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Selected Middle Ordovician key conodont species from the Santa Gertrudis Formation (Salta, Argentina): an approach to its biostratigraphical significance

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Abstract – We have analysed a newly exposed conodont association from the Santa Gertrudis Formation in the Mojotoro Range, Eastern Cordillera of Salta province, Argentina. The key species *Baltoniodus triangularis* (Lindström), *Trapezognathus quadrangulum* (Lindström) and *Erraticodon patu* Cooper are present. A new species of the genus *Baltoniodus* (*Baltoniodus cooperi* sp. nov.) and elements of *Periodon* aff. *P. flabellum* are included in this conodont study. The key conodont *B. triangularis* indicates an age of lower Dapingian (Middle Ordovician) for the bearing strata. This was also recognized in other localities of the Eastern Cordillera, allowing their correlation. The conodonts from the Santa Gertrudis Formation provide conclusive elements on palaeogeographic interpretation by sharing species with Baltoscandia, South China and Australia, suggesting strong faunal affinities with these provinces.

Keywords: Conodonts, Dapingian, Santa Gertrudis Formation, Argentina

1. Introduction

The Santa Gertrudis Formation crops out in the Sierra de Mojoroto, Eastern Cordillera of Salta province and represents lower Palaeozoic successions in the region. The geology of this area was described by Harrington (1938, 1957), Ruiz Huidobro & González Bonorino (1953), Ruiz Huidobro (1955, 1968, 1975), Moya (1988, 1998), Hong & Moya (1993), Malanca (1996), Moya *et al*. (1994) and Waisfeld (1996), among others.

The first mention of conodonts from the Santa Gertrudis Formation is due to Monaldi & Monaldi (1978), followed by Sarmiento & Rao (1987) and Albanesi & Rao (1996). Lately, Moya *et al*. (2003) and Albanesi *et al.* (2007) have contributed to the knowledge on conodont biostratigraphy. Carlorosi *et al*. (2011) exposed several controversies regarding the conodont content of this unit, mentioning the presence of *Baltoniodus triangularis* (Lindström) and proposing a possible reworking of the conodont association.

This contribution deals with the taxonomic analysis of the conodont assemblage recovered from the Santa Gertrudis Formation, presenting new species of the genus *Baltoniodus* and proposing innovative considerations of the biostratigraphy and correlation of the Santa Gertrudis Formation.

2. Stratigraphy

The Eastern Cordillera geological province (Fig. 1) located in northwestern Argentina (Salta and Jujuy provinces) displays a remarkable lower Paleozoic stratigraphy. The Santa Gertrudis Formation is one of the classical Ordovician units of the Eastern Cordillera; it crops out at the Gallinato and Santa Gertrudis creeks, 14 km north of Salta City (Fig. 1). It was defined by Harrington (in Harrington & Leanza, 1957) and comprises dark grey shale with abundant intercalations of greenish-grey shaly sandstone and dark grey marl, and a few interspersed beds of dark bluish-grey limestone of 70 m thickness. This limestone yields *Hoekaspis schlagintweiti* Harrington & Leanza, *Synhomalonotus kobayashii* Harrington & Leanza, large undeterminable asaphids, cephalopods and bivalves. Harrington (in Harrington & Leanza, 1957) has indicated a Llanvirnian age for this unit.

Moya *et al*. (2003) described the Santa Gertrudis Formation as composed of fine–medium slightly micaceous wacke and dark-greenish grey silt, with ripple cross-lamination and weak stratification. This formation was interpreted by Carlorosi *et al.* (2011) as comprising intensive burrowed quartz wacke and grey siltstone alternating with limestone. The entire unit reaches 80 m thickness in the Gallinato Creek, where the Santa Gertrudis Formation is best exposed. This unit paraconformably overlies the Lower Ordovician Mojotoro Formation and its top is covered in modern deposits (Fig. 2). The fossiliferous levels are immediately above the wacke beds. The fossil record comprises trilobites (Harrington, 1957; Monaldi & Monaldi, 1978; Monaldi, 1982), bivalves (Sánchez, 1986), brachiopods (Benedetto, 1999) and conodonts.

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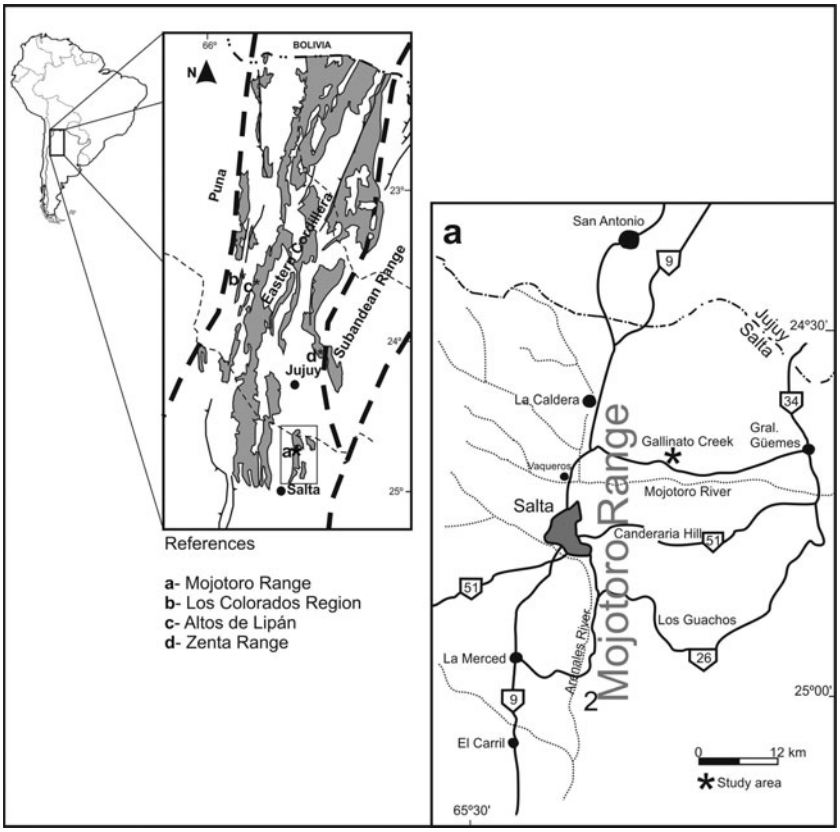

Figure 1. Location map showing the Eastern Cordillera geological province in NW Argentina: (a) area of study and (b–d) areas with similar associations of conodonts previously studied. (a) Santa Gertrudis Formation, Mojotoro Range; (b)Alto del Condor Formation, Los Colorados Region; (c) Altos de Lipán and (d) Zenta Range.

