Geologica Acta, Vol.9, Nº 2, June 2011, 187-197
DOI: 10.1344/105.000001691
Available online at www.geologica-acta.com

geologica acta

Ordovician conodonts of the Devendeus Formation at the Angosto de La Quesera (Cordillera Oriental of Salta, Argentina): Taxonomic considerations and biostratigraphic significance

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ABSTRACT

Conodonts recovered from the Devendeus Formation at the Angosto de La Quesera locality (Cordillera Oriental of Salta) in northwestern Argentina include *Nogamiconus* sp., *Problematoconites perforatus, Drepanoistodus* sp., *Oneotodus* sp., *Scolopodus filosus, Teridontus nakamurai* and *Variabiloconus* sp., as a part of an association that defines a pre-*Paltodus deltifer* Zone. The material most likely represents the *Cordylodus angulatus* and/or the lower part of the *Rossodus manitouensis* Zone. These microfossils support the dating of the Devendeus Formation as Tremadocian (Early Ordovician).

KEYWORDS | **Ordovician. Conodonts. Devendeus Formation. Northwestern Argentina.**

INTRODUCTION

The Angosto de La Quesera is a typical locality in the geological studies of the Argentine Cordillera Oriental of northwest Argentina (Keidel, 1943; Kilmurray and Igarzábal, 1971; Ramos, 1973). The sequence that crops out in this area is represented by an impressive coarse conglomeratic unit, unique in the Lower Paleozoic Central Andean Basin of South America. Research in the area has resulted in numerous observations and interpretations focused mainly on stratigraphic and genetic aspects of the unit (Keidel, 1943; Moya, 1988, 1999; Hongn et al., 2001a, b).

This peculiar conglomeratic sequence has been defined as the Devendeus Formation by Astini (2005), and its geological interest was renewed through recent investigations that have focused on the several aspects of relevance, such as the chronostratigraphy and the fossils of the Cambro-Ordovican sequences in NW Argentina (Moya et al., 2003; Aceñolaza et al., 2003; Hongn et al., 2003; Astini, 2005).

In this sense, the finding of several faunal elements as conodonts and graptolites clarified the chronostratigraphic positioning of the Devendeus Formation, allowing a better understanding of the temporal evolution, and the regional

bio- and lithostratigraphic scheme (Moya, 1988; Moya et al., 1994, 2003; Aceñolaza, 1997; Leme et al., 2003; Ortega and Albanesi, 2005; Beresi et al., 2006).

This contribution extends the paleontological information related to the Devendeus Formation (Angosto de La Quesera conglomerate), providing additional elements to define its chronostratigraphical framework. The analyzed conodont association of the Devendeus Formation was recovered from the conglomerate clasts constraining its age up to the *Cordylodus angulatus* or pre-*Paltodus deltifer* Zones (early Tremadocian) thus supporting the age pointed out by Aceñolaza et al. (2003). No conodonts were recovered from matrix. In addition, the overlying graptolite fauna places a minimum age of Lower Tremadocian for the analyzed unit (Moya, 1988; Moya et al., 1994).

STRATIGRAPHY

The Angosto de La Quesera locality is situated in the upper part of the Quebrada del Toro in the western sector of the Cordillera Oriental of Salta Province (Fig. 1).

The Devendeus Formation has been interpreted as an incised valley depositional system on a shallow marginal marine platform (Aceñolaza et al., 2003). Given the particular genetic nature of the unit, it is stratigraphically limited by other Paleozoic units that crop out in the area. At the investigated locality, the base of the unit is an erosive surface developed on the Padrioc Formation, and underlies the sandstones and shales of the Saladillo Formation (Aceñolaza, 2005) (Fig. 2).

