
New late Tremadocian (Early Ordovician) conodont and graptolite records from the southern South American Gondwana margin (Eastern Cordillera, Argentina)

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| ABSTRACT |

New late Tremadocian (Early Ordovician) conodont and graptolite faunas from the eastern and central belts of the Eastern Cordillera (Jujuy Province, northwestern Argentina) are reported. The conodont fauna includes the guide species *Paltodus deltifer pristinus*, *Paltodus deltifer deltifer*, and *Acodus deltatus (sensu lato)*, in association with other taxa, and the graptolites *Aorograptus victoriae*, *Ancoragraptus cf. bulmani*, and *Adelograptus cf. altus*. Overlapping ranges of the recorded species allow for a partial correlation between the *Acodus deltatus-Paroistodus proteus* and *Aorograptus victoriae* zones, and the *Notopeltis orthometopa* trilobite Zone. The conodont fauna includes a mixture of forms typical of the Baltoscandian and Laurentian provinces, respectively. The Early Ordovician basin of northwestern Argentina may correspond to the Shallow-Sea Realm and Cold Domain and probably records the development of a differentiated conodont province in the southern South American margin of Gondwana.

KEYWORDS | Conodonts. Graptolites. Tremadocian. Ordovician. Eastern Cordillera.

INTRODUCTION

Ordovician rocks of the Eastern Cordillera in northwestern Argentina have been studied from several points of view. Pioneer works by Brackebusch (1883), Keidel (1910, 1917 and 1943), Hausen (1925), and Schlagintweit (1937) were devoted mainly to the stratigraphy, paleontology, and mineral deposits of this region. Later, Harrington and Leanza (1957) proposed a trilobite-based stratigraphic scheme, which is still used as a reference scheme. More recently, Turner (1972), Turner and Mon (1979),

Moya (1988, 2002), Benedetto et al. (1992) and Astini (2003) have examined the regional geology and stratigraphy of the area. In a recent paper, Ortega and Albanesi (2005) revised the Tremadocian graptolite-conodont biostratigraphy of the Eastern Cordillera. However, a detailed biostratigraphic scheme integrating data of the most important guide fossils of the Ordovician (*i.e.*, conodonts and graptolites) continues to be urgently needed. This contribution attempts to elucidate some aspects of the conodont-graptolite correlation of Lower Ordovician outcrops in the Eastern Cordillera, with particular emphasis

on the eastern belt, and the late Tremadocian units exposed at both sides of the Quebrada de Humahuaca.

The paleontological material is deposited in the Museo de Paleontología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Argentina, with repository code CORD-PZ for macrofossils and CORD-MP for microfossils.

most accepted classification is that of Turner (1960) who coined the name Santa Victoria Group for the whole Ordovician succession, and the Santa Rosita Fm (Tremadocian) for its lower part. Actually, the Santa Rosita Fm has been considered Cambro-Ordovician in age (Astini, 2003; Buatois et al., 2006; and references cited therein).

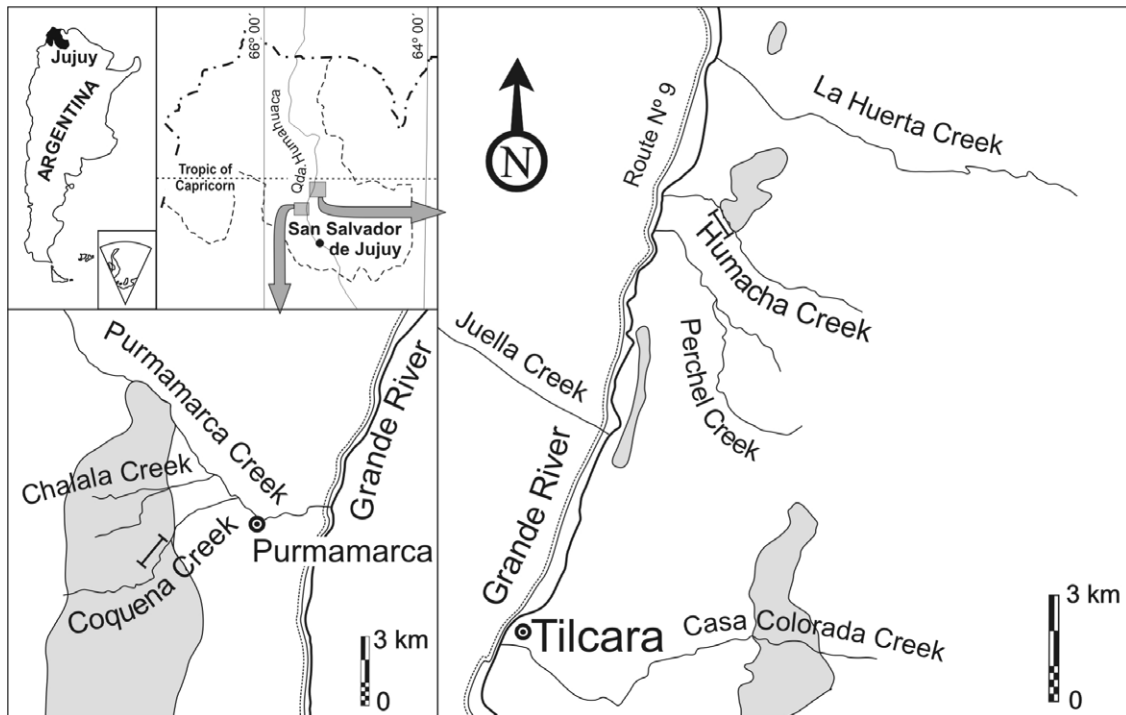


FIGURE 1 | Regional and location maps showing the studied sections and fossiliferous localities. The grey pattern corresponds to the Cambro-Ordovician outcrops (Coquena and Santa Rosita Formations).

GEOLOGICAL SETTING

The Eastern Cordillera of Argentina is located between the Subandean and Santa Bárbara Ranges to the east and the Puna region to the west (Fig. 1). The depositional record in this geological region of northwestern Argentina is considered to be deposited in a continuous basin, which connects with the Chaco plains to the east and represents the Argentine part of the larger Central Andean Basin of Bolivia and Perú (Benedetto et al., 1992; Astini, 2003). In this basin, a thick Proterozoic basement sequence (Puncoviscana Formation) is overlain by Cambrian (Mesón Group) and Ordovician rocks. These deposits are more than 5,000 m thick, and their nomenclature is confusing because of the application of different formation names in each area for equivalent units. The

In this contribution, upper Tremadocian units from several localities are discussed (Fig. 2). These units have been known as the 'Coquena shales' (Harrington and Leanza, 1957) in the Purmamarca area, and as the Humacha Fm (Moya, 1988) in the Huacalera area in the eastern belt of the Eastern Cordillera. This paper deals with late Tremadocian biostratigraphic units present in the lower and upper members of the Coquena Fm (*sensu* Benedetto and Carrasco, 2002) and in the Humacha Member, *i.e.*, the uppermost part of the Santa Rosita Fm (Buatois et al., 2006).

