Conodonts from the Cambrian-Ordovician Boundary in the Cordillera Oriental, NW Argentina

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ABSTRACT: The Cambrian-Ordovician boundary in NW Argentina was originally proposed for the lower upper section of the Cardonal Formation in the Amarilla Creek, Cajas Range, Cordillera Oriental of Jujuy, based on the first appearance of the conodont *Cordylodus lindstromi*. After the finding of the index fossil *Iapetognathus,* the intersystemic boundary in this stratigraphic unit was recently verified. Through the upper 42 meters of the Cardonal Formation, which is 160 m in total thickness, conodonts of the *Cordylodus lindstromi*, *Iapetognathus* and *Cordylodus angulatus* zones were recovered. The lower upper section of the formation where is located the referred boundary consists of grey-greenish shales interbedded with calcareous sandstones that represent an upper off-shore environment which deepens upwards. The associated species belong to the genera *Acanthodus*, *Cordylodus*, *Eoconodontus*, *Furnishina*, *Iapetognathus*, *Orminskia*, *Phakelodus*, *Problematoconites*, *Proconodontus* and *Teridontus*. Importantly, the index species *Iapetognathus fluctivagus* and *I. jilinensis* were documented for the region in this study. The conodont species are mostly cosmopolitan, integrating a local fauna that is interpreted as representing the Transitional Faunal Realm of Mid-latitudes in the Cold Water Domain or to the lately defined Southwestern Gondwana Province from the Cold Domain in the Shallow-Sea Realm. The conodont elements exhibit a black color (CAI 5 = 300º and 480º), with a significant alteration caused by a Jurassic-Cretaceous boundary hydrothermal influence.

INTRODUCTION

The global Cambrian/Ordovician inter-systemic boundary was a controversial problem regarding the fossil record and reference stratigraphic section. The Cambrian/Ordovician Boundary Working Group of the International Subcommission on Ordovician Stratigraphy (ICS-IUGS) selected the conodont species *Iapetognathus fluctivagus* as the index fossil for establishing the boundary after comprehensive taxonomic studies. Nicoll et al. (1999) monographed *I. fluctivagus* and other species of *Iapetognathus* as well as its purported ancestor *Iapetonudus ibexensis,* and they documented their known occurrences, ranges and correlations with other fossils considered significant to define the base of the Tremadocian. Cooper, Nowlan and Williams (2001) proposed the section of Green Point in western Newfoundland, Canada, for the GSSP of the Cambrian/Ordovician (C/O) boundary, which is determined by the first appearance of *I. fluctivagus*, and was later approved by the IUGS executive.

Terfelt, Bagnoli and Stouge (2012) revisited the taxonomy, stratigraphic ranges and lineage of *Iapetognathus*, with interpretations that were refuted by Miller et al. (2014). The latter authors concluded that the homotaxial succession of *Iapetognathus* species, as defined by Nicoll et al. (1999), should be maintained for determining the base of the Ordovician System globally.

The definition of the C/O boundary in Argentina was evaluated following the conodont biostratigraphic concepts (Nicoll et al. 1999; Cooper, Nowlan and Williams 2001) in the Volcancito Formation at the Famatina Range of western Argentina (Albanesi, Esteban and Barnes 1999; Albanesi et al. 2005). Previous studies of the stratigraphy and paleontology of this interval were carried out in the Cajas Range of the Cordillera Oriental, northwestern Argentina. The first work was that of Aceñolaza (1966), who documented *Parabolina argentina* and *Kainella meridionalis* in Tremadocian rocks. Suárez Riglos, Sarmiento and Hünicken (1982) and Hünicken, Súarez Riglos and Sarmiento (1985) first reported the conodonts *Cordylodus oklahomensis* and *Cordylodus proavus* (now *Cordylodus proavus* Zone) in the Lampazar Formation, at the Amarilla Creek in the northern Cajas Range. The studies carried out by Rao (1994, 1999), Rao and Hünicken (1995) and Ortega and Rao (1995) in the same section recognized conodont biozones that span the Cambrian/Ordovician transitional interval (*Cordylodus caboti*, *Cordylodus intermedius* and *Cordylodus lindstromi* zones), as well as the index taxa *Rhabdinopora flabelliformis parabola* and *Jujuyaspis keideli.* According to Ortega and Rao (1995), *R. f. parabola* was recorded ca. 26m above the base of the *C. lindstromi* Zone and *J. keideli* ca. 10m over the base of the same conodont zone (Tortello et al. 1999). In this way, according to the definition of the C/O boundary proposed by Barnes (1988) on the base of the *Cordylodus lindstromi* Zone, that boundary was determined within the lower upper part of the Cardonal Formation, exposed in the referred section. Recently, other study areas, such as Lari in the Puna region (Giuliano et al. 2013a) and new localities in the Cordillera Oriental; e.g., Santa Victoria, Nazareno, El Moreno, Alfarcito (e.g., Buatois et al. 2006; Zeballo and Albanesi 2009; Voldman et al. 2014), were surveyed as potential sites for the location of the C/O boundary. Albanesi and Pacheco (2010) recorded *I. fluctivagus* for the first time in the Amarilla Creek section of the Cajas Range, close to the base of the upper succession of the Cardonal Formation.

The present contribution attempts a better approximation of the C/O boundary considering a stratigraphic resampling for conodonts through the critical interval, with the definition of successive conodonts zones and the record of the FAD of *I. fluctivagus* in the same section. We analyzed 40 samples from the Cardonal Formation, each weighting 3 kg on average, which were processed in 10% formic acid solution following the standard techniques (Stone 1987). Twenty eight of the forty samples were productive, and yielded 3942 conodont elements, which are moderately well preserved with a black color alteration (CAI 5, *sensu* Epstein et al. 1977).

The conodont collections are deposited in the Museo de Paleontología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Argentina, under the repository codes CORD-MP 16001 to 16290 and 29677 to 29788.

GEOLOGICAL FRAMEWORK

The analyzed area is located in the northern portion of the Cajas Range at the Amarilla Creek. Access to the study area from Humahuaca town is along the National Route 9 to the Tres Cruces locality, then turns 48 km to the west from a paved road to the mining camp El Aguilar. The final track is 7 km distance, by a secondary road that links El Aguilar with Casa Grande localities along the northwest side of the range, to reach the Amarilla Creek at ca. 3800 m altitude (Figure 1).

The stratigraphic succession initiates with the Padrioc Formation (equivalent to the Chalhualmayoc Formation of the Mesón Group), which consists of pinkish-gray fine sandstones and white quartzites with planar stratification, sigmoidal cross bedding, undulitic lamination and hummocky cross bedding stratification (HCS). This unit makes up the nucleus of the Cajas Range anticline (Ortega and Rao 1995; Rao 1999; Aceñolaza 2003). The Padrioc Formation is unconformably overlain by the Lampazar Formation that consists of black to greenish shales with parallel lamination, light green shales intercalated with calcarenites and greenish-gray very fine to fine sandstones with HCS structures; subordinate gray mudstones with rippled cross lamination are intercalated. The uppermost part of the section corresponds to the *Cordylodus proavus* Zone, which indicates a late Cambrian age (Hünicken, Suárez Riglos and Sarmiento 1985; Rao and Hünicken 1995; Ortega and Rao 1995; Rao 1999; Aceñolaza 2003; Moya et al. 2003; Ortega and Albanesi 2005; Albanesi, Ortega and Zeballo 2008). The contact with the overlying Cardonal Formation is through a marine erosive contact. The Cardonal Formation consists of yellow-ocher massive and tabular sandstones, with fossil traces and stratigraphic plane surfaces with ripple marks in its lower part. The middle section is made up of light gray quartzitic-sandstones intercalated with calcarenites. In this part of the stratigraphic unit, more frequent coquinas appear interbedded with quartzites. The upper section is characterized by light gray, medium to coarse sandstones, which alternate with calcarenites and a minor portion of mudstones. This succession culminates with a major proportion of horizons of coquinas, interbedded with greenish-gray fine sandstones and shales, and laminated green and gray mudstones. The environment of deposition of the sequence is interpreted as intertidal to subtidal. The *Kainella meridionalis* and part of *Parabolina (N.) frequens argentina* zones were determined through the upper to the basal part of the studied section, respectively. In the lower upper section, *Rhabdinopora flabelliformis parabola* and *Anisograptus matanensis* were recognized, while towards the top portion the *Rhabdinopora flabelliformis anglica* Zone was identified. The conodont biozones are recorded in the upper section of the formation, including the *Cordydodus lindstromi* (upper part), *Iapetognathus* and *Cordylodus angulatus* zones, through the previously recognized interval that spans the Upper Cambrian - Lower Ordovician (Ortega and Rao 1995; Rao 1999; Aceñolaza 2003; Ortega and Albanesi 2005; Albanesi, Ortega and Zeballo 2008; Albanesi et al. 2015). At Amarilla Creek, the contact between the Cardonal and Acoite formations is tectonic. The latter stratigraphic unit consists of gray shales and minor portions of sandstones in the middle portion, which bears graptolites of Floian age (Toro 1993; Ortega and Rao 1995; Aceñolaza 2003). In the study area, the Ordovician succession ends upward with the Alto del Cóndor Formation, which consists of sandy and shaly intervals deposited in estuarine environments during the Dapingian (Astini et al. 2004; Carlorosi, Heredia and Aceñolaza 2013).

According to the traditional models, the geological setting of the Cordillera Oriental is proposed as a foreland basin formed in a passive margin with evidence of acid volcanism in the Tremadocian (e.g., Moya et al. 1993; Aceñolaza et al. 1999; Buatois et al. 2006). Astini (2008) considered a model of retroarc foreland basin with variations in the angle of subduction during the Cambrian and Ordovician periods.

CONODONT BIOSTRATIGRAPHY

The conodont biozones are defined by the first appearance datum (FAD) of the index species (i.e., interval zones) according to the reference biozonal scheme established in North America (Ross et al. 1997; Cooper, Nowlan and Williams 2001) (Figures 2, 3, 4).

Cordylodus lindstromi Zone

In the study area, *Cordylodus lindstromi* is recorded for the first time from the lowest fertile sample at level C1+1m in the lower middle part of Cardonal Formation. The stratigraphic distribution of the conodont species from this level until the top productive level of the column is ca. 42 m in thickness. The stratigraphic interval of the *C. lindstromi* Zone covers 6 m up to the FAD of *Iapetognathus fluctivagus* –the next zonal fossil. The conodont association of this zone includes the eponymous species together with *Cordylodus caseyi*, *C. deflexus*, *C. intermedius*, *C proavus*, *Phakelodus tenuis*, *Proconodontus muelleri*, *Teridontus gallicus*, *T. nakamurai*, *T. obesus* and *Orminskia rexroadae*. This conodont association indicates a latest Cambrian age. The *C. lindstromi* Zone has worldwide distribution, with records in different sections of Argentina, China, USA, Kazakhstan, Iran, Australia and Canada (references in Barnes 1988, Nicoll 1990, Dubinina 2000, Albanesi et al. 2005, Tolmacheva and Abaimova 2009).