The sandstones underlying the Devendeus Formation conglomerate belong to the Padrioc Formation, and the previous assignment to the Cardonal Formation is discarded. In the northwest sector of the area, the Padrioc Formation is overlaid by the highly fossiliferous Lampazar Formation, with the well-developed biozone of *Parabolina* (*N.*) *frequens argentina* (uppermost Cambrian) (Pinilla et al., 2007, 2008; Simoes and Aceñolaza, 2009). The Lampazar Formation is stratigraphically followed by a scarcely developed outcrop that could be partially related to the Cardonal Formation, and both units are overlain by the conglomerates representing the base of the Ordovician Devendeus Formation (Aceñolaza, 2005).

The assignment to Mesón Group of the sandstones below the conglomerates in Aceñolaza et al. (2003), and to the Mesón Grupo *s.l.* in Leme et al. (2003) was carried out following the classical stratigraphical schemes for this area. These schemes were replaced after a detailed stratigraphic characterization of the rocks which, together with the finding of additional fossil associations, helped on the identification and differentiation of units. In addition,

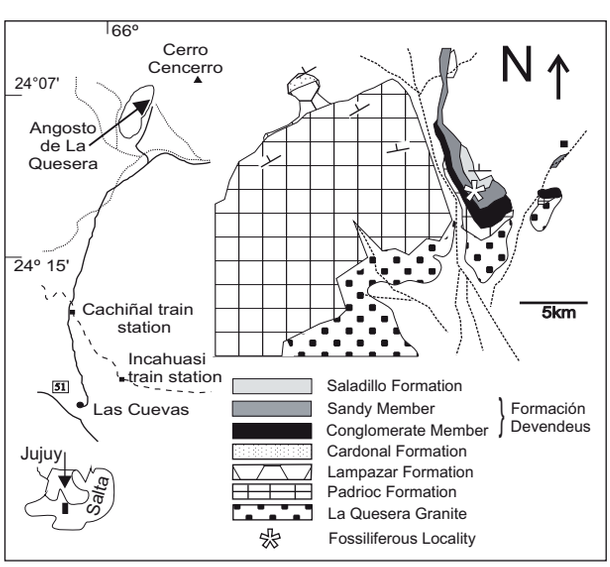

FIGURE 1 | **Location map of the Angosto de La Quesera in the Cordillera Oriental of Salta province (modified from Hongn et al., 2001b and Aceñolaza et al., 2003).**

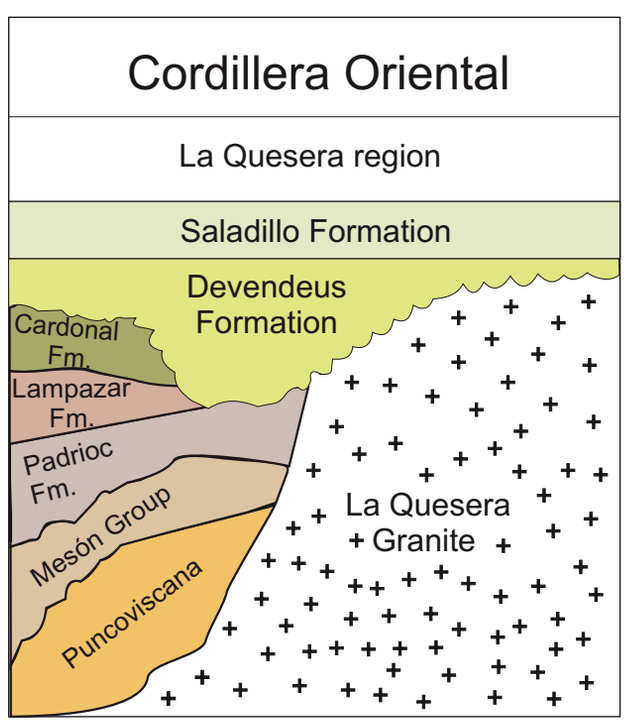

FIGURE 2 | **Stratigraphic relations of the lithological units at the Angosto de La Quesera locality, Cordillera Oriental of Salta province, NW Argentina.**

the lack of faunas that support an assignment of sandstones located below the Devendeus Formation to the Cardonal Formation is particularly remarkable. Local bio and chronostratigraphic information that considers lithology, stratigraphy, ichnology, and faunas, does not contribute to a clear differentiation between the Padrioc and Cardonal formations in the area.