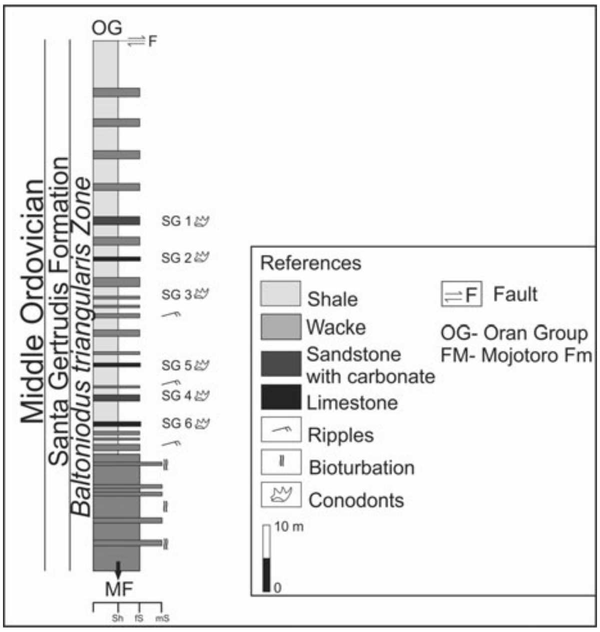

Figure 2. Stratigraphical section of the Santa Gertrudis Formation, Mojotoro Range, Salta Province.

3. Methodology

Six samples were collected randomly; some of them correspond to dark grey limestone beds, while other samples were collected from limestone with bioclastic accumulations (brachiopods) (Fig. 2). The samples were processed in the laboratory using standard methods of formic acid (Stone, 1987). The conodonts are housed at the Instituto Superior de Correlación Geológica (INSUGEO; CONICET, Universidad Nacional de Tucumán), in the Collection Lillo-microvertebrates/Conodonts (CML-C) under the code MLC–C (7000-10000).

4. Conodonts

A total of 3000 conodonts were obtained from the type area of the Santa Gertrudis Formation (SGF). The faunal diversity is relatively poor, but almost all identified species are biostratigraphically significant. Most of the recovered specimens exhibit excellent state of preservation, with different growth stages (juvenile, adult and mature) of each species recovered. The Color Alteration Index corresponds to 1.5–2 of the Epstein, Epstein & Harris (1977) table.

Key conodont species were photographed with a scanning electron microscope in the National Centre of Electronic Microscopy, Complutense University of Madrid, Spain and in the SEM laboratory of CCT, Mendoza (Argentina).

The taxonomic and taphonomic analysis of these recovered conodont assemblages were carried out. The taphonomic aspect revealed that the conodonts from SGF are not reworked (as proposed by Carlorosi *et al*.

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2011) because the preservation is excellent; they are not broken or cracked and fractures with padding are not evident. Taking into account certain taphonomic processes such as disarticulation and transportation that act on conodont apparatus, we can rebuilt the apparatuses from individual elements that are disjointed; each element, mainly the balognathiid P elements, consists of crown and basal fillings (or basal body) which, during the disarticulation of the apparatus, were detached from each other (basal filling–crown). The recovered specimens are only composed of basal filling or basal filling with parts of crown. Another taphonomic detail to note is the presence of all the elements (P, M and S) that constituted the conodontal apparatus of recovered species with more abundance, refuting any suggestion that segregation and therefore displacement has occurred.

Finally, a little evidence of dissolution is observed in the aboral margin of the basal cavity and in a few denticles; furthermore, there are no distortion effects present such as changes in side and form or alteration in the texture.

5. Systematic palaeontology

The conventional notation system was used in the descriptions of taxa (Sweet 1981, 1988) which defines the spatial positions M, S and P, from the anterior extremity to the posterior of the multielemental apparatus. Corresponding subpositions of the symmetry were also considered, and do not necessarily reflect location within the oral cavity of the conodont animal.

Five conodont species have been selected for description and illustration: *Baltoniodus triangularis*, *B. cooperi* sp. nov., *Erraticodon patu* Cooper, *Periodon* aff. *P. flabellum* (Lindström) and *Trapezognathus quadrangulum* Lindström. We also mention the occurrence of *Gothodus* sp. and *Drepanoistodus* sp.

Class Conodonta Pander, 1856
Order Prioniodontida Dzik, 1976
Superfamily Prioniodontacea Bassler, 1925
Family Balognathidae Hass, 1959
Genus *Baltoniodus* Lindström, 1971

Original diagnosis (Lindström, 1971): The multielemental genus *Baltoniodus* Lindström (1971) has a septimembrate apparatus. The elements are pectiniform, pastinate, alate, tertiopedate, bipennate, quadriramate and geniculate and occupied the P (Pa and Pb), S (Sa, Sb, Sc and Sd) and M position, respectively.

Type specie *Prioniodus navis* Lindström, 1955

Baltoniodus cooperi sp. nov.
Figure 3a–m

1981. *Baltoniodus navis*, Cooper, p. 160, pl. 29, figs 9–10, pl. 30, fig. 2.
1994. *Baltoniodus navis* (*sensu* Cooper), Albanesi & Vaccari, p. 133, pl. 2, figs 1–13 (not 4, 12)
2003. *Plectodina* n. sp. A Moya *et al.*, p. 64, fig. 12, 3.
2007. *Plectodina* n. sp. Albanesi *et al.*, p. 12, text-fig. 3Q.

Derivation of name: in honour of Dr Barry J. Cooper, an Australian geologist who originally recognized and described these elements.

Diagnosis: This species is characterized by a marked change in the indentations of the elements. In the case of the P elements these denticles are of triangular shape, fusiform and pointy; in the case of the M and S elements denticles are long, thin and rod-like.

Type locality: Gallinato Creek, Mojotoro Range, Salta province, Argentina.

Type stratum: Sampled level SG5 from the Santa Gertrudis Formation, approximately 50 m from the base of the section. Collection Lillo-Microvertebrates/ Conodonts (CML-C) (J. Carlorosi, collector).

Holotype: Pa element, CML-C 7100 (1) (Fig. 3a).

Paratypes: Pa elements, CML-C 7100 (2–39); Pb elements, CML-C 7101 (1–45); M elements, CML-C 7102 (1–8); Sa elements, CML-C 7103 (1–14); Sb elements, CML-C 7104 (1–15); Sc elements, CML-C 7105 (1–19); Sd elements, CML-C 7106 (1–39).

Description: The Pa element is pastinate. This element is characterized by its lateral compressed form with sharp flanks in the short cusp. The cusp has a triangular shape in a cross-section view with a shark tooth-like appearance. From the flanks two long processes develop, the lateral and the posterior both denticulate, the anterior face of the cusp is concave and ends in a short anterior process without denticles. From the posterior process and close to the junction of this with the cusp a small lobe develops whose location represents right and left forms. The denticles present on the processes are small and triangular in shape. The denticles on the posterior process begin on the cusp and the first denticle marks the development of the lobe. The basal cavity is elongated and deep; below, the cusp is subrounded to oval in shape, corresponding to the anterior process and the lobe. The basal sheath linking processes is wide and wavy.

Pb element: pastinate with three processes. The cusp is similar to those of the Pa elements. It is triangular in shape in a cross-section view with sharp sides from which two processes develop, the shortest lateral and the longest posterior. From the middle part of the cusp, a marked rib extends along the anterior process. The three processes carry small triangular denticles; the first denticle of the lateral and posterior processes arise about half-way along the cusp. The basal cavity is deep and extends to the processes; the basal sheath connects the processes but is less developed than that of the Pa element.

