Andean Geology
ISSN: 0718-7092
ISSN: 0718-7106
andeangeology@sernageomin.cl
Servicio Nacional de Geología y Minería
Chile

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Andean Geology, vol. 45, no. 3, 2018
Servicio Nacional de Geología y Minería, Chile
Available in: https://www.redalyc.org/articulo.oa?id=173956934006
DOI: https://doi.org/10.5027/andgeoV45n3-3095

Artículos de Investigación

Tips on the SW-Gondwana margin: Ordovician conodont-graptolite biostratigraphy of allochthonous blocks in the Rinconada mélange, Argentine Precordillera

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DOI: https://doi.org/10.5027/andgeoV45n3-3095
Redalyc: https://www.redalyc.org/articulo.oa?id=173956934006

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Received: 31 July 2017
Accepted: 27 February 2018

Abstract:

The Rinconada Formation is a mélange that crops out in the eastern margin of the Argentine Precordillera, an exotic terrane accreted to Gondwana in Ordovician times. Its gravity-driven deposits have been studied by means of conodont and graptolite biostratigraphy, and complemented with stratigraphic analyses. 46 rock samples (85 kg total weight) were obtained from blocks of limestones and of carbonate-cemented quartz-arenites, and from limestone clasts included in conglomerate blocks and debrites. 16 of these samples were productive after standard laboratory acid procedures, yielding 561 conodont elements. The specimens occur in variable number per sample and are frequently fragmented, but they reveal the occurrence of phantom stratigraphic units in the Darriwilian of the Precordillera. Lithological and fossil evidence from the Rinconada Formation provide new constraints on the biostratigraphy, palaebiogeography and tectonostratigraphic history of the southwestern margin of Gondwana during the Ordovician to Lower Devonian times.

Keywords: Conodont, Graptolite, Biostratigraphy, Rinconada Formation, Mélange, Argentine Precordillera, Ordovician, Silurian, Lower Devonian.

1. Introduction

Sedimentary mélanges are mappable units displaying a chaotic internal structure and containing exotic blocks. They occur in different tectonic settings and derive from a broad range of sedimentary and deformational, gravitationally driven processes (see a review in Festa et al., 2016). Their formation involves dismembering of a variably lithified sedimentary cover, potentially accompanied by parts of its substrate, and their gravitational transport and accumulation in slope to base-of-slope and oceanic basin settings. As a result, the original stratigraphy of the parent successions becomes variably destroyed, following a continuum from broken formations that retain the internal stratigraphy up to debris flows that may incorporate exotic fragments (e.g., Cowan, 1985).

Mélanges may constitute the unique vestige of their parent successions when the latter are completely cannibalised, and thus missing from their original locations (phantom stratigraphic units of Hsü and Ohrbom, 1969). Thereby, the fossils and rocks included in a mélange may reveal important aspects on the biostratigraphy, palaebiogeography and the tectonostratigraphic history of a basin. This is the case of the Rinconada Formation, a thick, mainly siliciclastic mélange containing large limestone blocks that overlies the lower Palaeozoic carbonates of the Argentine Precordillera (Heim, 1948), an allochthonous terrane accreted to Gondwana during the Ordovician (Astini et al., 1995). In this contribution, we analyse new Ordovician conodont and graptolite records from the Rinconada Formation They provide high-resolution biostratigraphic constraints on the mobilised blocks that compose the mélange, and reveal the occurrence of Ordovician phantom units in the Rinconada Formation, currently unknown in other sectors of the Precordillera, and have important palaeogeographic implications.

2. Geological setting

The Rinconada Formation is exposed in the eastern margin of the Eastern Precordillera, close to the boundary with crystalline basement uplifts of the Sierras Pampeanas to the east (Fig. 1). It crops out in three main areas in the Villicum (Mogotes Negros), Rinconada (Chica de Zonda) and Pedernal ranges. There, it unconformably overlies Ordovician strata and is in turn overlain by Carboniferous (Jejenes Formation) or Neogene deposits through an angular unconformity. The Rinconada Formation consists of a ca. 3,750 m-thick stacking of "broken formations", comprising shales, subordinate sandstone-shale alternations, rare conglomerates and sandstones, and huge, up to 2.5 km-long, limestone blocks (Fig. 2). They exhibit extensional faults, boudinaged intervals and slump folds that attest for soft-sediment deformation during submarine sliding. The conglomerate blocks contain extrabasinal clasts, derived from igneous-metamorphic sources to the east. The upper part of the Rinconada Formation comprises debris-flow deposits with quartzite and limestone lithoclasts and shale and sandstone intraclasts.

