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High resolution conodont-graptolite biostratigraphy in the Middle-Upper Ordovician of the Sierra de La Invernada Formation (Central Precordillera, Argentina)

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ABSTRACT

Outcrops on the western slope of the La Invernada Range, San Juan Precordillera (W Argentina), were surveyed for lithofacial analysis and graptolite-conodont high resolution biostratigraphy. The study profile for the upper Sierra de La Invernada Formation is approximately 500 m thick and is located in the northern part of the La Invernada Range. Successive shallowing-deepening sedimentary cycles crop out throughout the upper part of the formation. The dominantly lower turbiditic sandy deposits alternate with shaly pelagic sedimentation, and occasional coarser intervals that record gravitational flows. Hummocky structures occur in the uppermost part of the formation, indicating sedimentation under storm weather conditions. Rich graptolite faunas representing six upper Middle to lower Upper Ordovician biozones have been recorded from this section: *Pterograptus elegans* (tentative assignment), *Hustedograptus teretiusculus*, *Nemagraptus gracilis*, *Climacograptus bicornis*, *Diplacanthograptus caudatus*, and *Climacograptus tubuliferus* biozones. This graptolite biostratigraphy is complemented by the conodont records from successive productive levels, which yielded conodonts that represent the *Pygodus serra, P. anserinus, Amorphognathus tvaerensis,* and *A. superbus* biozones. The recorded conodont-graptolite assemblages allow for a correlation with the upper Darriwilian, Sandbian and lower Katian global stages, and provide preliminary biofacies records for the upper Sierra de La Invernada Formation.

KEYWORDS **Graptolites. Conodonts. Ordovician. Argentine Precordillera.**

INTRODUCTION

A new stratigraphic profile through the upper part of the Sierra de La Invernada Formation (Fm) (Precordillera Argentina), which is exposed ca. 3 km to the south of the La Puerta Creek in the northern La Invernada Range and covers the Mid-Late Ordovician time span, is investigated in the present contribution (Fig. 1). Graptolites are the most frequent fossils in this section that also yielded a variety of conodonts, chitinophosphatic brachiopods, chitinozoans, and scarce crinoid remains. This rich fossil record has enabled the authors to carry out a detailed biostratigraphic study.

This paper deals with integrating the previously available information on these Ordovician fossil assemblages (Ortega et al., 2004, 2006, 2007; Banchig et al., 2007) together with new additional stratigraphic and paleontological data that resulted from the study of the above mentioned section. As a result, an improved, high resolution conodont-graptolite biostratigraphic scheme is provided for the Mid-Late Ordovician of the upper part of the Sierra de La Invernada Fm.

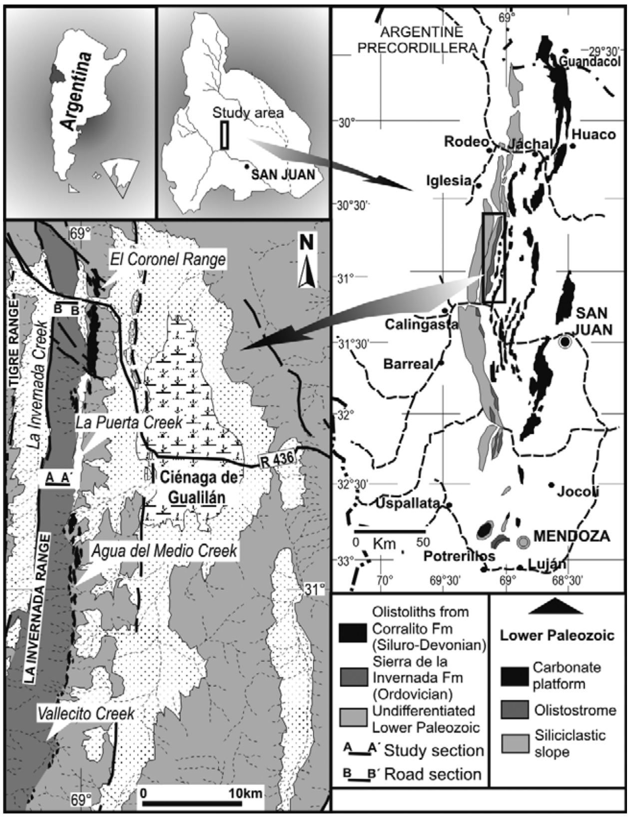


FIGURE 1 | **Location map of the study area. Modified from Banchig et al. (2007)**

PREVIOUS BIOSTRATIGRAPHIC WORK

This unit was subject of several studies since the pioneering works by Furque (1983) and Furque and Caballé (1985, 1988). Furque (1983) originally defined the La Invernada Fm as a siliciclastic sedimentary succession, with basaltic intercalations, and interpreted it as the flysch stage in a geosyncline development. Afterwards, the unit was redefined as the Sierra de La Invernada Fm by Furque and Caballé (1985).

The first studies on graptolites from the La Invernada Range were by Furque et al. (1990), who recorded the following taxa: *Cryptograptus* cf. *C. tricornis* (CARRUTHERS), *Dicranograptus ramosus* (HALL), *Climacograptus invernadensis* FURQUE, CUERDA, CABALLÉ and ALFARO, *Climacograptus* aff. *C. brevis* ELLES and WOOD, *Pseudoclimacograptus scharenbergi* (LAPWORTH), *Amplexograptus* aff. *A. arctus* (ELLES and WOOD), *Amplexograptus minutus* CUERDA, CINGOLANI, SCHAUER and VARELA, *Orthograptus* aff. *O. calcaratus* var. *vulgatus* LAPWORTH, *Hallograptus* aff. *H. mucronatus* (HALL) and ?*Neurograptus* sp., among others. These authors suggested a Llanvirn-Caradoc age for the Sierra de La Invernada Fm in accordance with reported fauna. Later, Caballé et al. (1992) described a graptolite association recovered from the Vallecito Creek, in the southern sector of the La Invernada Range, and referred it to the *Nemagraptus gracilis* Zone. That fossil assemblage included *Glossograptus hincksii* (HOPKINSON), *Cryptograptus tricornis* (CARRUTHERS), *N. gracilis* (HALL), *Hustedograptus* cf. *H. teretiusculus* (HISINGER), "*Climacograptus*" cf. "*C*". *antiquus* LAPWORTH, *Retiograptus* aff. *R. geinitzianus* HALL, and *Dicellograptus* spp. as the most common forms.

Banchig (1995, 1996) analized the lithofacial characteristics of Ordovician rocks in the range, and reconsidered the concept of the Vallecito Group, which includes the Corralito, Sierra de La Invernada and Cántaro de Oro Fms (Furque and Caballé, 1988; Furque et al., 1990). The author considered the Cántaro de Oro Fm as a lateral variation of the Sierra de La Invernada Fm and new aspects about sedimentation and coeval volcanism that demonstrate important geotectonic features of the Eopaleozoic continental margin were later published by Banchig et al. (2004, 2007).

Brussa (1997a, 1997b, 1997c) described a Darriwilian graptolite fauna from newly measured outcrops of the Sierra de La Invernada Fm in the section of the provincial road nº 436 (Fig. 1, B-B"). The lower association of this fauna consists of *Undulograptus austrodentatus* (HARRIS and KEBLE), *U. sinicus* (MU and LEE), *Isograptus horridus* HARRIS, *Isograptus caduceus* (SALTER), *Xiphograptus svalbardensis* (ARCHER and FORTEY), *Tetragraptus* spp., *Pseudotrigonograptus ensiformis* (HALL), *Cryptograptus antennarius* (HALL) and *P. tentaculatus* (HALL), among most conspicuous forms. The higher association includes *Holmograptus spinosus*, *C. antennarius,* and *P. tentaculatus* (Da2-Da3 in age) (Brussa, 1999).

Outcrops of the Cántaro de Oro Fm (= Sierra de La Invernada Fm in the present paper) placed ca. 19 km to the south of road 436 were described by Caballé et al. (1997) and Cuerda et al. (1999). The authors recorded a graptolite assemblage referred to the *Climacograptus bicornis* Zone, which is composed of *Dicranograptus ramosus* cf. *D. r. spinifer* ELLES and WOOD, *D. nicholsoni nicholsoni* HOPKINSON, *D. kirki* RUEDEMANN, *O.* cf. *O. spinigerus* (ELLES and WOOD), *Cryptograptus tricornis* (CARRUTHERS), *Climacograptus bicornis bicornis* (HALL), *Leptograptus* sp., *Neurograptus* cf. *N. margaritatus* (LAPWORTH), *Orthoretiolites* cf. *O. hami* Wittington, and *O.* cf. *O. tigris* BRUSSA.

Astini (2003) and Basilici et al. (2005) correlated Sierra de La Invernada, Yerba Loca, and Portezuelo del Tontal Fms. The first paper provides an updated correlation chart for the formations from the Argentine Precordillera.

The occurrence of late Darriwilian and younger assemblages of the *Nemagraptus gracilis* (early Sandbian), *Climacograptus bicornis* (late Sandbian), *Diplacanthograptus caudatus* and *Climacograptus tubuliferus* zones (early Katian) from the Sierra de La Invernada Fm were noted by Ortega et al. (2004, 2006, 2007) and Banchig et al. (2007) in a section located 300 m to the north of the profile studied here (the reader should take into account the graphic scale of text-fig. 2 in the paper by Ortega et al. (2007) is mistaken: it should say 30 m instead of 10 m in the scale bar).

GEOLOGICAL SETTING

The La Invernada Range is the westernmost morphostructural unit of the Central Precordillera (San Juan Province, Argentina). It stretches for about 60 km with north-south orientation, and is bounded by two longitudinal valleys, the Bolsón de Gualilán – La Cantera River to the east and the La Invernada creek – Seco de La Invernada River to the west. The western boundary is a defined lineament that obliquely cuts the northern outcrops. This structure extends through the whole range. The eastern boundary, where some greenish Siluro-Devonian exposures occasionally appear, is more irregular due to the development of coalescent alluvial fans.

The La Invernada Range includes the outcrops of Ordovician siliciclastic rocks of the Sierra de La Invernada Fm (Middle-Upper Ordovician, i.e. Darriwilian-Katian) that crop out in its western flank, and the rocks of the Corralito Fm (Siluro-Devonian) in the eastern exposures. The Sierra de La Invernada Fm is a heterolithic succession with scarce calcarenites and interbedded conglomerates. This unit is about 2,000 m thick on average, although maximum and minimum thicknesses of 4,000 m and 1,000 m, respectively, are measured due to partial wedging of the succession to the north and frequent fault repetition to the south. In the eastern range flank, large Ordovician carbonate blocks resedimented in a greenish sandstone matrix of the Siluro-Devonian Corralito Fm crop out (Furque and Caballé, 1988; Furque et al., 1990; Banchig, 1995).

Sedimentological facies

The Sierra de La Invernada Fm includes five main depositional lithofacies (conglomerates, sandstones, carbonates, shales, and calcareous breccias) that make up coarsening and thinning upwards submarine fan sequences developed over gentle paleoreliefs and ranging from platform margin to slope (Banchig et al., 2004).

The selected profile for this study is located ca. 18 km south of provincial road nº 436 between Rodeo and Talacasto localities, San Juan Province. This section includes approximately 500 m of the upper Sierra de La Invernada Fm, the base of which is a conspicuous basalt body, 50 to 70 m thick on average, which lies parallel to the stratification strike and extends regionally (Fig. 1). Although this new selected profile is located ca. 300 m to the south of the section described by Banchig et al. (2007) and Ortega et al. (2007), it is possible to correlate most of the samples of these previous contributions with the new graptolite and conodont records from the new profile. It is important to emphasize that this correlation is feasible, despite of the significant lateral facies variations between neighbouring sections within the Sierra de La Invernada Fm, resulting from the occurrence of interbedding conglomerate lenses.

The lower part of the sedimentary succession overlies a sharp contact between the basalt body and immature coarse grained graded wackes (Fig. 2). They consist of thick bedded (0.5-1 m) accumulations with sedimentary structures that characterize the Ta-b, Ta-c Bouma sets and correspond to turbidite deposits. Amalgamation surfaces on thick beds are widespread, and sandy intervals no more than 10 cm thick, which could record dense grain flows associated to submarine extrusions, appear occasionally.

A sharp sandstone-basalt contact that seldom shows pillow structures with vesicles on the basaltic surface was observed. Moreover, there appear spherical and subspherical basaltic bodies, partly amalgamated with development of peripheral contact aureoles (probable fragments of pillow lavas that were detached during subaqueous extrusions), which are incorporated in the sandy packages. This feature is indicative of a contemporaneous process of intrusion-extrusion of lavas with turbidite sedimentation.