The M element is a modified geniculate laterally compressed with sharp edges. The cusp is erect to procline. The anterior margin of the cusp extends in a short anterior extension directed downwards. The

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Figure 3. Plate of scanning electron microscope microphotographs. The bar indicates 0.1 mm. *Baltoniodus cooperi* sp. nov. Elements recovered from de Santa Gertrudis Formation in the Mojotoro Range, Salta Province. (a–d) P elements. (a–c) Pa element, aboral, postero-lateral and anterior views, sample SG2, CML-C 7101(1). (d) Pb element, anterior view, sample SG2, CML-C 7102(1). (e) M element, postero-lateral view, Sample SG5, CML-C 7102(1). (f, g, l) Sa elements, posterior and postero-lateral views, sample SG5, CML-C 7103(1-3). (h) Sb element, posterior view, sample SG5, CML-C 7104(1). (i, j) Sc elements, lateral views, sample SG5, CML-C 7105(1-2). (k) Sd element, postero-lateral view, sample SG5, CML-C 7106(1).

margin of the posterior process carries large rod-like denticles. The basal sheath connects the posterior and the anterior ribs and a flare is observed in a lateral view. The basal cavity is deep.

Sa element: alate element. It has a long and thin proclined cusp with three strong ribs that extend beyond the cusp and form three processes, two lateral and one posterior; the lateral processes carries long denticles which are directly perpendicular to the cusp, almost forming an 90° angle. The basal cavity is deep and extends into the processes.

Sd element: tertiopedate element. The cusp is slightly proclined with sub-rounded cross-section; a strong rib on the inner side of the cusp gives rise to a posterior process. Two lateral processes are continued from the cusp below the basal cavity, and present a different angle which grants an asymmetry to the element. Denticles are long and rod-like, a main feature of this new species. The basal cavity is deep and runs into the processes.

Sc element: bipennate element. The cusp is long with the external flank curved. The anterior process extends beyond the basal cavity and is directed to the posterior side, this process ended in a keel; the inner flank is flat and extends in a posterior process that carries 4–5 wide and long denticles. The basal sheath connects the two processes and presents an undulation near the anterior process. The basal cavity is deep.

Sd element: quadriramate element. It has a long proclined cusp, four processes are developed and their position are two latero-anterior and two latero-posterior. The denticles in most of the samples are broken, but these are long and rod-like shape. The basal cavity is deep. The basal sheath connecting the four processes gives a quadrangular shape to the base.

Remarks: This species is here considered as belonging to the Balognathidae family. The strong relation with *B. triangularis* is supported by the presence of main characters that define the family and the genus proposed by Hass (1959) and Lindström (1971), such as a septimembrate apparatus, microstructure with lateral lamination, robust pectiniform P elements and delicate geniculate M and ramiform S elements. The transition series remains the patron of the S elements of the genera *Trapezognathus* Lindström and *Baltoniodus* Lindström.

Cooper (1981) assigned this species to *Baltoniodus navis*, and at that time the description was supported only by few elements from the Horn Valley Siltstone, Amadeus Basin, Australia. The former author compared this species with *Baltoniodus navis* Lindström from Baltica, but the illustrated elements shows strong differences from the *Baltoniodus navis* redescribed by Stouge & Bagnoli (1990). Later, Albanesi & Vaccari (1994) recorded it in the Suri Fomation (Famatinian Range). These authors described the complete apparatus but they proposed a different M element compared with that figured by Cooper (1981). In this contribution we define this *Baltoniodus navis* (*sensu* Cooper) as a new species, recognizing the diagnostic characters that defined it.

Furthermore, in those samples taken from this section, the conodont species *Baltoniodus cooperi* sp. nov. is well represented in number of elements with juvenile, adult and mature forms, suggesting that this species was well adapted to the environment.

Provenance: Santa Gertrudis Formation, Mojotoro Range, Salta Province. Beds SG1 to SG6.

Age: The occurrence of *Baltoniodus triangularis* (Lindström) in the same samples indicates for *Baltoniodus cooperi* sp. nov. a Middle Ordovician age (early Dapingian).

Distribution: Northwestern Argentina, Famatinian Belt (Albanesi & Vaccari, 1994) and Amadeus Basin, Australia (Cooper, 1981). The co-occurrence of *Baltoniodus cooperi* sp. nov. and *Erraticodon patu* indicates a strong relation with the Australian conodont Province.

Baltoniodus triangularis (Lindström, 1955)
Figure 4a–i

1955 *Prioniodus triangularis* Lindström, pp. 591, pl. 5, figs 45–46.
1971 *Baltoniodus triangularis* (Lindström), Lindström, p. 55, pl. 1, fig. 12.
1974 *Prioniodus navis* Lindström, Wamel, pp. 89–90, pl. 12, figs 2, 3?
1994 *Baltoniodus triangularis* (Lindström), Löfgren, fig. 8: 28–29.
1994 *Trapezognathus argentinensis* Rao, Hünicken & Ortega, p. 73, lám. III, figs 2, 8, 10, 12, lam. VII, fig. 7.
1997 *Baltoniodus? triangularis* (Lindström), Bagnoli & Stouge, pp. 137–138, pl. 3, figs 1–12.
1998 *Baltoniodus triangularis* (Lindström), Albanesi, p. 159, pl. 2, fig. 12.
2003 *Baltoniodus* sp. A Zhen *et al.*, p. 182, pl. 11, fig. S.
2005 *Baltoniodus triangularis* (Lindström), Wang *et al.*, fig. 4.
2009 *Baltoniodus triangularis* (Lindström), Bergström & Löfgren, p. 7, pl. 4, figs a–ac.
2009 *Baltoniodus triangularis* (Lindström), Wang *et al.*, p. 104, fig. 9, 1–5, 7–11.
2010 *Baltoniodus triangularis* (Lindström), Li *et al.*, pp. 117, 118, pl. II, figs 1–15.
2013 *Baltoniodus triangularis* (Lindstöm), Carlorosi, Heredia & Aceñolaza, pp. 2, fig. 3, A–I.
2013 *Trapezognathus*? *argentinensis* Rao *et al.*, Voldman *et al.*, pp. 126, 127, fig. 2, n16–18.
2016 *Zentagnathus primitivus* Voldman *et al.*, Voldman *et al.*, fig. 6, G, H.

Original diagnosis (Lindström, 1955): The apparatus of *Baltoniodus triangularis* is septimembrate, composed for well-defined pastinate P elements, geniculate M element and transitional series of the S elements. All the elements have denticles, a deep basal cavity and a large basal sheath.