The Coquena Fm (about 400 m thick on the eastern side of the Coquena Creek) is represented by two members. The lower member is a shaly-sandy heterolithic unit, with some interbedded coquinas in the coarser strata. The

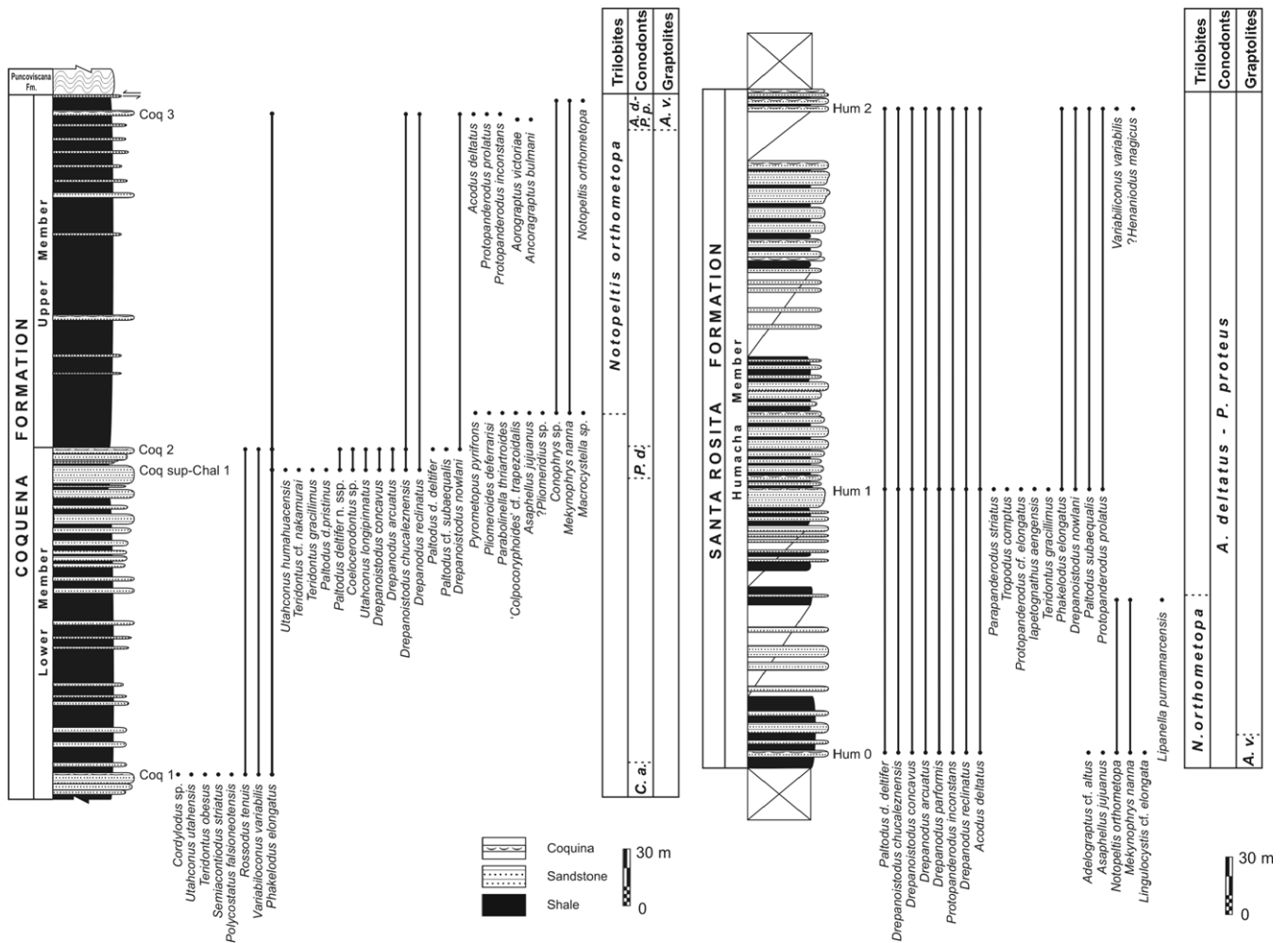


FIGURE 2 | Stratigraphic columns from Coquena-Chalala (A) and Humacha (B) creeks with sampled levels, ranges of recorded fossil species (conodonts, graptolites, trilobites, bivalves, and echinoderms), and biozones. C.a.: *Cordylodus angulatus*, P.d.: *Paltodus deltifer*, A.d.-P.p.: *Acodus deltatus*-*Paraioistodus proteus* and A.v.: *Aorograptus victoriae* zones.

upper member is mostly shaly (Benedetto and Carrasco, 2002). The boundary between these units is a marine flooding surface as recognized by the latter authors. The Humacha Fm (about 350 m thick) is made up of green shales with interbedded sandy layers, and with a few coquinas in the lower part. The upper part consists of reddish sandstones with abundant interbedded coquinas and profuse trace fossils. The calcareous/siliceous coquinas in this upper part of the unit occur at the top of the sandy strata.

BIOSTRATIGRAPHY

A preliminary conodont-graptolite biostratigraphy has been established in the Humacha, Coquena, and Chalala creek sections. Trilobites, as well as bivalves and echinoderms occur in the associated fauna (Figs. 2 to 5).

In view of the fact that the fossil record is not continuous through the succession, boundaries between the biostratigraphic units are necessarily tentative. However, the identification of guide species at successive levels makes it possible to assign particular intervals to specific biozones, and correlate them at a regional and global scale (Fig. 3).

An updated synthesis of conodont-graptolite based biostratigraphy and correlation of Tremadocian strata in the Eastern Cordillera, Argentina, have been provided by Ortega and Albanesi (2005).

Location and sampling

The Humacha Creek is located on the eastern margin of the Quebrada de Humahuaca, in the Huacalera area, 12 km NNE of Tilcara City. In the Purmamarca area, the

adjacent Coquena and Chalala creeks are situated in the proximity of the town of Purmamarca (Fig. 1).

Trilobite, graptolite, and echinoderm specimens occur on bedding plane surfaces of diverse muddy rocks. The conodont collection (made of 2,056 elements) was yielded by interbedded calcareous rocks and carbonate coquinas. Specimens were recovered after dissolution of these rocks by conventional acid etching techniques (Stone, 1987). In a preliminary study, four calcareous levels were collected (ca. 3 kg sample size) and yielded a significant conodont collection from the Coquena and Chalala sections. Three digested samples of similar size from the Humacha section also proved to be productive (Fig. 2). The recovered specimens exhibit good preservation with a brown color alteration index (*i.e.*, CAI 3), corresponding to burial paleotemperatures of 110°–200° (Epstein et al., 1977).

Conodonts

The conodont collections from the Coquena and Chalala sections clearly include three different species assemblages. Two of them are from the lower member of the Coquena Fm and the third is from the formation top. These assemblages represent from bottom to top, three conodont zones: *Cordylodus angulatus*, *Paltodus deltifer*, and *Acodus deltatus-Paroistodus proteus* zones. Conodonts recorded in the Humacha section represent the uppermost zone at the previous localities (Figs. 2 and 3).

Cordylodus angulatus Zone

The *Cordylodus angulatus* Zone, as previously recognized by Zeballo et al. (2005a) in the Alfarcito area of the Eastern Cordillera, is poorly represented by only a few elements that are referable to the lower *Rossodus tenuis* Zone of North America. *Cordylodus* sp., *Polycostatus falsioneotensis* JI and BARNES, 1937, *Rossodus tenuis* (MILLER, 1980), *Semiacontiodus striatus* ZEBALLO, ALBANESI and ORTEGA, 2005, *Teridontus obesus* JI and BARNES, 1994, *Utahconus utahensis* (MILLER, 1980), and *Variabiloconus variabilis* (LINDSTRÖM, 1955) are recorded from the lowermost part of the Coquena Fm, and the paraconodont *Phakelodus elongatus* (AN, 1983) ranges from this zone through successive zones. Despite the fact that the zone index species is not recorded in the studied sections, the composition of the conodont assemblages suggests reference to the *Cordylodus angulatus* Zone.