The conglomerates of the Devendeus Formation have been divided into two members separated by a hiatus with evidence of reworking on the upper surface of the lower member (Aceñolaza et al., 2003). The lower member of the unit displays a strong conglomeratic character with two depositional sequences, with features suggesting some glacigenic related origin (striated clasts). The upper member of the Devendeus Formation is composed of fine sandstones that alternate with medium and coarse sandstones, the latter ones interpreted herein as turbidites. The sequence displays a coarsening and thickening upward arrangement, denoting an increase in the average energy (Aceñolaza et al., 2003) (Fig. 3).

PALEONTOLOGIC CONTENT

The Devendeus Formation records conodonts, trilobites, brachiopods, echinoderms, conularids, and trace fossils, which have been described and mentioned in several papers since 2003 (Aceñolaza et al., 2003; Leme et al., 2003; Moya et al., 2003; Aceñolaza, 2005). In this sense, the mix of *Kainella meridionalis*, *Parabolina (N.) frequens argentina* (Trilobita), unidentified brachiopods and echinodem stems shall be highligted, with the presence of the South American oldest conularid *Teresconularia argentinensis* (Leme et al., 2003). This last occurrence has expanded the conulata fossil record to the Ordovician; previous records of the group were for Devonian marine strata in the central Andean area (e.g. Bolivia, Babcock et al., 1987), the Brazilian cratonic basins (e.g. Paraná Basin, Simoes et al., 2000, with references) and Uruguay (Méndez-Alzola and Sprechmann, 1973).

Conodonts

The clasts of the lower conglomeratic sequence of the Devendeus Formation yielded the conodonts *Problematoconites perforatus* (Müller), *Oneotodus* sp., *Teridontus nakamurai* (Nogami) and *Scolopodus* sp., while the examined pebbles from the upper part of the unit records *Nogamiconus* sp., *Teridontus nakamurai* (Nogami), *Scolopodus* sp., *Scolopodus filosus* Ethington and Clark, *Variabiloconus* sp. and *Drepanoistodus* sp. This association of conodonts was preliminary mentioned by Aceñolaza et al. (2003) as suggesting a time span ranging within the Lower Ordovician, within the *Cordylodus angulatus-Rossodus manitouensis* Zone. Moya et al. (2003) and Ortega and Albanesi (2005) mentioned *Variabiloconus variabilis*, *Teridontus nakamurai* and *Drepanoistodus chucaleznensis* from the conglomerate matrix and tentatively assigned the association to the *Paltodus deltifer* Zone.

The succession overlying the Devendeus Formation is composed of sandstones and shales assigned to the Saladillo Formation, which exhibits a graptolite fauna indicative of the *Bryograptus kjerulfi* Zone, suggesting that these levels do not extend over the late lower Tremadocian. Moya et al. (1994) were the first to present a biostratigraphical scheme for the area, with a graptolite association represented by *B. kjerulfi*, *Staurograptus* (*Radiograptus*) *flexibilis* at levels placed above *Adelogratus* sp. cf. *A. tenellus,* and trilobite coquinas with *Kainella meridionalis* (Moya et al., 2003).

After the conodont study the age of the Devendeus Formation is restricted to the lower Tremadocian, recording a peculiar event in the Cambrian/Ordovician sequences of northern Argentina and the South American Central Andean Basin.