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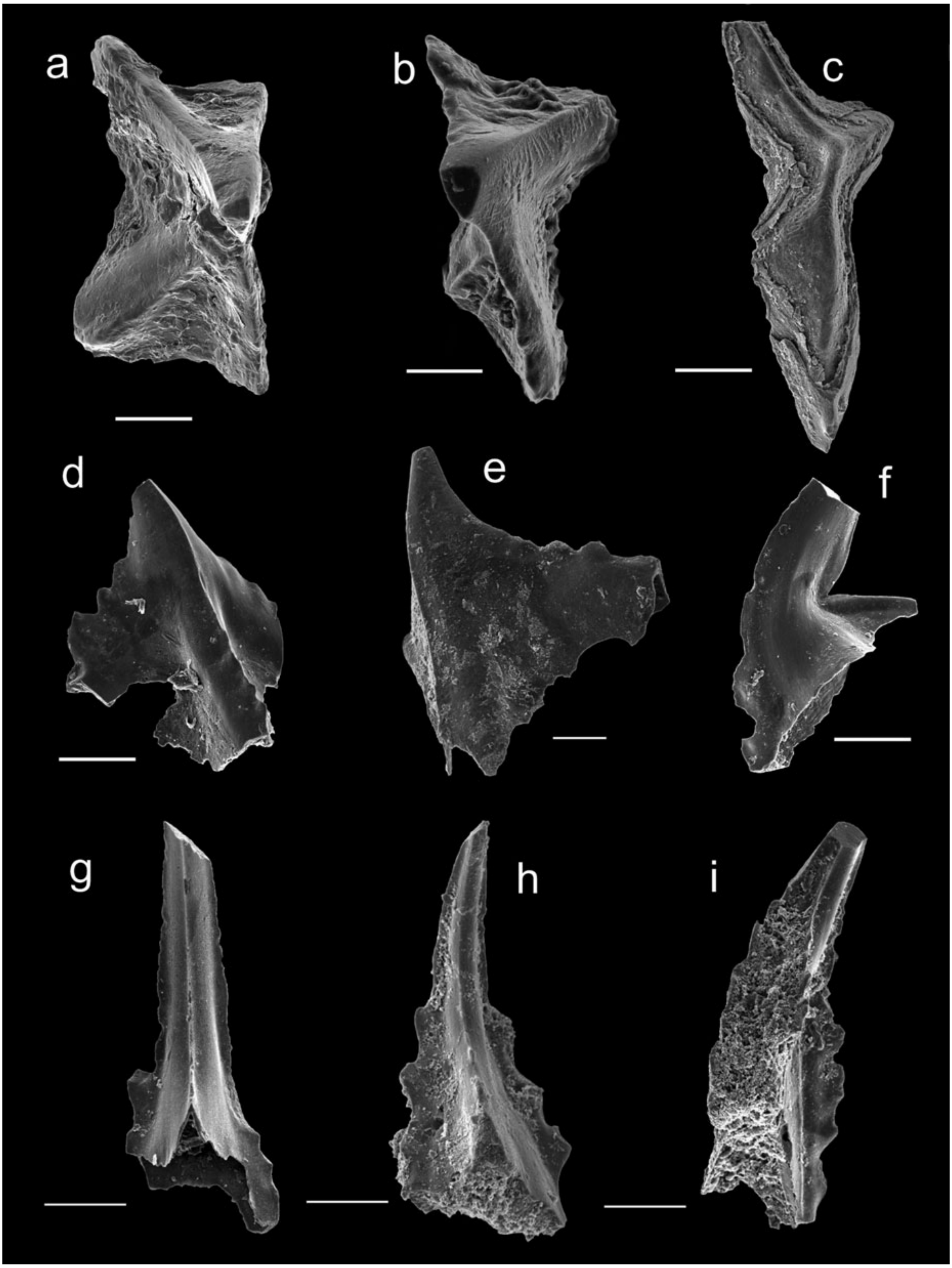

Figure 4. Plate of scanning electron microscope microphotographs. The bar indicates 0.1 mm. *Baltoniodus triangularis* (Lindström). Elements recovered from de Santa Gertrudis Formation in the Mojotoro Range, Salta Province. (a–e) P elements. (a–c) Pa elements, upper views, samples SG4, 5, CML-C 7008(1-3). (d, e) Pb elements, latero-anterior and latero-posterior views, samples SG2, 3, CML-C 7009(1-2). (f) M element, lateral view, sample SG4, CML-C 7010(1). (g) Sa element, posterior view, sample SG6, CML-C 7011(1). (h) Sb element, postero-lateral view, sample SG2, CML-C 7012(1). (i) Sd element, lateral view, sample SG2, CML-C 7013(1).

Remarks: *Baltoniodus triangularis* was described for the first time from northwestern Argentina (Los Colorados section, Alto del Cóndor Formation) by Carlorosi, Heredia & Aceñolaza (2013). Detailed observations made on the recovered P elements of *Baltoniodus triangularis* from this region and those from the Gallinato section (SGF) allow us to propose subtle but identifiable differences between these apparatuses. Based on these differences, we propose the recognition of early and late forms of *B. triangularis* both from the Alto del Cóndor Formation (ACF) and Santa Getrudis Formation (SGF). This interpretation allows us to recognize different time intervals in the *B. triangularis* Zone. A brief list of differences follows.

Pa elements

Cusp: Elements from ACF show cusps round and straight and the costae are less prominent than those present in specimens from SGF.

Processes: There is a difference in length between the anterior and lateral processes of both forms, and the relation of the angles between them is also different. Additionally, there are differences in the length of the posterior process and its relation with the angles of the anterior processes. The connection of the lobe with the posterior process occurs at different distance from the cusp.

Basal sheath and general shape of the basal cavity: Specimens present different development in both cases, and the shape of the basal cavity is more compressed in the Pa elements from SGF.

Pb elements

Cusp: this is rounded with a slight posterior tilt in the Pa elements from the ACF; it is more pronounced than those SGF elements where the cusp is thinner with concave front edge and a medial well-marked rib where the anterior process rises.

Processes: the primitive (ACF) Pb elements demonstrate a relationship between the angles of the anterior, lateral and posterior processes different from those of SGF in terms of the direction towards its point of origin.

Basal sheath: the specimens of SGF have a less-developed basal sheath compared with those of ACF.

The denticles of the P elements recovered from the SGF are larger compared to those from ACF. They also seem to be further apart.

It must be noted that morphological differences between S and M elements (comparing early and advanced forms) were not observed.

Material: Pa elements, CML-C 7008 (1–7); Pb elements, CML-C 7009 (1–12); M elements, CML-C 7010 (1–5); Sa elements, CML-C 7011 (1–25); Sb elements, CML-C 7012 (1–49); Sc elements, CML-C 7013 (1–63); Sd elements, CML-C 7014 (1–24).

Age: This key species is recorded in the early Dapingian (Middle Ordovician) in the Santa Gertrudis Formation.

Distribution: Los Colorados Section, northwestern Argentina. Baltoscandia (Bagnoli & Stouge, 1997; Bergström & Löfgren, 2009) and South China (Wang *et al*. 2009).

Provenance: Santa Gertrudis Formation, Mojotoro Range, Salta Province. Beds SG1 to SG6.