The *Cordylodus angulatus* Zone has been recognized at other localities of the Eastern Cordillera, *e.g.*, Cajas Range (Suárez Riglos et al., 1982; Rao and Hünicken, 1995a; Rao, 1999), and the Alfarcito (Zeballo et al., 2005a, b), Angosto del Moreno (Moya and Albanesi, 2000; Moya et al., 2003), Parcha (Rao and Tortello, 1998;

Tortello et al., 1999; Tortello and Rao, 2000), and Purmamarca areas (Rao and Hünicken, 1995b).

Paltodus deltifer Zone

The first conodont records that allows for identification of the *Paltodus deltifer* Zone are from near the boundary between the lower and upper members of the Coquena Fm. This biozone, originally defined in the Baltoscandian region (Lindström, 1971; and revised by Löfgren, 1997) corresponds in its upper part with the *Ceratopyge* regressive event (Erdtmann, 1986), and correlates with the Low Diversity Interval of North America (Ross et al., 1997; Miller et al., 2003), which is characterized by low diversity and high abundance conodont assemblages (Ji and Barnes, 1993). In this interval, a major extinction event took place, including the demise of several forms, such as species of *Utahconus* and *Teridontus*. These forms are replaced by taxa that have a long record through the Ordovician, and are rooted in the genera *Acodus* and *Protopanderodus*. Unlike the case in the North American region, as postulated by Ji and Barnes (1993), this interval in the study sections represents a transitional faunal replacement rather than an abrupt change of lineages, where representative species such as *Rossodus tenuis*, *Utahconus longipinnatus* JI and BARNES, 1994, *U. humahuacensis* ALBANESI and ACEÑO-LAZA, 2005, *Variabiloconus variabilis*, and *Teridontus* cf. *nakamurai* (NOGAMI, 1967) coexist with stratigraphically younger species, *e.g.*, *Drepanoistodus nowlani* JI and BARNES, 1994, *Drepanoistodus concavus* (BRANSON and MEHL, 1933), and *Drepanodus reclinatus* (LINDSTRÖM, 1955).

The guide species *Paltodus deltifer pristinus* (VIIRA, 1970) and *P. d. deltifer* (LINDSTRÖM, 1955) characterize the eponymous subzones of the *Paltodus deltifer* Zone, in the Baltoscandian scheme proposed by Löfgren (1997). Some elements of *Paltodus deltifer*, whose morphology is intermediate between *P. d. pristinus* and *P. d. deltifer*, are provisionally identified as *Paltodus deltifer* n. ssp. (Figs. 2 and 4.3) pending detailed taxonomic descriptions. The long-ranging species *Drepanodus arcuatus* PANDER, 1856, and *Drepanoistodus chucaleznsensis* ALBANESI and ACEÑO-LAZA, 2005, as well as *Paltodus* cf. *subaequalis* PANDER, 1856, (*sensu* Löfgren, 1997), *Teridontus gracillimus* NOWLAN, 1985, a probably new early species of the genus *Kallidontus* PYLE and BARNES, 2002, and one specimen identified as Gen. et sp. nov also occur in this zone. Recently, Pyle and Barnes (2002) proposed the *Drepanoistodus nowlani* Zone for the upper part of this biostratigraphic interval in the “Atlantic Realm scheme” for western Canada. Despite of the fact that *D. nowlani* is present in the Coquena section, the succession of subspecies of *Paltodus deltifer* (*i.e.*, *P. d. pristinus* and *P. d. deltifer*) is homotaxial with records of the Baltoscandian

region. Therefore, the *P. deltifer* Zone is maintained in northwestern Argentina as previously proposed by Albanesi and Ortega (2002) and Ortega and Albanesi (2005), following the Baltoscandian scheme of Löfgren (1997).

The *Paltodus deltifer pristinus* Subzone has been previously documented from the Rupasca Member of the Santa Rosita Fm in the Alfarcito area (Zeballo et al., 2005a, b) as well as in the Chucalezna section (Albanesi and Aceñolaza, 2005), while the *P. d. deltifer* Subzone has been recognized in the El Aguilar Range (Rao and Flores, 1998), Nazareno (Manca et al., 1995), and in the uppermost part of Saladillo Fm in the Parcha area (Ortega and Albanesi, 2003).

***Acodus deltatus*-*Paroistodus proteus* Zone**

This zone is represented in the uppermost Coquena Fm and through the entire Humacha Member of the Santa Rosita Fm. The guide species *Acodus deltatus* LINDSTRÖM, 1955, *sensu lato* typifies the eponymous biozone, and is accompanied by *Drepanodus arcuatus*, *D. parformis* LÖFGREN and TOLMACHEVA, 2003, *D. reclinatus*, *Drepanoistodus concavus*, *D. nowlani*, *Iapetognathus aengensis* (LINDSTRÖM, 1955), *Paltodus d. deltifer*, *P. subaequalis* PANDER, 1856, *Parapanderodus striatus* (GRAVES and ELLISON, 1941), *Protopanderodus inconstans* (BRANSON and MEHL, 1933), *P. prolatus* JI and BARNES, 1994, *P. cf. elongatus* SERPAGLI, 1974, and *Teridontus gracillimus*. The parataxon *?Henaniodus magicus* HE and PEI, 1984, is reported from the upper part of this biozone.

Our *Acodus deltatus sensu lato* specimens resemble early forms of the species from both the North American

and Baltoscandian regions. In the study area it appears numerically much scarcer than associated taxa. This fact and possible sampling bias preclude a precise dating of the beds that yielded these early *A. deltatus* forms and thus these beds are assigned to the *A. deltatus*-*P. proteus* Zone pending further studies.

Bultynck and Martin (1982) identified *A. deltatus*, based on fragmentary specimens, from upper levels of the Coquena section. This biozone also has been recognized in the basal part of the Parcha Fm in the Parcha area (Ortega and Albanesi, 2003, 2005).

Graptolites

Juvenile and mature rhabdosomes, early astogenetic stages and fragmentary branches of *Aorograptus victoricae* (T.S. HALL, 1899) occur in grey-greenish shales in the upper member of the Coquena Fm (Fig. 5.2-5.3). Specimens of *Ancoragraptus cf. bulmani* (SPJELDNAES, 1963) (*sensu* Jackson and Lenz, 2003), which are present at the same level, are extremely scarce in our graptolite collection. The colony illustrated in Figure 5.1 is a deformed specimen, partially preserved in relief. The graptolite material is usually carbonized and poorly preserved.