The lithological monotony of the shale-dominated succession makes it difficult to unravel the size and shape of the fragments that compose the Rinconada mélange, except for the blocks of sandstone or limestone. The former are made of quartz-arenites, calcareous in some cases, and reach up to some tens of metres in size. Carbonate blocks greatly vary in size and shape and range from metre-scale bodies to slabs up to 2.5 km in length and ca. 100 m in thickness (Figs. 1A, 2C). The larger carbonate blocks are found in the Rinconada area, whereas in Villicum they rarely reach 100 metres in size. Carbonate blocks tend to be concentrated in certain intervals, suggesting a possibly multiepisodic deposit (Gosen et al., 1995) or a stacking of "broken formations" sensu Raymond (1984), linked to submarine mass transport processes.

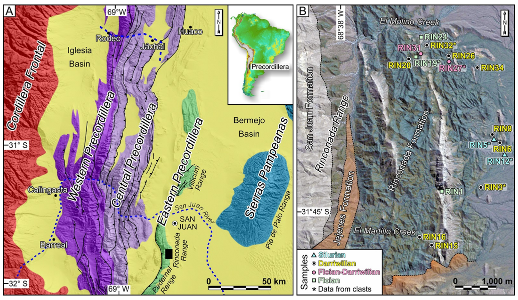

FIG. 1

FIG. 1. A. Location map of the study area (black square), Eastern Precordillera, San Juan Province, Argentina; B. Simplified geological map of the Rinconada area showing position of the fossiliferous samples discussed in the text.

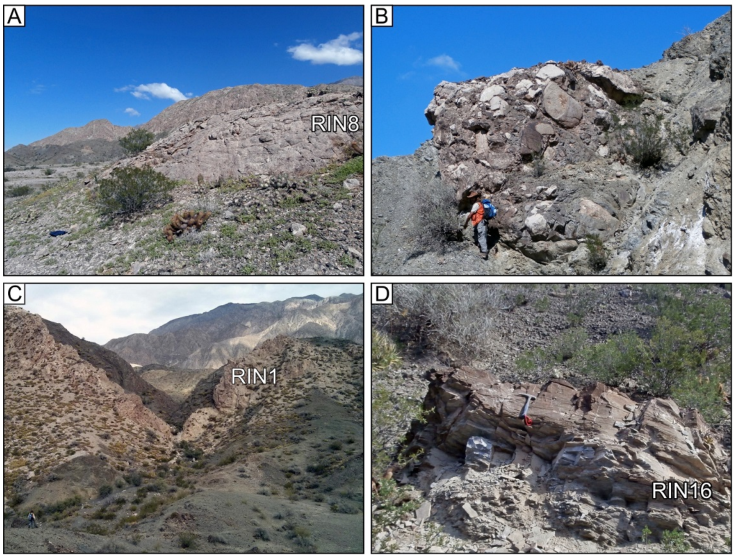

FIG. 2

FIG. 2. Outcrops of the Rinconada mélange in the study area, with examples of the sampled lithologies. A. Limestone block (sample RIN8); B. Conglomerate block containing rounded clasts of limestones, sandstones and of crystalline rocks; C. km-scale limestone slab of the San Juan Formation (sample RIN1) enclosed in a greenish fine-grained sandy matrix; D. dm-scale block of graptolitic quartz-arenite with calcareous cement (sample RIN16).

3. Age constraints on the deposition of the Rinconada mélange

The age of the Rinconada Formation is difficult to establish due to the inherent reworked nature of the mélange and the scarcity of its fossil content. Regionally, it overlies through an erosional hiatus the passive-margin limestones of the San Juan Formation (Lower to Middle Ordovician). The lacuna is narrower in the Villicum and Pedernal sections where the mélange rests over late Middle-Late Ordovician siliciclastic foreland deposits (Gualcamayo, La Pola and La Cantera formations), or the glacial-related Hirnantian-Llandovery Don Braulio Formation (Peralta, 1993; Astini, 2001; Mestre and Heredia, 2014). Considering that the base of the formation is synchronous, a maximum age is given by the latter stratigraphic unit, which contains Rhuddanian fossils (Volkheimer et al., 1980; Peralta, 1986).

