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This paper describes and analyzes the significance of a conodont fauna from the Alto del Cóndor Formation, exposed in the Los Colorados region of the Argentine Eastern Cordillera. Identified taxa are *Baltoniodus triangularis*, *Baltoniodus* sp. cf. *B. triangularis*, *Drepanodus* sp., *Drepanoistodus basiovalis*, *Drepanoistodus* sp. B., *Erraticodon patu*, *Gothodus costulatus*, *Oistodus* sp., *Trapezognathus diprion*, *T. quadrangulum*, *Triangulodus* sp. and *Triangulodus*? sp. The presence of *Baltoniodus triangularis* indicates the base of the Dapingian stage (Middle Ordovician). In addition, we report the coexistence of *T. diprion* and *T. quadrangulum*. The conodont association suggests a faunal affinity with Baltica and South China, both belonging to the Shallow-Sea Realm of the Temperate-Cold Domain.

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THE CENTRAL Andean Basin is characterized by the exposure of Palaeozoic strata distributed mainly in northwest Argentina. This sector is divided into four geological provinces based on their tectonostratigraphic, sedimentary and igneous features. The studied Ordovician strata are exposed at Chamarra Creek, which is located north of Los Colorados village in the Eastern Cordillera of Jujuy province (Fig. 1). Extensive outcrops assigned to the Acoite and Alto del Cóndor formations are represented by a succession of siliciclastic rocks (sandstone and shale), that were deposited in a shallow marine basin within a shoreface setting.

The studied succession was originally defined as part of the Acoite Formation by Benedetto & Malanca (1975). Later, Astini & Waisfeld (1993) designated the sediments transitionally overlying the Acoite Formation as the Sepulturas Formation. These authors described the composition of the Sepulturas Formation as pinkish, reddish and purple quartz sandstone.

Astini (1994) differentiated within the Sepulturas Formation a sandy, a muddy and a heterolithic facies, the latter with pinkish and white sandstone associated with red and purple mudstone. A sharply differentiated unit composed of green shale was described in the uppermost part of the section, with interbedded fossiliferous sandstone and limestone. According to Astini (1994), this unit extends to various parts of the Eastern Cordillera and the Subandean Ranges of northern Argentina.

Later, Astini *et al.* (2004) revised the stratigraphy of this section, recognizing the Alto del Cóndor Formation overlying the Acoite Formation, and the Sepulturas Formation in the uppermost part. Recently, the stratigraphy of the area was further reorganized, and these formations were redefined informally as the lower member (Alto del Cóndor Formation *sensu* Astini *et al.* 2004) and the upper member (Sepulturas Formation *sensu* Astini *et al.* 2004) of the Alto del Cóndor Formation (Carlorosi 2012).

This contribution documents the first records of Dapingian conodonts from both members of the Alto del Cóndor Formation, including the first record of *Baltoniodus triangularis* (Lindström) in the lower Palaeozoic of the South American Central Andean Basin. *Baltoniodus triangularis* is of a particular interest since it is a global index fossil for the lower Dapingian (Wang *et al.* 2003a, b, 2005, 2009) and contributes to the correlation of sequences at a local and regional scale.

Geological setting

The studied outcrops are located in the western part of the Eastern Cordillera of Argentina, approximately 30 km northwest of Purmamarca village (Fig. 1) at 23°31′56.4″S and 65°40′04.3″W, and an average altitude of 3693 m. The stratigraphic succession is represented by

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the Lower Ordovician Acoite Formation and Middle Ordovician Alto del Cóndor Formation, overlain by the Upper Ordovician Zapla Formation, and Silurian Lipeón and Arroyo Colorado formations. The entire sequence is covered by the Cretaceous–Cenozoic Salta Group. The thickness of the Ordovician succession is estimated to be 2500 m, but the section measured in this study was restricted to the upper 300 m of the Acoite Formation and the entire Alto del Cóndor Formation.

The Alto del Cóndor Formation is represented by two distinctive members: a lower member composed of a heterolithic succession of yellowish sandstone (10–40 cm thick) and green shale (1–5 cm thick). Parallel lamination and cross-bedding structures are common in the succession, with some surfaces bearing desiccation cracks, erosive truncations, and an increase in the amount of bioturbation (dominated by *Skolithos* isp.). Mudstone beds locally host intense bioturbation with the consequent loss of most of the original lamination (Fig. 2).

The upper member of the unit consists of green shale and red sandstone with minor heterolithic intercalations of whitish sandstone and greenish shale. The green shale is finely laminated and hosts sparse remains of trilobites. Additional macrofaunal elements are represented by brachiopods and trilobites in the fine red sandstone with interbedded green shale. Erosive contacts characterize this portion of the succession, in which beds average 40 cm thick (Fig. 2).

There is a facies-related increase in fossil content from the lower to the upper member of this unit, with a transitional decrease towards the whitish sandstone at the top. Despite being poorly preserved, the recovered conodont association from the lower member of the Alto del Cóndor Formation allowed the recognition of: *Baltoniodus triangularis*, *Baltoniodus* sp. cf. *B. triangularis* (Lindström), *Gothodus costulatus* Lindström, *Erraticodon patu* Cooper, *Trapezognathus diprion* (Lindström) and *Triangulodus* sp. (Fig. 2).

The upper member of the unit has yielded numerous conodont elements, including the following species: *Baltoniodus triangularis*, *Baltoniodus* sp. cf. *B. triangularis*, *Drepanodus* sp., *Drepanoistodus basiovalis* (Sergeeva), *Drepanoistodus* sp. B., *Gothodus costulatus*, *Erraticodon patu*, *Oistodus* sp., *Trapezognathus diprion*, *Trapezognathus quadrangulum* Lindström, *Triangulodus* sp. and *Triangulodus*? sp. (Fig. 2).