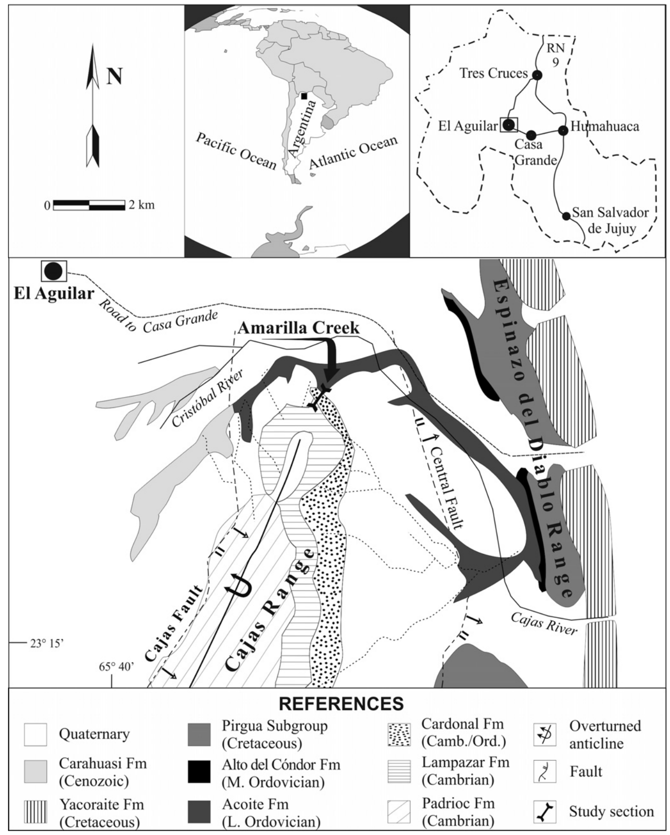
***Iapetognathus* Zone**

At the Amarilla Creek section, the first appearance of *Iapetognathus fluctivagus* in the level C2 defines the base of the biozone, and the upper limit is marked by the first appearance of the index species of the overlying zone, at QA12 level. The *Iapetognathus* Zone is 25 m thick, and records the greater number and diversity of conodonts in the study section. This biozone is recognized in the lower-upper part of the Cardonal Formation, where the basal exposed strata of the upper part of the section represent the mid to upper *Cordylodus lindstromi* Zone as recognized in previous studies. *Rhabdinopora praeparabola*, which is considered a most proximate index graptolite to determine the global C/O boundary (Nicoll et al. 1999; Cooper, Nowlan and Williams 2001), has still not been found in Argentina. The trilobite *Jujuyaspis keideli* was traditionally used to mark the base of the Ordovician System in South America (Aceñolaza and Aceñolaza 1992); however, its lowest record was verified with late Cambrian conodonts of the *Hirsutodontus simplex* Subzone of the *Cordylodus intermedius* Zone in the Cordillera Oriental by Zeballo and Albanesi (2009).

Most associated conodont species continue their records from the underlying zone, such as *Cordylodus caseyi*, *C. deflexus*, *C. hastatus*, *C. intermedius*, *C. lindstromi*, *C. proavus*, *Orminskia rexroadae*, *Phakelodus tenuis*, *Teridontus gallicus*, *T. nakamurai*, *T. obesus,* adding the appearance of *Iapetognathus fluctivagus*, *I. aengensis*, *I. jilinensis*, *Iapetognathus* sp., *Acanthodus uncinatus*, *Drepanodus simplex*, *Cordylodus* cf. *andresi*, C. cf. *viruanus*, *C. prolindstromi*, *Cordylodus* n. sp., *Eoconodontus notchpeakensis*, *Furnishina furnishi*, *Furnishina* n. sp., *Phakelodus elongatus* and *Problematoconites perforatus*. Several of these species continue into the following *Cordylodus angulatus* Zone. The record of *I. jilinensis* in Argentina is the first outside of China, where it has a stratigraphic range similar to that of *I. fluctivagus* (Nicoll et al. 1999). The *Iapetognathus* Zone was first discussed in Argentina in terms of the record of *I. aengensis* in the Volcancito Formation for the Famatina System (Albanesi, Esteban and Barnes 1999; Albanesi et al. 2005). In the Cajas Range, the zone was originally documented in unpublished works (Pacheco 2009) or abstracts that anticipated the present study (Albanesi and Pacheco 2010; Albanesi et al. 2015). This key biostratigraphic unit was documented in Kazakhstan (Dubinina in Apollonov et al. 1988), United States (Utah, Nevada, Idaho, Colorado, Oklahoma, Texas and Nuevo Mexico) (Landing, Westrop and Knox 1996; Nicoll et al. 1999, among others), and China (Wushan) (Miller et al. 2014). The GSSP for the C/O boundary was established in Canada, at the Green Point section in western Newfoundland (Cooper, Nowlan and Williams 2001) and documented in northeastern British Columbia, Canada, as well (Pyle and Barnes 2002).

***Cordylodus angulatus* Zone**

The base of the zone is at the FAD of the index species in the QA12 layer, 11 m below the top of the Cardonal Formation. The upper limit is unknown because the sequence is interrupted by a fault at the top of the Cardonal Formation. The conodont association consists of *Cordylodus angulatus, C. caseyi*, *C. deflexus*, *C. hastatus*, *C. intermedius*, *C. lindstromi*, *C. proavus*, *C. prolindstromi*, *Drepanodus simplex, Eoconodontus notchpeakensis*, *Furnishina furnishi*, *Furnishina* n. sp., *Iapetognathus aengenis*, *Phakelodus elongatus*, *Ph. tenuis*, *Orminskia rexroadae*, *Problematoconites perforatus*, *Teridontus gallicus*, *T. nakamurai* and *T. obesus*. The extension of the zone is restricted to the lower Tremadocian. This biozone has been recorded in diverse localities of the Cordillera Oriental, such as Alfarcito and Angosto del Moreno (Zeballo, Albanesi and Ortega 2005a, b; Albanesi in Moya et al. 2003) and the Cardonal Formation in the Lampazar-Incahuasi and Cajas area (Rao and Tortello 1998; "Pacheco 2009"), and the Famatina System (Albanesi et al. 2005). The zone has a wide distribution elsewhere in the world, including detailed records in Canada (Bagnoli, Barnes and Stevens 1987; Ji and Barnes 1994; Pyle and Barnes 2002), China (Chen and Gong 1986), United States (Ethington and Clark 1971; Miller 1980), Australia (Druce and Jones 1971; Nicoll 1990), Russia (Pander 1856), and Sweden (Löfgren 1996).



TEXT-FIGURE 1
Geological map and location of the study area (modified after Rao 1999).

CONODONT PALEOENVIRONMENTS

Stratigraphic distribution of conodont taxa

The analyzed conodont species were recovered from different calcarenite and coquinoid strata interbedded with sandstones and pelitic horizons through the Cambrian/Ordovician boundary interval in the upper part of the Cardonal Formation.

The genus *Cordylodus* is dominant through the entire study section. A greater proportion of *Cordylodus proavus* elements relative to *Cordylodus lindstromi* occurs in the lower upper section of the formation, whereas in the uppermost section this relationship is reversed. *Proconodontus* and *Problematoconites* were found in small quantities at the bottom of the unit; in turn, *Eoconodontus* appear with low absolute frequency in the middle and upper sections. It is assumed that the proto- and paraconodonts had a pelagic life habit and were abundant in open water environments (Miller 1984: Zhang and Barnes, 2004). *Acanthodus* and *Drepanodus* are present throughout the section, with the largest number of elements in the lower and middle sections; meanwhile, *Teridontus* and *Orminskia* are distributed consistently in all samples. The presence of *Cordylodus* in the lower and middle sections is comparable with that of *Acanthodus*, but gradually decreases towards the top of the formation. Finally, *Furnishina furnishi* is the most frequent species in the uppermost part of the Cardonal Formation.

Discussion and interpretation

Teridontus is represented by a large number of elements in the three biozones defined in this study. Miller (1984) interpreted that this genus is pelagic and is well represented in platform environments; following this author, another widely distributed pelagic genus is *Phakelodus*, although the former was related to shallow to deep water and aerobic conditions whereas the latter preferred a deep-water environment and anaerobic conditions (Zhang and Barnes, 2004). *Cordylodus* is considered as a pelagic representative of open-sea environments, although younger species of *Cordylodus* are interpreted as nectobenthics according to Zhang and Barnes (2004).

The presence of the *Skolithos* ichnofacies in sandstones of the basal portion represents the colonization of organisms adapted to periods of high energy and storms. The low number of *Proconodontus* specimens in the basal strata and *Furnishina* towards the upper section of the Cardonal Formation, along with a consistent increment in the pelitic fraction up section indicates a deepening of the depositional environment.

During the late Cambrian and Early Ordovician the second phase of provincialism of Miller (1984) occurs. This interval begins with a global sea level rise by the end of LREE (= Lange Ranch Eustatic Event in North America) coinciding with major changes in conodont evolution, adaptation, and development of conodont provincialism. The proto-paraconodont faunas continue to inhabit cold water environments and the pelagic euconodont genus *Cordylodus* became cosmopolitan, evolving to necktobentic and invading areas of shallow shelves in the warm waters realm, reducing the provincialism in the late Cambrian - Early Ordovician (Miller 1984; Miller, Ethington and Rosé 2006; Zhang and Barnes, 2004).

The conodont fauna recovered from the Amarilla Creek section represents an association similar to that of western Newfoundland, northwestern Canada, or Oaxaquia, México, which are typical of deep peripheral environments (Bagnoli, Barnes and Stevens 1987, Barnes 1988; Pyle and Barnes 2002; Landing, Westrop and Keppie 2007). The conodont fauna of the Cardonal Formation (Rao 1999; this study) does not present a large number of paraconodonts in relation to euconodonts compared with that relationship in the characteristic high latitude environments of the Baltic region (Viira, Sergeyeva and Popov 1987); however, it presents species related to this region, such as *Cordylodus* cf. *andresi* and *Cordylodus* cf. *viruanus*. Nor it has abundant species of the typical warm-shallow waters, like those distributed in Laurentia, North China and Australia (Druce and Jones 1971; Miller 1984; Ji and Barnes 1994; Nowlan and Nicoll 1995; Pyle and Barnes 2002; Dong, Donoghue and Repetski 2005).

The relative abundance of protoconodonts, paraconodonts and euconodonts, considering the aforementioned conodont paleobiogeographic preferences, suggests an outer continental shelf to open sea paleoenvironment for the studied profile, in the middle latitudes of the Transitional Faunal Realm of Dubinina (2000). Albanesi, Zeballo and Bergström (2007) proposed a new paleobiogeographic province for the Cordillera Oriental, i.e., the Southwestern Gondwana Province from the Cold Domain in the Shallow-Sea Realm derived from the original scheme of Zhen and Percival (2003). This paleobiogeographic unit was characterized by Zeballo and Albanesi (2013), including new endemic species.

According to paleogeographic reconstructions for the Cambro-Ordovician boundary interval, based on facies distribution, paleotectonic models, and paleomagnetic analysis (e.g., Scotese 2010), the southern epicontinental margin of Gondwana in the region of northwestern basins of Argentina, would have been located in mid-high latitudes, near the sites of Avalonia, Baltica and Laurentia. The presence of a cosmopolitan fauna, associated with species from the Baltic region, Oaxaquia, and western Newfoundland, enable to interpret a significant faunal exchange with these terranes through the Iapetus Ocean during the late Cambrian and Early Ordovician.