In the Rinconada Range, Sarmiento et al. (1988) obtained a conodont fauna composed of Cordylodus horridus, Periodon aculeatus, Staufferella? sp., Histiodella sp. and Amorphognathus? sp. from the top of the San Juan Formation and the basal part of the Rinconada Formation, which they referred to the lower Llanvirn. The conodont fauna is fragmentary but the occurrence of Paroistodus horridus points out to a middle Darriwilian age. Peralta and Uliarte (1986) obtained graptolites of the Paraglossograptus tentaculatus Zone from the same interval, and interpreted the contact between the San Juan and the Rinconada formations as transitional. However, their figured stratigraphic section shows that their samples proceed from a limestone slab. In the same area, Lehnert (1995) recovered a conodont association of the Histiodella sinuosa Zone from the top of the San Juan Formation, and two fragmentary conodont associations from limestone blocks of the Rinconada Formation that he referred to the Amorphognathus variabilis Zoneand the uppermost Arenig. Limestone pebbles included in polymictic conglomerate blocks provided him elements of the Lenodus variabilis and the Eoplacognathus suecicus zones.

The upper part of the Rinconada Formation yielded a graptolite association composed of Climacograptus cf. minutus, Diplograptus sp. and Monograptus sp., which indicates a Llandovery age (Cuerda, 1981), whereas the record of the articulate brachiopod Leangella (Leangella) sp. suggests a Wenlock age (Benedetto and Franciosi, 1998). The record of Dapsilodus obliquicostatus, Decoriconus fragilis, Oulodus sp., Pseudooneotodus beckmanni, P. b. bicornis, Wurmiella excavata along with "Ozarkodina" aff. snajdri in calcareous sandstone clasts from the debrites of the upper part of the formation, suggests a late Homerian-early Gorstian (late Wenlock-early Ludlow) maximum age for these deposits in the Rinconada Range (Voldman et al., 2017a). In the Bola Range, Amos and Fernández (1977) obtained the Lower Devonian brachiopod Leptocoelia nunezi, verifying the diachronous character of the preserved top of the Rinconada Formation due to truncation by younger stratigraphic units.

4. Methods and results

Conodont analysis involved 46 rock samples (85 kg total weight) obtained from blocks of limestone, blocks of carbonate-cemented quartz-arenites, and from limestones clasts in conglomerate blocks and debrites (Figs. 1B, 2). These were digested following the standard laboratory procedures (Stone, 1987), resulting in 16 productive samples and 561 conodont elements (Fig. 3). The specimens have a moderate preservation with a CAI 3. They are housed in the Museo de Paleontología (Universidad Nacional de Córdoba, repository code CORD-MP 56001 up to 56562). For the conodont zonation of the Rinconada Formation, we have followed the regional biostratigraphic schemes of Albanesi and Ortega (2016) and Feltes et al. (2016). Ordovician stage slices are based on Bergström et al. (2009) and Cooper et al. (2012). Data from this work (summarised in Table 1) are complementary to those of Voldman et al. (2015), including additional samples and the reprocessing of previously collected material that allowed to enhance the biostratigraphic resolution. The low number of conodont elements and the high degree of fragmentation challenged the biozone determination in some cases. The conodont taxonomy has already been described extensively in the literature (e.g., Serpagli, 1974; Löfgren, 1978; Ethington and Clark, 1981; Repetski, 1982; Dzik, 1994; Lehnert, 1995; Albanesi, 1998; Stouge, 2012) and no further comments are required herein. We follow here the morphotype designations of Sweet (in Clark et al., 1981) that include P, M, and S elements and their subdivisions.