Materials and methods

Samples were collected throughout the Alto del Cóndor Formation, four each from the lower and upper members. These are designated as MI1–4 and MS1–4 (Fig. 2). Material was processed in the laboratory using dilute formic acid (Stone 1987) complemented with standard separation procedures. Conodonts obtained from the lower member are poorly preserved and textural changes on their surfaces are due to the nature of their depositional environment (Mestre and Carlorosi 2011). Conodonts from the upper member are extremely well preserved, with CAI of 1.5 to 2 (Epstein *et al.* 1977).

Systematic palaeontology

A total of 1514 conodonts were obtained from the type area of the Alto del Cóndor Formation at Los Colorados (Jujuy province). The faunal diversity is relatively poor, but almost all identified species are biostratigraphically significant.

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 multi-elemental apparatus. Corresponding subpositions of the symmetry were also considered, and do not necessarily reflect location within the oral cavity of the conodont animal. Key conodont species were photographed with a scanning electron microscope at the CIME (Centro Integral de Microscopía Electrónica–CONICET/Universidad Nacional de Tucumán). All specimens are housed at the Instituto Superior de Correlación Geológica (CONICET–Universidad Nacional de Tucumán), in the Collection Lillo-Conodonts/microvertebrates (CML-C).

Baltoniodus Lindström, 1971

Type species. Prioniodus navis Lindström, 1955.

Baltoniodus triangularis (Lindström, 1955) (Fig. 3A–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; van Wamel, pp. 89–90, pl. 12, figs 2, 3?.

1994 *Baltoniodus triangularis* (Lindström); Löfgren, fig. 8: 28–29.

1994 *Trapezognathus argentinensis* Rao & Hünicken; Rao *et al.*, p. 73, lám. III, figs 2, 8, 10, 12, lám. VII, fig. 7.

1994 *Baltoniodus navis* (Lindström); Albanesi & Vaccari, p. 144, pl. 2, figs 1–3, 8–13, 16, 17.

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.

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.

Material. Fourteen Pa, 128 Pb, 33 Sa, 49 Sb, 20 Sc, 32 Sd and 49 M elements. The recovered elements were sampled from levels MI2, MS1 and MS4 of the Alto del Cóndor Formation exposed in Chamarra Creek, Los Colorados region; basal Dapingian, *Baltoniodus triangularis* Zone. MI2: CML-C 5093(1), MS1: CML-C 5070 (1–5), MS4: CML-C 5078(1–319).

Discussion. This is a septimembrate apparatus consisting of two P elements (Pa and Pb), M and four elements representative of the transition series S (Sa, Sb, Sc and Sd). It was originally defined by Lindström (1955) but its diagnosis has been revised several times (Bagnoli and Stouge 1997, Wang *et al.* 2005, Bergström and Löfgren 2009).

Description. *Pa element*. Short, stout and reclined cusp with a gentle backwards slope. From this cusp, three processes extend anteriorly, laterally and posteriorly; all are denticulate, the posterior process is the longest and bears small blunt fused denticles. The posterior process develops a lobe that may have small denticles. The basal sheath is wavy. The basal cavity is wide and deep and extends to each of the processes (Fig. 3A). In plan view, this element has a high pyramidal shape similar to those Pa elements illustrated by Li *et al.* (2010, pl. II, figs 5A sinistral element? and 6B, dextral element?).

Pb element. This element has a short and stout cusp, curved at its midpoint in anterior view with two prominent carina extending from the apex to form two thin processes. In posterior view, another strongly marked keel arises from the cusp and extends as a long posterior process bearing blunt and fused denticles. The basal cavity is wide and deep, and in cross-section is shaped like an elongate triangle; it connects all the processes (Fig. 3B, C, D). It is similar to examples illustrated by Li *et al*. (2010, pl. II, figs 1–2 and 3).

M element. This geniculate element has a short and stout cusp that ranges from erect to suberect or proclined. Well-marked short ribs arise from the cusp in three directions (anterior, posterior and lateral); the anterior and posterior may carry small denticles that are blunt and fused (Fig. 3E).

The S elements are more stylized in contrast to P and M elements, with thin cusps and denticulate processes.

Sa element. The element displays a straight and thin cusp with a circular cross-section near the apex. Two ribs extend from the cusp under the base forming two lateral processes, which bear many small denticles, the anterior view is flat, whereas at the posterior end a process bearing several denticles arises from the beginning of the base and extends below it (Fig. 3F, G).

Sb element. This element has a short, thin and proclined cusp with four fine ribs that are transformed into processes beyond the base. The processes are asymmetric, two are evident on the front face, which is flat, and the other two are viewed from the postero-lateral side. The angle between the posterior and lateral processes is about 45°. Each of these processes has very small blunt denticles, except the posterior, on which the denticles are better developed. The basal sheath connects the processes but it is short and excavated (Fig. 3H).

Sc element. This element has a long, thin and proclined cusp, with sharp edges that extend as three processes bearing multiple denticles. The posterior process is slightly asymmetrical having long, distinct, upward-directed denticles borne very close to the point of origin of the base. The basal cavity is excavated and is circular in cross-section.

Sd element. This has a short reclined cusp, from which emerge four well-marked ribs that extend beyond the base and form four denticulate processes (Fig. 3I).

Remarks. A distinct character of *Baltoniodus triangularis* is the presence of fine striae covering the surface of the elements. We consider that this character is diagnostic for older species of *Baltoniodus*.

Synonymy of the *Trapezognathus argentinensis* elements figured by Rao *et al*. (1994, lám. III, p. 73, 75, figs 10, 11) is based on a comparison with the drawing due to the poor quality of the original microphotograph. The accompanying description of '*Trapezognathus argentinensis'* is consistent with that of *B. triangularis*.

Baltoniodus sp. cf. **B. triangularis** (Lindström, 1955) (Fig. 3J–L)

1994 *Baltoniodus crassulus andinus* Rao & Hünicken; Rao *et al*., p. 70, lám. III, fig. 1.
2009 *Baltoniodus* cf. *Baltoniodus triangularis* (Lindström); Wang *et al*., p. 103, fig. 8: 1–13.
2010 *Baltoniodus* cf. *Baltoniodus triangularis* (Lindström); Li *et al*., pp. 118, 119, pl. I, figs 5–8, pl. III, figs 1–23.