SYSTEMATIC PALEONTOLOGY

The purpose of this part is to provide an updated synoptic review with reference synonymy citations for the conodont species recorded in the study section.

Genus ***Furnishina*** Müller 1959
Type species: *Furnishina furnishi* Müller 1959, original designation.

Furnishina furnishi Müller 1959
Plate 2, figures 3 and 11

Furnishina furnishi n. sp. MÜLLER 1959, p. 452, pl. 11, figs. 5, 6, 9, 11-13, 15; fig. 6D. – MÜLLER and HINZ 1991, p. 17-20, pl. 13, figs. 1-7, 11, 12; fig. 8a (*cum syn.*). – RAO 1999, p. 29, 30, pl. 3, figs. 4, 7 (*cum syn.*). – LANDING, WESTROP and KEPPIE 2007, fig. 9: c.

Material examined: 82 elements (CORD-MP 16197/1, 16247/1-7, 16275/1, 29686/1-10, 29723/1-54, 29740/1-3, 29776/1-5).

Occurrence: Samples QA5, QA6, QA7, C11, A16, C16+3m and C19.

Discussion: Some recovered coniform elements are rounded and other elements are bilaterally compressed. Compressed elements are more abundant and present a large base and a thin slightly recurved cusp.

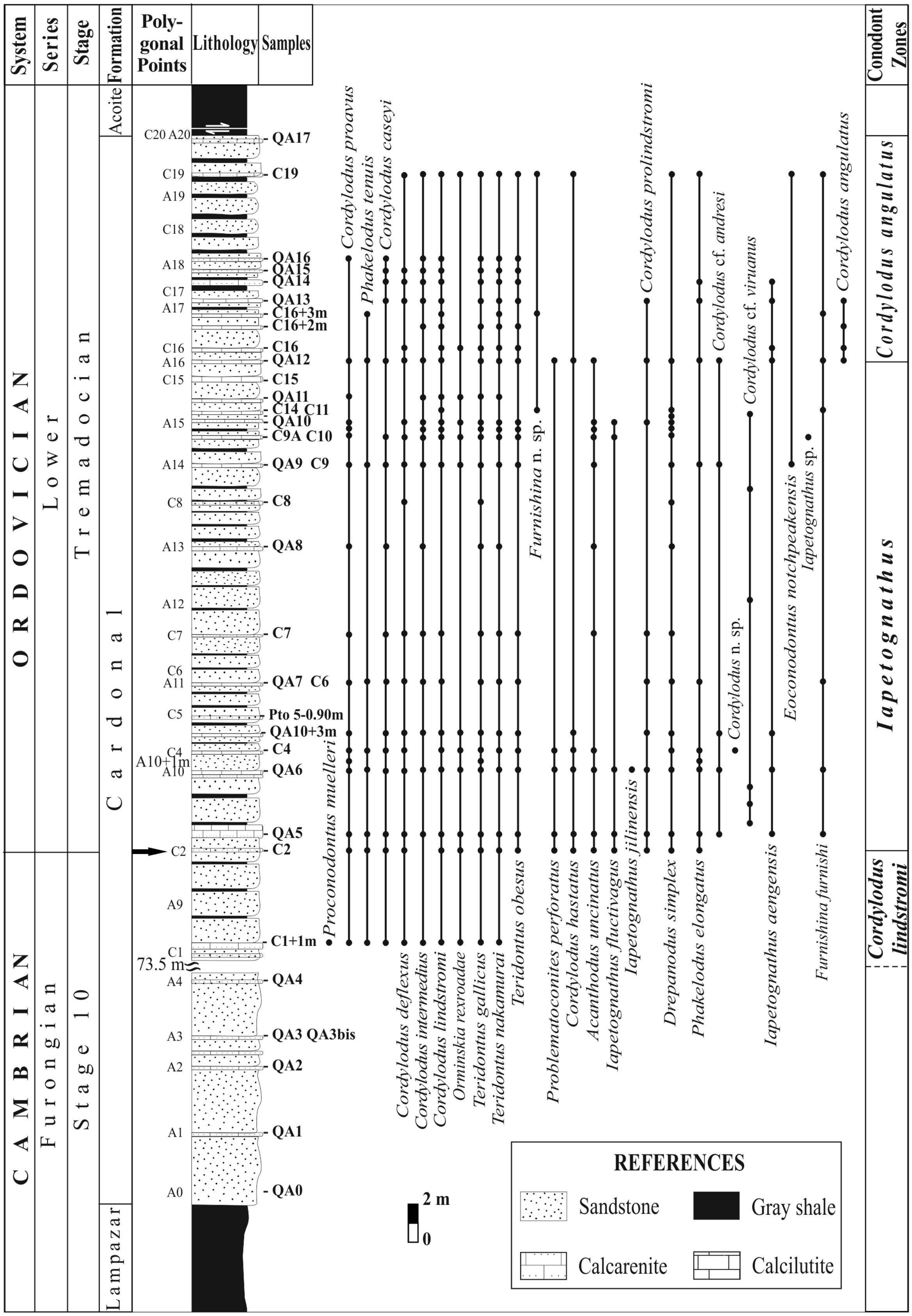
Furnishina n. sp. Albanesi, Giuliano and Pacheco
Plate 2, figures 1-2

Furnishina furnishi Müller- Pacheco 2009, p. 43-44, pl. 2, figs. 1-2.

Material examined: 10 elements (CORD-MP 16197/1, 16247/1-7, 16275/1).

Occurrence: Samples C11, C16+3m and C19.

Discussion: The recovered coniform elements are slender and rounded, with proclined cusps. The crown is completely excavated by the basal cavity. All elements have characteristic equi-



TEXT-FIGURE 2
Stratigraphic column of the Cardonal Formation with conodont ranges and biozones (samples C are from the same levels labeled as C by Ortega and Hünicken 1995, Rao and Hünicken 1995, and Rao 1999).

distant annular expansions along the crown, which are not observed in others species of the genus.

Genus ***Phakelodus*** Miller 1984
Type species: *Oneotodus tenuis* Müller, 1959, original designation.

Phakelodus elongatus (Zhang in An et al. 1983)
Plate 2, figures 10 and 17

Proconodontus elongatus Zhang in An et al. 1983, p. 125, pl. 5, figs. 4-5.
Phakelodus elongatus Zhang- MÜLLER and HINZ 1991, p. 32, 33, pl. 1, figs. 1-5, 7-9, 12-14, 22 (*cum syn.*). – RAO 1999, p. 30, pl. 1, figs. 1, 3, 4. – Zhang- LANDING, WESTROP and KEPPIE 2007, figs. 6: u. – VOLDMAN, ALBANESI, MONALDI and ZEBALLO 2013, p. 317, pl. 2, fig. 21.

Material examined: 47 elements (CORD-MP 16023/1-3, 16079/1, 16244/1, 16255/1, 16271/1, 29693/1-2, 29708/1-7, 29712/1, 29732/1-22, 29744/1-2, 29763/1, 29782/1-5).

Occurrence: Samples C2, QA5, A10, QA6, A10+ 1m, C4, QA7, C9, A16, QA13, QA14 and C19.

Discussion: The conodont elements have an ogival cross section due the presence of a keel in the posterior edge. In some cases, sets of striated rings are observed, which are arranged obliquely in the posterior flank.

Phakelodus tenuis (Müller 1959)
Plate 2, figure 13

Oneotodus tenuis n. sp. MÜLLER 1959, p. 457, pl. 13, figs. 13, 14, 20.
Phakelodus tenuis (Müller)- MÜLLER and HINZ 1991, p. 33, 34, pl. 1, figs. 6, 10, 11, 15-21, 23; pl. 2, figs. 1-24 (*cum syn.*). – RAO 1999, p. 30, 32, pl. 1, fig. 5 (*cum syn.*). – LANDING, WESTROP and KEPPIE 2007, fig. 6: s. – VOLDMAN, ALBANESI, MONALDI and ZEBALLO 2013, p. 317, 318, pl. 2, fig. 22.

Material examined: 55 elements (CORD-MP 16015/1, 16032/1-3, 16069/1, 16080/1-2, 16135/1, 16234/1, 29692/1-7, 29707/1-6, 29731/1-15, 29743/1-5, 29781/1-13).

Occurrence: Samples C1+1m, C2, QA5, A10, QA6, C4, QA7, C9, A16 and C16+3m.

Discussion: These typical coniform elements are thin and long, with a deep basal cavity, and a cusp with oval or circular cross section.

Genus ***Acanthodus*** Furnish 1938
Type species: Acanthodus uncinatus Furnish 1938, original designation.

Acanthodus uncinatus Furnish 1938
Plate 1, figures 4-6

Acanthodus uncinatus n. sp. FURNISH 1938, p. 337, pl. 32, fig. 30, text-fig. 2B. – JI and BARNES 1994, p. 24, 25, pl. 1, figs. 9-13; tex-fig. 22B (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, figs. 7. T, U. – MILLER, ETHINGTON and ROSÉ 2006, table 1, fig. 3 R, S. – LANDING, WESTROP and KEPPIE 2007, fig. 9: v.

Material examined: 112 elements (CORD-MP 16026/1-18, 16055/1-8, 16062/1-6, 16078/1-2, 16089/1-20, 16134/1-8, 16145/1, 16154/1-5, 16164/1-3, 16174/1, 161797/1-6, 16185/1-6, 29685/1, 29702/1, 29722/1-12, 29754/1-2, 29760/1, 29775/1-4).

Occurrence: Samples C2, QA5, A10, QA6, C4, C7, A13, C9, C9A, C10, QA10 and A16.

Discussion: The base is expanded, with laterally compressed cusp and keeled anterior and posterior margins. The presence of a carina in the posterior flank of the cusp is common. The recovered elements of *Acanthodus uncinatus* are larger than the ones of *A. lineatus*.

Genus ***Drepanodus*** Pander 1856
Type species: Drepanodus arcuatus Pander 1856.

Drepanodus simplex Branson and Mehl 1933
Plate 1, figures 1-3

Drepanodus lineatus n. sp. BRANSON and MEHL 1933, p. 58, pl. 4, fig. 2.
Oneotodus sp. indet., MÜLLER 1959, p. 458, pl. 13, figs. 15.
Drepanodus simplex Branson and Mehl 1933. – WOLSKA 1961, p. 349, pl. 2, figs. 8. – DRUCE and JONES 1971, p. 74, pl. 13, figs. 1a-4c; text-fig. 24b.

Material examined: 115 elements (CORD-MP 16029/1-15, 16058/1-6, 16071/1-8, 16090/1-29, 16107/1, 16121/1, 16128/1, 16141/1-8, 16153/1-4, 16180/1-2, 16191/1-13, 16198/1, 16214/1, 16276/1, 29684/1-4, 29701/1-2, 29721/1-13, 29739/1-3, 29747/1, 29753/1).

Occurrence: Samples C2, QA5 A10, QA6, C4, QA10 + 3m, QA7, C7, A13, C8, C9, QA9, C9A, C10, QA10, C11, A16, QA12 and C19.