Genus *Trapezognathus* Lindström, 1955
Type species: *Trapezognathus quadrangulum* Lindström, 1955
Figure 5a–l

1955 *Prioniodus triangularis* Lindström, pp. 591, 592 (partim), pl. 5, fig. 45 (only).
1955 *Prioniodus navis* Lindström, pp. 590, 591 (partim), pl. 5, figs 31, 32 (only).
1955 *Trapezognathus quadrangulum* Lindström, p. 598 (partim), pl. 5, figs 38, 39 (only).
1974 *Prioniodus navis* Lindström, Wamel, pp. 89, 90, pl. 8, figs 10, 11.
1977 *Baltoniodus triangularis* (Lindström), Lindström, in Ziegler, pp. 81–82 (partim), *Baltoniodus*, pl. 2, figs ?8, ?9, 10, 11.
1978 *Prioniodus (Baltoniodus) triangularis* Lindström, Löfgren, pp. 81, 82, pl. 12, figs 1–7.
1990 *Trapezognathus quadrangulum* Lindström, Stouge & Bagnoli, pp. 26, 27, pl. 10, figs 1–5, 7–10.
1994 *Trapezognathus argentinensis* Rao & Hünicken, Rao *et al*., p. 73, lám. III, figs 9a–c, 11a, lám. VII, figs 1, 3, 5.
1994 *Baltoniodus navis* (*sensu* Cooper), Albanesi & Vaccari, p. 133, pl. 2, fig. 4.
1995 *Lenodus*? sp. A, Löfgren, fig. 9 j–n.
1997 *Trapezognathus quadrangulum* Lindström, Bagnoli & Stouge, p. 160, pl. 8, figs 1–8.
2001 *Trapezognathus quadrangulum* Lindström, Viira *et al*., fig. 6c–f.
2003 *Baltoniodus* sp. A, Zhen *et al*., p. 182, fig. 11V.
2003 *Icriodella* n. sp. A., Moya *et al*., p. 64, pl. 12, figs 13, 15.
2013 *Baltoniodus* cf. *triangularis* Lindström, Voldman *et al*., p. 126, pl. 2, fig. 6.

Original diagnosis (Stouge & Bagnoli, 1990): The *Trapezognathus* Lindström apparatus is septimembrate, with pectiniform P elements, geniculate M elements and a complete series of S elements (alate, tertiopedate, bipennate, quadriramate). P elements are adenticulate to weakly denticulate. M element is adenticulate to denticulate and the cusp forms an angle about 90° with the upper margin of the base. S elements are stubby, with a base higher than the cusp, weakly denticulate to denticulate. All elements are albid and have a deep basal cavity and large basal sheath.

Description: The material recovered from Santa Gertrudis Formation was previously described by Carlorosi & Heredia (2013), who illustrated only Pb elements. New Pa elements were recovered from this unit and are described here. It is important to highlight that the recovered material shows different evolution-

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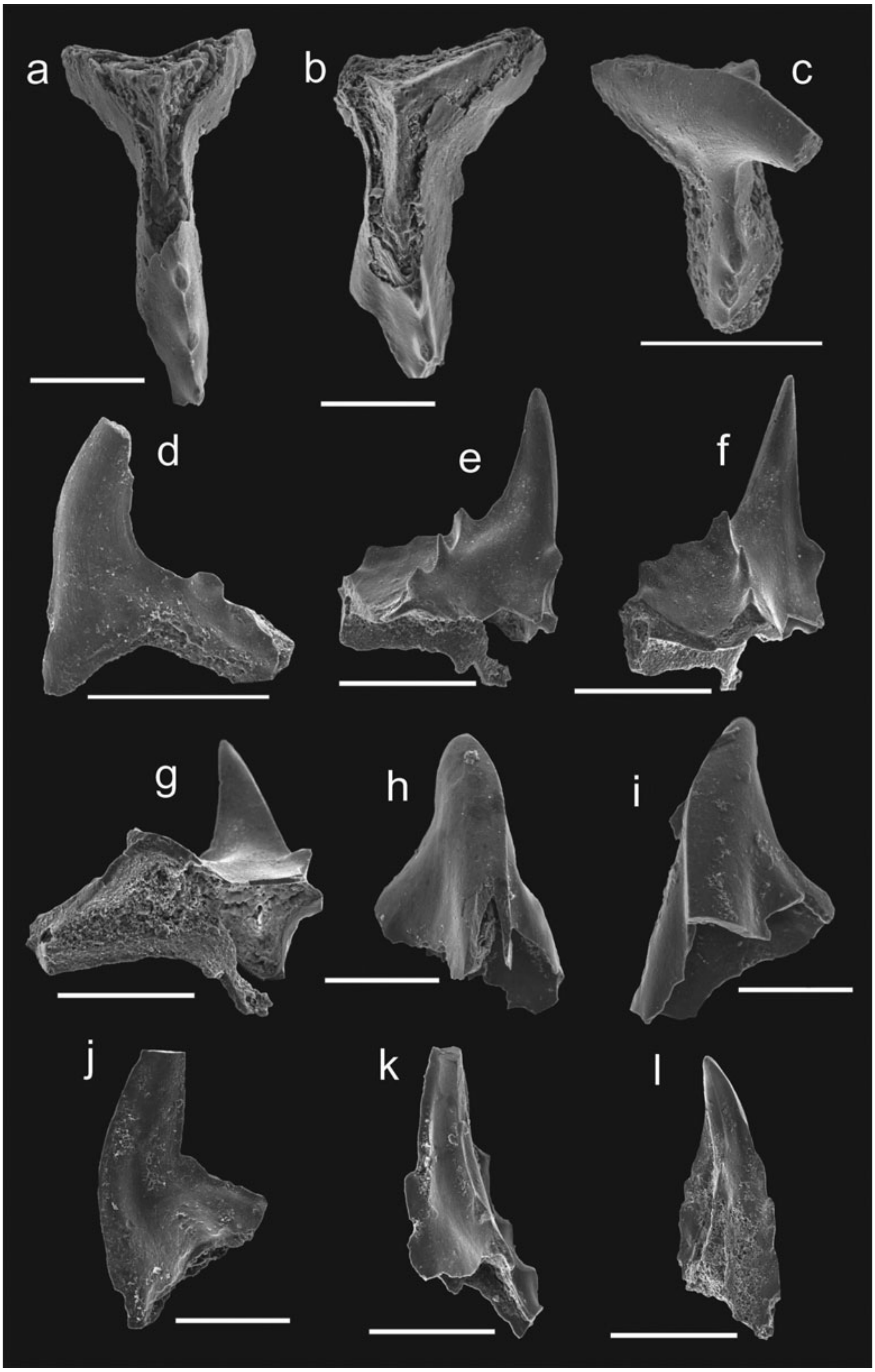

Figure 5. (a–l) Plate of scanning electron microscope microphotograph. The bar indicates 0.1 mm. *Trapezognathus quadrangulum* Lindström. Elements recovered from de Santa Gertrudis Formation in the Mojotoro Range, Salta Province. (a–i) P elements. (a–g) Pa elements, upper, lateral and basal views, samples SG2, 5 CML-C 7015(1-4). (h, i) Pb elements, latero-anterior and lateral views, sample SG5, CML-C 7016(1-2). (j) M element, lateral view, sample SG5, CML-C 7017(1). (k) Sb element, postero-lateral view, sample SG2, CML-C 7019(1). (l) Sd element, postero-lateral view, sample SG5, CML-C 7021(1).

ary stages, where the transition from basal morphology of the Pa elements of *Trapezognathus quadrangulum s.l.* to advanced forms with features that link it with the genus *Lenodus*, corroborating the lineage proposed by Löfgren & Zhang (2003), is visible. In addition it should be noted that all these different morphologies were found coexisting in the same place and at the same time.