The conodont records reveal the presence of species typical from the Floian Oepikodus evae Zone [e.g., Tropodus sweeti (Serpagli), Bergstroemognathus extensus (Graves and Ellison), Juanognathus variabilis Serpagli, Reutterodus andinus Serpagli, Oepikodus evae (Lindström), Paroistodus originalis (Sergeeva)], the lower Darriwilian Lenodus variabilis Zone (in particular, represented by the illustrated species of Histiodella), and the middle Darriwilian Yangtzeplacognathus crassus Zone [indicated by the presence of Paroistodus h. horridus (Barnes and Poplawski)].

In addition, current field studies in the Rinconada Range yielded the graptolites Holmograptus spinosus Ruedemann, undetermined sinograptid stipes, Pseudophyllograptus sp., Bergstroemograptus crawfordi Harris, Cryptograptus schaeferi Lapworth, Glossograptus sp., Xiphograptus? sp. and Archiclimacograptus spp. (preliminary reported in Ortega et al., 2016; Fig. 4). The fauna comes from blocks of carbonate-cemented quartz-arenites (Figs. 1B, 2D), being indicative of the middle Darriwilian H. spinosus Zone of North America, Australasia, and equivalent levels from the Scandinavia and China (Maletz, 2009).

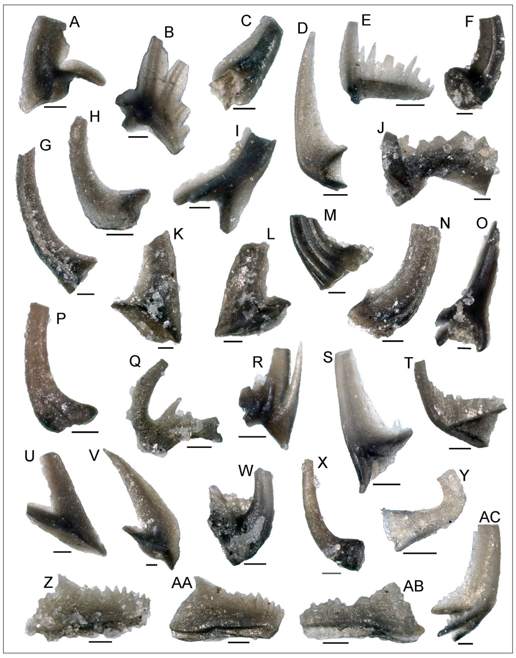

FIG. 3

FIG. 3. Selected conodonts from the Rinconada Formation Scale bar 0,1 mm. A. Tropodus sweeti (Serpagli), M element, RIN1, CORD-MP 56001; B. Bergstroemognathus extensus (Graves and Ellison), M element, RIN1, CORD-MP 56002; C. Juanognathus variabilis Serpagli, Sa element, RIN1, CORD-MP 56003; D. Reutterodus andinus Serpagli, M element, RIN1, CORD-MP 56004; E. Oepikodus evae (Lindström), P element, RIN1, CORD-MP 56005; F. Scolopodus striatus Pander, P? element, RIN3, CORD-MP 56006; G. Juanognathus variabilis Serpagli, Sa element, RIN1, CORD-MP 56007; H. Paroistodus originalis (Sergeeva), Sb element, RIN1, CORD-MP 56008; I. Tropodus sweeti (Serpagli), Sb element, RIN1, CORD-MP 56009; J. Periodon macrodentatus (Graves and Ellison), Sb element, RIN3, CORD-MP 56010; K.Rossodus barnesi Albanesi, Sb element, RIN6, CORD-MP 56011; L. Drepanoistodus bellburnensis Stouge, M element, RIN6, CORD-MP 56012; M. Costiconus costatus (Dzik), S element, RIN3, CORD-MP 56013; N. Protopanderodus gradatus Serpagli, S element, RIN24, CORD-MP 56014; O. Pteracontiodus cryptodens (Mound), Sa element, RIN3, CORD-MP 56015; P. Parapanderodus paracornuformis (Ethington and Clark), S element, RIN15, CORD-MP 56016; Q.Paroistodus h. horridus (Barnes and Poplawski), S element, RIN15, CORD-MP 56017; R. Erraticodon sp., Pb? element, RIN15, CORD-MP 56018; S.Gothodus sp., Pa element, RIN19, CORD-MP 56019; T. Ansella jemtlandica (Löfgren), Sa element, RIN8, CORD-MP 56020; U. Paltodus deltifer deltifer (Lindström), M element, RIN19, CORD-MP 56021; V. Rossodus barnesi Albanesi, M element, RIN15, CORD-MP 56022; W. Periodon macrodentatus (Graves and Ellison), Sb element, RIN20, CORD-MP 56023; X. Semiacontiodus potrerillensis Albanesi, S element, RIN6, CORD-MP 56024; Y. Cornuodus longibasis (Lindström), Sa element, RIN24, CORD-MP 56025; Z. Histiodella serrata Harris, Pa, RIN15, CORD-MP 56026; AA. Histiodella sinuosa Graves and Ellison, Pa element, RIN15, CORD-MP 56027; AB. Histiodella minutiserrata Mound, Pa element, RIN20, CORD-MP 56028; AC. Tropodus sweeti (Serpagli), P element, RIN19, CORD-MP 56029.