Material. Twenty-nine Pb elements, Sample MS1: CML-C 5071(1–2), Sample MS4: CML-C 5079(1–27). Represented in level AC2 in the Acoite Formation of the Los Colorados section (Carlorosi 2012) and ranging into the upper member of the Alto del Cóndor Formation. This species is restricted to the *Baltoniodus* sp. cf. *B. triangularis* Zone (Li *et al.* 2010), of late Floian (Early Ordovician age) to the *Baltoniodus triangularis* Zone, Dapingian (Middle Ordovician).

Discussion. This species was reported by Wang *et al.* (2009) as a similar species to *Baltoniodus triangularis* recorded in Baltica (based on comparisons with the original material of Lindström 1955); the main difference being the lack of confluent denticles at the top of the anterior process of the Pb element.

Description. The recovered elements of this species represent mainly Pb forms since this element bears the most diagnostic characters; other elements interpreted to be representatives of this species were determined based on their similarity to (but not complete correspondence with) the original description of *Baltoniodus triangularis*. These elements are pastinate with a rib on the cusp, from which project three processes connected by the basal sheath. These elements differ in the degree of rib development at the apex, the angle between the processes and the degree of development of denticles.

Remarks. The element described and figured by Rao *et al*. (1994—*Baltoniodus crassulus andinus* Rao & Hunicken, p. 70, lám. III, fig. 1) has a denticulate anterior and lateral processes, which are diagnostic of *B*. sp. cf. *B. triangularis* (Wang *et al.* 2009). The designation of this as a Pa element by Rao *et al.* (1994) is incorrect because the latter is characterized by a pastiniscaphate (basal wide) element; we reinterpret it as a pastinate Pb element.

Trapezognathus Lindström, 1955

Remarks. The diagnosis of *Trapezognathus* Lindström was revised by Stouge and Bagnoli (1990) and Bagnoli and Stouge (1997) who recognized Pa and Pb elements that were virtually indistinguishable in their interpretation of the apparatus. Löfgren and Zhang (2003) described Pa elements of *T. quadrangulum* to include a pastiniscaphate element (Pa) that was not recognized by Bagnoli and Stouge (1997), following a proposal by Viira *et al.* (2001) that lineages of platform-equipped conodonts originated with *Trapezognathus*.

Following this interpretation, we identify a Pa element for each of the species, whereas the Pb element adheres strictly to that described by Stouge and Bagnoli (1990) and Bagnoli and Stouge (1997) as Pa and Pb elements. These authors did not report Pa forms in their Baltic collections and they based their classification of P elements on subtle morphological differences. This species was recorded in the same interval in the Huanghuachang region of China by Li *et al.* (2010). The synonymies for both *Trapezognathus* species described here are based (up to 1997) on those of Stouge and Bagnoli (1990) and Bagnoli and Stouge (1997).

Type species. Trapezognathus quadrangulum Lindström, 1955.

Trapezognathus diprion (Lindström, 1955) (Fig. 4A–G)

1955 *Prioniodina diprion*. Lindström; p. 587, pl. 5, fig. 43.
1971 *Gothodus costulatus* Lindström; Lindström, pp. 54–55 *(partim)*, pl. 1, figs 1–3 (only).
1974 *Prioniodus navis* Lindström; van Wamel, pp. 89–90 *(partim)*, pl. 8, figs 13, 15 (only).
1977 *Baltoniodus crassulus* (Lindström); Lindström, in Ziegler pp. 69–70 *(partim)*, *Baltoniodus* pl. 1, fig. 3 (only).
1994 *Trapezognathus argentinensis* Rao & Hünicken; Rao *et al*., p. 73, pl. III, figs 7, 14.
1997 *Trapezognathus diprion* (Lindström); Bagnoli & Stouge, pp. 154, pl. 7, figs 1–8.
1999 *Trapezognathus argentinensis* Rao & Hünicken; Rao, p. 46, pl. 9, fig. 6.
2008 *Trapezognathus diprion* (Lindström); Aceñolaza *et al*., p. 152, fig. 4A, B.
2010 *Trapezognathus diprion* (Lindström); Li *et al*., pp. 119, 120, pl. I, figs 4, 11, 13?

Material. Three Pa, 13 Pb, 32 Sa, 24 Sb, 13 Sc, 25 Sd, 42 M, one fragment of P and two fragments of M elements. CML-C 5061(1), 5064(1–8), 5066(1–3), 5069 (1), 5074(1–2), 5089(1–139). The species occurs in the upper and lower members of the Alto del Cóndor Formation. This species characterizes the *Trapezognathus diprion* Zone of the upper Floian (Lower Ordovician) and it is recorded in the *Baltoniodus triangularis* Zone, basal Dapingian (Middle Ordovician) in this report.

Description. *Pa element*. A pectiniform scaphate element having a thin triangular cusp, from which three processes are developed, one anterior, one lateral and one posterior. The anterior and the lateral processes are positioned at an angle of 80° in primitive forms, ranging to 120° in advanced forms; both these processes have well-developed ribs but they differ in their length with the anterior being longer. The posterior process, which is the most developed among the three, has small denticles that become more pronounced distally. The three processes are connected by the basal sheath; the basal cavity is deep, becoming less so in advanced forms (Fig. 4A).

Pb element. This element is pectiniform and is characterized by a proclined, small and robust cusp. Three ribs are developed; the posterior is short and concave in posterior view and has denticles on its posterior part, the lateral process is longer and is directed backward, whereas the anterior is curved at the junction between the apex and base and continues straight downward. The basal cavity is wide and the basal sheath is wavy and links the three processes (Fig. 4B).