One juvenile flattened specimen preserved in horizontal orientation, and scarce remains of branches and proximal stages of *Adelograptus cf. altus* WILLIAMS and STEVENS, 1991, were collected in grey-greenish shales in the lower part of the Humacha Member at Humacha Creek (Fig. 5.4). A few meters above, black siltstones with shelly fauna (trilobites, ostracods, gastropods, bra-

| Global Series | Global Stage | GRAPTOLITES | | | | TRILOBITES | CONODONTS | | | | LITHOSTRATIGRAPHIC UNITS | | | | | | | | |
|------------------|--------------|-----------------|-----------------------------------|---------------------------------|----------------------------------|---|------------------|--------------------|-----------------------|------------------------|--------------------------|--------------------|------------|--------------|-----------------|----------------|------------------------------|-----------------------------|------------------------|
| | | NW Newfoundland | Baltoscandia | NW ARGENTINA | | | Laurentian Prov. | Baltosc. Prov. | Purmamarca area | Huacalera area | | | | | | | | | |
| LOWER ORDOVICIAN | Tremadocian | LANCEFIELDIAN ↑ | <i>H. copiosus</i> | <i>H. copiosus</i> | <i>H. copiosus</i> | <i>Thysanopyge</i> | IBEXIAN ↑ | P. <i>deltifer</i> | P. <i>d. deltifer</i> | P. <i>d. pristinus</i> | P. <i>proteus</i> | P. <i>gracilis</i> | Coquena Fm | Upper Member | Santa Rosita Fm | Humacha Member | | | |
| | | | <i>Araneograptus murrayi</i> | <i>Araneograptus murrayi</i> | <i>Araneograptus murrayi</i> | <i>A. deltatus</i> | | | | | | | | | | | <i>O. costatus</i> | <i>Tripodus</i> | |
| | | | ? | <i>K. supremus</i> | <i>K. supremus</i> | <i>Notopeltis orthometopa</i> | | | | | | | | | | | <i>M. diana</i> | <i>D. aff. amoenus</i> | |
| | | | <i>Aorograptus victoricae</i> | <i>K. stoermeri</i> | <i>A. victoriae/Kierograptus</i> | <i>Bienvillia tetragonalis-Conophrys minutula</i> | | | | | | | | | | | Low Diversity I. | <i>P. d. deltifer</i> | |
| | | | ? | <i>B. ramosus</i> | <i>Bryograptus</i> | <i>Kainella meridionalis</i> | | | | | | | | | | | <i>Rossodus manitouensis</i> | <i>"Paltodus spurius"</i> | <i>P. d. pristinus</i> |
| | | | <i>?A. tenellus</i> | <i>?A. tenellus</i> | ? | <i>Cordylodus angulatus</i> | | | | | | | | | | | <i>L. bransoni</i> | | |
| | | | <i>Triog./Anisor.</i> | <i>R. flabelliformis (s.l.)</i> | <i>"R. f. anglica"</i> | <i>A. matanensis</i> | | | | | | | | | | | <i>Cordylodus angulatus</i> | | |
| | | | <i>R. flabelliformis parabola</i> | | "No zones recognized" | <i>P. f. argentina</i> | | | | | | | | | | | <i>Jujuyaspis keideli</i> | <i>Cordylodus angulatus</i> | |
| | | | | | | <i>Iapetognathus</i> | | | | | | | | | | | <i>Iapetognathus</i> | | |
| | | | | | | | | | | | | | | | | | | | |

FIGURE 3 | Correlation chart showing conodont, graptolite, and trilobite biozones, and studied lithostratigraphic units, from northwestern Argentina and other regions (modified after Webby et al., 1997, 2004, and Ortega and Albanesi, 2005). Baltoscandian Province, after Lindström, 1971, and Löfgren, 1997; Laurentian Province, after Ross et al., 1997, and Miller et al., 2003.

chiopods, bivalves) yielded a fragmentary rhabdosome, presumably of *A. cf. altus* as well.

The *Ao. victoriae* Zone was named by Williams and Stevens (1991) in western Newfoundland. Its fauna is easily identified by the presence of the genera *Aorograptus* and *Kiaerograptus*, and multiramous species of *Adelograptus*, *Paradelograptus*, and *Parathemnograptus*. An extended taxonomic list of this zone was given by Maletz and Egenhoff (2001). It corresponds to the “*Kiaerograptus* interval” of Maletz (1999) and has been identified in western Newfoundland and Quebec, Canada (Williams and Stevens, 1991; Maletz and Egenhoff, 2001), in the Culpina and Cieneguillas sections, southern Bolivia (Maletz et al., 1999; Maletz and Egenhoff, 2001), and in North and South China (Zhang and Erdtmann, 2004; Zhang et al., 2004). It is also equivalent to the *Kiaerograptus kiaeri* and *Kiaerograptus stoermeri* zones of the upper Alum Shale Fm, Scandinavia (Maletz and Egenhoff, 2001). A correlation with the *Adelograptus victoriae* Zone (= *Aorograptus victoriae* sensu Williams and Stevens, 1991) of Lancefieldian La2 of Australasia (VandenBerg and Cooper, 1992) and with the *Aorograptus victoriae* Zone of Yukon, Canada (Jackson and Norford, 2004) is proposed.

The *Kiaerograptus* fauna was identified in the Parcha area in the western belt of the Eastern Cordillera (Ortega and Albanesi, 2002, 2003), and referred to the *Ao. victoriae* / *Kiaerograptus* Zone by Ortega and Albanesi (2005). At that time, *Ao. victoriae* was still not recorded in the western sections of the Eastern Cordillera but it was identified in the Mojotoro Range, on the eastern border of this geologic province (Monteros and Moya, 2002, 2003). Recently, Monteros (2005) proposed that the *Kiaerograptus*

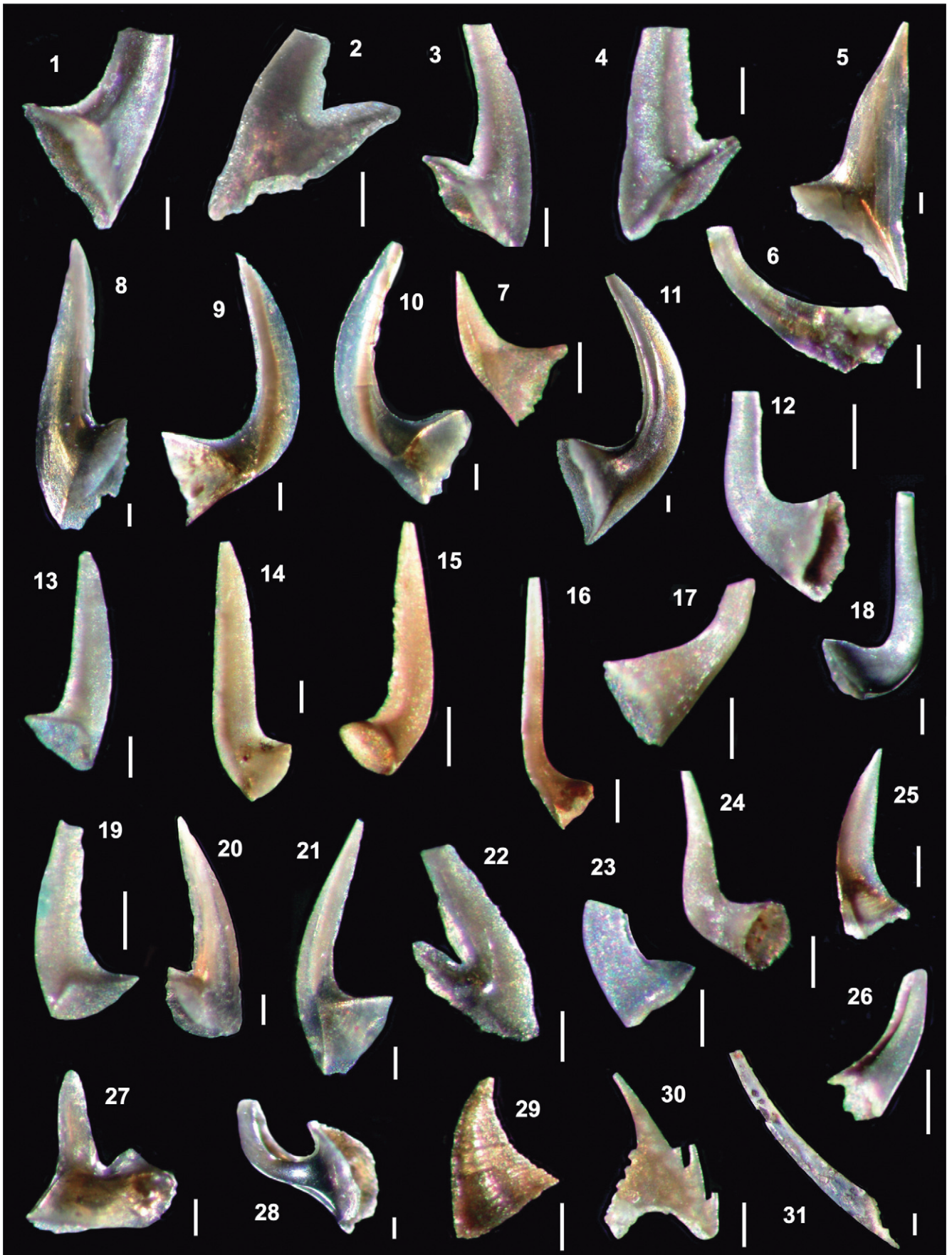
Zone in the Áspero Fm and the *Ao. victoriae* Zone range throughout the lower part of the San Bernardo Fm in the Mojotoro range.

