *Conodonts: Investigative Techniques and Applications* (pp. 17–34). Chichester: Ellis Horwood Limited.
- Stouge, S. (2001). Geological Association of Canada, meeting St. John's 2001, abstracts.
- Stouge, S. (2012). Middle Ordovician (late Dapingian–Darriwilian) conodonts from the cow head group and lower head formation, western Newfoundland, Canada. *Canadian Journal of Earth Sciences*, 49(1), 59–90.
- Stouge, S., Du, P. D., & Zhao, Z. X. (2011). Middle Ordovician (Darriwilian) global conodont zonation based on the Dawangou and Saergen formations of the Western Tarim Region, Xinjiang Province, China. In J. C. Gutiérrez-Marco, I. Rábano, & D. Garcia-Bellido (Eds.), *Ordovician of the World* (vol. 14) (pp. 581–586). Madrid: Cuadernos Del Museo Geominero Instituto Geológico y Minero de España.
- Tortello, M. F., & Peralta, S. H. (2004). Trilobites del miembro inferior de la Formación Gualcamayo (Llanvirniano temprano) en el cerro La Chilca, Precordillera de San Juan, Argentina. *Boletín Geológico y Minero*, 115, 665–662.
- VandenBerg, A. H. M., & Cooper, R. A. (1992). The Ordovician graptolite sequence of Australasia. *Alcheringa*, 16, 33–85.
- Voldman, G. G., Ortega, G., & Albanesi, G. L. (2013). Middle Ordovician conodonts and graptolites at Los Cauquenes Range, Central Precordillera of San Juan, Argentina. In G. L. Albanesi, & G. Ortega (Eds.), *Conodonts from the Andes International Conodont Symposium* (vol. 3) (pp. 117–121). Buenos Aires: Asociación Paleontológica Argentina.
- Waisfeld, B. G., Vaccari, N. E., Edgecombe, G. D., & Chatterton, B. D. E. (2011). The upper Ordovician trinucleid *Bancroftolithus* from the Precordillera of Argentina. *Journal of Paleontology*, 85, 1160–1180.
- Zhang, J. H. (1998). Conodonts from the Guniutan Formation (Llanvirnian) in Hubei and Hunan provinces, south-central China. *Stockholm Contributions in Geology*, 46, 1–161.

- Zhen, Y. Y., Percival, I. G., Cooper, R. A., Simes, J. E., & Wright, A. J. (2009). Darriwilian (middle Ordovician) conodonts from Thompson Creek, Nelson Province, New Zealand. *Memoirs of the Association of Australasian Palaeontologists*, 37, 25–53.
- Zhen, Y. Y., Wang, Z. H., Zhang, Y. D., Bergström, S. M., Percival, I. G., & Cheng, J. F. (2011). Middle to late Ordovician (Darriwilian-Sandbian) conodonts from the Dawangou section, Kalpin area of the Tarim Basin, northwestern China. *Records of the Australian Museum*, 63, 203–266.

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