M element. This element displays a straight and proclined cusp with a sharp angle of 90° relative to the base. In anterior view, a well-defined rib extends along the cusp, projecting as a short anterior process. In posterior view, a small rib emerges where the base starts and undulates with the basal sheath. The basal cavity is wide. The upper anterior and posterior edges bear denticles on either one or both sides (Fig. 4C).

S elements

Sa element. This element has a short and proclined cusp, from which emerge two finely denticulate lateral ribs that create two processes under the base line. The posterior margin has a weak rib (Fig. 4D).

Sb element. The element has a curved elongate cusp, from which two lateral ribs are developed and extend as two processes that carry a few small denticles. The posterior process has well-developed denticles. The base is wide and the basal sheath connects the processes (Fig. 4E).

Sc element. This element has a shorter cusp than the previously described element and it is widely curved backward. From this cusp emerge lateral ribs that develop into finely denticulate lateral processes. The anterior margin of the cusp projects a short process, and the basal cavity is wide (Fig. 4F).

Sd element. This element has a short small cusp that is recurved. Four ribs run down the cusp and extend beyond the aboral margins forming finely denticulate processes. These processes give the element a quadrate section. The basal sheath links them all (Fig. 4G).

Trapezognathus quadrangulum Lindström, 1955 (Fig. 4H–P)

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; van 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 9 a–c, 11 a, lám. VII, figs 1, 3, 5.
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. 6 c–f.
2003 *Baltoniodus* sp. A; Zhen *et al*., p. 182, fig. 11V.

Material. One Pa, 2 Pb, 38 Sa, 60 Sb, 33 Sc, 38 Sd and 29 M elements. Chamarra Creek, Alto del Cóndor Formation, sample MS4. CML-C 5090(1–201). Middle Ordovician (Dapingian).

Description. *Pa element*. One pectiniform scaphate Pa element was recovered. The cusp is short and stout and indistinct in plan view. Three well-defined ribs extend as short processes (lateral, anterior and posterior) from the base of the cusp: the lateral process is shortest and the posterior is longest. The upper edges of the processes show evidence of denticles. A fourth rib forms a small lobe on the postero-lateral side. The basal sheath is expanded, linking the processes and giving the element a rectangular shape in plan view. The basal cavity is excavated and extends as grooves under the processes (Fig. 4H, I).

Pb Element. This element has a robust, short and straight cusp with an angle of about 100° between the upper edge of the base and the inner side of the cusp. Three strong ribs emerge from the apex of the cusp and form a lateral, an anterior and a posterior process. The first is relatively long and has a keel at the upper margin, the anterior is shorter, with a keel denoted by rudimentary denticles on its upper edge, whereas the posterior is the longest, and is directed backward. The basal cavity is wide, deep and reaches the apex of the cusp. The basal sheath is well developed and links the three processes with a well-marked undulation (Fig. 4J, K).

M element. The morphology of this element is very similar to that of other species of *Trapezognathus*, and to M elements of *Baltoniodus* sp. cf. *B. triangularis* and *Baltoniodus triangularis* (Li *et al.* 2010). This geniculate element has a short and stout cusp, from which emerges anterior and posterior extensions that may or may not have denticles on their edges. The basal cavity is excavated and concave (Fig. 4L).

S elements. These elements are characterized by the serrated edges of the processes and their thin and graceful cusps.

Sa element. This element has a slender and thin strongly recurved cusp. Fine ribs run down it from the apex and persist as small extensions beyond the aboral margin. Each of these (anterior, posterior and lateral extensions) has multiple blunt denticles. The basal cavity is deep and has a triangular cross-section; the basal sheath connects the processes. This element is almost indistinguishable from the Sa element of *Trapezognathus diprion* (Fig. 4M).

Sb element. This element is similar to the Sa element, with a curved cusp bearing three ribs that form three processes that extend beyond the basal margin. These extensions are denticulate and are connected by the basal sheath. The Sb elements differ by virtue of their slight asymmetry and lateral compression (Fig. 4N) from those described above.

Sc element. This element has a proclined to curved cusp, on the sides of which two ribs are developed that extend as lateral processes bearing denticles directed inwards. The element has a strong curvature so that the outer side is convex, and the inner is concave. The base has a higher development than the cusp and is deeply excavated. The basal sheath connects the processes (Fig. 4O).

Sd element. This element has a recurved cusp, furrowed by four ribs that extend basally to form four denticulate processes connected laterally by the basal sheath. The element has a slight asymmetry (Fig. 4P).

Remarks. The recovered Pa specimen has primitive characters compared with the Pa element figured by Viira *et al.* (2001). According to Löfgren and Zhang (2003), *T. quadrangulum* Lindström ranges from the *B. navis* Zone to *L. antivariabilis* Zone; this report expands its range to the lower part of the *B. triangularis* Zone, in which it coexists with its presumed direct predecessor *T. diprion*.

Erraticodon Dzik, 1978

Type species. Erraticodon balticus Dzik, 1978.

Erraticodon patu Cooper, 1981 (Fig. 5A–H)

1981 *Erraticodon patu* Cooper, p. 166, pl. 32, figs 1–6, 8.
1987 *Erismodus quadridactylus* (Stauffer); Sarmiento & Rao, pp. 90, 91, pl. 1. Figs 2–4, 7, 9 and 12, pl. 2, Figs 1–6.
1990 *Erraticodon patu* Cooper; Nicoll, fig. 2.1.
1994 *Erraticodon patu* Cooper; Albanesi & Vaccari, p. 137, pl. 1, figs 11–16.
2003 *Erraticodon patu* Cooper; Zhen *et al*., pp. 195–198, figs 16 A–K, 17 A–O.
2007 *Erraticodon balticus* Dzik; Albanesi *et al*., p. 46, text-Fig. 3A–D.