The *Ao. victoriae* Zone includes records of kiaerograptids (e.g., *Kiaerograptus kiaeri*, *Kiaerograptus* spp., *Adelograptus cf. altus*, *Ancoragraptus cf. bulmani*), and *Ao. victoriae* from eastern and western outcrops of the Eastern Cordillera. This graptolite zone is partly equivalent to the *N. orthometopa* trilobite Zone and the *Acodus deltatus-Paroistodus proteus* conodont Zone. The *Ao. victoriae-Kiaerograptus* Zone of the biostratigraphic scheme proposed by Ortega and Albanesi (2005) for northwestern Argentina, and the local *Kiaerograptus* and *Ao. victoriae* zones of the Mojotoro Range (Monteros, 2005), correspond in part to the *Ao. victoriae* Zone as interpreted in present study.

Associated fauna

Trilobites were found in few samples from the upper member of the Coquena Fm, and are herein considered a control group for conodont and graptolite information at the regional scale. Recorded species include *Notopeltis orthometopa* (HARRINGTON, 1938), *Asaphellus jujuanus* HARRINGTON, 1938, ‘*Colpocoryphoides*’ cf. *trapezoidalis* (HARRINGTON, 1938), *Conophrys* sp., *Mekynophrys nanna* HARRINGTON, 1938, *Parabolinella triarthroides* HARRINGTON, 1938, *Pliomeroides deferraris* (HARRINGTON, 1938), ?*Pliomeridius* sp., and *Pyrometopus pyriformis* (HARRINGTON, 1938), which represent the *Notopeltis orthometopa* Zone (HARRINGTON AND LEANZA, 1957). Tortello (1996, 2003) described a fauna of agnostoids from the Purmarca area, and the whole trilobite fauna was analyzed in detail by Waisfeld and Vaccari (2003).

FIGURE 4 | Tremadocian conodonts from the studied sections. 1) *Paltodus deltifer pristinus* (VIIRA, 1970), M element, inner-lateral view, sample Chal 1, CORD-MP 11293. 2) *Paltodus deltifer deltifer* (LINDSTRÖM, 1955), M element, inner-lateral view, sample Coq 2, CORD-MP 11356. 3) *Paltodus deltifer* n. ssp., M element, inner-lateral view, sample Coq 2, CORD-MP 11294. 4) *Paltodus cf. subaequalis* PANDER, 1856 (sensu Löfgren, 1997), M element, inner-lateral view, sample Coq 2, CORD-MP 11295. 5) *Paltodus subaequalis* PANDER, 1856, Sa element, lateral view, sample Hum 2, CORD-MP 11296. 6) *Protopanderodus cf. elongatus* SERPAGLI, 1974, S element, lateral view, sample Hum 1, CORD-MP 11298. 7) *Acodus deltatus* LINDSTRÖM, 1955 (sensu lato), P element, inner-lateral view, sample Hum 1, CORD-MP 11297. 8-9) *Drepanodus arcuatus* PANDER, 1856, 8) Pb element, inner-lateral view, sample Hum 2, CORD-MP 11299, 9) Sa element, lateral view, sample Hum 1, CORD-MP 11300. 10) *Drepanodus parformis* LÖFGREN and TOLMACHEVA, 2003, Sd element, outer-lateral view, sample Hum 2, CORD-MP 11301. 11) *Drepanodus reclinatus* (LINDSTRÖM, 1955), Sd element, sample outer-lateral view, Hum 2, CORD-MP 11302. 12) *Teridontus obesus* JI and BARNES, 1994, Sc element, lateral view, sample Coq 1, CORD-MP 11303. 13) *Protopanderodus inconstans* (BRANSON and MEHL, 1933), M element, inner-lateral view, sample Hum 2, CORD-MP 11304. 14) *Protopanderodus prolatus* JI and BARNES, 1994, M element, inner-lateral view, sample Hum 2, CORD-MP 11305. 15) *Utahconus longipinnatus* JI and BARNES, 1994 M element, inner-lateral view, sample Coq sup, CORD-MP 11306. 16) *Teridontus gracillimus* NOWLAN, 1985, Sc element, lateral view, sample Coq sup, CORD-MP 11307. 17) *Parapanderodus striatus* (GRAVES and ELLISON, 1941), Sb element, lateral view, sample Hum 1, CORD-MP 11308. 18) *Variabiliconus variabilis* (LINDSTRÖM, 1955), Sa element, lateral view, sample Chal 1, CORD-MP 11309. 19) *Rossodus tenuis* (MILLER, 1980), M element, inner-lateral view, sample Coq 2, CORD-MP 11310. 20) *Drepanoistodus concavus* (BRANSON and MEHL, 1933), M element, inner-lateral view, sample Hum 2, CORD-MP 11311. 21) *Drepanoistodus chucaleznesis* ALBANESI and ACEÑOLAZA, 2005, P element, inner-lateral view, sample Hum 2, CORD-MP 11312. 22) *Drepanoistodus nowlani* JI and BARNES, 1994, M element, outer-lateral view, sample Chal 1, CORD-MP 11313. 23) *Polycostatus falsioneotensis* JI and BARNES, 1994, M element, lateral view, sample Coq 1, CORD-MP 11314. 24) *Teridontus cf. nakamurai* (NOGAMI), Sc element, lateral view, sample Chal 1, CORD-MP 11315. 25) *Utahconus humahuacensis* ALBANESI and ACEÑOLAZA, 2005, P element, inner-lateral view, sample Chal 1, CORD-MP 11316. 26) *Utahconus utahensis* (MILLER, 1980), Sc element, postero-lateral view, sample Coq 1, CORD-MP 11317. 27) *Iapetognathus aengensis* (LINDSTRÖM, 1955), lateral view, sample Hum 1, CORD-MP 11318. 28) Gen. et sp. nov., lateral view, sample Chal 1, CORD-MP 11319. 29) *Kallidontus* n. sp., lateral view, sample Coq sup, CORD-MP 11320. 30) ?*Henaniodus magicus* HE and PEI, 1984, lateral view, sample Hum 2, CORD-MP 11321. 31) *Phakelodus elongatus* (AN, 1983), lateral view, sample Coq sup, CORD-MP 11322. Scale bar: 0.1 mm.