The sedimentary succession exhibits prograding and retrograding cycles. The alternate sequences result in gradual and sustained changes for a thickness around 154 m. Massive sandy beds at the base allow for identification of Ta-c and Tb-c type turbidite sequences, and levels of fine to very fine sandy beds, which typifies the Tb-e, Td-e tubidites.

Overlying these sedimentary cycles (between LIC1 and LIC4, Fig. 2), ca. 105 m of fine-grained and monotonous sediments that show a gradual upward change from light green to black colour (reflecting a gradual increase in organic matter and sulphide content) were deposited. Several horizons that contain graptolites are located in this part of the succession.

The upper part of the Sierra de La Invernada Fm, between LIC4 and LIC11 (Fig. 2), consists of a sandy and coarser succession, whose exposed thickness (ca. 230 m) is controlled by the presence of a reverse fault of regional magnitude that cut obliquely the western border of the outcrops. The conglomerate beds present channelized erosive bottoms and planar tops with frequent erosion and amalgamation. These intervals are normally gradated and the internal arrangement is grain and matrix supported. Laminate carbonate intervals frequently appear at the top of the channelized beds. This part presents a general prograding arrangement, which is frequently associated with coarse sandy bodies and sabulitic lenses of erosive bases and normal or transitional top, with high flow regime planar laminations, vertical agradation, and lateral wedging. In this part of the column, medium-coarse grain sandy intervals are frequent with dome laminations and tangent wedging that define hummocky structures, and truncated waving lamination. The thinner sandy intervals with fine and very fine grain often present wave structures and coeval plastic sedimentary deformation to the top. Interbedded shales alternate with massive sandy levels or tabular levels in relation to the sharp contacts.

Present study and earlier contributions by Banchig et al. (2007) and Ortega et al. (2007) regarding northern sections of the La Invernada Range, demonstrate that the basal part of the Sierra de La Invernada Fm is placed to the east, in tectonic contact with the Corralito Fm. This real polarity of the formation was missunderstood in previous works (e.g., Caballé et al., 1997; Cuerda et al., 1999). Actually, the polarity is inverted in the southern sections of the La Invernada Range; for example, in the Vallecito creek, where the top levels of the Sierra de La Invernada Fm contact tectonically with the Corralito Fm.

The homotaxial faunal succession in the described profile indicates that the correlative early Darriwilian strata described by Brussa (1997a, 1997b, 1997c) in the section of road 436 (see Fig. 1) are dislocated from the main structure of the La Invernada Range.

The inversions of bed polarity and dislocations in certain parts of the Sierra de La Invernada Fm reveal a complex structure along the La Invernada Range, as significant effects of the recent Andean Orogeny.

Paleoenvironments

In a recent paper (Basilici et al., 2005), the Sierra de La Invernada Fm together with the Portezuelo del Tontal and the Yerba Loca Fms are considered as corresponding to the same depositional system, which is dominated by storm activity. The authors noted the prevalence of the sandy over the shaly fraction for the Portezuelo del Tontal and Yerba Loca Fms, which are characterized by the combination of gravitational deposits and turbiditic flows of very low density that would reflect deeper and anoxic conditions. In the Sierra de La Invernada Fm, however, the coarser and more bioturbated intervals record sedimentation under shallower and more oxygenated conditions. The presence of hummocky structures in the upper parts of the referred units indicates that the sedimentation occurred within the interval of storm weather waves, and gravitational flows would have developed at the same time of storm action.

We divide the upper Sierra de La Invernada Fm into two parts based on the sedimentary architecture and the nature of involved deposits. In the lower part, the identification of thinning upwards strata is interpreted as corresponding to the development of a sedimentary prism of turbiditic character. The stacking of proximal to distal turbidites would correspond to the development of the depositional space, a stage of eustatic rise that evolves towards conditions of pelagic deposition under anoxic environments as indicated by black shales of high organic content. This stratigraphic interval spans the upper Darriwilian - lower Sandbian (*P. elegans*, *H. teretiusculus*, and *N. gracilis* zones).

The second interval is characterized by a similar thinning upwards arrangement. The irregular lithofacies (e.g., carbonate/conglomerate alternations), the lensoidal geometry of the sandy-shaly deposits, as well as the presence of sedimentary structures of oscillatory flows (HCS), reveal conditions of deposition under shallow waters within storm wave base. This interval evidences the sudden appearance of paleoenvironmental conditions that

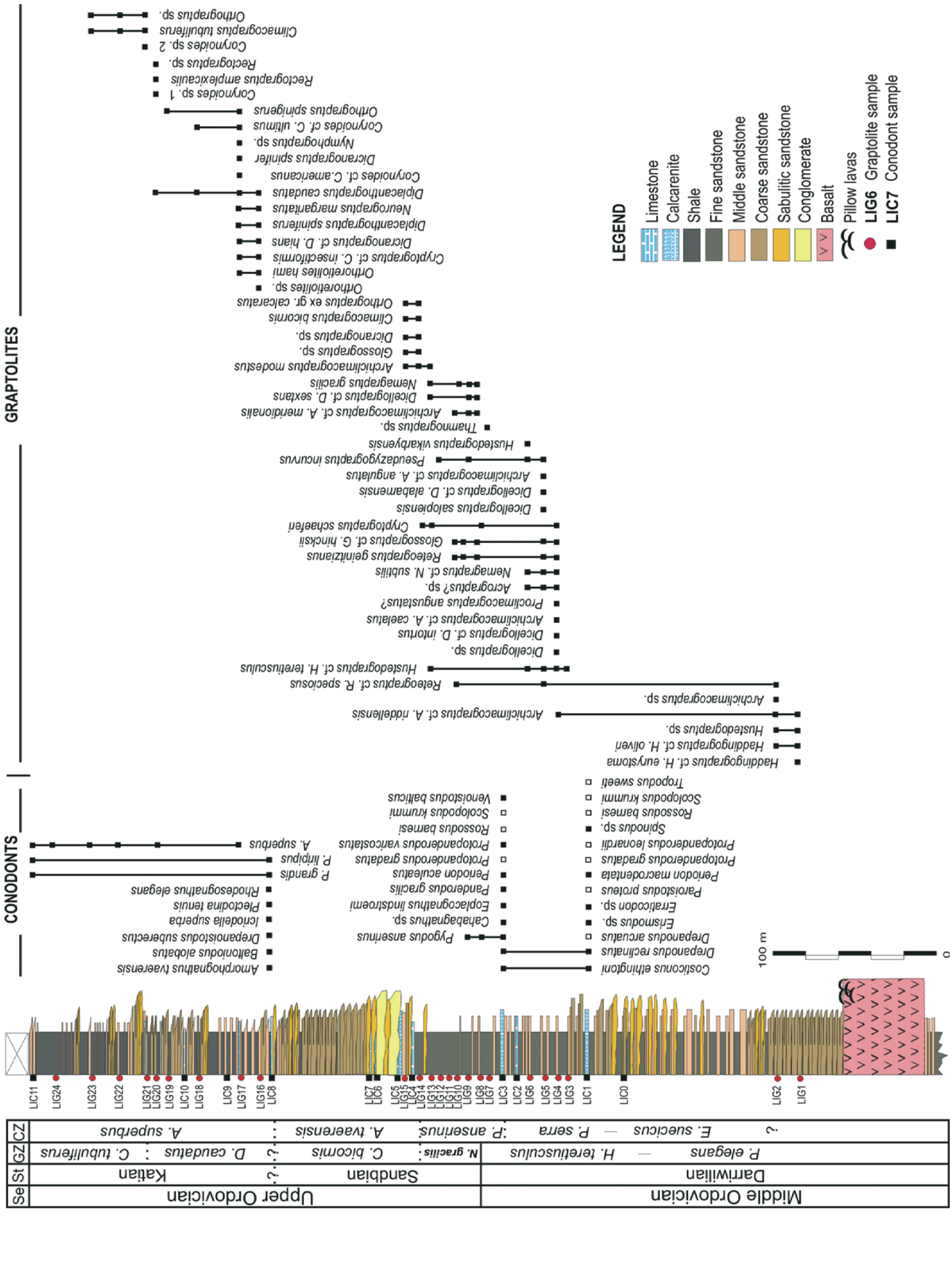


FIGURE 2 | **Stratigraphic column of the study section and ranges of conodont and graptolite species (white dots indicate reworked conodont species). Abbreviations: Se: Global Ordovician Series, St: Global Ordovician Stages, GZ: Graptolite Zones, CZ: Conodont Zones.**

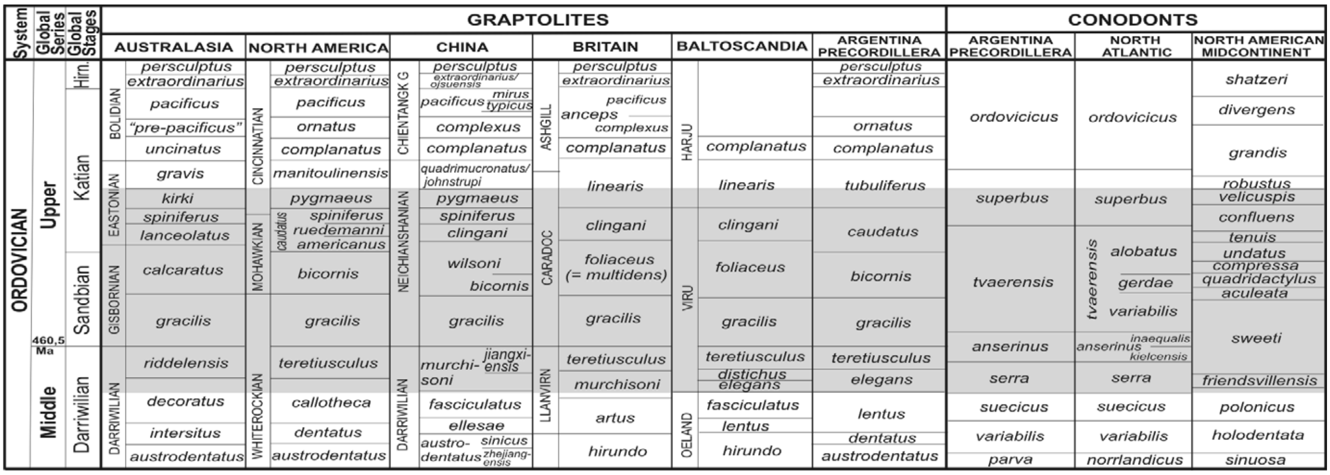


FIGURE 3 | **Correlation chart of graptolite and conodont zones. Modified from Albanesi and Ortega (2002), Webby et al. (2004), and updated after the ISOS-ICS-IUGS web site: www.ordovician.cn**

favour the development of a low sea-level sedimentary sequence. It is mainly associated with tractive deposits within regimes of high energy and progradation of a depositional system, and the development of channels and sandy bars in a siliciclastic platform. This interval represents a shallowing event that gradually evolves again to deepening conditions. The changing depositional conditions are indicated by intervals of black shales punctuated by sandy tabular levels that correspond to more defined tractive intervals and are followed, in turn, by background suspension fallout sedimentation. This upper interval is constrained to the upper Sandbian – lower Katian stages. The sandy interval contains the *Climacograptus bicornis* Zone graptolites, and the *Diplacanthograptus caudatus* and *Climacograptus tubuliferus* zones are represented above the thickest conglomerate, where black shales become more frequent.