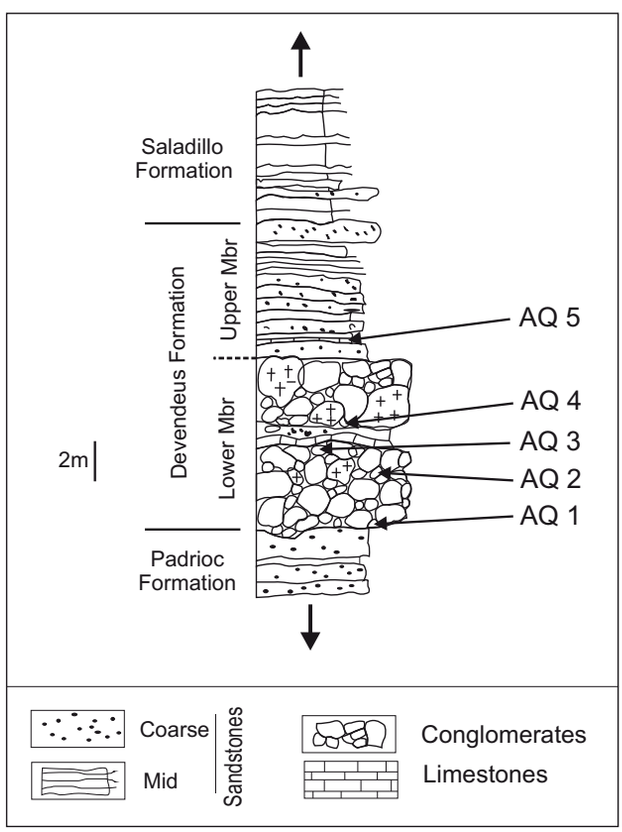

FIGURE 3 | **Stratigraphic section of the Devendeus Formation cropping out on the Eastern flank of La Quesera Creek (Salta province), indicating horizons of conodont samples (AQ1 through AQ5). Conodonts were recovered from clasts included in the Lower Member of the Devendeus Formation (AQ3 and AQ4), while matrix samples resulted barren.**

MATERIALS AND METHODS

The samples collected in the conglomeratic member of the Devendeus Formation of the Angosto de La Quesera were processed in the laboratory using conventional methods with acetic acid (Jeppson et al., 1985; Stone, 1987). Only two of five samples proved to be productive of conodonts (AQ3: 475g; AQ4: 290g). The barren samples: AQ1 (340g), AQ2 (460g), AQ5 (420g).

The conodont elements are partially fragmented, with a fair preservation. Their color corresponds to 1.5-2 of the CAI (Color Alteration Index of Epstein et al., 1977), which represents some 60º-80º of burial temperature.

The fossils recovered are displayed in the photomicrographs on Figure 4, taken by scanning electronic microscopy in the Laboratory of Electronic Microscopy of Northwestern Argentina (NOA) (LAMENOA-Tucumán). All the material studied is housed in the Microvertebrate Collection Lillo-Conodonts of the Facultad de Ciencias Naturales and Miguel Lillo Institiute under the prefix CML–C.

TAXONOMY

This paper presents for the first time the taxonomical analysis of the conodont fauna of the Devendeus Formation. Paraconodonts and euconodonts were recovered together from the unit, and the analysis is given following the classical terminology for each group. Guidelines and nomenclature of Müller and Hinz (1991) and Heredia (1994, 1999) were used for paraconodonts, and Robison (1981) was followed for euconodont nomenclature.

Class: Conodonta PANDER, 1856
Order: Paraconodontida MÜLLER, 1962
GENUS ***Nogamiconus*** MILLER, 1980
Nogamiconus sp.
Figure 4 (A)
Synonymy:
1991 *Nogamiconus* sp., Müller and Hinz, p. 31, fig. 11B, pl. 21, 7, 8, 10.

Description. Small-size elements, represented by a laterally extended simple asymmetric cone. On its upper extreme it presents a well-marked crest that decreases in height both anteriorly and posteriorly and ends in a keel. Denticles are developed mainly on the crest from the anterior extreme to its medial zone. On its flanks the surface is delineated by weak ribs converging to the crest. The basal cavity is extremely deep and occupies nearly the whole element length. The flanks show very small holes similar to those described for *Problematoconites*.