Discussion: The morphology of the recovered elements matches with the detailed description provided by Druce and Jones (1971). Following these authors, *Drepanodus simplex* is similar to *Acanthodus uncinatus* but differs on the lack of ancillary dentition on the posterior-oral edge. These two species occur together in the *Iaptognathus* Zone but the range of *Drepanodus simplex* continues into the *Cordylodus angulatus* Zone in the studied section.

Genus ***Eoconodontus*** Miller 1980
Type species: *Proconodontus notchpeakensis* Miller 1969

Eoconodontus notchpeakensis (Miller 1969)
Plate 2, figure 12

Proconodontus notchpeakensis n. sp. MILLER 1969, p. 438, pl. 66, figs. 13-29.
Eoconodontus notchpeakensis (Miller). – RAO 1999, p. 40-42, pl. 3, figs. 3, 5, 6, 8 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7. N, O. – ZHEN and PERCIVAL 2006, table 1, fig. 4: A-C. – LANDING, WESTROP and KEPPIE 2007, fig. 6: q, r.

Material examined: 3 elements (CORD-MP 16143/1, 16278/1).

Occurrence: Samples C9 and C19.

Discussion: Laterally compressed coniform elements, with short, proclined to erect cusp and moderately deep basal cavity. The anterior and posterior margins are keeled. The white matter is distributed in the cusp.

Genus ***Cordylodus*** Pander 1856
Type species: *Cordylodus angulatus* Pander 1856, original designation.

Discussion: The first reconstruction of the multielemental apparatus of *Cordylodus* Pander was proposed by Bergström and Sweet (1966). They determined a bimembrate design, including two rounded elements with different morphology. Miller (1980) and Landing, Ludvigsen and von Bitter (1980) assigned two elements one rounded and other compressed. Smith, Donoghue and Repetski (2005) discussed the special architecture of this genus on the base of a cluster of *C. lindstromi* Druce and Jones, concluding that it presents a similar design to that of the panderodontids. Nicoll (1990) distinguished six morphotypes: M, Pa, Sa, Sb, Sc, Sd, and Ji and Barnes (1994) recognized the morphotypes a, c, and two variations of e. In the present work, we adopt the apparatus structure proposed by Nicoll (1990).

Cordylodus* cf. *andresi Viira and Sergeyeva (in Kaljo et al. 1986)
Plate 3, figures 14-15

cf. *Cordylodus* sp.- ANDRES 1981, p. 23, figs. 11-19.
cf. *Cordylodus andresi* Viira and Sergeyeva-in KALJO, BOROVKO, HEINSALU, KHAZANOVICH, MENS, POPOV, SERGEYEVA, SOBELEVSKAYA and VIIRA 1986, p. 103, pl. 2, figs. 1-6, 9, 10. – ZEBALLO and ALBANESI 2009 p.547, 548, figs. 6.1-4 (*cum syn.*).

Material examined: 27 elements (CORD-MP 16044/1-2, 16057/1-2, 16097/1-2, 29683/1-4, 29720/1-13, 29759/1, 29772/1-3).

Occurrence: Samples QA5, QA6, QA10+3m, C9 and A16.

Discussion: The recovered elements are similar to those described by Andres (1981). The elements are laterally compressed, with a wide base and an erect very short cusp. One to three denticles are developed close to the cusp. The basal cavity is deep and conical.

Cordylodus angulatus Pander 1856
Text-figure 4: 3, 7

Cordylodus angulatus n. sp. PANDER 1856, p. 33, pl. 2, figs. 28-31; pl. 3 fig. 10; table A, fig. 10. – BAGNOLI, BARNES and STEVENS 1987, p. 150, 152, pl. 1, figs. 19-21 (*cum syn.*). – ZEBALLO, ALBANESI and ORTEGA 2005b, p. 3, 4, fig. 3G (*cum syn.*).

Material examined: 11 elements (CORD-MP 16212/1, 16226/1-2, 16229/1, 16242/1-3, 29764/1-3).

Occurrence: Samples A16, QA12, C16, C16+2m and QA13.

Discussion: Laterally compressed elements with cusps recurved. Posterior process with denticles recurved or reclined. The anterior margin of the basal cavity is concave in lateral view and the apex recurves sigmoidally (see Nicoll, 1990).

Cordylodus caseyi Druce and Jones 1971
Plate 1, figure 18

Cordylodus caseyi n. sp. DRUCE and JONES 1971, p. 67, 68, pl. 2, figs. 9-12; text-figs. 23d, e. – NICOLL 1990, p. 543-545, figs. 3(a-c), 13-15 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7J. – LANDING, WESTROP and KEPPIE 2007, fig. 5: m-t.

Material examined: 87 elements (CORD-MP 16005/1, 16013/1, 16020/1-2, 16041/1-7, 16049/1-6, 16065/1-2, 16092/1-6, 16118/1, 16126/1, 16140/1-3, 16160/1, 16168/1, 16213/1-4, 16238/1-7, 16253/1-2, 16263/1, 29677/1-11, 29695/1, 29713/1-17, 29733/1-2, 29749/1-5, 29765/1-4, 29783/1).

<table>
<tr><th rowspan="2">SYSTEM</th><th rowspan="2">SERIES</th><th rowspan="2">STAGE</th><th colspan="4">CONODONT ZONE</th></tr>
<tr><th colspan="2">North America</th><th colspan="2">Northwest Argentina</th></tr>
<tr><td rowspan="2">ORDO-VICIAN</td><td rowspan="2">Lower</td><td rowspan="2">Trema-docian</td><td colspan="2">Cordylodus angulatus</td><td colspan="2">Cordylodus angulatus</td></tr>
<tr><td colspan="2">Iapetognathus</td><td colspan="2">Iapetognathus</td></tr>
<tr><td rowspan="7">CAMBRIAN</td><td rowspan="7">Furongian</td><td rowspan="7">10</td><td colspan="2">Cordylodus lindstromi</td><td colspan="2">Cordylodus lindstromi</td></tr>
<tr><td rowspan="2">Cordylodus intermedius</td><td>Clavohamulus hintzei</td><td rowspan="2">Cordylodus intermedius</td><td>?</td></tr>
<tr><td>Hirsutodontus simplex</td><td>Hirsutodontus simplex</td></tr>
<tr><td rowspan="3">Cordylodus proavus</td><td>Clavohamulus elongatus</td><td rowspan="3">Cordylodus proavus</td><td rowspan="2">?</td></tr>
<tr><td>Fryxellodontus inornatus</td></tr>
<tr><td>Hirsutodontus hirsutus</td><td>Hirsutodontus hirsutus</td></tr>
</table>

TEXT-FIGURE 3
Conodont biostratigraphic chart of the Upper Cambrian-Lower Ordovician (modified after Zeballo and Albanesi 2009).

Occurrence: Samples C1+1m, C2, QA5, A10, QA6, C4, QA10+3m, QA7, C7, A13, QA9, C9, C9A, A16, QA12, QA13, QA14, QA15 and QA16.

Discussion: Robust elements with large cusp of oval cross section, which usually have keels on the lateral or anterior margin. Posterior process with one to three slightly recurved denticles. The elements develop a short adenticulate lateral expansion.

Cordylodus deflexus Bagnoli, Barnes and Stevens 1987
Plate 1, figure 19

Cordylodus deflexus n. sp. BAGNOLI, BARNES and STEVENS 1987 p. 153, pl. 2, figs. 1-3 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7. D, F. – GIULIANO, ORTEGA, ALBANESI and MONALDI, 2013a, p. 35, fig. 3: 8.

Material examined: 96 elements (CORD-MP 16003/1, 16008/1-3, 16028/1-11, 16039/1-11, 16054/1-7, 16063/1-2, 16084/1, 16093/1-14, 16117/1, 16122/1, 16139/1, 16193/1-9, 16210/1-4, 16225/1-2, 16241/1-11, 16254/1-2, 16260/1, 16279/1, 29715/1-4, 29735/1, 29767/1).

Occurrence: Samples C1+1m, C2, QA5, QA6, C4, QA10+3m, QA7, C7, C8, C9, C9A, QA10, A16, QA12, C16, QA13, QA14, QA15 and C19.

Discussion: Compressed and rounded elements with proclined to erect cusp and rounded anterior margin. Short posterior process with one to three denticles, process laterally flexed out of the plane of the cusp. Anterior margin of the basal cavity parallel to the anterior margin of the element and slightly convex near the apex.

Cordylodus hastatus Barnes 1988
Plate 3, figure 4

Cordylodus prion Lindström. – DRUCE and JONES 1971, p. 70, pl. 2, fig. 4.
Cordylodus hastatus n. sp. BARNES 1988, p. 411, 412, figs. 13 s-x, 14d (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7 A. – GIULIANO, ALBANESI, ORTEGA, ZEBALLO and MONALDI, 2013b, p. 40, figs. 2, 3: 31.

Material examined: 46 elements (CORD-MP 16019/1-2, 16037/1-2, 16047/1-5, 16072/1-2, 16094/1-9, 29679/1-7, 29697/1-2, 29716/1-7, 29768/1-9, 29784/1).

Occurrence: Samples C2, QA5, A10, QA6, C4, QA10+3m, A16 and QA16.

Discussion: Robust elements, laterally compressed with prominent cusp, which is proclined to erect. Acute anterior and posterior margins of the cusp. Recovered specimens show short posterior processes (broken in some specimens) with one to three denticles, short, laterally compressed and confluent basally.

Cordylodus intermedius Furnish 1938
Plate 1, figure 17 and Plate 3, figures 1-3

Cordylodus intermedius n. sp. FURNISH 1938, p. 338, pl. 42, fig. 31; text-fig. 2 (c). – ZEBALLO, ALBANESI and ORTEGA 2005b, p. 4, figs 3.M (*cum syn.*).

Material examined: 111 elements (CORD-MP 16009/1-3, 16040/1-2, 16051/1-2, 16068/1-2, 16096/1-26, 16119/1, 16130/1-3, 16137/1, 16158/1-4, 16167/1, 16182/1-3, 16189/1-5, 16204/1, 16211/1-3, 16221/1-2, 16227/1-4, 16240/1-13, 16252/1-2, 16262/1-3, 16267/1, 16274/1-3, 29678/1-3, 29696/1-6, 29714/1-8, 29734/1, 29750/1, 29766/1-8).

Occurrence: Samples C1+1m, QA5, A10, QA6, QA10+3m, QA7, C7, A13, QA9, C9, C9A, C10, QA10, QA11, QA12, A16, C16+2m, QA13, QA14, QA15, QA16 and C19.

Discussion: In this work, we consider that *C. caboti* and *C. drucei* are morphotypes of the multielemental apparatus of *C. intermedius* (*sensu* Miller et al. 2003; cf. Zeballo and Albanesi 2009 for other interpretation when the quality of element preservation allow for a detailed description of the whole basal cavity).

Cordylodus lindstromi Druce and Jones 1971
Plate 3, figures 13, 17-20 and Text-figure 4: 1-2

Cordylodus lindstromi n. sp. DRUCE and JONES 1971, p. 68, text-fig. 23h, pl. 1, figs. 7-9; pl. 2, fig. 8. – JI and BARNES 1994, p. 32, pl. 5, figs. 19-22 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7 H, K. – GIULIANO, ORTEGA, ALBANESI and MONALDI 2013a, p. 34, 35, fig 3: 5-8.