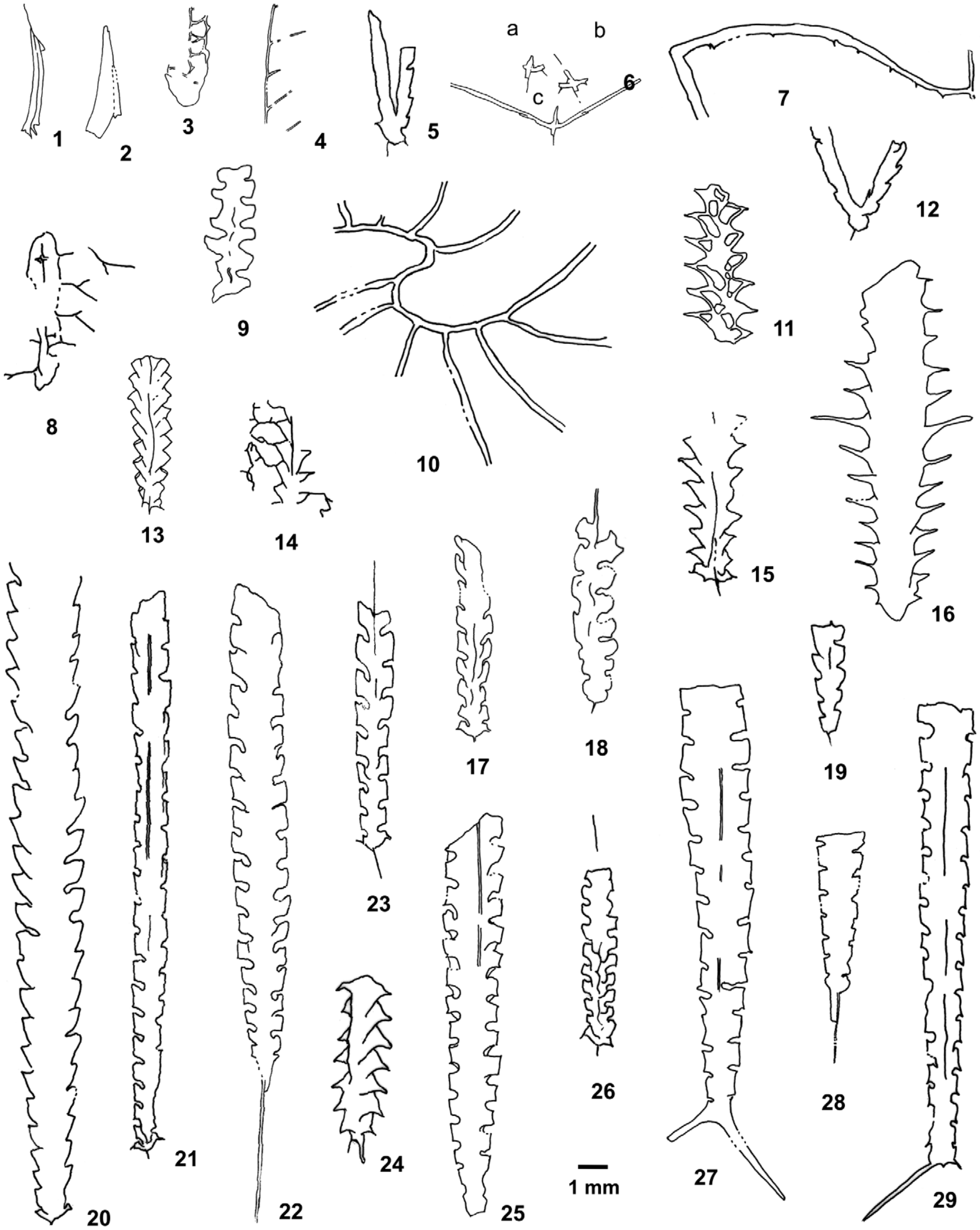
BIOSTRATIGRAPHY AND CORRELATION

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

Graptolites

The study profile contains at least six different graptolite assemblages localized in the upper part of the Sierra de La Invernada Fm, above the upper basic dike: the *"Pterograptus elegans"*, *Hustedograptus teretiusculus*, *Nemagraptus gracilis*, *Climacograptus bicornis*, *Diplacanthograptus caudatus,* and *Climacograptus tubuliferus* zones. Recorded species ranges through these units are depicted in Fig. 2, spanning the upper Darriwilian to the lower Katian stages, and the correlation chart for the mentioned zones is presented in Fig. 3. Characteristic species of the faunas represented in the study section are illustrated in Figs. 4 and 5. Unfortunately, the preservation of rhabdosomes collected from sandstones is frequently poor, making their study difficult. The poorly preserved material is most prevelant in the *"P. elegans"* and *C. bicornis* zones.

FIGURE 4 | **Late Darriwilian to early Katian graptolite faunas from the Sierra de La Invernada Formation at study section. Graptolite samples (LIG) are indicated in Figure 2. 1) *Corynoides ultimus* RUEDEMANN, LIG17, CORD-PZ 24696. 2) *Corynoides* sp. 1, LIG20, CORD-PZ 24728. 3) *Reteograptus* cf. *R. speciosus* HARRIS, LIG2, CORD-PZ 24670. 4) *Thamnograptus* sp., LIG1, CORD-PZ 24690-B. 5) *Dicranograptus* cf. *D. intortus* LAPWORTH, LIG4, CORD-PZ 24975. 6) *Nemagraptus* cf. *N. subtilis* HADDING, LIG4, CORD-PZ 24967, b, CORD-PZ 24957, LIG5, c, CORD-PZ 25041. 7) *Pseudazygograptus incurvus* (EKSTRÖM), LIG12, CORD-PZ 25222. 8) *Nymphograptus* sp., LIG17, CORD-PZ 24854-A. 9) *Haddingograptus* cf. *H. oliveri* (BOUČEK), LIG2, CORD-PZ 24669. 10) *Nemagraptus gracilis* (HALL), LIG8, CORD-PZ 25167. 11) *Orthoretiolites hami* WHITTINGTON, LIG16, CORD-PZ 24811. 12) *Dicellograptus salopiensis* ELLES and WOOD, LIG5, CORD-PZ 25042. 13) *Rectograptus amplexicaulis* (HALL), LIG20, CORD-PZ 24730. 14) *Neurograptus margaritatus* (LAPWORTH), LIG17, CORD-PZ 24697. 15) *Orthograptus* ex gr. *calcaratus* (LAPWORTH), LIG15, CORD-PZ 25258. 16) *Orthograptus spinigerus* (ELLES and WOOD), LIG17, CORD-PZ 24721. 17) *Archiclimacograptus* cf. *A. riddellensis* (HARRIS), LIG1, CORD-PZ 24670. 18) *Haddingograptus* cf. *H. euristoma* (JAANUSSON), LIG1, CORD-PZ 24671. 19) *Proclimacograptus angustatus*? (EKSTRÖM), LIG4, CORD-PZ 24944. 20) *Hustedograptus vikarbyensis* (JAANUSSON), LIG6, CORD-PZ 25053. 21) *Archiclimacograptus* cf. *A. angulatus* (BULMAN), LIG4, CORD-PZ 25031. 22) *Archiclimacograptus* cf. *A. meridionalis* (RUEDEMANN), LIG8, CORD-PZ 25172. 23) *Archiclimacograptus* cf. *A. riddellensis* (HARRIS), LIG4, CORD-PZ 24973. 24) *Cryptograptus schaeferi* LAPWORTH, LIG13, CORD-PZ 25231-A. 25) *Climacograptus tubuliferus* LAPWORTH, LIG21, CORD-PZ 24739. 26) *Archiclimacograptus modestus* (RUEDEMANN), LIG15, CORD-PZ 25261. 27) *Diplacanthograptus spiniferus* (RUEDEMANN), LIG16, CORD-PZ 24854. 28) *Diplacanthograptus caudatus* (LAPWORTH), LIG17, CORD-PZ 24728. 29) *Climacograptus bicornis* (HALL), LIG15, CORD-PZ 25260.**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Compared with the rich faunas of the *D. caudatus* Zone, the monotonous overlying *C. tubuliferus* fauna, which is almost exclusively composed of the eponymous taxon, reveals a strong biodiversity loss in the graptolite assemblages of the Sierra de La Invernada Fm.

"Pterograptus elegans" Zone

A graptolite assemblage composed by biserial rhabdosomes and scarce branches, probably referable to *Acrograptus*, were collected in greenish gray fine sandstones, ca. 27 m above the basalt body (LIG1, LIG2). It contains poorly preserved early astogenetic stages, juveniles and fragmentary mature rhabdosomes, usually flattened with distinct orientations. It is composed of *Archiclimacograptus* cf. *A. riddellensis* (HARRIS), *Archiclimacograptus* cf. *A. caelatus* (LAPWORTH), *Haddingograptus* cf. *H. oliveri* (BOUČEK), *Haddingograptus* cf. *H. eurystoma* (JAANUSSON), *Hustedograptus* sp., and *Reteograptus* cf. *R. speciosus* HARRIS. The presence of *Archiclimacograptus* and *Haddingograptus* as the dominant elements of the fauna suggests a tentative correlation with the *Pterograptus elegans* Zone of the Baltic area (Maletz, 1997). Considering the absence of the guide taxon for the biozone we refer this interval as the "*Pterograptus elegans* Zone", mid-late Darriwilian in age.

Similar graptolite faunas were described for the lower member of the Los Azules Fm at Viejo Hill of Huaco, San Juan Precordillera (Ortega, 1987; Ottone et al., 1999; Brussa et al., 2003b) and in the Estancia San Isidro Fm (ex lower member of the Empozada Fm), Mendoza Precordillera (Ortega et al., 2007). The former is a rich graptolite fauna composed of diplograptids, dichograptids, glossograptids, and sigmagraptines. The latter, present at Estancia San Isidro Fm, is a low diversity, poorly preserved graptolite fauna distinguished principally by biserial rhabdosomes, with abundant *Archiclimacograptus* and *Haddingograptus* specimens.

Hustedograptus teretiusculus Zone

Above the greenish gray sandstones a facies change marked by the appearance of gray siltstones is observed. A graptolite fauna dominated by biserial graptolites is present in samples LIG3 and LIG4. It is composed of *Thamnograptus* sp., *Cryptograptus schaeferi* LAPWORTH , *Glossograptus* cf. *G. hincksii* (HOPKINSON), *Nemagraptus* cf. *N. subtilis* HADDING, *Dicellograptus* spp., *Hustedograptus teretiusculus* (HISINGER), *H. vikarbyiensis* (JAANUSSON), *Hustedograptus* sp., *Archiclimacograptus* cf. *A. riddellensis* (HARRIS), *A.* cf. *A. angulatus* (BULMAN), *Archiclimacograptus A.* cf. *A. caelatus* (LAPWORTH), *Proclimacograptus angustatus*? (EKSTRÖM), *Reteograptus geinitzianus* HALL, *R.* cf. *R. speciosus* HARRIS, and *Acrograptus*? sp. *Pseudazygograptus incurvus* (EKSTRÖM), a form comparatively scarce at these levels, is recorded for the first time in the Argentine Precordillera (Fig. 4.7).

Nemagraptid records include growth stages, juvenile rhabdosomes and several stipe fragments without cladial branches, suggesting the presence of a form comparable to *N. subtilis* HADDING. At least three different forms of *Dicellograptus* were collected in this interval, resembling *Dicellograptus intortus* LAPWORTH, *D. salopiensis* ELLES and WOOD and *D. alabamensis* RUEDEMANN. Conodont elements of *Pygodus anserinus* (LAMONT and LINDSTRÖM) are present in the same strata ranging to the next *N. gracilis* assemblage.

N. subtilis precedes the appearance of *N. gracilis* (see Nõlvak and Goldman, 2007) in the Baltic area, ranging to the lowest Sandbian. Based on the presence of forms similar to *N. subtilis* and the absence of the guide taxon *N. gracilis*, the assemblage from samples LIG3 and LIG4 of the Sierra de La Invernada Fm seems to be older than the *N. gracilis* Zone. Accordingly, these samples are referred to the upper *H. teretiusculus* Zone, which is late Darriwilian in age. Similar assemblages do not seem to be present in other parts of the Precordillera. In some sections of the cerro Viejo area, nemagraptids of the *N. subtilis* type were recorded together with *H. teretiusculus* and the conodont *Pygodus serra* in a slightly older assemblage of the *H. teretiusculus* Zone (Ortega, 1987, 1995). Both faunas represent the only records of the entrance of nemagraptids and dicellograptids in the Argentine Precordillera.

Nemagraptus gracilis Zone

True specimens of *Nemagraptus gracilis* (HALL) were found in the sample LIG8, ca. 223 m above the basalt body. The specimens are preserved in dark gray shales, which comprise the dominant lithology in the next 40 m of the succession. Samples LIG8-LIG13 yielded *Pseudazygograptus incurvus*, *Cryptograptus schaeferi*, *Glossograptus* sp., *Dicellograptus* cf. *D. alabamensis* RUEDEMANN, *Dicellograptus* cf. *D. sextans* (HALL), *Dicranograptus* cf. *D. furcatus* (HALL), *Nemagraptus gracilis* (HALL), *Reteograptus geinitzianus* HALL, *Reteograptus* cf. *R. speciosus* HARRIS, *Archiclimacograptus* cf. *A. meridionalis* (RUEDEMANN), and *Hustedograptus* cf. *H. teretiusculus*. Conodont elements of the *Pygodus anserinus* Zone were found on shales associated with the graptolite fauna.