Pa element: Pastiniscaphate element. The illustrated material in Figure 5a, b represents Pa elements that correspond to a typical form of the species. It is possible to recognize two degrees of development – (a) a primitive form and (b) an advanced form – which is differentiable due to the development of the lobe. Vestiges of the crown attached to the basal body can also be distinguished. Three processes are developed from the cusp: the anterior, posterior and lateral. The anterior process is longer than the lateral, and they are related by an angle of c. 60°; the lateral process carries hints of denticles near the cusp. The posterior process is the longest of the three and is developed almost straight from the cusp; its terminal portion is curved backwards. This posterior process also has an adenticulated lobe. The distal part of the posterior process carried sub-rounded denticles. The general shape of the element differs from those previously illustrated; the shape in this case is more elongated and compressed (Fig. 5a, b).

Figure 5c, d represents the next evolutionary step. The complete Pa element with the preservation of the crown is shown for the first time. The evolutionary trend is to laterally compress the general shape and grow in height. The cusp is high and directed towards the back with a marked turn towards the inner side of the element; the anterior and posterior edges of the cusp are sharp; its cross-section is triangular; and the base of the cusp is wide and exhibits the longitudinal striations characteristic of the Balognathidae family. From the cusp, the anterior and posterior processes are developed and are almost of the same length (the lateral being a little longer). The posterior process is fragmented but is the longest of the three, this process carries sub-rounded denticles of central position. The basal cavity is deep; a small basal sheath links the processes.

The last specimen illustrated (Fig. 5e–g) represents a major evolutionary step compared with the previous Pa elements figured; it is possible to observe the diagnostic features of Pa elements of *Trapezognathus quadrangulum*, as well as morphological characters that show an evolutionary trend towards *Lenodus* genus that appears in the basal Darriwilian. The cusp is high and posteriorly pointed with sharp edges. Three ribs indicate the origin of the anterior, lateral and posterior processes; all processes carried sharp denticles similar to the shape of the cusp. The posterior process is the longest and develops a denticulate lobe that arise from the first denticle of the posterior process. This character is one that is present in the descendant *Lenodus*. The basal cavity is deep and wide and extends through the processes and the lobe; a narrowing in the middle of the element is evident.

Remarks: *T. quadrangulum* was recorded from the *Baltoniodus navis* Zone to the *L. antivariabilis* Subzone in South China and Baltica. Löfgren & Zhang (2003) proposed that the stratigraphic record of *T. quadrangulum* is short, being restricted to zones and subzones of the Arenig (British Series). Carlorosi, Heredia & Aceñolaza (2013) mentioned the co-ocurrence of *Trapezognathus quadrangulum* and *Baltoniodus triangularis* in the Los Colorados section (Alto del Condor Formation), representing the oldest record of *T. quadrangulum* worldwide. The presence of this species in the Santa Gertrudis Formation confirms this datum and allows a continuous record of *T. quadrangulatum* since the beginning of the *B. triangularis* Zone (Basal Dapingian) to be determined.

Material: Pa elements, CML-C 7015 (1–4); Pb elements, CML-C 7016 (1–8); M elements, CML-C 7017 (1–4); Sa elements, CML-C 7018 (1–16); Sb elements, CML-C 7019 (1–15); Sc elements, CML-C 7020 (1–22); Sd elements, CML-C 7021 (1–20).

Age: Middle Ordovician age (early Dapingian).

Distribution: Los Colorados Section and Altos de Lipán, northwestern Argentina, Baltoscandia (Stouge & Bagnoli, 1990; Bergström & Löfgren, 2009).

Provenance: Santa Gertrudis Formation, Mojotoro Range, Salta Province. Beds SG3 and SG5.

Family Periodontidae Lindström, 1971
Genus *Periodon* Hadding, 1913
Type Species: *Periodon aculeatus* Hadding, 1913
Periodon aff. *P. flabellum* (Lindström, 1955)
Figure 6a–e

1997 *Periodon* sp. A, Bagnoli & Stouge, p. 151, pl. 6, figs 8, 12–15.

Original diagnosis (Stouge & Bagnoli, 1988): The genus *Periodon* has a septimembrate apparatus comprising Pa, Pb, M, Sa, Sb, Sc and Sd.

Comments of the original diagnosis: Following Stouge (2012), this species evolved from *Periodon flabellum* (Lindström) and is characterized by the development of a denticulated anterior process on the anterior margin. *P.* cf. *P. flabellum* has one small denticle on the anterior process. *P*. aff. *P. flabellum* has two denticles on the anterior process, one short and the other long. In our collection the latter species is present.

Description: Pa element: Bipennate element. The reclined cusp is long and laterally compressed with flat margins from which two processes originate; the anterior one is short and carries two denticles, one of which is long and rectangular while the second seems to be an aberrant small denticle. The posterior process is long and carries six denticles; the first two are over the cusp and are more reduced in size than the remaining, the next three

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Figure 6. Plate of scanning electron microscope microphotograph. The bar indicates 0.1 mm. Elements of the apparatus of *Periodon* aff. *P. flabellum* Lindström and *Erraticodon patu* Cooper, recovered from de Santa Gertrudis Formation in the Mojotoro Range, Salta Province. (a–e) *Periodon* aff. *P. flabellum* Lindström. (a) Pb element, lateral view, CML-C 7023(1). (b) Pa element, postero-lateral view, CML-C 7022(1). (c) M element, lateral view, CML-C 7024(1). (d) Sc element, lateral view, CML-C 7027(1). (e) Sd element, lateral view, CML-C 7028(1). (f, l) *Erraticodon patu* Cooper. (f, g) P elements. (f) Pa element, posterior view, sample SG3, CML-C 7001(1). (g) Pb elements, anterior view, Sample SG5, CML-C 7002(1). (h) M element, lateral view, sample SG5, CML-C 7003(1). (i) Sa element, posterior view, sample SG3, CML-C 7004(1). (j) Sb element, lateral view, sample SG2, CML-C 7005(1). (k) Sc element, lateral view, sample SG5, CML-C 7006(1); (l) Sd element, postero- lateral view, sample SG5, CML-C 7007(1).

are large and rectangular and the sixth is small. All the denticles in the posterior process are directed backwards. The basal cavity is thin and continues to the processes.