Material. Forty-four Pa, 6 Pb, 51 Sa, one 141 Sb, 84 Sc, 70 Sd and 25 M elements and four fragments of S elements. CML-C 5060(1–5), 5063(1–8), 5065(1), 5067 (1–3), 5072(1–4), 5075(1–6), 5077(1–3), 5084(1–393); upper Floian, *Trapezognathus diprion* Zone to the basal Dapingian, *Baltoniodus triangularis* Zone.

Discussion. This apparatus consists of seven elements that correspond to the morphotypes Pa, Pb, M, Sa, Sb, Sc and Sd. This species was originally defined by Cooper (1981) and subsequently reviewed by Zhen *et al.* (2003) who distinguished ramiform digyrate P elements, makelate M, alate Sa, bipennate Sb and Sc, and tertiopedate Sd elements. All are hyaline with prominent cusps and two or three denticulate processes with denticles similar to stakes. The cusp bears two or three fine ribs that extend basally to form the upper margin of the processes. The basal cavity is superficial, extending as deep grooves to the tip of the processes.

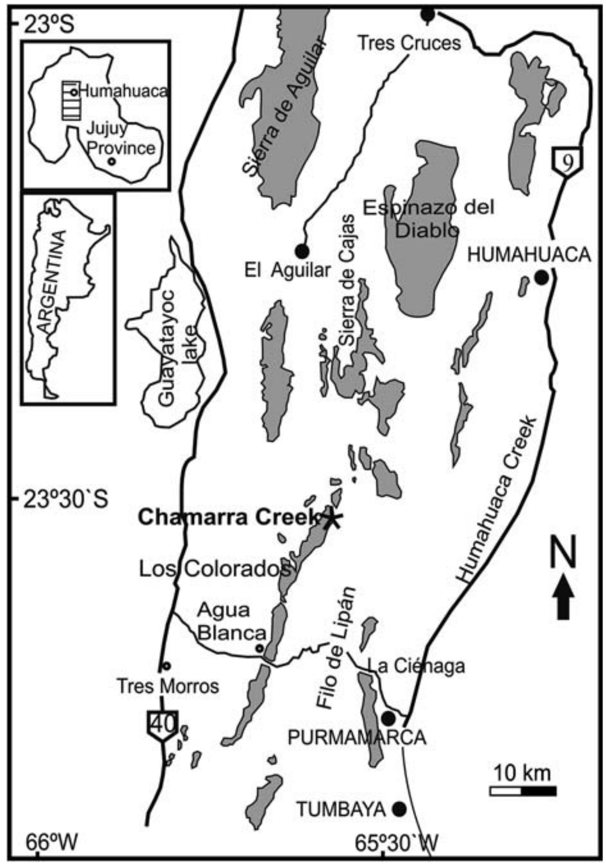

Fig. 1. Location map of de Los Colorados region (Jujuy province), Eastern Cordillera, Northwest Argentina. The Ordovician outcrops are indicated in grey.

Description. *Pa element*. The cusp is thin and elongated. The anterior and posterior processes are arranged upright with respect to the cusp but are directed downwards, the lateral process is directed away from the anterior process at an angle of 60°; all processes are denticulate. The base is deep and excavated and expands into each of the processes (Fig. 5A).

Pb element. The cusp is slender and straight with sharp keel-like edges that continue laterally as processes. The inner lateral process is short and extends horizontally with respect to the cusp, the outer lateral process is longer and is directed downwards at an angle to the cusp of about 130°; both processes have two to three thin and recurved denticles compressed antero-posteriorly with sharp edges. Denticles are shorter on the inner lateral process and longer (similar in length to the cusp) on the outer lateral process. The basal margin is extended and arched in the case of the anterior lateral process. The basal cavity is reduced to a small pit below the apex of the cusp and extends as a barely perceptible groove into the processes (Fig. 5B, C).

M element. This element has long, robust and sharp margins. The antero-posteriorly compressed cusp gives rise basally to two processes, a small anterior process that usually carries a denticle and a longer posterior