The first appearance of *N. gracilis*, which is considered synchronous worldwide, marks the base of the global Sandbian Stage of the Upper Ordovician Global Series (Finney and Bergström, 1986; Bergström et al., 2000, 2006). The presence of the guide taxon indicates a correlation with the *N. gracilis* Zone of the Baltic region, Great Britain, North America, Australia, and China.

In the Argentine Precordillera, the *N. gracilis* Zone is documented from diverse lithologies and paleoenvironments in several localities of the San Juan Precordillera. It has been identified at the Portezuelo del Tontal Fm, El Tontal Range (Cuerda et al., 1986; Peralta et al., 2003), Las Aguaditas Fm (Los Blanquitos and Las Chacritas sections) (Brussa, 1996), Los Azules Fm (La Chilca Hill) (Blasco and Ramos, 1976), and Sierra de La Invernada Fm (Peralta and Finney, 2002), Central Precordillera. It was also reported from the Yerba Loca Fm, Jáchal River section (Blasco and Ramos, 1976) in the Western Precordillera, and in the La Cantera Fm, Villicum Range, Eastern Precordillera (Peralta, 1990). According to Peralta and Finney (2002) the aforementioned graptolite assemblages comprise different taxonomic compositions, which suggest slightly different ages, and they consider that the fauna present in the La Invernada Range is younger. However, since our graptolite collections are associated with the conodont *P. anserinus*, we think that the basal part of the *N. gracilis* Zone is present in this locality.

Climacograptus bicornis Zone

Graptolites of this zone are recorded from level LIG14, where the succession becomes dominantly sandy, ranging several meters up to LIG15 just below the conglomerate. Rhabdosomes are frequently orientated, partially piritized or limonitized, and poorly preserved, making their identification difficult. In all cases the fossils were collected in fine to coarse sandstones. In addition to graptolites, a few crinoid remains were found.

The graptolite assemblage contains *Glossograptus* sp., remains of *Dicellograptus* sp., *Archiclimacograptus modestus* (RUEDEMANN), *Climacograptus bicornis* (HALL), *Orthograptus* ex. gr. *calcaratus* (LAPWORTH), and scarce stipes of probable dichograptids or sigmagraptines. Although this low diversity graptolite fauna is poorly preserved, the presence of *C. bicornis* allows identifying the homonymous zone, late Sandbian in age. A fauna composed by *O. calcaratus*, *C. bicornis*, dicellograptids and dicranograptids, characterizes the interval overlying the *N. gracilis* Zone in many sections of the world (Finney and Bergström, 1986) and precedes the entrance of the *Diplacanthograptus caudatus* fauna (Goldman, 2003; Goldman et al., 2007). The assemblage present in the La Invernada Range can be correlated with the *O. calcaratus* Zone of Australasia (VandenBerg and Cooper, 1992), *C. bicornis* Zone of North America (*e.g.,* Berry, 1960; Finney, 1986), *C. bicornis* Subzone (*C. wilsoni* Zone) of China (Webby et al., 2004), and *D. foliaceus* (= *D. multidens*) Zone of Britain and Scania (Williams, 1994; Webby et al., 2004).

Graptolites of the *C. bicornis* Zone are distributed throughout the Central Precordillera, an interval usually assigned to the *N. gracilis* Zone in the past (see Ortega, 1987; Ortega and Brussa, 1990; Ortega and Albanesi, 1998). Fossils of this age were recorded in the Las Plantas Member (Las Vacas Fm) at Guandacol area, La Rioja Province (Astini and Brussa, 1997), and in the Potrerillo Mountain section (Benedetto et al., 1991; Ortega and Albanesi, 1998), northern San Juan Province. In the Viejo Hill, west of Huaco, a rich graptolite assemblage of this biozone is present in the upper member of the Los Azules Fm, where a hiatus that involve the upper Darriwilian and lower Sandbian was recognized between the *H. teretiusculus* and *C. bicornis* zones (Ortega, 1987; Ortega and Albanesi, 1998). Other records of the *C. bicornis* Zone correspond to the Sierra de La Invernada Fm in the eponymous locality (Furque et al., 1990), San Juan Precordillera.

Records of this biozone were also documented for the siliciclastic succession of the Cántaro de Oro Fm at El Tigre Range (Caballé et al., 1993), Western Precordillera. In the La Pola Fm, Villicum range, Eastern Precordillera, specimens of *D. ramosus ramosus* (HALL) and *D. nicholsoni* HOPKINSON suggesting the *C. bicornis* Zone were mentioned by Brussa et al. (2003a). Two other units containing *C. bicornis* Zone graptolites crop out in the Mendoza Province. One of them is the Empozada Fm, west of Mendoza city (Alfaro, 1988; Cuerda and Alfaro, 1993; Mitchell et al., 1998; Ortega and Albanesi, 1998; Ortega et al., 2007) in the Precordillera, and the other one is the Arroyo Pavón Fm at San Rafael Block, southern Mendoza Province (Cuerda et al., 1998).

Diplacanthograptus caudatus Zone

Strata between LIG16 and LIG20 yielded a younger graptolite assemblage preserved in shales and sandstones. In the lower part of this interval there were recorded *Corynoides* cf. *C. ultimus* RUEDEMANN, *Corynoides* cf. *C. americanus* RUEDEMANN, *Cryptograptus* cf. *C. insectiformis* RUEDEMANN, *Dicranograptus spinifer* ELLES and WOOD, *Dicranograptus* cf. *D. hians* T.S. HALL, *Neurograptus margaritatus* (LAPWORTH), *Orthograptus spinigerus* (ELLES and WOOD), *Orthoretiolites hami* WHITTINGTON, *Diplacanthograptus spiniferus* (RUEDEMANN), and *Diplacanthograptus caudatus* (LAPWORTH). Specimens of *Dicranograptus spinifer* and *Diplacanthograptus spiniferus* are particularly abundant in these levels. At LIG20, *D. caudatus* is associated with *Corynoides* sp. 1, *Dicellograptus*? sp., *Leptograptus*? sp., *Rectograptus* *amplexicaulis* (HALL), and *Rectograptus* sp. Elements of *Amorphognathus superbus* Rhodes are present on the same black shale bedding surfaces.

The mentioned graptolite assemblage was recently referred to the *D. caudatus* Zone by Ortega et al. (2007) following the scheme by Goldman (2003) and Goldman et al. (2007), as a distinguishable interval ranging between the *C. bicornis* Zone and the first appearance of the *Climacograptus tubuliferus* LAPWORTH. The first appearance datum (FAD) of *D. caudatus* marks the base of the Katian global Stage for the Upper Ordovician Series (Goldman et al., 2007), a level that can also be identified by the entrance of *C. americanus*, *D. hians*, *O. quadrimucronatus*, *O. pageanus*, and *N. margaritatus* (Goldman, 2003; Goldman et al., 2007). In the La Invernada Range, conglomerate and sandstone deposits make up a barren interval present between the *C. bicornis* assemblage and the entrance of the *D. caudatus* fauna. The record of *D. spiniferus* at LIG16 may indicate that the basal part of the *D. caudatus* Zone is not present in the studied section.

The *D. caudatus* Zone is nearly equivalent to the *Diplacantograptus lanceolatus* and *D. spiniferus* zones of Australasia (VandenBerg and Cooper, 1992), and the *Dicranograptus clingani* Zone from Scotland (Zalasiewicz et al., 1995) and Newfoundland (Williams, 1995). It also corresponds with the *Corynoides americanus* and *Diplacanthograptus spiniferus* zones of the south central USA (Finney, 1986; Goldman et al., 1999) and the *C. americanus*, *Orthograptus ruedemanni* and *D. spiniferus* zones of eastern North America (Riva, 1969, 1974). The studied interval is also coeval with the *Diplacanthograptus lanceolatus* and *Diplacanthograptus spiniferus* from the Kalpin area, Tarim region, China (Chen et al., 2000).

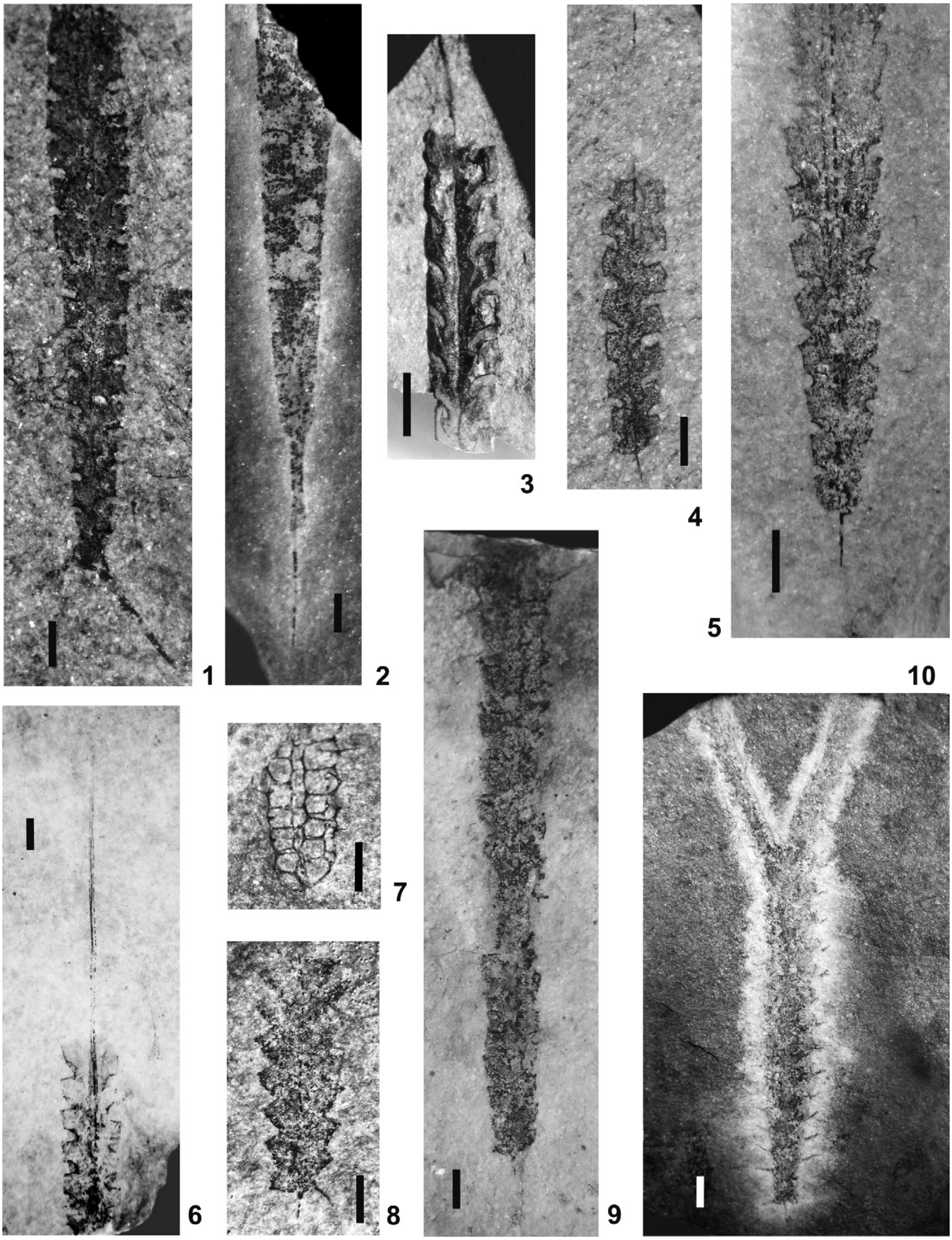
In the Argentine Precordillera a graptolite fauna probably equivalent to the *D. caudatus* Zone was mentioned by Ortega et al. (1991) in the Yerba Loca Fm (lately the Cántaro de Oro Fm sensu Caballé et al., 1993) on the profile of road nº 425 at El Tigre Range. This fauna, composed by *Dicellograptus* sp., *Orthograptus* spp. and *Orthoretiolites* spp., was identified as the "Caradoc post-*gracilis* assemblage" by the authors and correspond to the "not nominated interval" of the graptolite zonal scheme proposed by Albanesi and Ortega (2002). A similar assemblage comprising *Cryptograptus insectiformis* RUEDEMANN, *Corynoides calicularis* NICHOLSON, *Dicellograptus flexuosus* LAPWORTH, *Phormograptus sooneri* WHITTINGTON, *Orthoretiolites* cf. *hami robustus* SKEVINGTON, *Rectograptus* cf. *R. amplexicaulis* (HALL), *Orthograptus quadrimucronatus* (HALL) and *D. caudatus* (present only at the base of the succession) among others, was mentioned for the Yerba Loca Fm at El Tigre Range by Brussa (1995) and Brussa et al. (1999). The authors correlated that assemblage with the *Dicranograptus clingani* Zone and equivalents. Specimens of *Neurograptus* cf. *N. margaritatus* from the Cántaro de Oro Fm (= Sierra de La Invernada Fm in this paper) that crops out ca. 19 km south of provincial road nº 436 were reported by Cuerda et al. (1999). These fossils were referred to the *C. bicornis* Zone by the authors, although they seem to correspond to the younger *D. caudatus* Zone.