The bivalve *Lipanella purmamarcensis* SÁNCHEZ, 2005, previously reported by Sánchez (2005) from the upper member of the Coquena Fm in the Chalala section, was recovered by us from the lower part of the Humacha Member.

An almost complete specimen of the echinoderm *Linguilocystis* cf. *elongata* THORAL, was collected in the lowermost strata of the Humacha Member. Gutiérrez-Marco and Aceñolaza (1999) described the first Argentine record of this eocrinoid from the San Bernardo Fm in the Mojotoro Range, and analyzed the paleobiogeographic relationships with the type locality of the genus in Montagne Noire, France. Also fragmentary thecal plates of *Macrocystella* sp. were recovered in the upper member of the Coquena Fm. Undetermined hyolithid specimens were recorded in the same unit as well.

REGIONAL CORRELATION

The biostratigraphic succession at the studied localities enables us to propose a partial correlation between the *Paltodus deltifer*, *Acodus deltatus*-*Paroistodus proteus*, *Aorograptus victoriae*, and *Notopeltis orthometopa* zones, which have previously been documented in different reports. The correlation chart in Fig. 3 presents a refined biostratigraphy for conodonts, graptolites, and trilobites of the Eastern Cordillera, based on new data from the studied localities. The lowermost part of the Humacha Member turns out to be equivalent in age to the uppermost upper member of the Coquena Fm (Fig. 3), and to the Áspero Fm in the Mojotoro Range in the Salta Province, whereas the upper part of the lower member of the Coquena Fm corresponds to the uppermost part of the Rupasca Member of the Santa Rosita Fm, and probably also correlates with the ‘Chañarcito limestones’ of Harrington and Leanza (1957).

In other basins of Argentina, strata correlative of the *P. deltifer* and *A. deltatus* – *P. proteus* zones have been documented in reports dealing with the La Silla, San Juan, and San Jorge formations of the Cuyania terrane (e.g., Lehnert, 1995; Albanesi et al., 1998, 2003, 2006) and the Bordo Atravesado Fm in the Famatina System (Albanesi et al., 2005). The *Cordylodus angulatus* Zone also has been recognized in the Volcancito Fm in the Famatina Range by Albanesi et al. (2005).

The age of the studied faunas and the lithostratigraphic units that include them is late early to late, but not latest, Tremadocian.

ENVIRONMENTAL CONSTRAINTS

The time interval corresponding to the uppermost lower member and upper member of the Coquena Fm

seems to have been critical for faunal evolution. The *P. d. deltifer* Subzone begins at the top of the lower member and this apparently correlates with beginning of the well documented “*Ceratopyge* Regressive Event” in the Baltoscandian region (Erdtmann, 1986), and probably also coincides with the “*Notopeltis orthometopa* Regressive Event” (NORE of Moya, 1997) in the Eastern Cordillera basin. As discussed above, these beds can also be correlated with the “Low Diversity Interval” of the North American region (Ross et al., 1997). This time interval with its replacement of faunas has been interpreted as the result of a major global oceanic change (Bagnoli, 1994; Nielsen, 2004), i.e., a worldwide progressive shallowing of the sea and the subsequent eustatic sea-level rise that accompanied turnover of the faunas with phylogenetic innovations (Ethington et al., 1987; Ji and Barnes, 1993; Miller et al., 2003; Albanesi and Bergström, 2004).

The Early Ordovician conodont faunas of north-western Argentina have traditionally been regarded as belonging to a transitional realm (T Realm of Dubiniina, 1991), where cold and warm faunas coexisted in a low-mid latitude basin (Rao, 1999; Albanesi et al., 1999; Zeballo et al., 2005b). In a recent revision of the Early Ordovician conodont provincialism, Zhen and Percival (2003) proposed a hierarchical scheme, with two realms (Shallow-Sea and Open-Sea realms) and six domains (Tropical, Temperate, and Cold domains in each realm) ecologically defined, and seven provinces (Laurentian, Australian, North and South China, Argentine Precordillera, and Balto-Scandian Provinces) with specific biogeographical meaning. Early Ordovician conodont faunas in the Eastern Cordillera may correspond to the Cold Domain of the Shallow-Sea Realm (with low species diversity and high population abundance). They show a particularly close relationship to those of the Baltoscandian Province, since the main guide and frequent species from that region are recorded. However, it is important to note the presence of some taxa previously recognized as typical from the warm-shallow water Laurentian Province (see taxonomic references in Appendix, see 144), as well as a few endemic forms that dominate the assemblages. For this reason, new data from the studied localities, and other areas of the Andean belt, are needed in order to verify the presence of a suggested biogeographic province in the southern South American margin of Gondwanaland.

Graptolite provincialism had apparently not yet been developed during the late Tremadocian (Maletz and Egenhoff, 2001), except for the *Psigraptus* fauna that was restricted to low latitudes (Erdtmann, 1988; Zhang and Erdtmann, 2004) and is not present in the