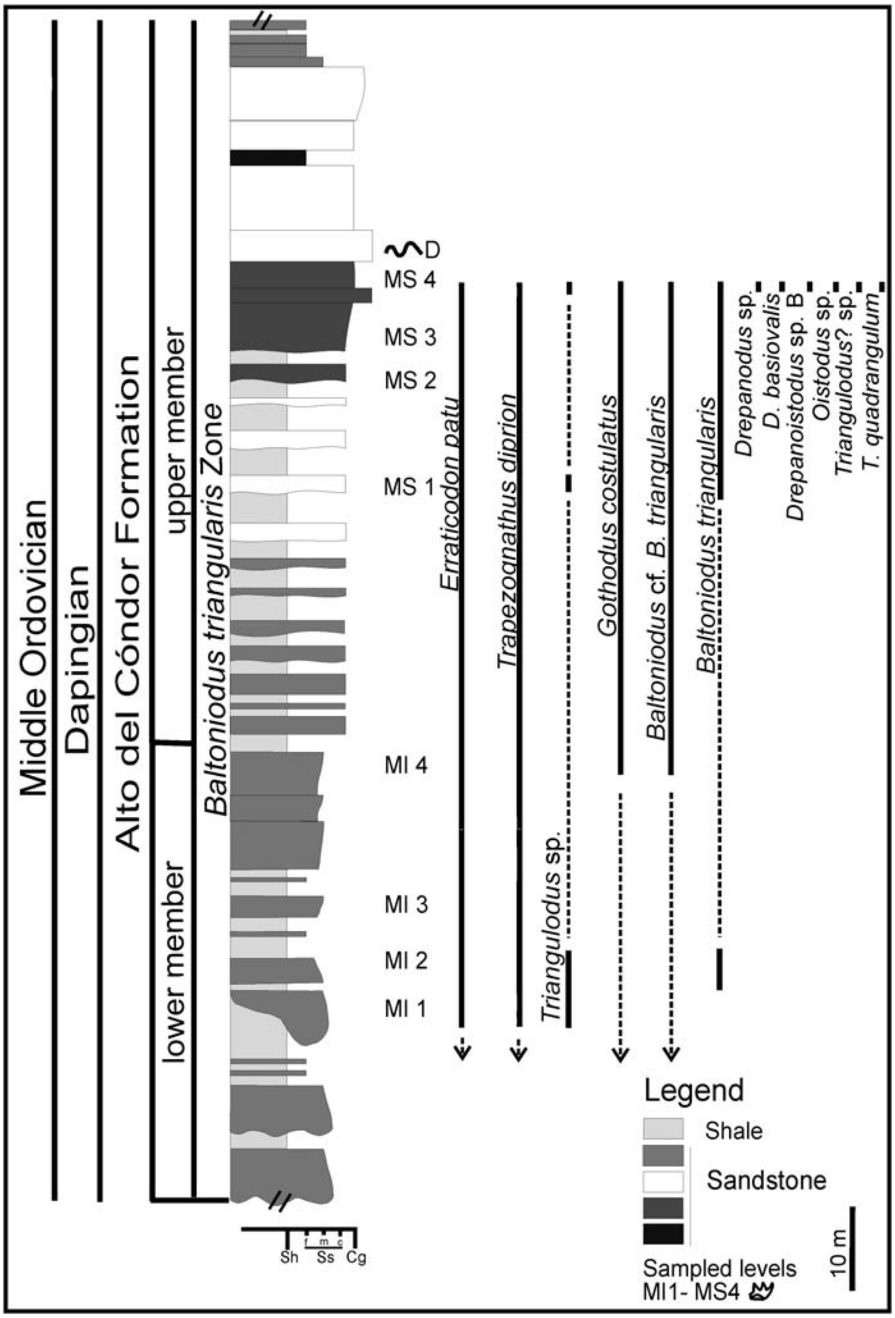

Fig. 2. Stratigraphical section of the Alto del Cóndor Formation at Chamarra Creek, Los Colorados region (Jujuy province). Stratigraphic distributions of selected species are displayed. Arrows directed downward indicated that these species are also present in the Acoite Formation.

process bearing two denticles. The denticles are short and antero-posteriorly compressed. The basal cavity is small and excavated (Fig. 5D).

Sa element. This is a symmetrical alate element. The cusp is long, thin and recurved with acute flanks. The longer lateral processes each bear two to four denticles. A short posterior process bears a single denticle. The basal margin is formed by deep arches under each lateral process, whereas the basal cavity is excavated underneath the cusp (Fig. 5E).

Sb element. The robust and strongly recurved cusp of this element has three well-marked ribs, two of which extend as lateral processes directed downward forming a closed arc between them, each carrying thin denticles compressed antero-posteriorly. Denticles of the anterior lateral process are directed backwards. The posterior process is short. The basal cavity is excavated and extends deeply into the interior of the processes (Fig. 5F).

Sc element. The cusp is enlarged near the base and tapers apically; generally suberect, with sharp edges. The anterior face is flat, whereas the posterior face is concave. Two curved lateral processes arise from it carrying three downwardly directed denticles. The first denticle of the lateral process is attached to the apex