Climacograptus tubuliferus Zone

The entrance of *C. tubuliferus* was recorded at LIG21 in the uppermost part of the Sierra de La Invernada Fm, where most of the graptolites from the *C. caudatus* Zone have already disappeared (Ortega et al., 2007). The assemblage is composed of *C. tubuliferus*, which is the dominant taxon, and scarce rhabdosomes of *Corynoides* sp. 2, *R. amplexicaulis*, *Rectograptus* sp., *Orthograptus* sp., as well as probable retiolitid fragments. Graptolites are associated with conodonts of the *A. superbus* Zone, *Obolus* sp., particularly abundant in some layers, chitinozoans and scolecodonts. The monotonous *C. tubuliferus* fauna reveals a strong impoverishment in the diversity of the graptolite assemblages of the studied unit.

As pointed out by Goldman (2003) and Goldman et al. (2007), *C. tubuliferus* has a world-wide distribution (e.g., USA, Yukon Territory, Alaska, Newfoundland, Australasia, Scotia) appearing just above the *D. caudatus* assemblage. In the Argentine Precordillera it was recorded in the upper part of the Empozada Fm (Mendoza Province) in strata of the *D. complanatus* and *D. ornatus* zones (Mitchell et al., 1998). Other findings of this taxon correspond to the Pavón Fm, at San Rafael Block (Cuerda et al., 1998), and to the Alcaparrosa Fm, in the Western Precordillera (Brussa et al., 1999). The lowest *C. tubuliferus* record in the Sierra de La Invernada Fm, seems to correspond well with the FAD of this species in other parts of the world.

FIGURE 5 | **Late Darriwilian to early Katian graptolites of the Sierra de La Invernada Formation. Graptolite samples (LIG) are indicated in Figure 2. 1) *Diplacanthograptus spiniferus* (RUEDEMANN), LIG16, CORD-PZ 24854. 2) *Diplacanthograptus caudatus* (LAPWORTH), LIG20, CORD-PZ 24733. 3) *Archiclimacograptus* cf. *A. meridionalis* (RUEDEMANN), LIG8, CORD-PZ 24880, 4) *Archiclimacograptus modestus* (RUEDEMANN), LIG15, CORD-PZ 24261. 5) *Climacograptus tubuliferus* LAPWORTH, LIG23, CORD-PZ 25121. 6) *Climacograptus tubuliferus* LAPWORTH, LIG24, CORD-PZ 25132. 7) *Reteograptus geinitzianus* (HALL), LIG8, CORD-PZ 25155. 8) *Rectograptus amplexicaulis* (HALL), LIG20, CORD-PZ 24730. 9) *Hustedograptus* cf. *H. teretiusculus* (HISINGER), LIG8, CORD-PZ 25162. 10) *Dicranograptus spinifer* ELLES and WOOD, LIG17, CORD-PZ 24695. Scale bar: 1 mm.**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C. tubuliferus is part of the cosmopolitan mesopelagic biotope of the tropical Pacific Province during the Upper Ordovician (Goldman et al., 1995). Its presence represents the Oceanic biofacies in the upper part of the Sierra de La Invernada Fm, where it is associated with cosmopolitan epipelagic elements, such as *R. amplexicaulis*.

Conodonts

In the studied section, the Sierra de La Invernada Fm was sampled at levels LIC 0, 1, 2, 3, 4, 5, 8, and 11 for conodont biostratigraphy (Fig. 2). About 12 kg of calcarenite rocks, which are interbedded with fine sandstones and siltstones, were processed using conventional acid etching techniques (Stone, 1987) for the recovery of conodonts. Only samples LIC1 (2.4 kg, 555 conodont elements), LIC3 (1.2 kg, 332 conodonts), LIC8 (1.2 kg, 103 elements), and LIC11 (1.2 kg, 27 elements) were productive, yielding a total of 1017 conodont elements that represent the *Pygodus serra, P. anserinus, Amorphognathus tvaerensis*, and *A. superbus* zones. Some of these conodonts are moderately preserved showing signs of attrition, probably because of sedimentary transport as coeval intraclasts in early biostratinomic phases. All of collected conodont elements show CAI 3 indicating overburden paleotemperatures around 200ºC. Conodont specimens from samples LIG17, 20, 22, 23 and 24 are preserved as casts on bedding plane surfaces of shales, including species that represent the *Pygodus anserinus* and *Amorphognathus superbus* zones. Conodont elements from samples LIC1 and LIC3 were reworked from eroded lower strata. They show the same CAI 3 as the authochthonous elements, but their surfaces are slightly worn with a less vitreous reflectance. These conodont specimens are most probably referable to the Floian Stage, i.e., the *Prioniodus elegans* and *Oepikodus evae* zones.

All recorded species, illustrated in Figs. 6 and 7, are well-known taxa and were fully described by previous authors (see references in the following discussion of conodont zones). Additional comments on the taxonomy of these forms are not considered in present contribution.

Pygodus serra Zone

The conodont association recovered from sample LIC1 includes authochthonous and reworked specimens. The latter specimens are determined because of their restricted range to lower levels than those of the bearer bed, whose age is constrained by the dominant fauna. The latter taxa include, *Costiconus ethingtoni* (FÅHRAEUS), *Drepanodus reclinatus* (LINDSTRÖM), *Erismodus* sp., *Erraticodon* sp., *Periodon macrodentata* (GRAVES and ELLISON), and *Spinodus* sp. The ranges of these species are restricted to the Darriwilian Stage (Albanesi et al., 1998), and the appearance of the genus *Erismodus* probably represents the *Eoplacognathus suecicus* to *Pygodus serra* zonal interval, since the oldest members of the genus were recorded within the late Darriwilian in North American localities (cf. Harris et al., 1979; Bauer, 1987, 1994). The guide species *P. serra* (HADDING) was recorded in the study area of the La Invernada Range. It was recovered from a new section, between the Cerro Bayo and Vallecito localities, located about 15 km to the south of present profile, in a stratigraphic position that correlates closely with the location of level LIC1. Accordingly, it is possible to propose a confident assignment of the bearer level to the *P. serra* Zone, despite the absence of the guide species in the collection of the study section.

FIGURE 6 | **Late Darriwilian to early Katian conodonts from the Sierra de La Invernada Formation at study section. Conodont samples (LIC) are indicated in Figure 2. 1) *Baltoniodus alobatus* (BERGSTRÖM), Pb element, posterior view, LIC8, CORD-MP 11285. 2 and 3) *Drepanoistodus suberectus* (BRANSON and MEHL), 2: S element, lateral view, LIC8, CORD-MP 11286, 3: M element, lateral view, LIC8, CORD-MP 11287. 4-6) *Plectodina tenuis* (BRANSON and MEHL), 4: Sc element, lateral view, LIC8, CORD-MP 11288, 5: Pa element, lateral view, LIC8, CORD-MP 11289, 6: Sa element, posterior view, LIC8, CORD-MP 11290. 7 and 8) *Rhodesognathus elegans* (RHODES), 7: Pa element, inner lateral view, LIC8, CORD-MP 11291, 8: Pa element, outer lateral view, LIC8, CORD-MP 11292, 9) *Amorphognathus tvaerensis* BERGSTRÖM, Pb element, upper view, LIC8, CORD-MP 11293. 10) *Icriodella superba* RHODES, Pa element, upper view, LIC8, CORD-MP 11294. 11) *Pygodus anserinus* (LAMONT and LINDSTRÖM), Pa element, upper view, LIC3, CORD-MP 11295. 12) *Periodon macrodentata* (GRAVES and ELLISON), Sc element, lateral view, LIC1, CORD-MP 11296. 13) *Periodon aculeatus* HADDING, Pa element, lateral view, LIC3, CORD-MP 11297. 14) *Periodon grandis* (ETHINGTON), M element, lateral view, LIC11, CORD-MP 11298. 15) *Panderodus gracilis* (BRANSON and MEHL), S element, lateral view, LIC8, CORD-MP 11299. 16) *Scolopodus krummi* LEHNERT, lateral view, LIC3, CORD-MP 11300. 17, 18) *Drepanodus reclinatus* (LINDSTRÖM), 17: Sc element, lateral view, LIC3, CORD-MP 11275, 18: Sd element, lateral view, LIC3, CORD-MP 11276. 19) *Venoistodus balticus* LÖFGREN, M element, lateral view, LIC3, CORD-MP 11273. 20, 21) *Protopanderodus varicostatus* (SWEET and BERGSTRÖM), 20: M element, lateral view, LIC3, CORD-MP 11279; 21: P element, lateral view, LIC3, CORD-MP 11280. 22) *Costiconus ethingtoni* (FÅHRAEUS), S element, lateral view, LIC3, CORD-MP 11281. 23, 24) *Rossodus barnesi* ALBANESI, 23: P element, lateral view, LIC3, CORD-MP 11282; 24: Sa element, posterior view, LIC3, CORD-MP 11283. 25, 26) *Eoplacognathus lindstroemi* HAMAR, 25: Sinistral Pb element, upper view, LIC3, CORD-MP 11288; 26: Dextral Pb element, upper view, LIC3, CORD-MP 11289. 27, 28) *Drepanodus arcuatus* PANDER, 27: M element, lateral view, LIC1, CORD-MP 11336; 28: Sa element, lateral view, LIC1, CORD-MP 11337. 29) *Erismodus* sp. Sa element, posterior view, LIC1, CORD-MP 11338. 30) *Spinodus* sp., posterior process, undetermined element, lateral view, LIC1, CORD-MP 11339. 31) *Cahabagnathus* sp., Pa element, upper view, LIC1, CORD-MP 11340. 32) *Protopanderodus gradatus* SERPAGLI, Sa element, lateral view, LIC1, CORD-MP 11341. 33) *Paroistodus proteus* LINDSTRÖM, P element, lateral view, LIC1, CORD-MP 11342. 34) *Protopanderodus leonardii* SERPAGLI, S element, lateral view, LIC1, CORD-MP 11343. 35) *Erraticodon* sp., P element, lateral view, LIC1, CORD-MP 11344. 36, 37) *Tropodus sweeti* SERPAGLI, 36: M element, lateral view, LIC1, CORD-MP 11345; 37: Sa element, lateral view, LIC1, CORD-MP 11346. All illustrated conodont elements are conventional optical microphotographs.**


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The associated stratigraphic ranges of recorded reworked specimens span the time interval represented by the *Prionidous elegans* and *Oepikodus evae* zones: i.e., the Floian Stage of the Lower Ordovician Series. These species are *Paroistodus proteus* (LINDSTRÖM), *Protopanderodus gradatus* SERPAGLI, *P. leonardii* SERPAGLI, *Rossodus barnesi* ALBANESI, *Scolopodus krummi* (LEHNERT), and *Tropodus sweeti* (SERPAGLI). A similar species assemblage was recovered from transported clasts of basal conglomerates in the lower section of the Sierra de La Invernada Fm that crops out along the provincial road nº 436. The guide species *Oepikodus evae* is present in the conodont collection yielded by allochthonous clasts; in turn, this material is included in a matrix where the authochthonous assemblage is mid Darriwilian in age (Albanesi, unpublished collections).

The *P. serra* Zone was originally defined by Bergström (1971) in the Kalgärde Limestone, which is exposed at Dalarna, south-central Sweden. The intercontinental correlation of this unit and the lineage of *Pygodus* were discussed by Bergström (1983) and Zhang (1998). In the Argentine Precordillera, the *P. serra* Zone was identified firstly by Hünicken and Ortega (1987) in the Los Azules Fm of Central Precordillera, and subsequently recorded in dissimilar stratigraphic settings of the region (e.g., Albanesi et al., 1995; Heredia, 2001). A recent paper by Albanesi et al. (2007) discusses the correlation of this interval with the Capillas Fm from the Subandean Ranges and the corresponding Santa Gertrudis and Sepulturas formations from the Eastern Cordillera in northwesten Argentina.