Remarks. This conspicuous element is described by Müller and Hinz (1991) and may represent a transitional series between *Nogamiconus sinensis* (Nogami, 1966) and *N. falcifer* (Müller and Hinz, 1991). It is a scarcely-encountered genus in the paraconodont collections of the Upper Cambrian, and this finding represents its first record in South American tremadocian deposits.

Distribution. Central and Southern Sweden (Müller and Hinz, 1991), and northern Argentina. Ocurrence: Late Cambrian and, due to the present record early Early Ordovician.

Studied Material: AQ4-1 element.

Repository. CML-C 1000 (1).

GENUS ***Problematoconites*** MÜLLER, 1959
Type Species: *Problematoconites perforata* MÜLLER, 1959.
Problematoconites perforatus MÜLLER, 1959
Figure 4 (B)
Synonymy:
1959 *Problematoconites perforata* n. sp., Müller, p. 417.
1983 *Problematoconites perforata,* Müller, An et al., p. 123-124, pl. III. fig. 6.
1991 *Problematoconites perforatus,* Müller, Müller and Hinz, p. 36-37, pl. 23: 1-10, 14, 15, 18-20, 22. With complete synomymy up to 1986.
1999 *Problematoconites perforatus,* Müller, Heredia, p. 353, figs. 6 H-J.

Description. simple asymmetric robust cone; proclined to erect cusp with a circular section. The basal cavity is wide, deep and large, showing thin walls with perforations of variable size and arrangement; which are a diagnostic characteristic of the genus. Due to the poorly-preserved material it is impossible to distinguish any ornamentation on its outer surface, while in its inner wall it is possible to do so (Fig. 4B).

Distribution. United States of America (Müller, 1971), Australia (Druce and Jones, 1971), in China (An et al., 1983), Iran (Müller, 1973) and Argentina (Heredia, 1999).

Ocurrence. Late Cambrian-Early Ordovician. *Proconodontus* and *Cordylodus* Zones.

Studied Material: AQ3-1 element.

Repository. CML-C 1001 (1).

Order: Protopanderodontida SWEET, 1988
Family: Distacodontidae BASSLER, 1925
GENUS ***Drepanoistodus*** LINDSTRÖM, 1971
Type species: *Oistodus forceps* LINDSTRÖM, 1955.

Drepanoistodus sp.
Figure 4 (C-D)

Description. The genus *Drepanoistodus* exhibits a multielement apparatus composed of five morphological types (Dzik, 1994). The elements described here are drepanodiform elements or Sb elements. The element studied (Fig. 4C) presents a recurved cusp and its base is subrounded, the latter being more robust than the cusp. The element is marked by conspicuous keels both on its anterior and its posterior edges.The element figured as D in the same figure is smaller, its cups is proclined and its basal cavity is broken. The outer surface is marked by conspicuous ribs both on its anterior and posterior edges.

Distribution. Angosto de La Quesera, Devendeus Formation.

Ocurrence. Ordovician.

Studied material. AQ4-2 elements.

Repository. CML-C 1002 (1-2).

Family: Protopanderodontidae LINDSTRÖM, 1970

GENUS ***Oneotodus*** LINDSTRÖM, 1955
Type species: *Distacodus? simplex* FURNISH, 1938.
Oneotodus sp.
Figure 4 (E-F)

Description. Simple cone with a robust appearance with variable morphological types, the cusp being erect to reclined. The basal openning is wide with a circular to subcircular section, its basal cavity being deep. The surface of the elements is cut through by weak ribs.

Distribution. Angosto de La Quesera, Devendeus Formation.

Ocurrence: Late Cambrian-Ordovician.

Studied material. AQ3-2 elements.

Repository. CML-C 1003 (1-2).

GENUS ***Scolopodus*** PANDER, 1856
Type Species: *Scolopodus filosus* ETHINGTON and CLARK, 1964.
Scolopodus filosus Ethington and Clark, 1964
Synonymy:
1981 *Scolopodus filosus,* Ethington and Clark, Ethington and Clark, p. 100, pl. 11, fig. 22.
1982 *Scolopodus filosus,* Ethington and Clark, Repetski, p. 47, pl. 22, fig. 2.
1995 *Scolopodus filosus,* Ethington and Clark, Heredia, p. 341, illustration 1, fig. 11 and illustration 2, fig. 10.