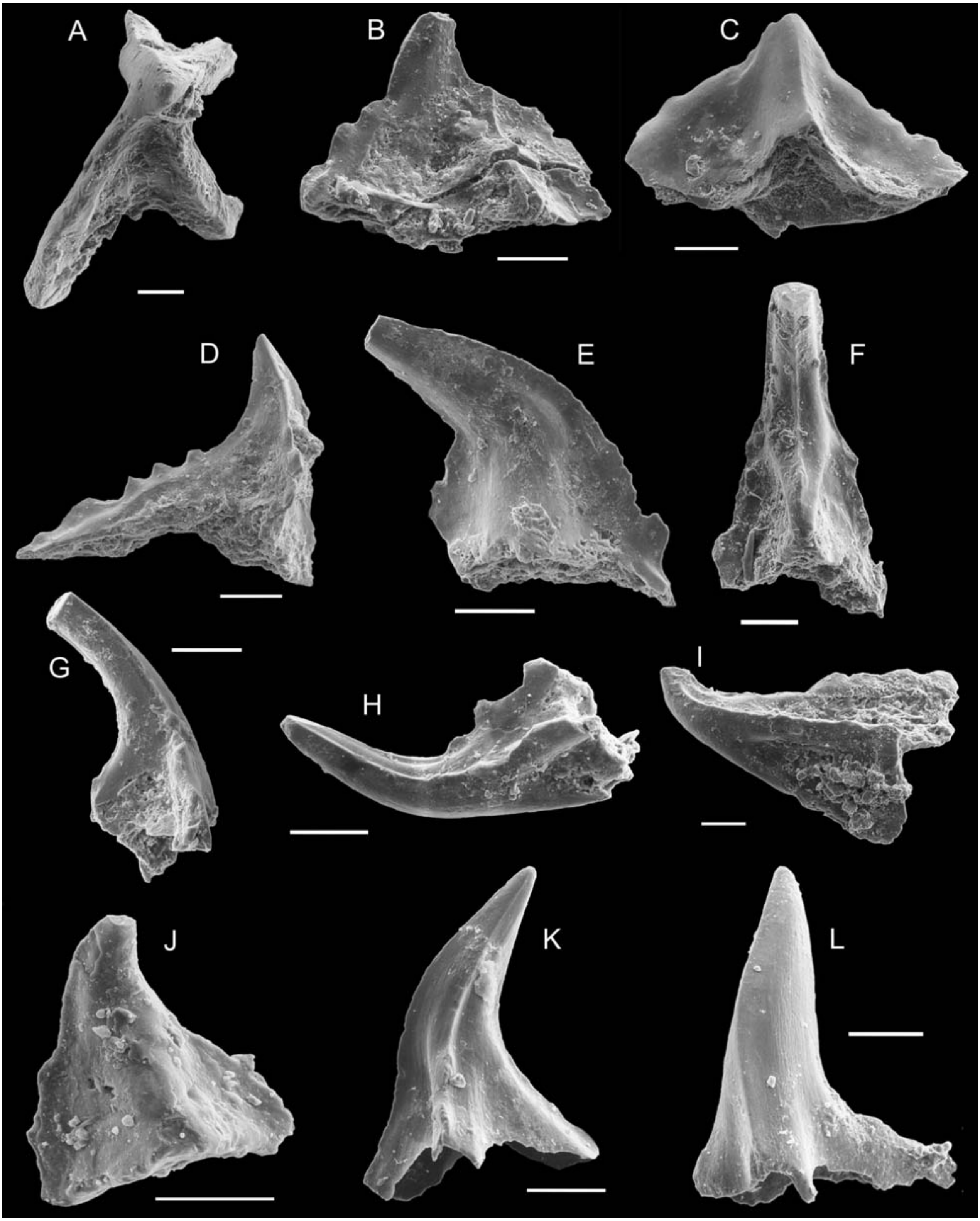

Fig. 3. **A–I**, *Baltoniodus triangularis* (Lindström, 1955). **A–C**, Pa elements, CML-C 5078 (1–3), **A**, upper view, CML-C 5078 (1), **B**, posterior view, CML-C 5078(3), **C**, front view, CML-C 5078(2); **D**, Pb element, posterior view, CML-C 5078(15); **E**, M element, lateral view, CML-C 5078 (150); **F, G**, Sa elements, CML-C 5078 (187–188), **F**, front view, CML-C 5078(187), **G**, lateral view, CML-C 5078(188); **H**, Sb element, lateral view, CML-C 5078(220); **I**, Sd element, lateral view, CML-C 5078(288). **J**–**L**, *Baltoniodus* sp. cf. *B. triangularis* (Lindström, 1955). **J**–**L**, Pb elements, CML-C 5079(1–5). **J**, posterior view, CML-C 5079(1), **K**, postero-lateral view, CML-C 5079(2), **L**, front view, CML-C 5079(3). All elements were obtained from sample MS4, Chamarra Creek, Los Colorados region. Scale bar = 10 µm.