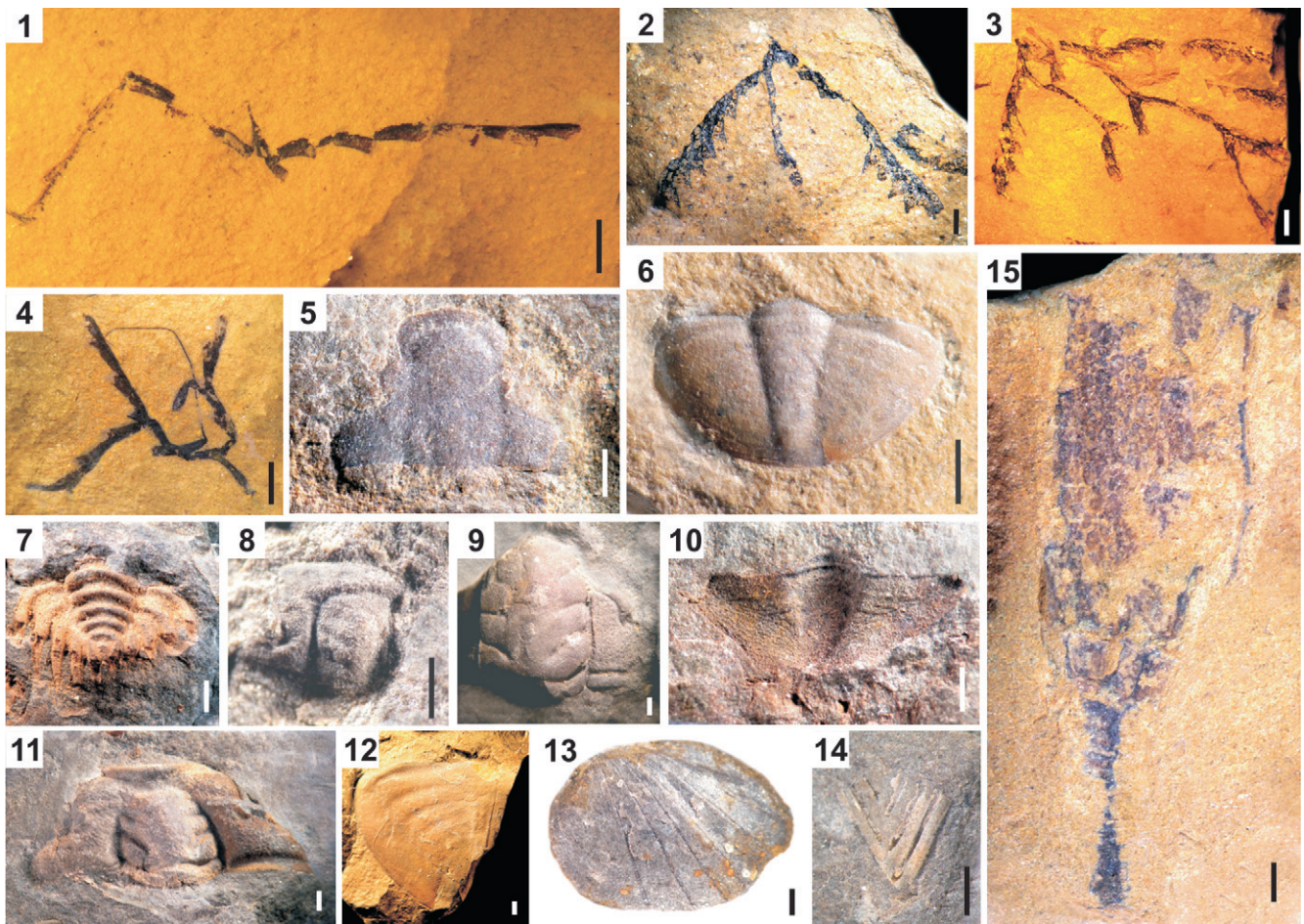


FIGURE 5 | Late Tremadocian graptolites and associated taxa from studied sequences. 1-4) Mature graptolite rhabdosomes: 1) *Ancoragraptus cf. bulmani* (SPJELDNAES, 1963), sample Coq 3 - 10 m, CORD-PZ 31867. 2-3) *Aorograptus victoriae* (T.S. HALL, 1899), sample Coq 3 - 10 m, CORD-PZ 32001 and 32002 3) 4) *Adelograptus cf. altus* WILLIAMS and STEVENS, 1991, sample Hum 0, CORD-PZ 31727. 5-12) Trilobites: 5-6) *Notopeltis orthometopa* (HARRINGTON, 1938), 5) Cranidium, sample Hum 0,5, CORD-PZ 31657, 6) Pygidium, sample Hum 0, CORD-PZ 31957. 7) ?*Pliomeridius* sp., pygidium, sample Coq 2,5, CORD-PZ 31823. 8) *Parabolinella triarthroides* HARRINGTON, 1938, fragmentary cranidium, sample 2,5, CORD-PZ 31834. 9) *Pliomeroides deferraris* (HARRINGTON, 1938), cranidium, sample 2,5, CORD-PZ 31847. 10) *Pyrometopus pyrifrons* (HARRINGTON, 1938), pygidium, sample 2,5, CORD-PZ 31861. 11) "*Colpocoryphoides*" cf. *trapezoidalis* (HARRINGTON, 1938), cranidium, sample 2,5, CORD-PZ 31841. 12) *Mekynophrys nanna* HARRINGTON, fragmentary pygidium, sample Coq 2,5, CORD-PZ 31834. 13) Bivalve: *Lipanela purmamarcensis* SÁNCHEZ, 2005, left valve, sample Hum 0,5, CORD-PZ 31765. 14-15) Echinoderms: 14) *Macrocystella* sp., fragmentary lateral plate, sample Coq 2,5, CORD-PZ 31818. 15) *Lingulocystis cf. elongata* THORAL, 1935, fragmentary calyx, sample Hum 0, CORD-PZ 31968. Scale bar: 1 mm.

northwestern Argentine basins. Most species of the *Aorograptus victoriae* Zone in the Eastern Cordillera have a worldwide distribution, as expected in the absence of provincialism during that interval.

CONCLUSIONS

The analysis of the conodont fauna from the Humacha, Coquena, and Chalala sections, in the neighborhood of the Quebrada de Humahuaca, reveals a succession of conodont zones namely the *Cordylodus angulatus*, *Paltodus deltifer*, and *Acodus deltatus-Paroistodus proteus* zones. The species assemblage recorded in the upper part of the *Paltodus deltifer* Zone confirms its cor-

relation with the "Low Diversity Interval" of the Shallow-Sea Realm of the North American Midcontinent region. Graptolites of the *Aorograptus victoriae* Zone are linked with conodonts of the *Acodus deltatus-Paroistodus proteus* Zone, and trilobites of the *Notopeltis orthometopa* Zone. The referred faunal assemblage, as well as associated bivalves and echinoderms, point to a late Tremadocian age for the studied sequences. The present study proves a partial correlation between the Humacha Member and the upper member of the Coquena Fm.

The conodont faunal composition shows a clear relationship with that of the Baltoscandian Province, although it also includes forms typical of the Laurentian Province together with endemic regional taxa. The Early Ordovi-

cian basin of northwestern Argentina may correspond to the Shallow-Sea Realm and Cold Domain and probably belonged to a separate province in the southern South American Gondwana margin.

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APPENDIX

Taxonomy: selected synonymies

Conodonts (Fig. 4)