Material examined: 691 elements (CORD-MP 16006/1-8, 16017/1-42, 16038/1-17, 16046/1-37, 16066/1-16, 16075/1-2, 16091/1-91, 16108/1-5, 16113/1, 16138/1-10, 16147/1-2, 16155/1-51, 16165/1-11, 16172/1-2, 16181/1-18, 16186/1-64, 16196/1, 16203/1-3, 16208/1-39, 16220/1-15, 16228/1-4, 16232/1, 16239/1-22, 16251/1-5, 16261/1-2, 16268/1-2, 16273/1-3, 29680/1-45, 29698/1-17, 29717/1-117, 29736/1-8, 29746/1, 29757/1-3, 29769/1-19, 29785/1-4).

Occurrence: Samples C1+1m, C2, QA5, A10, QA6, C4, QA10+3m, QA7, C7, QA9, C9, C9A, C10, QA10, C11, QA11, A16, QA12, C16, C16+2m, C16+3m, QA13, QA14, QA15, QA16 and C19.

Discussion: Ramiform elements rounded and compressed, with basal cavity biapical, characteristic of this species. The secondary apex extends into the first denticle of the posterior process. The cusp is erect to recurved and the anterior and posterior margins are keeled. The first denticle is close to the cusp configuring a notch. The basal cavity is shallow and does not exceed the level of the denticles, its apex is near the anterior margin, and a secondary basal cavity is displayed in the first denticle. The white matter spreads in the cusp, above the level of the process and denticles.

Cordylodus proavus Müller 1959
Plate 3, figures 5-8

Cordylodus proavus n. sp. MÜLLER 1959, p. 448, pl. 15, figs. 11, 12, 18, text-fig. 3B. – NICOLL 1990, p. 550,551, figs. 3 (1a-d), 19-22 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7 G, I. – LANDING, WESTROP and KEPPIE 2007, fig. 5: h-l. – ZEBALLO and ALBANESI 2009, p.545, 546, figs. 6.11-13 (*cum syn.*). – GIULIANO, ORTEGA, ALBANESI and MONALDI, 2013a, fig 3: 9-12.

Material examined: 614 elements (CORD-MP 16004/1, 16007/1-25, 16016/1-72, 16036/1-41, 16048/1-57, 16064/1-19, 16074/1-2, 16088/1-100, 16109/1-6, 16115/1-2, 16129/1, 16136/1-11, 16148/1-2, 16156/1-13, 16169/1-4, 16173/1, 16188/1-15, 16201/1-3, 16209/1-12, 29681/1-72, 29699/1-18, 29710/1, 29718/1-100, 29737/1-10, 29751/1-2, 29758/1, 29770/1-17, 29786/1-6).

Occurrence: Samples C1+1m, C2, QA5, A10, QA6, A10+1m, C4, QA10+3m, QA7, C7, A13, QA9, C9, C9A, QA10, QA11, A16, QA12 and QA16.

Discussion: Ramiforms elements compressed and rounded morphotypes. The rounded elements have a large cusp, reclined to erect, wide base that support one to six denticles in its posterior process. The basal cavity has a large extension, conical, with the anterior margin parallel to the anterior margin of the element, and convex. In the compressed elements the cusp is erect to slightly bend sideways. The posterior process supports fused denticles with acute edges. The basal cavity extends inside the cusp and projects to the posterior process.

Cordylodus prolindstromi Nicoll 1991
Plate 1, figure 20

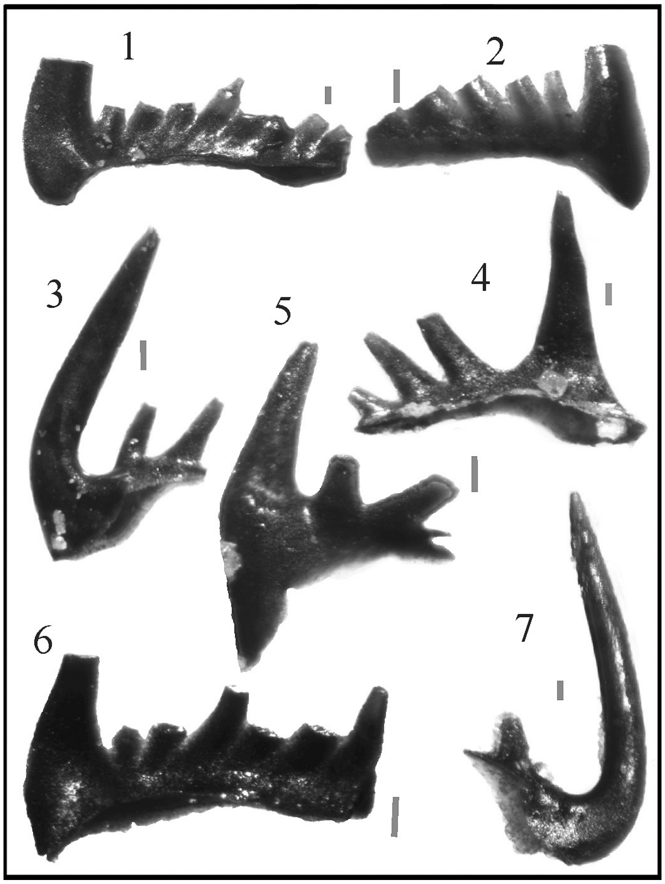
Cordylodus prolindstromi n. sp. NICOLL 1991 p. 233-239, figs. 2.4, 13-16. – TOLMACHEVA and ABAIMOVA 2009, p. 435; fig. 8R, 9Q, S.

Material examined: 19 elements (CORD-MP 16018/1, 16050/1, 16095/1-4, 16116/1, 16187/1-2, 16246/1-2, 29682/1-2, 29719/1-4, 29771/1-2).

Occurrence: Samples C2, QA5, QA6, QA10+3m, QA7, C7, QA10, A16 and QA13.

Discussion: This species is distinguished by the presence of elements with dual-tipped basal cavity, where the second apex is found below of the first denticle, truncated, with a flat apex, different from that of *C. lindstromi,* in which it is pointed. Furthermore, the main apex of the basal cavity projects slightly above the level of the posterior process.

Cordylodus* cf. *viruanus Viira, Sergeyeva and Popov 1987
Plate 3, figures 16



TEXT-FIGURE 4
Index conodont species from the Cardonal Formation.
All scale bars represent 0.1mm.

1 *Cordylodus lindstromi* Druce and Jones 1971, CORD-MP 29717, M element, inner-lateral view, sample QA6.

2 *Cordylodus lindstromi* Druce and Jones 1971, CORD-MP 9736, M element, outer-lateral view, sample QA7.

3,7 *Cordylodus angulatus* Pander 1856. 3, CORD-MP 29764, Pb element, inner-lateral view, sample A16; 7, CORD-MP 29764, Pa element, outer-lateral view, sample A16.

4 *Iapetognathus aengensis* (Lindström 1955), CORD-MP 29728, Sb element, sample QA6.

5 *Iapetognathus fluctivagus* Nicoll et al. 1999, CORD-MP 29691, Sc element, sample QA5.

6 *Iapetognathus jilinensis* Nicoll et al. 1999, CORD-MP 29730, Sc element, sample QA6.

cf. *Cordylodus viruanus* n. sp. VIIRA, SERGEYEVA and POPOV 1987, pl. 4, figs. 10, 13, 14.
cf. *Cordylodus* sp. Viira and Sergeyeva. – KALJO, BOROVKO, HEINSALU, KHAZANOVICH, MENS, POPOV, SERGEYEVA, SOBOLEVSKAYA and VIIRA 1986, pl. 3, figs. 17.
cf. *Cordylodus viruanus* Viira and Sergeyeva. – RAO 1999, p. 38, 40, pl. 9, figs. 1, 3 (*cum syn.*). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7.E.

Material examined: 14 elements (CORD-MP 16081/1, 16099/1-3, 16159/1-2, 29700/1-2, 29738/1, 29752/1-3, 29773/1-2).

Occurrence: Samples A10, C4, QA10+3m, A13, C9A and A16.

Discussion: The specimens are similar to those described by Viira and Sergeyeva (1986) and Viira, Sergeyeva and Popov (1987) according to synonymy. The elements are rounded, with erect cusp. Posterior process with two or three denticules widely spaced. The cusp and denticles are almost the same height. The base is low and the basal cavity extends conically inside the cusp and below the level of the posterior process.

Cordylodus n. sp. Albanesi, Giuliano and Pacheco
Plate 3, figures 9-12

Material examined: 2 elements (CORD-MP 16073/1-2).

Occurrence: Sample C4.

Description: Two types of ramiform laterally compressed elements were recovered. The anterior portion of the base is expanded respect the anterior margin of the cusp. The anterobasal margin is sharp and is projected as an anticusp. Its anterior margin is straight. The basal margin and the posterior process are arcuate. This process carries four to eight discrete denticles, moderately long and laterally compressed.

In one of the morphotypes, the cusp is erect and thinning upwards, the process carries eight denticles, which tend to merge into the base. The two denticles located in the central sector of the process are broken by the middle. Some denticles show an abrupt decrease in diameter in the middle part, similar to the characteristic form of the cusp.

On the other morphotype, the cusp is recurved, and in the process are four discrete denticles slightly reclined. The last two denticles are broken near the base. Some of the denticles exhibit a sharp decrease in its diameter in the middle, similar to the characteristic cusp of the other morphotype.

The section of the cusp and denticles of the two elements is oval.

The basal cavity is conical and shallow, and its tip reaches the base of the cusp, unable to get into it, and extends shallowing through the posterior process.

The specimens have no white matter or micro-surface ornamentation. The CAI of these elements is five.

Discussion: Ramiform elements, laterally compressed, with a distinctive projected anterior margin. The anterobasal margin is sharp, continuing in an incipient anticusp. The cusp is either recurved or erect and thinning upwards abruptly from the base. The posterior process carries four to eight characteristic denticles that are constrained in their middle parts.

These particular morphologies have not been previously described, and the restricted record within the *Iapetognathus* Zone verifies this new species of *Cordylodus* as an auxiliary index species to mark the base of the Ordovician System.

Genus ***Iapetognathus*** Landing (in Fortey, Landing and Skevington 1982)
Type species: *Pravognathus aengensis* Lindström 1955, original designation.

Emended diagnosis: "Septimembrate apparatus of S (Sc, Sb, Sd), P (Pb, Pa) and X (Xa, Xb) elements. All elements ramiform, with a large posteriorly recurved or inclined cusp and one or two denticulate processes. The major process is laterally directed, either as a posteriorly directed outer-lateral process or as an inwardly directed antero-lateral process. The X elements appear to have the cusp recurved over one of the processes, which may be in a posterior direction. No symmetrical (Sa) or makelliform (M) elements have thus far been associated with the apparatus, but Sc, Sb, Sd, Xa, Xb, Pb and Pa elements have been differentiated in one or more species. The cusp of most elements of this genus may have one or more well developed keels or carinae, usually anteriorly or laterally located, that terminate abruptly well above the basal margin of the element. The cusp may be either laterally or antero-laterally compressed. Most species are characterized by elements with smooth surfaces, but some have costae and one species has well developed striae. All species of *Iapetognathus* are characterized by elements with a prominent cusp that is erect at the base but tends to become recurved posteriorly above the level of the lateral or anterior process. In the S and P elements the cusp usually is curved posteriorly and out of the plane of any of the processes, but in the X elements the cusp is recurved over a posteriorly directed process. In *Ig. aengensis*, there is a denticulate posterior process in the Pa and Pb elements" (Nicoll et al. 1999).