Description. Simple symmetrical conodont. The cusp is erect, with oval cross section; the base is narrow, not very deep, with a rounded cross-section. The entire element surface is marked by thin ribs, a distinctive feature of this species.

Distribution. It has been found in the United States of America (Ethington and Clark, 1981; Repetski, 1982) and in the Mendoza Precordillera, Argentina (Heredia, 1995), elements from New Zealand being doubtfully assigned to this genus (Cooper and Druce, 1975).

Ocurrence. Early Ordovician.

Studied material. AQ4-1 element.

Repository. CML-C 1004 (1).

GENUS ***Teridontus*** MILLER, 1980
Type species: *Oneotodus nakamurai* NOGAMI, 1967.
Teridontus nakamurai (Nogami, 1967)
Figure 4 (G-I)
Synonymy
1982 *Teridontus nakamurai,* Nogami, An, p. 149-150, pl. 14, figs. 1-11, pl. 15, fig. 11. With the same synonymy up to 1980.
1983 *Teridontus nakamurai,* Nogami, An et al., p. 156-157, pl. 6, figs. 1-6.
1982 *Teridontus nakamura*i, Nogami, Fortey, et al., pl. 9, fig. N, Q and R.
1985 *Teridontus nakamurai,* Nogami, Nowlan, p. 116, pl. 5, figs. 26-32.
1987 *Teridontus nakamurai,* Nogami, Bagnoli et al., p. 156, pl. 2, fig. 15-16.
1987 *Teridontus nakamurai,* Nogami, Lee, p. 106-107, pl. 10, figs. 1-3, 5-12, text.-figs. 10. 1-3, 5-9.
1995 *Teridontus nakamurai,* Nogami, Heredia and Hünicken, p. 230, illustration 1, fig. 7.
2005 *Teridontus nakamurai,* s., l. Nogami, Zeballos, et al., p. 61, pl.3, fig. A-E.
2008. *Teridontus gallicus* n. sp., Serpagli et al., p.614-618, pl.3, fig. 1-15, pl. 4, fig. 1-15, pl.5, fig. 1-15.

Description. The cusp is long and reclined to recurved with a rounded acute angle between the cusp and the base with a variable degree. The basal cavity is broad and moderately deep, and the base has a rounded cross-secction. The whole surface is covered with fine striations.

Remarks. Conodonts in Figure 4, H and I, might be defined according to Ji and Barnes's criteria (1994) as *Teridontus obesus,* since their dimensions are much larger than the conodont element figured as G (Fig. 4); also,

FIGURE 4 | **A-J) Conodonts of the Devendeus Formation at the Angosto de La Quesera locality, Salta province. A) *Nogamiconus* sp. - upper view (dorsal), CML-C 1000 (1). B) *Problematoconites perforatus* Müller, 1959 - external lateral view, CML-C 1001 (1). C) *Drepanoistodus* sp. - inner lateral view, CML-C 1002 (1). D) *Drepanoistodus* sp. outer lateral view, CML-C 1002 (2). E) *Oneotodus* sp. - inner lateral view, 1003 (1). F) *Oneotodus* sp. - posterior view, CML-C 1003 (2). G) *Teridontus nakamurai* Nogami, 1967 - lateral view, CML-C 1005 (1). H-I) *Teridontus nakamurai* cf. *T. obesus* Ji and Barnes, 1994 - outer lateral views, CML-C 1006 (1-2). J) *Variabiloconus* sp. - inner lateral view, CML-C 1007 (1). Scale: 0.1mm.**

their bases are more extended (following to Zeballos et al., 2005 a, b). In agreement to the amendment of the Genus *Teridontus* carried out for Serpagli et al. (2008) the conodont figured as G (Fig. 4) might be considered like *T. gallicus* corresponding to a Sb element.