M element: Geniculate element laterally compressed. The cusp is reclined, long and thin. Their margins are sharp; the anterior margin of the cusp extends beyond the base forming a keel. The angle between the posterior margin of the cusp and the top margin of the base is *c.* 60°. The posterior margin of the base continues in a short extension; the margin of the oral cavity has an undulation, and in this region the oral cavity widens and expands and prolong towards the sides of the element. We have not recovered any element with denticles in the anterior margin of the base.

Sc element: Dolobrate element. The cusp is long and slightly reclined; the external face of the cusp is concave with sharp margins. A well-marked rib runs along the cusp and the base. From the posterior margin of the cusp a posterior denticulated process arises that carries five denticles: three small between the cusp and the two major distal denticles. The process and the denticles are directed backwards.

Sd element: Tertiopedate element. Has a long cusp nearly straight, with three ribs well-marked which extend beyond the base and form three processes: one very small adenticulated anterior, the adenticulated lateral and the larger posterior. The angle between the cusp and the posterior processes is almost 90°. The posterior process has evidence of four denticles located between the cusp and the last small denticle, which is the largest.

Remarks: This species is recorded in northwestern Argentina and Gondwana for the first time. Only a few elements were recovered from the SGF, and their description was based on the evolutionary scheme presented by Stouge (2012). According to this author, its FAD occurs in the basal Dapingian and the LAD occurs in the upper Dapingian, coincidently with the recovered conodont association. On the other hand, some elements from this collection coincide with those described as *Periodon* sp. A. by Bagnoli & Stouge (1997). The presence of this last species is also mentioned by Wang *et al.* (2009) in the *Baltoniodus triangularis* Zone as it occurs in the Santa Gertrudis Formation.

Material: Pa elements CML-C 7022(1–3), Pb elements CML-C 7023(1–3), M elements CML-C 7024(1–2), Sc elements CML-C 7027(1–5), Sd elements CML-C 7028(1–6).

Age: *Baltoniodus triangularis* Zone, Middle Ordovician age (early Dapingian).

Distribution: Baltoscandia (Bagnoli & Stouge, 1997), western Newfoundland (Stouge, 2012) and Central and South China (Wang *et al*. 2009; Wu *et al*. 2010).

Provenance: Santa Gertrudis Formation, Mojotoro Range, Salta Province. Beds SG1 to SG6.

Order Prioniodinida Sweet, 1988
Family Chirognathidae Branson & Mehl, 1944
Erraticodon Dzik, 1978
Type species *Erraticodon balticus* Dzik, 1978
Erraticodon patu Cooper, 1981
Figure 6f–l

1981 *Erraticodon patu* Cooper, p. 166, pl. 32, figs 1–6, 8.

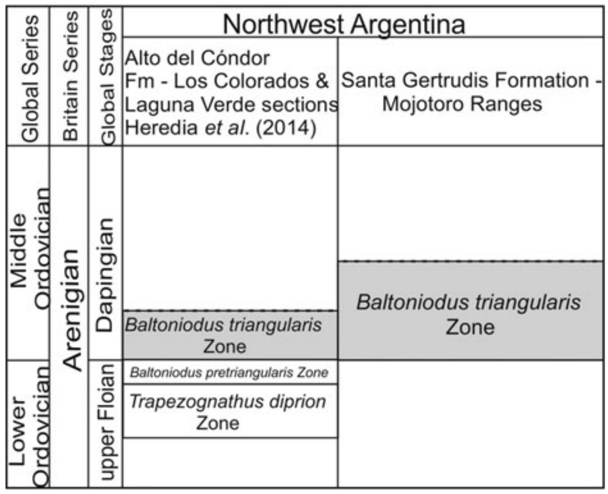

Figure 7. Biostratigraphic chart showing the conodont biozones, with an accurate correlation between different regions of northwestern Argentina.

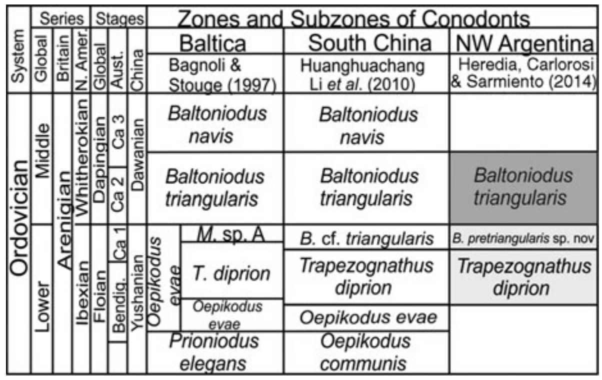

Figure 8. Lower–Middle Ordovician biostratigraphical chart comparing conodont biozones from Baltica, South China and northwestern Argentina.

1987 *Erismodus quadridactylus* (Stauffer), Sarmiento & Rao, p. 90–91, pl. 1, figs 2–4, 7, 9, 12; pl. 2, figs 1–6.
1994 *Erraticodon patu* Cooper, Albanesi & Vaccari, p. 137, pl. 1, figs 11–16.
2003 *Erraticodon* cf. *gratus* (Moskalenko, 1977), Moya *et al*., p. 64, pl. 12, figs 6, 7, 9.
2003 *Erismodus typus* Branson & Mehl, Moya *et al*., p. 64, pl. 12, figs 8, 11.
2007 *Erraticodon balticus* Dzik, Albanesi *et al*., p. 46, text-fig. 3A–D.
2010 *Erismodus* cf. *quadridactylus* (Stauffer), Aceñolaza, Carlorosi & Heredia, p. 168, pl. 4, fig. a.
2012 *Erraticodon patu* Cooper, Carlorosi (J. M. T. Carlorosi, unpub. PhD thesis, Universidad Nacional de Tucumán, 2012), p. 112–116, pls 2, 3, 27 (A, F), 28 (D).
2013 *Erraticodon patu* Cooper, Heredia *et al.,* p. 23 pl. 5, figs A–I.
2014 *Erraticodon patu* Cooper, Carlorosi, Heredia & Sarmiento, p. S2–9, fig. 1.

Remarks: According to Zhen, Percival & Webby (2003) the apparatus of this species is constituted by ramiforms digyrate P, makellate M, alate Sa, bipen-

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nate Sb and Sc and tertiopedate Sd elements. This species was previously mentioned and described from Los Colorados section (northwestern Argentina) by Heredia *et al*. (2013); the elements recovered in the SGF present the same features as those from Los Colorados. The elements are robust and all the ontogenetic stages are well represented. *Erraticodon patu* is very abundant compared with the other recovered species, indicating that it was well adapted to the environment.

The finding of *Erraticodon patu* in this section is of particular biostratigraphic interest since this species has been mentioned in different areas of geological provinces of Eastern Cordillera (Los Colorados Region, Altos de Lipan and Zenta Range), Famatina and Precordillera.

Material: Pa elements CML-C 7001(1–11), Pb elements CML-C 7002(1–3), M elements CML-C 7003(1–11), Sa elements CML-C 7004(1–24), Sb elements CML-C 7005(1–28), Sc elements CML-C 7006(1–25), Sd elements CML-C 7007(1–22).