Iapetognathus aengensis (Lindström 1955)
Plate 1, figures 9-10, 15-16 and Text-figure 4: 4

Pravognathus aengensis n. sp. LINDSTRÖM 1955, p. 585, pl. 5, figs. 10-13.
Iapetognathus aengensis (Lindström). – NICOLL, MILLER, NOWLAN, REPETSKI and ETHINGTON 1999, p. 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 (*cum syn*.). – ALBANESI, ESTEBAN, ORTEGA, HÜNICKEN and BARNES 2005, fig. 7. M.

Material examined: 7 elements (CORD-MP 16101/1-2, 16215/1, 16222/1-2, 16245/1, 16256/1, 29728/1).

Occurrence: Samples QA5, QA6, QA10+ 3m, QA12, C16, QA13 and QA14.

Discussion: The elements of this species are scarce in different basins of Argentina, such as the Famatina System (Volcancito River section) and Cordillera Oriental (Cajas Range, Amarilla Creek section). Ramiform elements, with one antero-lateral process and one postero-lateral process short or absent. Cusp laterally compressed, erect to posteriorly bent inwardly. The antero-lateral process has 3-5 denticles, discrete, laterally compressed, which tend to be splayed away from the cusp. The morphotypes recovered are Sb, P and X. The CAI (5) does not permit to observe the basal cavity and white matter distribution. The Sb elements possess a large cusp, with biconvex cross section, with anterior and posterior margins keeled. In general, the cusp and denticles are broken and the antero-lateral process possesses 2-3 discrete denticles. The basal cavity extends deeply into the cusp and under the process. In the P morphotype, the cusp is erect, laterally compressed, with acute anterior and posterior margin. The antero-lateral process is long and has 4 denticles, laterally compressed, at an angle away from the cusp and slightly curved inwards. The short posterior-lateral process only possesses one denticle, erect and compressed. The basal cavity extends into the cusp and is shallow under the processes. The X elements are not well preserved. The cusp is reclined, laterally compressed, with keeled borders. The anterior process has 3 denticles in one element, and the other are broken at the base. The plane of the axis of the process is located with a certain angularity in relation to the plane of the cusp.

Iapetognathus fluctivagus Nicoll, Miller, Nowlan, Repetski and Ethington 1999
Plate 1, figures 7-8, 11-12 and Text-figure 4: 5

Iapetognathus fluctivagus n. sp. NICOLL, MILLER, NOWLAN, REPETSKI and ETHINGTON 1999, p. 46-48, pl. 6, figs. 1a-5d; pl. 7, figs. 1a-4g; pl. 8, figs. 1a-2g; pl. 9, figs. 1a-7f; pl. 10, figs. 1a-6g; pl. 11, figs. 1a-6h. – COOPER, NOWLAN and WILLIAMS 2001, fig. 6: 1-11. – DONG, REPETSKI and BERGSTRÖM 2004, pl. 3, figs. 1-3.

Material examined: 9 elements (CORD-MP 16033/1, 16162/1-2, 16192/1-4, 29691/1, 29729/1).

Occurrence: Samples C2, QA5, QA6, C9A and QA10.

Discussion: The elements Sb and Sc are differentiated. Both morphotypes possess a cusp laterally compressed that bend posteriorly and have a prominent keel in the anterior margin, just above of the upper surface of the lateral process, and a keel in the posterior margin. The antero-basal margin is slightly curved to the lateral process. The denticulate main process is in inner lateral position. The denticles are compressed in the plane of the process and have sharp keels. The basal cavity extends deeply into the cusp, above the level of the process and continues under the process. White matter occurs in the upper part of the cusp and denticles. The surface is smooth. In some Sb elements only the cusp is preserved and other elements have one denticle in the process. The lateral process supports 2 denticles in the morphotype Sc, with the first of them broken near the base and are laterally compressed. The complete denticles are posteriorly inclined and the cusp is erect.

Iapetognathus jilinensis Nicoll, Miller, Nowlan, Repetski and Ethington 1999
Text-figure 4: 6

Iapetognathus jilinensis n. sp. NICOLL, MILLER, NOWLAN, REPETSKI and ETHINGTON 1999, p.48, 49, pl. 12, figs. 1a-4f; pl. 13, figs. 1a-3f, pl. 14, figs. 1a-4b (*cum syn.*).

Material examined: 2 elements (CORD-MP 29730/1-2).

Occurrence: Sample QA6.

Diagnosis: "Probable septimembrate apparatus of which only six element types are recognized. These included the Sc, Sb, Sd, Xa, Pa and Pb elements. All elements have a denticulate outer-lateral process; the Xa element also has a posterior process. The outer-lateral process supports two to four denticules. The cusp and denticles are antero-posteriorly compressed" (Nicoll et al. 1999).

Discussion: The authors follow the description of Nicoll et al. (1999): The Sc element is the only recovered morphotype from the Cardonal Formation. The cusp is posteriorly bent and compressed antero-posteriorly. The inner and outer lateral margins have keels. The outer-lateral process supports 5-8 denticles, discrete, erect to slightly splayed outward away from the cusp. The process is relatively narrow and low. The high CAI of the conodonts does not allow for observing the white matter and basal cavity.

Iapetognathus sp.
Plate 1, figures 13-14

Material examined: 1 element (CORD-MP 16163/1).

Occurrence: Sample C9A.

Description: Ramiform element, cusp reclined, laterally compressed, inclined posteriorly, with acute anterior and posterior margins, the cross section is oval to biconvex. The antero-lateral process supports 3 discrete denticles, compressed, with slight inclination away from the cusp. The postero-lateral process has a denticle, compressed, broken near the base. Cusp with distinctive adventitious denticle. Basal cavity extends from the process, with the tip below the cusp, just above of the base of the denticles of the antero-lateral process. White matter situated in the tip of the cusp and denticles.

Discussion: Although only one distinctive specimen has been recovered a larger collection could verify that this is not an aberrant or pathological specimen but a morphotype of a new species recorded within the *Iapetognathus* Zone, increasing this particular conodont lineage of the basal Ordovician System.

Genus ***Orminskia*** Landing (in Landing, Westrop and Keppie 2007)
Type species: Orminskia rexroadae Landing, in Landing, Westrop and Keppie 2007

Orminskia rexroadae Landing, in Landing, Westrop and Keppie 2007
Plate 2, figures 5-8

Material examined: 57 elements (CORD-MP 16011/1-3, 16030/1, 16045/1-9, 16059/1-10, 16070/1-7, 160100/1-4, 16131/1, 16142/1, 16151/1-5, 16194/1-9, 16202/1, 16224/1-4, 16277/1, 29761/1).

Occurrence: Samples C1+1m, C2, QA5, QA6, C4, QA10+ 3m, QA9, C9, C9A, QA10, QA11, C16 and C19.

Description: Coniform elements with soft surfaces, proclined to reclined, cross section of the cusp and bases circular to slightly laterally compressed. The basal cavity extends to the maximum inflexion of the cusp. No white matter is observed, as a particular condition to differentiate the species from other homeomorph elements like those of *Teridontus*.

Genus ***Problematoconites*** Müller 1959
Type species: *Problematoconites perforata* Müller 1959, original designation.

Problematoconites perforatus Müller 1959
Plate 2, figure 4

Problematoconites perforata n. sp. MÜLLER 1959, p. 471, pl. 15, fig. 17.
Problematoconites perforatus Müller. – MÜLLER and HINZ 1991, p. 36-37, pl. 23:1-10, 14, 15, 18-20, 22 (*cum syn*.). – ZEBALLO, ALBANESI and ORTEGA 2005, p. 62, 63, pl. 4.Z.

Material examined: 60 elements (CORD-MP 16031/1, 16083/1, 29687/1-2, 29703/1-5, 29724/1-47, 29777/1-4).

Occurrence: Samples, C2, QA5, A10, QA6, C4, and A16.

Discussion: Coniform elements laterally compressed and recurved. The cross section is circular in the apex of the cusp and oval in the base. The base exhibits perforations of different sizes and forms that are not caused by parasites but are proper of the element. The basal cavity is deep.

Genus ***Proconodontus*** Miller 1969
Type species: *Proconodontus muelleri* Miller 1969

Proconodontus muelleri Miller 1969
Plate 2, figure 9

Proconodontus muelleri n. sp. MILLER 1969, p. 437, pl. 66, figs. 30-40. – DONG, REPETSKI and BERGSTRÖM 2004, pl. 1, figs. 2, 8, pl. 2, figs. 2, 7, 27. – LANDING, in LANDING, WESTROP and KEPPIE 2007, fig. 6: n, o.

Material examined: 2 elements (CORD-MP 16010/1-2).

Occurrence: Sample C1+1m.

Discussion: Coniform elements, laterally compressed, with proclined cusp. The base of the elements has a form of funnel. The cross section is semi-triangular. Anterior and posterior margins keeled. Basal cavity deep extending throughout the specimens length.

Genus ***Teridontus*** Miller 1980
Type species: *Oneotodus nakamurai* Nogami 1967.

Teridontus nakamurai (Nogami 1967)
Plate 2, figures 18-20

Oneotodus nakamurai n. sp. NOGAMI 1967, p. 216, 217, pl. 1, figs. 9, 12, 13, tex-figs. 3A, B, C.
Teridontus nakamurai (Nogami). – JI and BARNES 1994, pl. 24, figs. 1-3, 5 (*cum syn.*). – LANDING, KEPPIE and WESTROP 2007, figs. 6: i-l. – ZEBALLO and ALBANESI 2009, figs. 6: 23.

Material examined: 837 elements (CORD-MP 16001/1, 16014/1-2, 16025/1-41, 16034/1-7, 16052/1-31, 16060/1-36, 16077/1-5, 16085/1-162, 16102/1, 16105/1-5, 16110/1-15, 16120/1, 16124/1-8, 16132/1-10, 16146/1, 16149/1-25, 16166/1-7, 16176/1-14, 16183/1-96, 16199/1-3, 16205/1-9, 16218/1-5, 16231/1-6, 16233/1-2, 16235/1-102, 16248/1-8, 16257/1-4, 16264/1-12, 16272/1, 29688/1-37, 29704/1-6, 29725/1-55, 29741/1-9, 29755/1-2, 29778/1-62, 29787/1-46).

Occurrence: Samples C1 + 1m., C2, QA5, A10, QA6, C4, QA10 + 3m., C6, QA7, C7, A13, C9,QA9, C9A, C10, QA10, QA11, A16, QA12, C16, C16 + 2m., C16 + 3m., QA13, QA14, QA15, QA16 and C19.

Discussion: Coniform specimens, with short and large base, recurved to reclined cusp, and circular to semi-circular cross section of the cusp, which is characterized by white matter through its lenght. They do not possess keels, carinas or grooves. Large basal cavity, shallow, with the tip centrally located. Fine striae are often observed in the base of specimens.