Distribution. North America (Miller, 1980), Iran (Müller, 1973), Russia (Abainova and Markov, 1977), Korea (Lee, 1975), China (An, 1982), France (Serpagli et al., 2008), Argentina (Heredia and Hünicken, 1995; Zeballos et al., 2005 a, b) and Australia (Druce and Jones, 1971).

Remarks. This is a typical species of the *Cordylodus proavus* Zone (Miller, 1980); however, there are records of its presence in pre-*C. proavus* Zone strata in the late Franconian–early Trempealeuan from Texas (United States of America) (Miller, 1980), in China (An, 1982) and Korea (Lee, 1987).

In Argentina, it has been mentioned in Famatina (Albanesi et al., 1999), Precordillera (Heredia and Hünicken, 1995) and Cordillera Oriental (Rao et al., 1994).

Ocurrence. Late Cambrian-Ordovician, but not extending to the Late Tremadocian according to Nicoll (1994).

Studied material. AQ3-AQ4-3 elements.

Repository. CML-C 1005 (1), 1006 (1-2).

GENUS ***Variabiloconus*** LANDING, BARNES and STEVENS, 1986
Type species: *Paltodus bassleri* FURNISH, 1938.
Variabiloconus sp.
Figure 4 (J)

Description. Simple conodont with a long, sharp, reclined cusp with circular section. Base short and wide, with deep basal cavity. In the join between the cusp and the base a well-marked rib is localized. Landing et al. (1986) described the genus *Variabiloconus* as characterized by a multielement apparatus composed of several ribbed, sulcate and microstriated elements exhibiting intergradational symmetries.

Remarks. The diagnosis of this element assigns this association an early Tremadocian age.

Distribution. Angosto de La Quesera, Devendeus Formation.

Ocurrence. Early Ordovician (Tremadocian).
Studied material. AQ4-1 element.

Repository: CML-C 1007 (1).

BIOSTRATIGRAPHIC AND PALEOBIOGEOGRAPHIC IMPLICATIONS

The *Cordylodus angulatus* Zone defines the upper part of the Lower Tremadocian (Fig. 5) which has a world wide distributed record. This conodont fauna is present in Baltica (Müller and Hinz, 1991), Newfoundland (Bagnoli et al., 1987; Barnes, 1988; Ji and Barnes, 1994), in the northwestern Canadian basins (Landing et al., 1980; Pyle and Barnes, 2002), Mexico (Robison and Pantoja-Alor, 1968), United States (Furnish, 1938; Orndorff, 1988; Orndorff et al., 1988; Harris et al., 1995), Russia (Pander, 1856), Sweden (Lindstöm, 1955, 1971; van Wamel, 1974; Löfgren, 1996), Kazakhstan (Dubinina, 1991, 2000), Australia (Druce and Jones, 1971; Jones, 1971; Nicoll, 1990), and China (Chen and Gong, 1986; An, 1987; Chen et al., 1988)(Fig. 6).

The *C. angulatus* Zone has been recognized in several localities of the Eastern Cordillera (Suárez Riglos et al., 1982; Rao and Hünicken, 1995a, b; Rao, 1999; Moya and Albanesi, 2000; Moya et al., 2003; Zeballo et al., 2005a, b; among others).