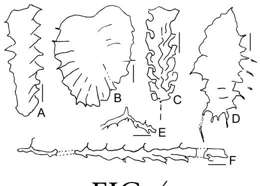

FIG. 4

FIG. 4. Sampled graptolites from the Rinconada Formation Scale bar 0,1 mm. A. Cryptograptus schaeferi (Lapworth), CORD-MP 25805; B. Bergstroemograptus crawfordi (Harris), CORD-MP 25895A; C. Archiclimacograptus sp., CORD-MP 25895A; D. Glossograptus sp., CORD-MP 25885; E. Holmograptus spinosus (Ruedemann), CORD-MP 25827; F. Holmograptus spinosus (Ruedemann), CORD-MP 25827.

TABLE 1. CONODONT SPECIES OBTAINED FROM BLOCKS AND DEBRITES OF THE RINCONADA MÉLANGE.

Sample	Lat.	Long.	Lithology	Source	N° of elements	Fauna	Biozone (Stage slice / Age)
RIN1	31°44.99'S	68°37.12'W	Limestone	km-scale block	128	*Bergstroemognathus extensus, Juanognathus variabilis, Oepikodus evae, Paroistodus originalis, Prioniodus adami, Protopanderodus gradatus, Reutterodus andinus, Scolopodus krummi, Semiacontiodus potrerillensis, Tropodus sweeti*	*O. evae* (Fl2-Fl3)
RIN3	31°44.97'S	68°36.76'W	Limestone	Clast in polymict conglomerate block	16	*Ansella jemtlandica, Baltoniodus* sp., *Costiconus costatus, Semiacontiodus potrerillensis, Periodon macrodentatus, Pteracontiodus cryptodens, Scolopodus striatus*	*L. variabilis* (Dw1)
RIN5	31°44.66'S	68°36.60'W	Calcareous sandstone	Clast in debrite	134	*Dapsilodus obliquicostatus, Decoriconus fragilis, Oulodus* sp., *"Ozarkodina"* aff. *snajdri, Pseudooneotodus beckmanni, P. b. bicornis, Wurmiella excavata* (Voldman *et al.*, 2017)	Silurian
RIN6	31°44.65'S	68°36.60'W	Limestone	dm-scale block	20	*Drepanoistodus bellburnensis, Histiodella sinuosa, Periodon* sp., *Protopanderodus* sp., *Rossodus barnesi, Scolopodus striatus, Semiacontiodus potrerillensis*	*L. variabilis* (Dw1)
RIN8	31°44.61'S	68°36.63'W	Limestone	dm-scale block	13	*Ansella jemtlandica, Drepanodus arcuatus, Drepanoistodus* sp., *Paltodus? jemtlandicus, Parapaltodus simplicissimus, Semiacontiodus potrerillensis*	Dp2-Dw1
RIN12	31°44.75'S	68°36.54'W	Calcareous sandstone	Clast in debrite	2	Ramiform broken fragments	Silurian
RIN15	31°45.34'S	68°37.21'W	Limestone	dm-scale block	46	*Cornuodus longibasis, Drepanoistodus* sp., *Paltodus? jemtlandicus, Histiodella serrata, H. sinuosa, Erraticodon alternans, Juanognathus serpaglii, Loxodus* sp., *Parapanderodus paracornuformis, Paroistodus horridus, Periodon macrodentatus, Rossodus barnesi, Semiacontiodus potrerillensis*	*Y. crassus* (Dw1-Dw2)
RIN16	31°45.29'S	68°37.32'W	Quartz-arenite	dm-scale block	2	*Periodon* sp. + graptolites of the *Holmograptus spinosus* Zone (Ortega *et al.*, 2016)	Dw2
RIN19	31°44.03'S	68°37.25'W	Limestone	Clast in polymict conglomerate block	48	*Drepanodus arcuatus, Drepanoistodus* sp., *Gothodus* sp., *Scolopodus krummi, Tropodus sweeti, Paltodus deltifer, Periodon primus, Variabiloconus variabilis*	Fl1