- Acodus deltatus* LINDSTRÖM, 1955, *sensu lato*, p. 544, pl.3, fig. 30. Bagnoli et al., 1988, pp. 208-209, pl. 38, figs. 8-14. Albanesi, 1998, p.146, pl. 1, figs. 1-5. Pyle and Barnes, 2002, pp. 86-87, pl. 1, figs. 3-10. Viira et al., 2006, pl. 2, figs. 1, 3-7.
- Drepanodus arcuatus* PANDER, 1856, p. 20, pl. 1, figs. 2, 4, 5, 17, 30, ?31. Löfgren and Tolmacheva, 2003, pp. 211-215, figs. 2, 3A-C, E-H, 5K-V, 6M-U, 7H-N, 8A-G.
- Drepanodus parformis* LÖFGREN AND TOLMACHEVA, 2003, pp. 217-219, figs. 6.A-L, 8.H-M.
- Drepanodus reclinatus* (LINDSTRÖM, 1955), p. 548, tex-fig. 3C. Löfgren and Tolmacheva, 2003, pp. 216-217, figs. 5.A-J, 7.A-G.
- Drepanoistodus chucaleznsis* ALBANESI AND ACEÑO-LAZA, 2005, pp. 301-302, pl. 4, figs. A-F. Zeballo et al. 2005b, pp. 54, 56, figs. 4.G-K.
- Drepanoistodus concavus* (BRANSON AND MEHL, 1933), p. 59, pl. 4, fig. 4. Kennedy, 1980, pp. 55- 57, figs. 26-34. Ji and Barnes, 1994, pp. 34-35, pl. 7, figs. 1-7. Pyle and Barnes, 2002, p. 62, pl. 6, figs. 1-4.
- Drepanoistodus nowlani* JI AND BARNES, 1994, p. 35, pl. 7, figs. 8-20, text-fig. 24A. Pyle and Barnes, 2002, p. 63, pl. 6, figs. 13-15.
- ?*Henaniodus magicus* HE AND PEI, in He et al., 1984, p. 354, pl. 1, figs. 1-3, 6, 8. Pei, 1988, pp. 180-182, pl. 1, figs. 1-8.
- Iapetognathus aengensis* (LINDSTRÖM, 1955), p. 585, pl. 5, figs. 10-13. Nicoll et al., 1999, pp. 44-46; pl. 1, figs. 1a-5f; pl. 2, figs. 1a-4g; pl. 3, figs. 1a-4e; pl. 4, figs. 1a-3f; pl. 5, figs. 1a-3f.
- Paltodus deltifer deltifer* (LINDSTRÖM, 1955), p. 562, pl. 2, figs. 42-43. Löfgren, 1997, pp. 264-265, figs. 5.Z-AG, 6.H-N.
- Paltodus deltifer pristinus* (VIIRA, 1970), p. 227, pl. 5-6, figs. 7-8. Löfgren, 1997, pp. 263-264, figs. 5.P-Y, 6.A-G.
- Paltodus subaequalis* PANDER, 1856 p. 24, fig. 4A. Löfgren, 1997, p. 265, figs. 5.AO-AW, 6.O-U. Viira et al., 2006, pl. 1, fig. 16.
- cf. *Paltodus subaequalis* PANDER, 1856, (*sensu* Löfgren, 1997), p. 265, fig. 5.AH-AN.
- Parapanderodus striatus* (GRAVES AND ELLISON, 1941), p. 11, pl. 1, figs. 3, 12. Albanesi, 1998, p. 117, pl. 7, fig. 27. Pyle and Barnes, 2002, pp. 76-77, pl. 25, figs. 17-22.
- Phakelodus elongatus* (AN, in An et al., 1983), p. 125, pl. 5, figs. 4-5. Müller and Hinz, 1991, pp. 32-33, pl. 1, figs. 1-5, 7-9, 12-14, 22. Zeballo et al., 2005b, p. 62, fig. 4.AG.
- Polycostatus falsioneotensis* JI AND BARNES, 1994, pp. 50-51, pl. 15, figs. 1-12, text-fig. 32C. Pyle and Barnes, 2002, p. 78, pl. 12, figs. 13-15.
- cf. *Protopanderodus elongatus* SERPAGLI, 1974, pp. 73-75, pl. 16, figs. 8a-11c; pl. 25, figs. 13-16; pl. 30, fig. 4, fig. 16. Albanesi, 1998, p. 128, pl. 11, figs. 5-8, text-fig. 14D.
- Protopanderodus inconstans* (BRANSON AND MEHL, 1933), pp. 63-64, pl. 4, fig. 1. Ji and Barnes, 1994, pp. 53-54, pl. 18, figs. 7-14., tex-fig. 33B.
- Protopanderodus prolatus* JI AND BARNES, 1994, p. 54, pl. 18, figs. 1-6, text-fig. 33C.
- Rossodus tenuis* (MILLER, 1980), pp. 36-37, pl. 2, figs. 5-7, text-fig. 4T. Pyle and Barnes, 2002, pp. 102-103, pl. 13, figs. 21-26.
- Semiactiodus striatus* ZEBALLO et al., 2005b, p. 58, figs. 4.U-Y.
- Teridontus gracillimus* NOWLAN, 1985 p. 116, figs. 8.2-8.3. Ji and Barnes, 1994, p. 64, pl. 24, figs. 18-25, tex-fig. 37A. Pyle and Barnes, 2002, p. 71, pl. 15, figs. 12-14.
- cf. *Teridontus nakamurai* (NOGAMI, 1967), pp. 216-217, pl. 1, figs. 15-16. Ji and Barnes, 1994, pp. 64-65, pl. 24, figs. 1-9, tex-fig. 37C.

Teridontus obesus JI AND BARNES, 1994, pp. 65-66, pl. 24, figs. 10-17, tex-fig. 37B. Zeballo et al., 2005b, p. 61, figs. 3.H-L.

Utahconus humahuacensis ALBANESI AND ACEÑO-LAZA, 2005. Ji and Barnes, 1994, pp. 44-45, pl. 14, figs. 19-22. Zeballo et al., 2005b, pp. 59-60, figs. 3.Z-AF.

Utahconus longipinnatus JI AND BARNES, 1994, pp. 66-67, pl. 25, figs. 1-4, 7-8 (only). Landing et al., 1996, pp. 675-676, figs. 7.8-7.19, 7.24, 9.22, 9.23. Pyle and Barnes, 2002, p. 72, pl. 17, figs. 1-3.

Utahconus utahensis (MILLER, 1980), p. 436, text-fig. 5F, pl. 63, figs. 33-40. Pyle and Barnes, 2002, p. 72-73, pl. 16, figs. 17-23. Zeballo et al., 2005b, p. 59, figs. 3.U-Y.

Variabiloconus variabilis (LINDSTRÖM, 1955), p. 582, pl. 2, figs. 14-18, 47, pl. 5, figs. 4-5, text-fig. 6. Löfgren et al., 1999, pp. 162-166, pls. 1, 2, text-fig. 2.

Graptolites (Fig. 5)

cf. *Adelograptus altus* WILLIAMS AND STEVENS, 1991, pp. 30-32, pl. 5, figs. 9-13, 14?, 15?, text-fig. 12 A-G.

Ancoragraptus bulmani (SPIELDNAES, 1963), pp. 127-130, pl. 18, figs. 1-8, text-fig. 3, 4. Jackson and Lenz, 2003, p. 142, figs. 6 m, o, 7 a-l.

Aorograptus victoriae (T.S. HALL, 1899), p. 165, pl. 17, figs. 1, 2. Williams and Stevens, 1991, pl. 4, figs. 9-14, pl. 5, figs. 1-8, text-fig. 11 A-Q.

Trilobites (Fig. 5, partim)

Asaphellus jujuanus HARRINGTON, 1937, p. 115, pl. 5, fig. 9. Waisfeld and Vaccari, 2003, pp. 319-320, pl. 22, figs. 1-2.

cf. '*Colpocoryphoides*' *trapezoidalis* (HARRINGTON, 1938), p. 191, pl. 6, fig. 22. Waisfeld and Vaccari, 2003, p. 317, pl. 20, figs. 7-8.

Mekynophrys nanna HARRINGTON, 1938, p. 207-209, pl. 6, figs. 7, 16-18. Waisfeld and Vaccari, 2003, pp. 320-321, pl. 23, figs. 9-12.

Notopeltis orthometopa (Harrington, 1938), p. 239, pl. 12, figs. 1-8. Waisfeld and Vaccari, 2003, p. 320, pl. 23, figs. 3-7.

Parabolinella triarthroides HARRINGTON, 1938, p. 242, pl. 13, figs. 1-2, 7. Waisfeld and Vaccari, 2003, p. 330, pl. 32, figs. 14-18.

Pliomerooides deferrarisi (Harrington, 1938), p. 184, pl. 6, figs. 13, 19, 21, 23, text-fig. 6. Waisfeld and Vaccari, 2003, p. 318, pl. 21, figs. 11, 12.

Pyrometopus pyrifrons (HARRINGTON, 1938), p. 219, pl. 10, figs. 3-5, 8-9, 13. Waisfeld and Vaccari, 2003, p. 326, pl. 28, figs. 11-15.

Bivalves (Fig. 5)

Lipanella purmamarcensis SÁNCHEZ, 2005, pp. 538-539, figs. 4.6 - 4.17.

Echinoderms (Fig. 5)

cf. *Lingulocystis elongata* THORAL, 1935, pp. 94-95, pl. 8, figs. 3a-b, 4a-b, 6. Aceñolaza and Gutiérrez-Marco, 2002, pp. 127-128, figs. 2.G-J.