Pygodus anserinus Zone

The conodont collection from sample LIC3 includes the following species: *Costiconus ethingtoni* (FÅHRAEUS), *Drepanodus reclinatus* (LINDSTRÖM), *Drepanoistodus suberectus* (BRANSON and MEHL), *Eoplacognathus lindstroemi* HAMAR, *Panderodus gracilis* (BRANSON and MEHL), *Periodon aculeatus* HADDING, *Protopanderodus gradatus* SERPAGLI (late form), *Protopanderodus varicostatus* (SWEET and BERGSTRÖM), *Pygodus anserinus* (LAMONT and LINDSTRÖM), and *Venoistodus balticus* LÖFGREN. We have also recorded some elements whose morphologies preclude taxonomic determination at the species level, and are illustrated under open nomenclature; i.e., *Cahabagnathus* sp. A few undetermined conodont fragments may belong to the genera *Amorphognathus, Baltoniodus, Erismodus,* and *Spinodus*.

The *Pygodus anserinus* Zone was defined by Bergström (1971) in a reference section at Dalarna, south-central Sweden. It is characterized by the eponymous species and other key taxa that allow for subdividing the unit in two subzones (Bergström, 1983), the *Sagittodontina kielcensis* and the *Amorphognathus inaequalis* subzones. The author remarked that in the absence of these species, the boundary between the subzones can be determined by transitional forms from the ancestral *Baltoniodus prevariabilis* to the evolved *B. variabilis*. Species of the genera *Complexodus* and *Cahabagnathus* could be also useful to recognize the lower or upper intervals of the *P. anserinus* Zone. Because none of these key taxa are present in our collection, we are not able to identify the subzone represented in sampled strata. The *P. anserinus* Zone spans a critical interval through the uppermost Middle Ordovician to the lowermost Upper Ordovician (i.e., upper Darriwilian to lower Sandbian stages). The base of the global Upper Ordovician Series, marked by the FAD of *Nemagraptus gracilis* coincides with the boundary between both subzones of the *P. anserinus* Zone (Bergström et al., 2000). Since the first appearance of *N. gracilis* in the studied section is a few meters above level LIC3, it is probable that the conodont fauna represents the lower subzone of the *Pygodus anserinus* Zone.

Significant information regarding the *P. anserinus* Zone, its associated fauna and biostratigraphic problems concerning the involved stratigraphic interval, was published by Bergström et al. (1987), and Bergström (1990) on the Welsh borderlands and the Girvan succession at south-west Scotland. Dzik (1994) provided related information on the Mójcza limestone, Poland, and Pålsson et al. (2002) on the Jämtland succession, central Sweden. Important referece papers that discuss the *P. anserinus* Zone in localities around the Laurentian margin are those by Bergström et al. (1974) in Newfoundland, Bergström (1978) in the Marathon area, west Texas, and Harris et al. (1979) in the Great Basin and Rocky Mountains. A recent paper by Agematsu et al. (2007) deals with significant information regarding the distribution of the *Pygodus* fauna in the southern peninsular Thailand. Zhen et al. (2003) recovered representatives of this fauna from the Wahring Limestone in Central New South Wales.

In the Argentine Precordillera, the *Pygodus anserinus* Zone has been recognized at several localities. Conodont associations of this unit were reported for the upper part of the Ponón Trehué Fm (= Lindero Fm of other authors), Mendoza Precordillera, which represents shallower environments than correlative studied strata of the Sierra de la Invernada Fm (Lehnert et al., 1999; Heredia, 2001). The nominal species of the *P. anserinus* Zone was also recorded from deeper water facies of the San Juan Precodillera in the Las Aguaditas Fm at Los Blanquitos Range (Keller et al., 1993) and Los Azules Fm at La Chilca Hill (Albanesi, unpublished data), south of Jáchal River.

Significantly, in the Central Precordillera of San Juan Province, an important hiatus that partly involves the

Pygodus serra and *P. anserinus* zones was documented in classical study localities, such as the Potrerillo Mountain (Albanesi et al., 1998) and Viejo Hill (Ottone et al., 1999). This hiatus corresponds to the Guandacol phase of the Ocloyic Orogeny (Furque, 1972), the name given to the extentional tectonics that caused deposition of thick slope megabrecchias, turbidites, and hypabisal intrusive bodies of Darriwilian age in different sectors of the Precordillera (Gosen, 1992; Ramos, 2004).

The conodont fauna from the late Darriwillian and early Sandbian of the Sierra de La Invernada Fm is largely dominated by *Periodon* and *Protopanderodus* species, which represent over 70% of the total fauna. This faunal composition was described by several authors as a recurrent conodont association or biofacies for deep-cold-water environments from platform margin to upper slope (Rasmussen, 1998). The conodont assemblage, which mostly comprises pandemic pelagic forms, refers to the Open-Sea Realm as defined by Zhen and Percival (2003). The fact that some Laurentian (warm) taxa, such as *Cahabagnathus*, occur in the samples from the Sierra de La Invernada Fm, suggests a temperate domain for the conodont paleobiogeography of the Precordillera at the end of Mid Ordovician times. Conodont paleoenvironmental constrains for the *Pygodus* zones in the Ponón Trehue Fm of the Cuyania terrane were published by Lehnert et al. (1999) and Heredia and Rosales (2006), who revealed the changing environmental conditions through the sedimentary unit by variations in the relative proportion of genera. The highest abundance of the genera *Periodon* and *Protopanderodus* corresponds to shelf margin environments, while *Periodon* is commonly replaced by *Pygodus* in deeper slope environments. Similar faunal changes are verified in the Sierra de la Invernada Fm although larger collections are required for statistical studies.

Amorphognathus tvaerensis Zone

The species assemblage yielded by sample LIC8 includes *Amorphognathus tvaerensis* BERGSTRÖM, *Baltoniodus alobatus* (BERGSTRÖM), *Drepanoistodus suberectus* (BRANSON and MEHL), *Icriodella superba* RHODES, *Plectodina tenuis* (BRANSON and MEHL), *Periodon grandis* (ETHINGTON), *Protopanderodus liripipus* KENNEDY, BARNES and UYENO, and *Rhodesognathus elegans* (RHODES). Although most of determined species were previously documented in the Precordillera from other formations (e.g., Heredia et al., 1990; Albanesi et al., 1998; Ortega and Albanesi, 1998), the presence of *B. alobatus*, which is here recorded for the first time from the Argentine Precordillera, indicates the homonymous subzone of the *A. tvaerensis* Zone as it was defined by Bergström (1971) in the Dalby Limestone of Sweden (upper Sandbian Stage). Apart from those localities with records of *B. alobatus* in the Baltoscandian region (Bergström, 1983) the biostratigraphic interval represented by this species has not been reported frequently, the data provided by Kennedy et al. (1979) is one of the few reports for North America. The characteristic and widespread species *I. superba*, *P. liripipus* and *R. elegans* make their first appearances in this interval and continue upwards through the next several Ordovician conodont zones. A remarkable example for these records is documented by Bergström and Mitchell (1992) dealing with the Mohawkian Utica Shale in the Eastern Midcontinent region of North America. In a recent work, Leslie (2000) demonstrates that the *Phragmodus undatus – Plectodina tenuis* zonal boundary of the North American scheme projects into Baltoscandian *Baltoniodus alobatus* Subzone of the *Amorphognathus tvaerensis* Zone on the basis of K-bentonite bed correlation (see discussion below).

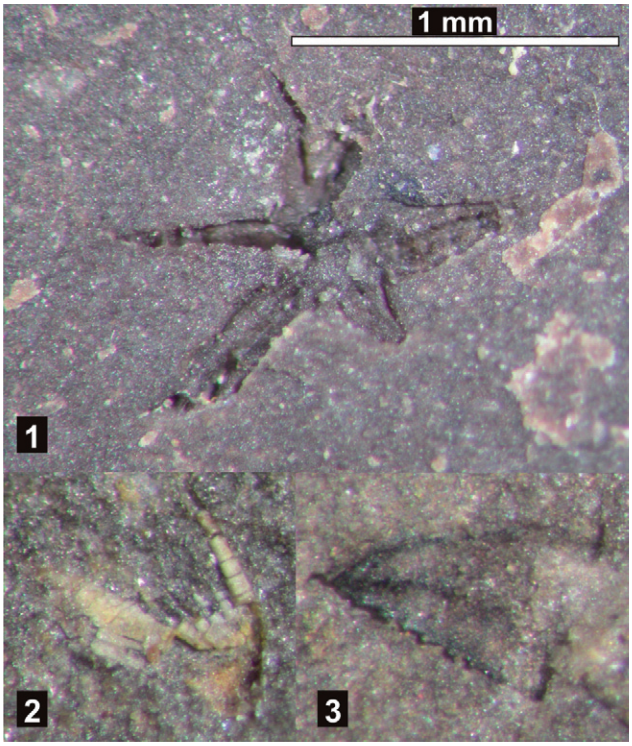

FIGURE 7 | **Conodonts preserved as casts on bedding planes from the Sierra de La Invernada Formation. These conodont elements are recorded from graptolitic samples (LIG) as indicated in Figure 2. 1) *Amorphognathus superbus* RHODES, sinistral Pa element, upper view, LIG17, CORD-MP 11290. 2) *Periodon aculeatus* HADDING, S element, lateral view, LIG8, CORD-MP 11291. 3) *Pygodus anserinus*? (LAMONT and LINDSTRÖM), Pa element, upper view, LIG 8, CORD-MP 11292.**

Amorphognathus superbus Zone

A number of specimens of *Amorphognathus superbus* Rhodes (Fig. 7) were recorded as casts on bedding plane surfaces of shales from the upper part of the studied section (samples LIG17, 20, 22, 24). The topmost calcareous sample of this section (LIC11) provided few remains of *Amorphognathus* associated with the dominant deep-water *Periodon grandis* - *Protopanderodus liripipus* conodont association. *A. superbus* is well known from cold-water environments in Europe and North America, its multielemental apparatus was fully described, and its evolutionary lineage depicted in detail (e.g., Bergström, 1983; Dzik, 1983, 1994).

A. superbus is the key index taxon for the homonymous zone of the Baltoscandian scheme, as originally defined by Bergström (1971) in Swedish reference sections. Although this author discussed the *Amorphognathus tvaerensis* - *A. superbus* zonal boundary to be near the top of the Dalby Limestone (near the Kinnekulle K-bentonite Bed), recent work by Leslie (2000) indicates that this zonal boundary could be within the overlying Skagen Limestone. In North America, the base of the *A. superbus* Zone is well above the Millbrig K-bentonite Bed (Bergström and Mitchell, 1994), supporting the correlations of Leslie (2000). Following the global chronostratigraphic standard, the *A. superbus* Zone spans in the lower Katian stage of the Upper Ordovician Series.

So far, the only record of related forms from the Argentine Precordillera was determined as *Amorphognathus* aff. *A. superbus* by Albanesi et al. (1995). This form was recorded in middle levels of the siliciclastic Trapiche Fm in the Potrerillo Mountain, Central Precordillera of San Juan Province.

CONCLUSIONS

According to the present study, the ancient layers (Darriwilian) of the Sierra de La Invernada Fm crop out in the eastern part of the investigated section in the northern La Invernada Range.

The upper Sierra de La Invernada Fm is divided on the basis of its sedimentary architecture and the nature of involved deposits into shallower and deeper environments recorded by changing facies intervals. The stratigraphic record resulted from response to sea level changes, which were in turn also reflected by variations of the graptolite-conodont faunal compositions throughout the surveyed column.

Six upper Middle to lower Upper Ordovician graptolite biozones are determined in this section; i.e., the *Pterograptus elegans* (tentative assignment), *Hustedograptus teretiusculus*, *Nemagraptus gracilis*, *Climacograptus bicornis*, *Diplacanthograptus caudatus*, and *Climacograptus tubuliferus* zones.

The *Pygodus serra* conodont zone is identified for the lower part of the section. The *P. anserinus, Amorphognathus tvaerensis,* and *A. superbus* conodont zones are recognized in the middle-upper section.

According to the graptolite and conodont records, the upper part of the Sierra de La Invernada Fm is referable to the upper Darriwilian, Sandbian and lower Katian stages, following the new global nomenclature (see ISOS-IUGS web site: http://www.ordovician.cn; Bergström et al., 2006), which correlates with the upper Llanvirn to upper Caradoc Series of the British scale.

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REFERENCES

Agematsu, S., Sashida, K., Salyapongse, S., Sardsud, A., 2007. Ordovician conodonts from the Satun area, southern Peninsular Thailand. Journal of Paleontology, 81, 19-37.

Albanesi, G.L., Ortega, G., 2002. Advances on conodont-graptolite biostratigraphy of the Ordovician System of Argentina. In: Aceñolaza, F.G. (ed.). Aspects of the Ordovician System in Argentina. Tucumán, INSUGEO, Serie Correlación Geológica, 16, 143-165.