Age: Heredia *et al.* (2013) suggest that the global record of *E. patu* ranges from late Early Ordovician to early Middle Ordovician. The record of this species in the Santa Gertrudis Formation confirms this proposal.

Provenance: Santa Gertrudis Formation, Mojotoro Range, Salta Province. Beds SG1 to SG6.

6. Biostratigraphic implications

Since the discovery of conodonts in the Santa Gertrudis Formation, its age has been controversial. The conodont association recovered from this unit was studied by many authors, who assigned different genus and species into the assemblage composition and consequently different ages for it. The first conodont fauna was recovered by Monaldi & Monaldi (1978), identifying an association composed of *Oistodus*, *Sagittodontus*, *Polycaulodus* and *Panderodus*; these conodonts and the macro fossils recovered suggested dissimilar ages for this formation. Later, Sarmiento & Rao (1987) described and illustrated *Erismodus quadridactylus* (Stauffer) proposing an Ordovician *s.l.* age for these strata.

Moya *et al*. (2003) mentioned the conodont species *Erismodus quadridactylus* (Stauffer), *Bryantodina* aff. *B. typicalis* Stauffer, *Plectodina* n. sp. A, *Erraticodon* cf. *E. gratus* (Moskalenko), *Erismodus typus* Branson & Mehl, *Icriodella* n. sp. A, *Polycaulodus* sp. and *Semiacontiodus* sp., and proposed a Llanvirnian – early Caradoc age (Darriwilian Sandbian) for this formation.

A review of the Santa Gertrudis conodont fauna was carried out by Carlorosi *et al.* (2011) who agreed with Moya *et al*. (2003) at that time, recognizing the conodont *Erismodus quadridactylus* but also the appearance for the first time of *Baltoniodus triangularis* and *Trapezognathus quadrangulum*. This conodont association was interpreted as reworked and we proposed a Darriwilian–Sandbian age for these outcrops.

Albanesi & Aldridge (2013) reiterated a list of conodont species such as *Erismodus*, *Erraticodon*, *Plectodina* and *Semiacontiodus*, introducing new genera that were not described or illustrated. These authors proposed a Late Ordovician age for the Santa Gertrudis Formation.

A review of previous taxonomic analysis and a new conodont collection from this formation allow us to propose a new biostratigraphic interpretation for it. First, it must be noted that *Erismodus quadridactylus* was not recorded in the conodont association; those misinterpreted elements correspond to *Erraticodon patu*.

The conodont species *Erraticodon patu* Cooper ranges in Gondwana from the uppermost Floian (*Oepikodus evae* Zone) to lower Dapingian (*Baltoniodus triangularis – Baltoniodus navis* zones) as proposed by Heredia *et al*. (2013). This species is also present in Los Colorados Region (Carlorosi, Heredia & Aceñolaza, 2013), Famatinian Range (Albanesi & Vaccari, 1994), and the Precordillera (Heredia *et al*. 2013), linking these regions.

We also introduce *Baltoniodus cooperi* nov. sp. which was already recorded as *B. navis* (*sensu* Cooper) in the Famatian Belt (Suri Formation) by Albanesi & Vaccari (1994). This finding suggests that these outcrops, although in two separate basins (Suri and Santa Gertrudis formations), are close in age.

The presence of *Baltoniodus triangularis* is of great importance. This key conodont represents the guide species for the lowest Middle Ordovician (Dapingian) (Wang *et al*. 2009; Li *et al*. 2010; Carlorosi, Heredia & Aceñolaza, 2013). This species was described for the first time in northwestern Argentina from the Alto del Cóndor Formation (J. M. T. Carlorosi, unpub. PhD thesis, Universidad Nacional de Tucumán, 2012; Carlorosi, 2013; Heredia *et al*. 2013) and from the Santa Gertrudis Formation (Carlorosi *et al*. 2011 and this contribution).

The taxonomic analysis indicates that those elements of *B. triangularis* recovered from the SGF present slight morphological differences that we interpreted as advanced forms compared with those from the Los Colorados region.

Also, several Pa elements of *Baltoniodus cooperi* nov. sp. exhibit characters that were considered as transitional between *B. triangularis* and this new species. This consideration allows us to interpret the Santa Gertrudis Formation as being stratigraphically younger than other Dapingian formations from northwestern Argentina (e.g. Alto del Cóndor Formation in Los Colorados region).

The recovered conodont association from Los Colorados is composed of *Baltoniodus triangularis*, *Baltoniodus pretriangularis* nov. sp. (Heredia, Carlorosi & Sarmiento, 2014); *Erraticodon patu*, *Gothodus costulatus* Lindström, *Trapezognathus diprion* (Lindström) and *Trapezognathus quadrangu-*

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lum, among others. This association represents the basal part of the Dapingian stage due to the presence of *B. pretriangularis* and *T. diprion*. Further, the presence of primitive characters in the Pa elements of *B. triangularis* and *T. quadrangulum* compared with those Pa elements of the same species recovered in the Santa Gertrudis Formation confirm this proposal. The conodont association recovered allows us to make an accurate correlation between different regions of northwestern Argentina (Fig. 7).

The conodont diversity from the Santa Gertrudis Formation is low; there are only eight different species. Several species such as *Baltoniodus triangularis*, *T. quadrangulum* and *Periodon* aff. *P. flabellum* allow the link to Baltoscandia and China to be confirmed. Bergström & Lögfren (2009) presented a list of shared conodont species from Baltica and Huanghuanchan (China). They mentioned, among others, *Baltoniodus triangularis*, *Microzarkodina flabellum* (Lindström), *Periodon flabellum*, *Gothodus costulatus*, *Drepanoistodus forceps* (Lindström) and *Trapezognathus diprion*. On the other hand, *Baltoniodus cooperi* nov. sp. and *Erraticodon patu* indicate a strong connection to Australia.

It is important to note that the finding of *Periodon* aff. *P. flabellum* is mentioned for the first time in deposits from northwestern Argentina; this species is typical from Baltoscandia and suggests an early–middle Dapingian age in agreement with the vertical distribution of *B. triangularis* (Bergström & Löfgren, 2009) (Fig. 8).

7. Conclusions

The classical Argentinean Ordovician succession, the SGF, is finally interpreted in its age. The presence of the index conodont *Baltoniodus triangularis* indicates lower Dapingian (Middle Ordovician). We have compared morphologically the oldest forms of this species from the Alto del Cóndor Formation with those recovered from the SGF, concluding that these Pa elements suggested advanced forms as well as the Pa forms of *Trapezognathus quadrangulum*. The conodont composition supports the proposal of an early Dapingian age for the SGF, but not the earliest due to the presence of *Periodon* aff. *P. flabellum*. Regarding provincialism, this region could be interpreted as a transitional zone due to its strong affinities with two different faunal provinces. On one hand the presence of *B. triangularis*, *T. quadrangulum* and *Periodon* aff. *P. flabellum* supports strong affinities with Baltoscandia and South China, while the record of *E. patu* and *B. cooperi* nov. sp. links this region with the Australian faunal province.

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