Zhen and Percival (2003) considered to this part of Gondwana as a Temperate Domain (Shallow-sea Realm) with a moderate diversities of conodont faunas. Usually, the Early Tremadocian conodont faunas of the

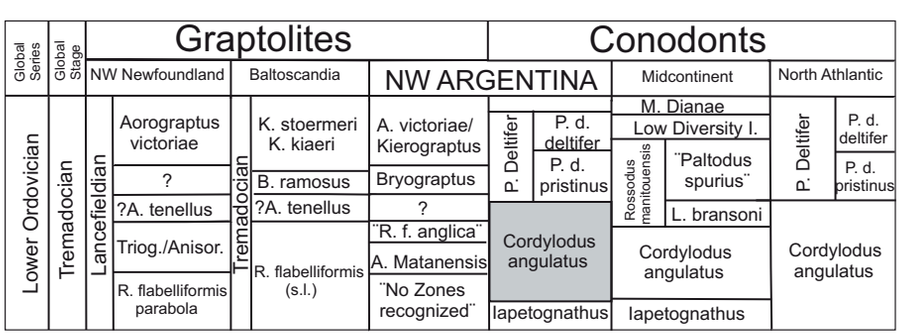

FIGURE 5 | **Biostratigraphic correlation chart of the Lower Ordovician of Northwestern Argentina Based on conodont and graptolite zonations.**

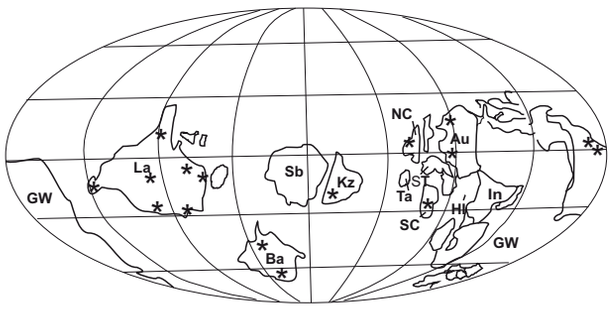

FIGURE 6 | **Ecuatorial view of the distribution of conodonts of the *Cordylodus angulatus* Zone (lower Tremadocian). Plates; GW: Gondwana; Ba: Baltica; La: Laurentia, Kz: Kazakhstan; Sb: Siberia; NC: North China; SC: South China; ST: Shan-Thai; HI: Hainan-Indo-China; Au: Australia; IN: India; Ta: Tarim; In: India (Modified from Scotese and McKerrow, 1990).**

Eastern Cordillera lack of paraconodonts in association with euconodonts but in the present samples there are paraconodonts and euconodonts as they are present in the North Atlantic Realm, e.g. Baltica (Müller and Hinz, 1991).

FINAL CONSIDERATIONS

The Conodonts recovered from the Devendeus Formation, along with the autochthonous graptofauna of the overlying Saladillo Formation, support an early Tremadocian age for the first unit.

The general stratigraphic relations in the area and the evident presence of the Lampazar Formation in the northwest sector of this locality (with the development of the *Parabolina* (*N) frequens argentina* Biozone ratifies the assignment of the sandy unit underlying the conglomerate to the Padrioc Formation (Pinilla et al., 2008).

The particular genetic signatures of the Devendeus Formation cropping out at the Angosto de La Quesera highlights this locality as an outstanding area due to the genetic geological processes involved.

The presence of graptolites of the *Bryograptus kjerulfi* biozone (Moya et al., 1994; Aceñolaza, 1997) in the lower part of the overlying Saladillo Formation suggests that these levels do not extend over the late lower Tremadocian; in terms of the conodont zonations, this corresponds to the *Cordylodus angulatus*/*Rossodus manitouensis* zones. Deposition of the Devendeus Formation, therefore, is restricted to an interval prior to *Paltodus deltifer* Zone. The age of productive clasts as well as the matrix holding them is inferred to be restricted to the Lower Tremadocian, discarding a late Tremadocian age for the conglomerate matrix.

ACKNOWLEDGMENTS

We thank M.F. Tortello and J.P. Milana for their worthy discussions carried out throughout our field tasks. This paper benefited from the insightful reviews done by J. Repetsky and anonymous referee, who are greatly aknowledge. E. Gómez-Hasselrot and D. Ruiz Holgado kindly helped with figures. This contribution was supported by PIP CONICET 114-200901 00125 (Argentina) and CGL2009–09583 (Spain).

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Manuscript received July 2009;
revision accepted September 2010;
published Online May 2011.