Albanesi, G.L., Hünicken, M.A., Barnes, C.R., 1998. Bioestratigrafía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, República Argentina. Córdoba, Actas de la Academia Nacional de Ciencias, 12, 7-72.

Albanesi, G.L., Hünicken, M.A., Ortega, G., 1995. Review of Ordovician conodont-graptolite bioestratigraphy of the Argentine Precordillera. 7th International Symposium on the Ordovician System, Las Vegas, 31-35.

Albanesi, G.L., Monaldi, C.R., Ortega, G., Trotter, L.A., 2007. The Capillas Fm (late Darriwilian) of Subandean Ranges, northwestern Argentina; age, correlation and environmental constraints. In: Li, J., Fan, J., Percival, I. (eds.). The Global Ordovician and Silurian. Acta Palaeontologica Sinica, 46, 9-15.

Alfaro, M., 1988. Graptolitos del Ordovícico Superior (Caradociano) de la quebrada Agua de la Cruz, Precordillera de Mendoza. Ameghiniana, 25, 299-303.

Astini, R.A., 2003. The Ordovician Proto-Andean basins. In: Benedetto, J.L. (ed.). Ordovician fossils of Argentina. Universidad Nacional de Córdoba, Secretaría de Ciencia y Tecnología: 1-74.

Astini, R.A., Brussa, E.D., 1997. Dos nuevas localidades fosilíferas en el Conglomerado de Las Vacas (Caradociano) en la Precordillera Argentina: Importancia cronoestratigráfica. Ameghiniana, 34, p. 114.

Banchig, A.L., 1995. Evolución del talud continental Cámbrico – Ordovícico entre el Río San Juan y Los Sombreros, San Juan. Doctoral thesis. Universidad Nacional de San Juan, 202 pp.

Banchig, A.L., 1996. Litofacies y paleoambiente sedimentario del Ordovícico clástico de la Sierra de La Invernada, (Formación Sierra de La Invernada), Precordillera Central, San Juan. VI Reunión Argentina de Sedimentología, Bahía Blanca, 111-116.

Banchig, A.L, Weidmann, C., Marchese, N., Federico, S., 2004. Vulcanismo submarino y flujos sedimentarios asociados, sur de la Sierra de La Invernada.Descripción e interpretación, Precordillera Occidental, San Juan. X Reunión Argentina de Sedimentología, San Luis, Actas de Resúmenes, 25-26.

Banchig, A.L., Ortega, G., Albanesi, G.L., Peralta, G.L., Voldman, G.G., 2007. Análisis litofacial y bioestratigráfico de eventos eustáticos en el lapso darriwiliano-katiano (Ordovícico Medio – Superior), en la sierra de La Invernada, Precordillera Central, Argentina. In: Díaz-Martínez, E., Rábano, I. (eds.). 4th European Meeting on the Palaeontology and Stratigraphy of Latin America, Madrid, Cuadernos del Museo Geominero, 8, 33-38.

Basilici, G., Cutolo, A., Gomes Borges, J.P., Henrique, A., Moretti, P.A., 2005. Ordovician storm-dominated basin and the evolution of the western Gondwana margin (Portezuelo del Tontal, Sierra de La Invernada and Yerba Loca formations, Argentine Precordillera). In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12 "Geological and Biological Heritage of Gondwana", Mendoza, Academia Nacional de Ciencias, Abstracts, p. 64.

Bauer, J.A., 1987. Conodonts and conodont biostratigraphy of the McLish and Tulip Creek Formations (Middle Ordovician) of south-central Oklahoma. Oklahoma Geological Survey Bulletin, 141, 1-53.

Bauer, J.A., 1994. Conodonts from the Bromide Formation (Middle Ordovician), South-Central Oklahoma. Journal of Paleontology, 68, 358-376.

Benedetto, J.L., Herrera, Z.A., Ortega, G., 1991. Bioestratigrafía del Ordovícico en el flanco occidental del cerro Potrerillo, Provincia de San Juan. Revista de la Asociación Geológica Argentina, 56, 60-68.

Bergström, S.M., 1971. Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and eastern North America. In: Sweet, W.C., Bergström, S.M. (eds.). Symposium on conodont biostratigraphy, Columbus, Geological Society of America Memory, 127, 83-157.

Bergström, S.M., 1978. Middle and Upper Ordovician conodont and graptolite biostratigraphy of the Marathon, Texas graptolite zone reference standard. Palaeontology, 21, 723-758.

Bergström, S.M., 1983. Biogeography, evolutionary relationships, and biostratigraphic significance of Ordovician platform conodonts. Fossils and Strata, 15, 35-58.

Bergström, S.M., 1990. Biostratigraphic and biogeographic significance of Middle and Upper Ordovician conodonts in the Girvan succession, South-west Scotland. Courier Forschungsinstitut Senckenberg, 118, 1-43.

Bergström, S.M., Mitchell, C.E., 1992. The Ordovician Utica Shale in the Eastern Midcontinent Region: age, lithofacies, and regional relationships. Oklahoma Geological Survey Bulletin, 145, 1-86.

Bergström, S.M., Mitchell, C.E., 1994. Regional relationships between late Middle and early Late Ordovician standard successions in New York and Quebec and the Cincinnati region in Ohio, Indiana, and Kentucky. New York State Museum Bulletin, 481, 5–10.

Bergström, S.M., Rhodes, F.H.T., Lindström, M., 1987. Conodont biostratigraphy of the Llanvirn-Llandeilo and Llandeilo-Caradoc Series boundaries in the Ordovician System of Wales and the Welsh Borderland. In: Austin, R.L. (ed.). Conodonts: Investigative Techniques and Applications. Chichester, Ellis Horwood Limited, 294-315.

Bergström, S.M., Riva, J., Kay, M., 1974. Significance of conodonts, graptolites, and shelly faunas from the Ordovician of Western and North-Central Newfoundland. Canadian Journal of the Earth Sciences, 11, 1625-1660.

Bergström, S.M., Finney, S.C., Chen Xu, Goldman, D., Leslie, S.A., 2006. Three new Ordovician global stage names. Lethaia, 39, 287-288.

Bergström, S.M., Finney, S.C., Chen Xu, Pålsson, C., Wang Zhi-hao, Grahn Y., 2000. A proposed global boundary stratotype for the base of the Upper Series of the Ordovician System: The Fågelsång section, Scania, southern Sweden. Episodes, 23, 102-109.

Berry, W.B.N., 1960. Graptolite faunas of the Marathon region, West Texas. University Texas Publication, 6005, 179 pp.

Blasco, G., Ramos, V.A., 1976. Graptolitos caradocianos de la Formación Yerba Loca y del cerro La Chilca, departamento de Jáchal, provincia de San Juan. Ameghiniana, 13, 312-329.

Brussa, E.D., 1995. Upper Middle Ordovician graptolites from the Western Precordillera, Argentina. 5th International Graptolite Conference, Long Beach, Graptolite News, 8, 15-16.

Brussa, E.D., 1996. Las graptofaunas ordovícicas de la Formación Las Aguaditas, Precordillera de San Juan, Argentina. Parte I. Ameghiniana, 33, 421-434.

Brussa, E.D., 1997a. La Biozona de *Paraglossograptus tentaculatus* (Graptolithina) en la Formación Sierra de La Invernada, Precordillera Occidental, Argentina. Geobios, 30, 15-29.

Brussa, E.D., 1997b. Graptolitos del Arenigiano tardío-Llanvirniano de la Formación Sierra de La Invernada, Precordillera Occidental sanjuanina, Argentina. Parte 1. Ameghiniana, 34, 357-372.

Brussa, E.D., 1997c. Graptolitos del Arenigiano tardío-Llanvirniano de la Formación Sierra de La Invernada, Precordillera Occidental sanjuanina, Argentina. Parte 2. Ameghiniana, 34, 373-383.

Brussa, E.D., 1999. El género *Holmograptus* (Graptolithina) en el Ordovícico de la Precordillera Occidental argentina. Revista Española de Paleontología, 14, 183-190.

Brussa, E.D., Mitchell, C.E., Astini, R.A., 1999. Ashgillian (Hirnantian ?) graptolites from the western boundary of the Argentine Precordillera. In: Kraft, P., Fatka, O., (eds.). Quo vadis Ordovician? 8th ISOS, Praghe, Acta Universitatis Carolinae, Geologica, 43, 199-202.

Brussa, E.D., Toro, B.A., Benedetto, J.L., 2003a. Biostratigraphy. In: Benedetto, J.L. (ed.). Ordovician fossils of Argentina. Universidad Nacional de Córdoba, Secretaría de Ciencia y Tecnología: 75-90.

Brussa, E.D., Mitchell, C.E., Ortega, G., Maletz, J., Astini, R.A, 2003b. Middle Ordovician graptolite biostratigraphy from the Los Azules Formation at Los Gatos Creek, Central Precordillera, Argentina. In: Ortega, G., Aceñolaza, G.F. (eds.). Proceedings 7th International Graptolite Conference and Field Meeting of the International Subcommission on Silurian Stratigraphy. Tucumán, INSUGEO, Serie Correlación Geológica, 18, 21-25.

Caballé, M., Cuerda, A.J., Alfaro, M., Furque, G., 1993. Nuevos hallazgos de graptolitos en el Ordovícico de la sierra del Tigre, Precordillera de San Juan. XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos, Mendoza, Actas II, 268-280.

Caballé, M., Furque, G., Cuerda, A.J., Alfaro, M., 1992. Nuevos hallazgos de graptolitos en la Formación Sierra de La Invernada (Ordovícico), Precordillera de San Juan, Argentina. Ameghiniana, 29, 9-26.

Caballé, M., Furque, G., González, P., Cuerda, A.J., Alfaro, M., 1997. Nuevos datos sobre la bioestratigrafía del Ordovícico de San Juan, Argentina. II Jornadas de Geología de Precordillera, San Juan, Actas, 22-28.

Chen, Xu, Ni, Yu-Nan, Mitchell, C.E., Qiao, Xin-Dong, Zhan, Shi-Gao, 2000. Graptolites from the Qilang and Yigan Formations (Caradoc, Ordovician) of Kalpin, Western Tarim, Xinjiang, China. Journal of Paleontology, 74, 282-300.

Cuerda, A.J., Alfaro, M., 1993. Faunas graptolíticas. In: Ramos, V.A. (ed.). XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos, Mendoza, Relatorio II, 287-292.

Cuerda, A.J., Alfaro, M., Caballé, M., 1999. *Neurograptus* cf. *N. margaritatus* (LAPWORTH) (Graptolithina) en la sierra de La Invernada (Ordovícico), Precordillera de San Juan, Argentina. Ameghiniana, 36, 49-54.

Cuerda, A.J., Cingolani, C.A., Manassero, M., 1998. Caradoc age of the graptolite assemblages and facial relations from the cerro Bola section, San Rafael Block, Mendoza Province, Argentina. In: Gutiérrez-Marco, J.C., Rábano, I. (eds.). Proceedings 6th International Graptolite Conference (GWG-IPA) and 1998 Field Meeting of the IUGS Subcommission on Silurian Stratigraphy, Madrid, Temas Geológico-Mineros ITGE, 23, 170-173.

Cuerda, A.J., Cingolani, C.A., Schauer, O.C., Varela, R., 1986. Bioestratigrafía del Ordovícico (Llanvirniano-Llandeiliano) de la sierra del Tontal, Precordillera de San Juan. Descripción de su fauna graptolítica. Ameghiniana, 23, 3-33.

Dzik, J., 1983. Relationships between Ordovician Baltic and North American Midcontinent conodont faunas. Fossils and Strata, 15, 59-86.

Dzik, J., 1994. Conodonts of the Mójcza Limestone. In: Dzik, J., Olempska, E., Pisera, A. (eds.). Ordovician carbonate platform ecosystem of the Holy Cross Mountains. Palaeontologia Polonica, 53, 43-128.

Finney, S.C., 1986. Graptolite biofacies and correlation of eustatic, subsidence, and tectonic events in the Middle and Upper Ordovician of North America. Palaios, 1, 435-461.

Finney, S.C., Bergström, S.M., 1986. Biostratigraphy of the Ordovician *Nemagraptus gracilis* Zone. In: Hughes, C.P., Rickards, B.R. (eds.). Palaeoecology and biostratigraphy of graptolites, Gelogical Society Special Publication, 20, 47-59.

Furque, G., 1972. Los movimientos caledónicos en Argentina. Revista Museo de La Plata, (n.s.) 8, 129-136.