RIN20	31°44.04'S	68°37.28'W	Quartz-arenite	hm-scale block	7	*Histiodella minutiserrata, Rossodus barnesi, Parapanderodus paracornuformis, Periodon macrodentatus*	*L. variabilis* (Dw1)
RIN24	31°43.87'S	68°37.19'W	Limestone	dm-scale block	48	*Ansella* sp., *Bergstroemognathus extensus, Cornuodus longibasis, Oelandodus costatus, Parapanderodus paracornuformis, Periodon flabellum, Protopanderodus gradatus, Tropodus australis, T. comptus, Reutterodus andinus, Rossodus barnesi*	Fl1-Fl2
RIN26	31°44.03'S	68°36.97'W	Limestone	dm-scale block	9	*Semiacontiodus potrerillensis, Eoplacognathus* sp., *Pteracontiodus cryptodens*	*Y. crassus* (Dw1-Dw2)
RIN27	31°44.06'S	68°36.97'W	Limestone	m-scale block	1	*Periodon* sp.	Fl-Dw
RIN31	31°44.02'S	68°37.21'W	Limestone	km-scale block	4	*Drepanodus arcuatus, Periodon* sp., *Rossodus barnesi*	Fl-Dw
RIN32	31° 43.96'S	68°37.16'W	Limestone	Clast in polymict conglomerate block	1	*Semiacontiodus* cf. *cornuformis*	Dw1
RIN34	31°44.10'S	68°36.74'W	Limestone	dm-scale block	82	*Ansella sinuosa, Bryantodina* aff. *typicalis, Drepanoistodus tablepointensis, Histiodella holodentata, Paltodus? jemtlandicus, Parapaltodus simplicissimus, Paroistodus horridus, Periodon macrodentatus, Protopanderodus gradatus, P. robustus, Scolopodus striatus, Venoistodus balticus*	*Y. crassus* (Dw1-Dw2)

Table 1

5. Discussion

The Ordovician conodont fauna obtained from reworked blocks and clasts of the Rinconada Formation include typical assemblages from the platform (e.g., Semiacontiodus and Cornuodus) and slope (e.g., Periodon and Paroistodus) settings of the Precordillera. The fauna consists of endemic and cosmopolitan species of Laurentian and Baltic affinity, representing the major Midcontinent and Atlantic Realms (e.g., Albanesi and Bergström, 2010). The record of Gothodus sp. (Fig. 3S) in limestone clasts may suggest a link with the perigondwanan cold-water assemblages of the Central Andean Basin, as similar priniodontiforms with poorly developed denticulation have been recognized in the Floian Acoite Formation (Voldman et al., 2017b). The presence of Erraticodon patu in the Precordillera, the Famatinian Range and the Central Andean Basin supports this palaeobiogeographic link as well (Albanesi and Bergström, 2010; Heredia et al., 2013).

Gosen et al. (1995) considered an inverse stratigraphy for the limestone blocks included in the Rinconada Formation in response to the progressive denudation of the adjacent Zonda Range to the west. Nevertheless, current biostratigraphic data indicate that, overall, the sets of blocks included in the Rinconada Formation actually maintain the stratigraphic order of the source area, i.e., with older blocks below and younger blocks above, as it frequently occurs in broken formations (Raymond, 1984).