Teridontus gallicus Serpagli, Ferretti, Nicoll and Serventi 2008
Plate 2, figures 14-16

Teridontus gallicus n. sp. – SERPAGLI, FERRETTI, NICOLL and SERVENTI 2008, p. 612-620, figs. 1, 3-5 (*cum syn.*). – ZEBALLO and ALBANESI 2009, p. 549-550, figs. 6: 26-28. – GIULIANO, ALBANESI, ORTEGA, ZEBALLO AND MONALDI 2013b, p. 39, 40, fig. 3: 30.
Teridontus nakamurai (Nogami). – BAGNOLI, BARNES and STEVENS 1987, pl. 2, fig. 17, 18.

Material examined: 345 elements (CORD-MP 16002/1-2, 16012/1, 16027/1-4, 16035/1-20, 16053/1-9, 16061/1-11, 16086/1-49, 16104/1, 16106/1-3, 16111/1-2, 16123/1, 16125/1-3, 16133/1-3, 16150/1-12, 16170/1, 16171/1-6, 16178/1-3, 16184/1-43, 16200/1-3, 16206/1-42, 16219/1-12, 16230/1-4, 16236/1-39, 16249/1-3, 16258/1-3, 16265/1-5, 16270/1-2, 29690/1-29, 29705/1-5, 29711/1, 29727/1-2, 29748/1-3, 29756/1-4, 29762/1-3, 29780/1-7).

Occurrence: Samples C1 + 1m., C2, QA5, A10, QA6, A10+1m, C4, QA10 + 3m., C6, QA7, C7, A13, C8, C9, QA9, C9A, C10, QA10, QA11, A16, QA12, C16, C16 + 2m., QA13, QA14, QA15, QA16 and C19.

Discussion: Characteristic great variation in the inclination of the cusp: proclined to recurved, suberect, erect and reclined. Cross section is circular in the cusp and oval to circular in the base. Basal cavity limited on the base. Fine striae through the surface of the elements, and albid tissue is present in the cusp.

Teridontus obesus Ji and Barnes 1994
Plate 2, figures 21, 22

Teridontus obesus n. sp. JI and BARNES 1994, pl. 24, figs, 10-17; tex-fig. 37B. – ZEBALLO, ALBANESI and ORTEGA 2005b, p. 15, figs. 3 H-L (*cum syn.*).

Material examined: 327 elements (CORD-MP 16022/1-11, 16043/1-4, 16056/1-20, 16067/1-12, 16076/1, 16087/1-30, 16114/1-6, 16127/1-3, 16152/1-9, 16177/1-5, 16190/1-9, 16207/1-3, 16223/1-3, 16237/1-30, 16250/1-4, 16259/1, 16266/1-7, 16269/1-3, 29689/1-60, 29726/1-89, 29742/1-2, 29779/1-15).

Occurrence: Samples C2, QA5, QA6, C4, QA10 + 3m, QA7, C7, QA9, C9A, C10, QA10, A16, QA12, C16, C16 + 2m, QA13, QA14, QA15, QA16 and C19.

Discussion: Coniform elements, which are distinguished by larger and wider forms compared to other species of the genus. Reclined cusp, expanded base and cross section circular. Some specimens have a weak costa in both lateral margins near the base. Basal cavity conical with the tip centrally situated. White matter is present in the cusp, and striae are better preserved in some specimens.

PLATE 1

Conodonts from the Cardonal Formation. All scale bars represent 0.1mm.

1-3 *Drepanodus simplex* Branson and Mehl 1933, CORD-MP 16090, sub-rounded elements, lateral view, sample QA10+3m.

4-6 *Acanthodus uncinatus* Furnish 1938. 4, CORD-MP 16089, compressed element, lateral view, sample QA10+3m; 5, CORD-MP 16089, compressed element, postero-lateral view, sample QA10+3m; 6, CORD-MP 16062, compressed element, lateral view, sample C4.

7, 8, 11-12 *Iapetognathus fluctivagus* Nicoll et al. 1999. 7, CORD-MP 16033, Sb element, posterior view, sample C2; 8, CORD-MP 16033, Sb element, anterior view, sample C2; 11, CORD-MP 16162, Sb element, posterior view, sample C9A; 12, CORD-MP 16162, Sb element, anterior view, sample C9A.

9-10, 15-16 *Iapetognathus aengensis* (Lindström 1955). 9, CORD-MP 16101, Sb element, posterior view, sample QA10+3m; 10, CORD-MP 16101, Sb element, anterior view, sample QA10+3m; 15, CORD-MP 16256, P element, posterior view, sample QA14; 16, CORD-MP 16256, P element, anterior view, sample QA14.

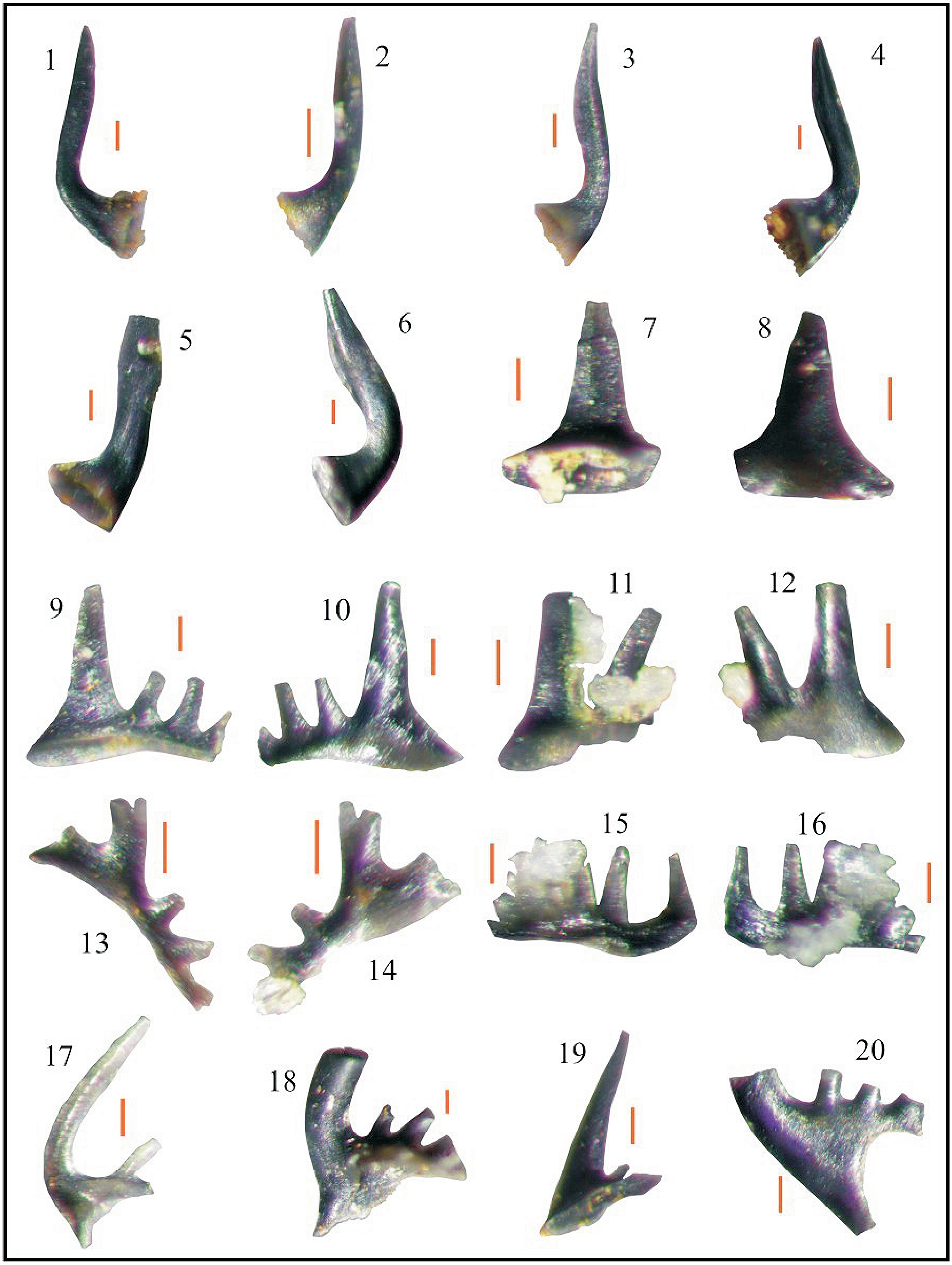
13-14 *Iapetognathus* sp. 13, CORD-MP 16163, "X" element, posterior view, sample C9A; 14, CORD-MP 16163, "X" element, anterior view, sample C9A.

17 *Cordylodus intermedius* Furnish 1938, CORD-MP 16241, compressed element, lateral view, sample QA13.

18 *Cordylodus caseyi* Druce and Jones 1971, CORD-MP 16049, rounded element, lateral view, sample QA6.

19 *Cordylodus deflexus* Bagnoli, Barnes and Stevens 1987, CORD-MP 16093, compressed element, lateral view, sample QA10+3m.

20 *Cordylodus prolindstromi* Nicoll 1991, CORD-MP 16018, rounded element, lateral view, sample C2.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DISCUSSION AND CONCLUSIONS

The detailed biostratigraphic record of conodonts through the Amarilla Creek section displays a continuous succession of biozones that spans the Furongian, upper Stage 10, to the lower Tremadocian Stage in the Cardonal Formation, which is truncated above by fault contact with the Floian Acoite Formation. In the upper Cardonal Formation the *Cordylodus lindstromi*, *Iapetognathus,* and *Cordylodus angulatus* zones are recognized. Specimens of the genus *Iapetognathus* are scarce throughout the studied section. The FAD of *I. fluctivagus* determines the Cambrian-Ordovician boundary in the upper part of the Cardonal Formation. This index species record defines the C/O boundary at a level located 36 m below the top of the Cardonal Formation in the studied section.

On the base of conodont paleobiogeographical distributions, the paleoenvironment for the Cordillera Oriental can be interpreted as an outer continental shelf to open sea of the Transitional Faunal Realm (Dubinina 2000). Albanesi, Zeballo and Bergström (2007) proposed the Southwestern Gondwana Province from the Cold Domain in the Shallow-Sea Realm, which is in accordance with the model proposed by Scotese (2010) that considers an epicontinental sea for the southern margin of Gondwana, at high latitudes near Avalonia, Baltica and Oaxaquia, based on paleomagnetic data, paleogeographic and paleotectonic reconstructions for the late Cambrian – Early Ordovician. The abundance of cosmopolitan species in Cordillera Oriental basin of the Gondwanan margin reflects the important faunal exchange during the late Cambrian and Early Ordovician across the Iapetus Ocean in middle to high latitudes (Zeballo and Albanesi 2009, 2013). The particular combination of species from different regions and endemic species that compose the studied collection allow for recognizing the new conodont province for the referred South American sector of Gondwana.

The conodont elements exhibit a black color alteration (CAI 5 = 300º and 480º), probably related to the influence of the nearby granite that intruded the Paleozoic rocks during the Jurassic-Cretaceous boundary interval.