Furque, G., 1983. Descripción Geológica de la Hoja 19c, Ciénaga de Gualilán. Buenos Aires, Boletín de la Secretaría de Minería, 193, 111 pp.

Furque, G., Caballé, M., 1985. Paleozoico Inferior en el Cerro Bayo, Sierra de la Invernada, San Juan. Revista del Museo de la Plata (Nueva Serie), Geología, 10(81), 1-18.

Furque, G., Caballé, M., 1988. Descripción Geológica de la Sierra de La Invernada, Precordillera de San Juan. Buenos Aires, Dirección Nacional de Geología y Minería, 120 pp. (unpublished)

Furque, G., Cuerda, A.J., Caballé, M., Alfaro, M., 1990. El Ordovícico de la Sierra de la Invernada y su fauna de graptolitos, San Juan. Revista del Museo de la Plata (N.S.) Paleontología 9(56), 159-181.

Goldman, D., 2003. The *Diplacanthograptus caudatus* Zone: a proposal for a new, globally recognizable, Upper Ordovician graptolite zone. In: Albanesi, G.L., Beresi, M.S., Peralta, S.H. (eds.). Ordovician from the Andes. INSUGEO, Serie Correlación Geológica, 17, 65-70.

Goldman, D., Bergström, S.M, Mitchell, C.E., 1995. Revision of the Zone 13 graptolite biostratigraphy in the Marathon, Texas, standar succession and its bearing on Upper Ordovicidan graptolite biogeography. Lethaia, 28, 115-128.

Goldman, D., Mitchell, C.E., Joy, M.P, 1999. The stratigraphic distribution of graptolites in the classic Middle Ordovician Utica Shale of New York State: an evolutionary succession or a response to relative see-level change? Paleobiology, 25, 273-294.

Goldman, D., Leslie, S.A., Nõlvak, J., Young, S., 2007. The Black Knob Ridge section, Southeastern Oklahoma, USA: The global stratotype-section and point (GSSP) for the base of the Katian Stage of the Upper Ordovician Series. Acta Palaeontologica Sinica, 46 (Suppl.), 144-154.

Gosen, W. von, 1992. Structural evolution of the Argentine Precordillera: the Río San Juan section. Journal of Structural Geology, 14, 643-667.

Harris, A.G., Bergström, S.M., Ethington, R.L., Ross, R.J., Jr., 1979. Aspects of Middle and Upper Ordovician conodont biostratigraphy of carbonate facies in Nevada and southeast California and comparison with some Appalachian successions. In: Sandberg, C.A., Clark, D.L. (eds.). Conodont Biostratigraphy of the Great Basin and Rocky Mountains. Brigham Young University Geology Studies, 26, 7-43.

Heredia, S., 2001. Late Llanvirn conodonts from the Ponón Trehué Formation, Mendoza, Argentina. Gaia, 16, 101-117.

Heredia, S., Rosales, C., 2006. Biofacies de conodontes de la Formación Ponon Trehué y la importancia bioestratigráfica, sección tipo para el límite del Ordovícico Medio- Ordovícico Superior de Cuyania (Argentina). Temas de la Geología Argentina, INSUGEO, Serie Correlación Geológica, 21, 7-16.

Heredia, S., Gallardo, G., Maldonado, A., 1990. Conodontes caradocianos en las calizas alóctonas del miembro superior de la Formación Empozada (Ordovícico Medio y Superior), San Isidro (Mendoza, Argentina). Ameghiniana, 27, 197-206.

Hünicken, M.A., Ortega, G., 1987. Lower Llanvirn-Lower Caradoc (Ordovician) conodonts and graptolites from the Argentine Central Precordillera. In: Austin, R.L. (ed.). Conodonts: Investigative Techniques and Applications. Chichester, Ellis Horwood Limited, 136-145.

Keller, M., Eberlein, S., Lehnert, O., 1993. Sedimentology of Middle Ordovician carbonates in the Argentine Precordillera: Evidence for regional relative sea-level changes. Geologische Rundschau, 82, 362-377.

Kennedy, D.J., Barnes, C.R., Uyeno, T.T., 1979. A Middle Ordovician conodont faunule from the Tetagouche Group, Camel Back Mountain, New Brunswick. Canadian Journal of Earth Sciences, 16, 540-551.

Lehnert, O., Bergström, S.M., Keller, M., Bordonaro, O., 1999. Ordovician (Darriwilian-Caradocian) conodonts from the San Rafael Region, west-central Argentina: biostratigraphic, paleoecologic, and paleogeographic implications. Boletino della Società Paleontologica Italiana, 37, 199-214.

Leslie, S.A., 2000. Mohawkian (Upper Ordovician) conodonts of Eastern North America and Baltoscandia. Journal of Paleontology, 74, 1122-1147.

Maletz, J., 1997. Graptolites from the *Nicholsonograptus fasciculatus* and *Pterograptus elegans* (Abereiddian, Ordovician) of the Oslo region, Norway. Greifswalder Geowissenschaftliche Beiträge, 4, 5-98.

Mitchell, C.E., Brussa, E.D., Toro, B.A., Astini, R.A., 1998. Late Ordovician graptolites from the Empozada Formation, Argentine Precordillera, an outer shelf, cool water, peri-Gondwanan assemblage? In: Gutiérrez-Marco, J.C., Rábano, I. (eds.). Proceedings 6th International Graptolite Conference (GWG-IPA) and 1998 Field Meeting of the IUGS Subcommission on Silurian Stratigraphy, Madrid, Temas Geológico-Mineros ITGE, 23, 224-226.

Nõlvak, J., Goldman, D., 2007. Bioestratigraphy and taxonomy of three-dimensionally preserved nemagraptids from the Middle and Upper Ordovician of Baltoscandia. Journal of Paleontology, 81, 254-260.

Ortega, G., 1987. Las graptofaunas y los conodontes de la Formación Los Azules, Cerro Viejo, zona de Huaco, Departamento Jáchal, San Juan. Doctoral Thesis. Universidad Nacional de Córdoba, 210 pp.

Ortega, G., 1995. Graptolite zones of the Los Azules Formation (Middle Ordovician) from Precordillera, western Argentina. 5º International Graptolite Conference, Long Beach, Graptolite News, 8, 57-59.

Ortega, G., Albanesi, G.L., 1998. The record of *Nemagraptus gracilis* Biozone in the Argentine Precordillera. In: Gutiérrez-Marco, J.C., Rábano, I. (eds.). Proceedings 6th International Graptolite Conference (GWG-IPA) and 1998 Field Meeting, IUGS Subcommission on Silurian Stratigraphy, Madrid, Temas Geológico-Mineros ITGE, 23, 231-235.

Ortega, G., Brussa, E.D., 1990. La Subzona de *Climacograptus bicornis* (Caradociano temprano) en la Formación Las Plantas en su localidad tipo, Precordillera de San Juan, Argentina. Ameghiniana, 27, 281-288.

Ortega, G., Brussa, E.D., Astini, R.A., 1991. Nuevos hallazgos de graptolitos en la Formación Yerba Loca y su implicancia estratigráfica, Precordillera de San Juan, Argentina. Ameghiniana, 28, 163-178.

Ortega, G., Albanesi, G.L., Banchig, L.A., Peralta, G.L., 2004. Bioestratigrafía de graptolitos y conodontes de la Formación Sierra de La Invernada (Ordovícico Medio a Superior), Precordillera de San Juan, Argentina. Ameghiniana, Suplemento, 41, p. 17.

Ortega, G., Albanesi, G.L., Banchig, L.A., Peralta, G.L., 2006. Graptolitos y conodontes del Ordovícico Medio y Superior en la Sierra de La Invernada, Precordillera de San Juan, Argentina. 9º Congreso Argentino de Paleontología y Bioestratigrafía, Simposio 2, Bioestratigrafía del Paleozoico Inferior, Córdoba, p. 162.

Ortega, G., Albanesi, G.L., Banchig, L.A., Peralta, G.L., 2007. Graptolites and conodonts of early Katian age (Late Ordovician) from the Sierra de La Invernada Formation, San Juan Precordillera, Argentina. Acta Palaeontologica Sinica, 46 (Suppl.), 357-363.

Ortega, G., Albanesi, G.L., Heredia, S.E., Beresi, M.S., 2007. Nuevos registros de graptolitos y conodontes ordovícicos de las formaciones Estancia San Isidro y Empozada, quebrada San Isidro, Precordillera de Mendoza. Ameghiniana, 44, 697-718.

Ottone, E.G., Albanesi, G.L., Ortega, G., Holfeltz, G.D., 1999. Palynomorphs, conodonts and associated graptolites from the Ordovician Los Azules Formation, Central Precordillera, Argentina, Micropaleontology, 45, 225-250.

Pålsson, C., Månsson, K., Bergström, S.M., 2002. Biostratigraphical and palaeoecological significance of graptolites, trilobites and conodonts in the Middle Upper Ordovician Andersö Shale: an unusual "mixed facies" deposit in Jämtland, central Sweden. Transactions of the Royal Society of Edinburgh, Earth Sciences, 93, 35-57.

Peralta, S.H., 1990. Nuevas graptofaunas de la Formación La Cantera, sierra de Villicum, Precordillera Oriental de San Juan, Argentina. V Congreso Argentino de Paleontología y Bioestratigrafía, Tucumán, Actas, 1, 59-66.

Peralta, S.H., Finney, S.C., 2002. The Upper Ordovician graptolite faunas of the Cuyania Terrane: Their biostratigraphic and paleogeographic significance in the western margin of Gondwana. In: Aceñolaza, F.G. (ed.). Aspects of the Ordovician System in Argentina. Tucumán, INSUGEO, Serie Correlación Geológica, 16, 41-70.

Peralta, S.H., Finney, S.C., Basilici, G., 2003. Portezuelo del Tontal Formation (Lower Caradoc), Western Precordillera, San Juan Province: its biostratigraphic and paleogeographic significance. In: Albanesi, G.L., Beresi, M.S., Peralta, S.H. (eds.). Ordovician from the Andes. Tucumán, INSUGEO, Serie Correlación Geológica, 17, 119-124.

Ramos, V.A., 2004. Cuyania, an exotic block to Gondwana: Review of a historical success and the present problems. Gondwana Research, 7, 1009-1026.

Rasmussen, J.A., 1998. A reinterpretation of the conodont Atlantic Realm in the late Early Ordovician (early Llanvirn). In: Szaniawski, H. (ed.). Proceedings of the Sixth European Conodont Symposium. Palaeontologia Polonica, 58, 67-77.

Riva, J., 1969. Middle and Upper Ordovician graptolite faunas of St. Lawrence Lowlands of Quebec, and of Anticosti Island. American Association of Petroleum Geologists Memoir, 112, 579-595.

Riva, J., 1974. A revision of some Ordovician graptolites of eastern North America. Palaeontology, 17, 1-40.

Stone, J., 1987. Review of investigative techniques used in the study of conodonts. In: Austin, R.L. (ed.). Conodonts: Investigative Techniques and Applications. Chichester, Ellis Horwood Limited, 17-34.

VandenBerg, A.H.M., Cooper, R.A., 1992. The Ordovician graptolite sequence of Australasia. Alcheringa, 16, 33-85.

Webby, B.D., Cooper, R.A., Bergström, S.M., Paris, F., 2004. Stratigraphic framework and time slices. In: Webby, B.D., Paris, F., Drosser, M.L., Percival, I.G. (eds.). The great Ordovician biodiversification event. New York, Columbia University Press, 41-47.

Williams, S.H., 1994. Revision and definition of the *C. wilsoni* graptolite Zone (middle Ordovician) of South Scotland. Transactions of the Royal Society of Edinburgh (Earth Sciences), 85, 143-157.

Williams, S.H., 1995. Middle Ordovician graptolites from the Lawrence Harbour Formation, central Newfoundland, Canada. Palaeontographica Abt. A, 235, 21-77.

Zalasiewicz, I., Rushton, A.W.A., Owen, A.W., 1995. Late Caradoc graptolitic faunal gradients across the Iapetus Ocean. Geological Magazine, 132, 611-617.

Zhang, J., 1998. The Ordovician conodont genus *Pygodus*. Palaeontologia Polonica, 58, 1-287.

Zhen, Y-Y., Percival, I.G., 2003. Ordovician conodont biogeography – reconsidered. Lethaia, 36, 357-370.

Zhen, Y-Y., Percival, I.G., Webby, B.D., 2003. Conodont faunas from the Mid to Late Ordovician Boundary interval of the Wahringa Limestone Member (Fairbridge Volcanics), Central New South Wales. Proceedings of the Linnean Society of New South Wales, 125, 141-164.

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