In a more plausible explanation, we envisage that the large carbonate blocks along with their sedimentary cover slid from an eastern orogenic front into the basin floor (Fig. 5). Accordingly, the middle Darriwilian quartz-arenite blocks of the Rinconada mélange would represent part of the synorogenic clastic wedge that was generated during the accretion of the Precordillera to Gondwana (Astini et al., 1995; Thomas et al., 2015). In addition, the Holmograptus spinosus Zone (sample RIN16) has been recorded in calcareous nodules from the top of the Gualcamayo Formation in the Villicum Range (Kaufmann and Ortega, 2016), but is absent in the Central Precordillera due to a hiatus (Ortega et al., 2007). Instead, the synorogenic sedimentation is partially represented in the Villicum Range by the La Cantera Formation (late Darriwilian), which includes at its base clasts with fragments of Sacabambaspis janvieri. This early agnathan fish inhabited the shallow water continental margins of Gondwana, thus strengthening the palaeobiogeographic connection of the Precordillera with Gondwana by the late Darriwilian times (Albanesi et al., 1995).

The repeated occurrence of km-scale blocks of the San Juan limestones in the Rinconada Formation records at least two major sliding events or, alternatively, the sliding of a Middle-Late Ordovician nappe stacking during Silurian-Early Devonian times. An Ordovician west-vergent thrust system has been described in the northern Precordillera (Guandacol area), where it is related to proximal deposits with olistoliths of the San Juan and Gualcamayo formations and extrabasinal clasts (Thomas and Astini, 2007). The Rinconada Formation may record the continuation of the Ordovician compressional deformation into the Silurian and early Devonian. An analogous compressional setting is found in the Iberian Variscan foreland basin, where submarine sliding with extensional deformation is related to denudation of an advancing thrust system (Alonso et al., 2006). This deformation is probably represented in the Central Precordillera forebulge as a hiatus between the La Chilca and the Los Espejos formations (Peralta, 1993; Astini and Maretto, 1996; García Muro and Rubinstein, 2015), whereas in the Sierras Pampeanas it is represented by ductile shear zones that have been associated with thrusting during the later stages of accretion of the Precordillera terrane to the southwestern Gondwana margin (e.g., Castro de Machuca et al., 2008).

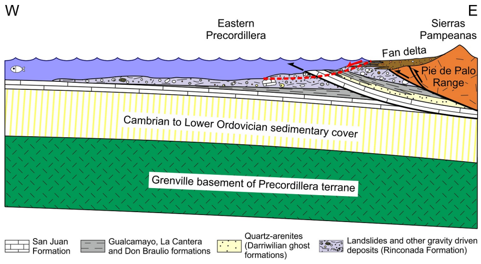

FIG. 5

FIG. 5. Schematic cross section showing the gravity driven deposits of the Rinconada Fm being sourced by listric normal faults (red arrow) developed in the Silurian-Early Devonian eastern orogenic front (black arrows).

6. Conclusions

Deciphering the geology of the boundary zone between the Precordillera and the Sierras Pampeanas is essential to understand the geodynamic evolution of the proto-Andean margin of Gondwana. In the present contribution, a systematic conodont and graptolite sampling of different lithologies in the Rinconada Formation at the eastern margin of the Precordillera allows suggesting that the mélange mirrors the stratigraphic succession of an eastern orogenic source area, with predominant younger ages to the east. The record of middle Darriwilian graptolites (H. spinosus Zone) and conodonts (L. variabilis-Y. crassus zones) in large blocks of quartz-arenites (phantom stratigraphic units) is consistent with cannibalization of the Ordovician synorogenic clastic wedge that was generated during the accretion of the Precordillera terrane to Gondwana (e.g., Thomas et al., 2015). Moreover, the repeated occurrence of km-scale blocks of the San Juan Formation in the Rinconada mélange may represent either a series of major sliding events or the sliding of an Ordovician nappe stacking during the Silurian - Early Devonian, subsequent to the accretion of the Precordillera terrane to SW Gondwana.

Acknowledgements

This study was funded by CONICET, Argentina (Resolución 3646/14 and PIP 112 201301 00447 CO) and the Ministerio de Economía y Competitividad of Spain (project CGL2012-34475). We appreciate critical comments of John Repetski (USGS) on an early draft. The manuscript was improved after the corrections of

Ana Mestre (CONICET), an anonymous reviewer and the editor, W. Vivallo. This paper is a contribution to the IGCP Project 653: The Onset of the Great Ordovician Biodiversification Event.

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