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PLATE 2

Conodonts from the Cardonal Formation. All scale bars represent 0.1mm.

1-2 *Furnishina* n. sp. Albanesi, Giuliano and Pacheco, CORD-MP 16247/1, element with semicircular section, lateral views, sample QA13.

3, 11 *Furnishina furnishi* Müller 1959. 3, CORD-MP 16197/1, compressed element, lateral view, sample QA13; 11, CORD-MP 16021, compressed element, lateral view, sample C2.

4 *Problematoconites perforatus* Müller 1959, CORD-MP 16031, compressed element, lateral view, sample C11.

5-8 *Orminskia* rexroadae (Landing, in Landing, Westrop and Keppie 2007). 5, CORD-MP 16059/1, rounded element, lateral view, sample QA6; 6, CORD-MP 16070/1, rounded element, lateral view, sample QA6; 7-8, CORD-MP 16100/2, compressed elements, lateral view, sample C4.

9 *Proconodontus muelleri* Miller 1959, CORD-MP 16010, compressed element, lateral view, sample C1+1m.

10, 17 *Phakelodus elongatus* (Zhang in An et al. 1983). 10, CORD-MP 16023, element with semicircular section, lateral view, sample C2; 17, CORD-MP 16244, element with semicircular section, lateral view, sample QA13.

12 *Eoconodontus notchpeakensis* (Miller 1969), CORD-MP 16143, compressed element, lateral view, sample C9.

13 *Phakelodus tenuis* (Müller 1959), CORD-MP 16080, element with circular section, lateral view, sample C4.

14-16 *Teridontus gallicus* Serpagli et al. 2008, CORD-MP 16086, elements with compressed bases with oval section, lateral view, sample QA10+3m.

18-20 *Teridontus nakamurai* (Nogami 1967), CORD-MP 16085, rounded elements, lateral view, sample QA10+3m.

21-22 *Teridontus obesus* Ji and Barnes 1994, CORD-MP 16087, rounded elements, lateral view, sample

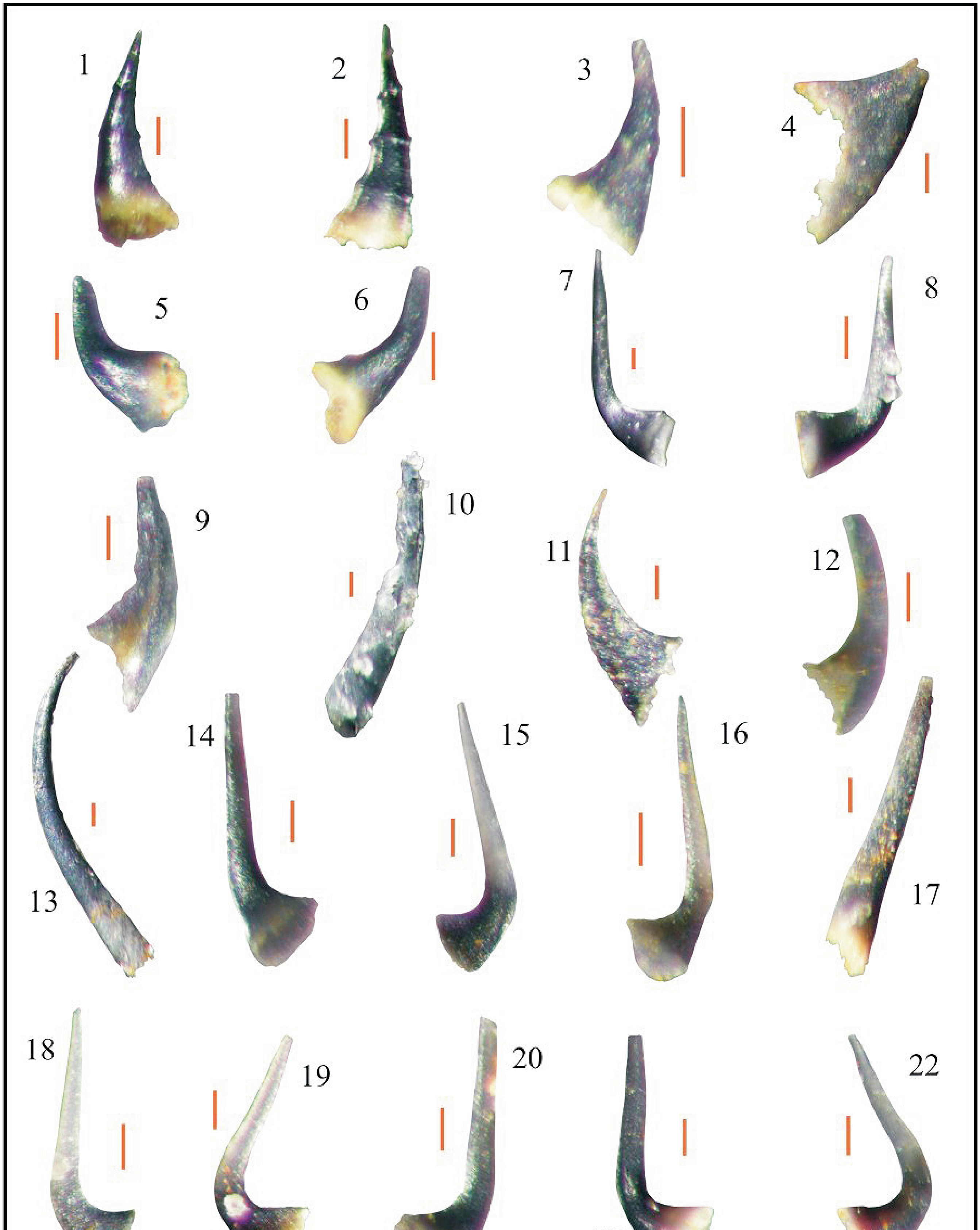
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PLATE 3

Conodonts from the Cardonal Formation. All scale bars represent 0.1mm.

1-3 *Cordylodus intermedius* Furnish 1938. 1, CORD-MP 16240/1, rounded element, lateral view, sample QA13; 2, CORD-MP 16137/1, rounded element, lateral view, sample C9; 3, CORD-MP 16158/1, compressed element lateral view, sample C9A.

4 *Cordylodus hastatus* Barnes 1988, CORD-MP 16094, compressed element, lateral view, sample QA10+3m.

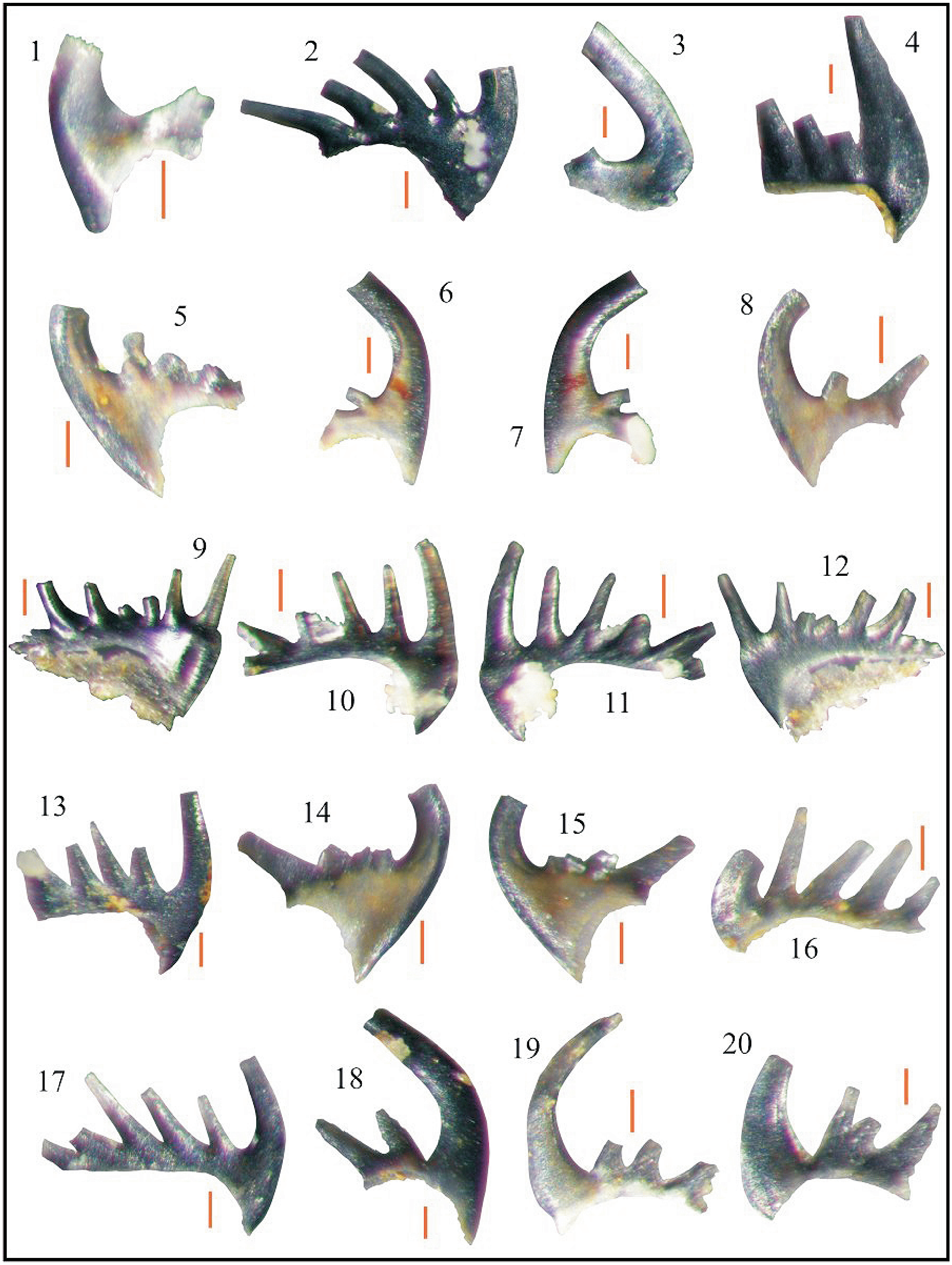
5-8 *Cordylodus proavus* Müller 1959. 5, CORD-MP 16016, compressed element, lateral view, sample C2; 6-7, ORD-MP 16016, compressed elements, lateral view, sample C2; 8, CORD-MP 16088, compressed element, lateral view, sample QA10+3m.

9-12 *Cordylodus* n. sp. Albanesi, Giuliano and Pacheco, CORD-MP 16073, compressed elements, lateral views of two elements (9, 12 and 10, 11), sample C4.

14-15 *Cordylodus* cf. *andresi* Viira and Sergeyeva 1986, CORD-MP 16097, compressed elements, lateral view, sample QA10+3m.

16 *Cordylodus* cf. *viruanus* Viira, Sergeyeva and Popov 1987, CORD-MP 16099, compressed element, lateral view, sample QA10+3m.

13, 17-20 *Cordylodus lindstromi* Druce and Jones 1971. 13, 18, CORD-MP 16091, compressed elements, lateral view, sample QA10+3m; 17, 19-20, CORD-MP 16155, compressed elements, lateral view, sample C9A.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