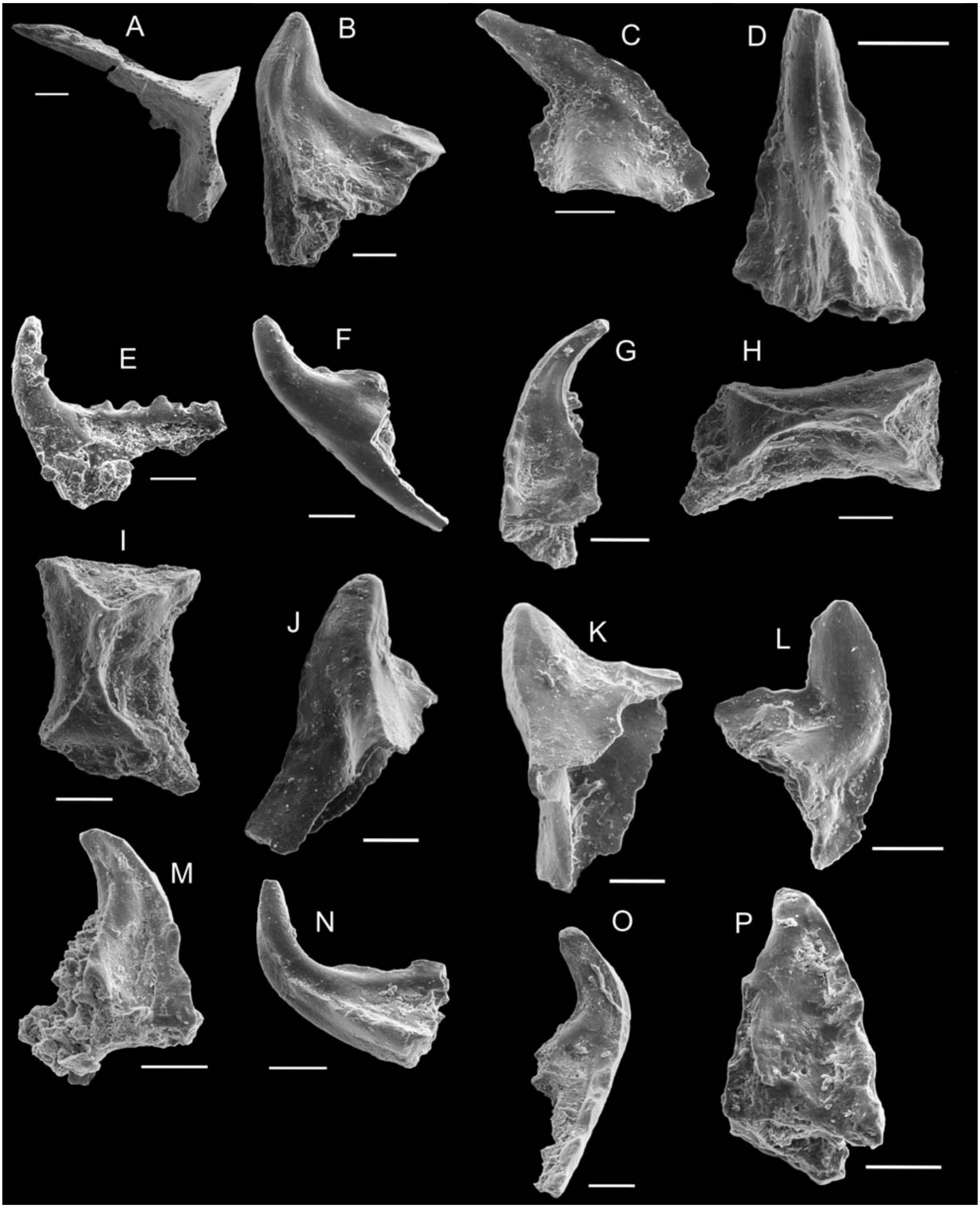

Fig. 4. **A**–**G**, *Trapezognathus diprion* (Lindström, 1955). **A**, Pa element, upper view, CML-C 5088(1); **B**, Pb element, postero-lateral view, CML-C 5088(4); **C**, M element, postero-lateral view, CML-C 5088(16); **D**, Sa element, postero-lateral view, CML-C 5089(56); **E**, Sb element, lateral view, CML-C 5089(89); **F**, Sc element, antero-lateral view, CML-C 5088(112); **G**, Sd element, postero-lateral view, CML-C 5088(125). **H–P**, *Trapezognathus quadrangulum*, Lindström, 1955. **H, I**, Pa elements, upper view, CML-C 5090(1); **J, K**, Pb elements, lateral and postero-lateral views, CML-C 5090(2); **L**, M element, lateral view, CML-C 5090(4); **M**, Sa element, postero-lateral view, CML-C 5090(34); **N**, Sb element, postero-lateral view, CML-C 5090(94); **O**, Sc element, postero-lateral view, CML-C 5090(127); **P**, Sd element, postero-lateral view, CML-C 5090 (166). All elements were obtained from sample MS4, Chamarra Creek, Los Colorados region. Scale bar = 10 µm.

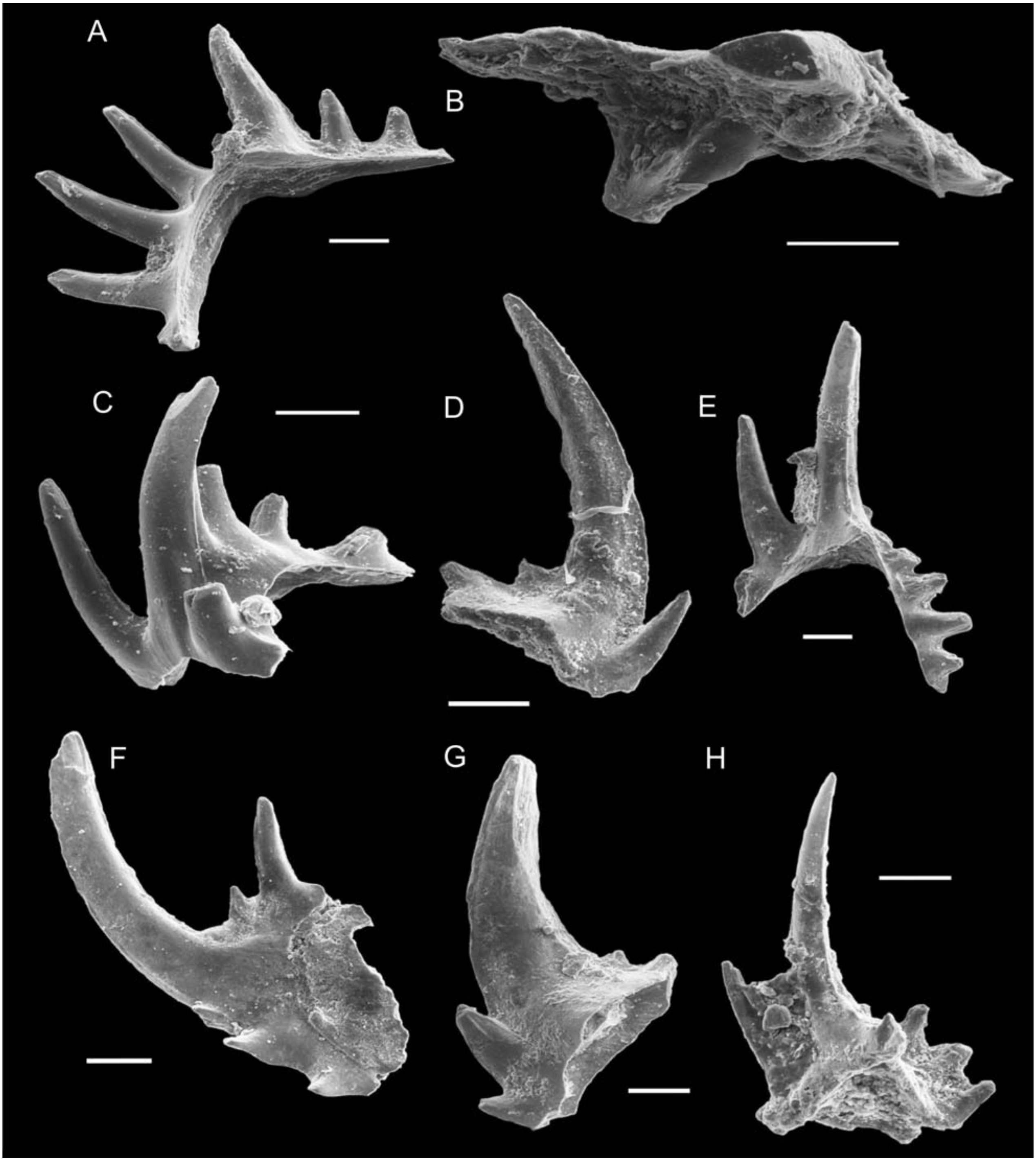

Fig. 5. **A**–**H**, *Erraticodon patu* Cooper, 1981. **A**, Pa element, posterior view, CML-C 5084(1); **B, C**, Pb elements, upper and lateral views, CML-C 5084(1); **D**, M element, postero-lateral view, CML-C 5084(48); **E**, Sa element, posterior view, CML-C 5078(73); **F**, Sb element, lateral view, CML-C 5078(119); **G**, Sc element, lateral view, CML-C 5078(248); **H**, Sd element, postero-lateral view, CML-C 5078(320). All elements were obtained from sample MS4, Chamarra Creek, Los Colorados region. Scale bar = 10 μm.

whereas the antero-lateral denticle is free. The basal cavity is widely excavated and extends to the end of each process (Fig. 5G).

Sd element. This element has a long, slender and straight to suberect cusp. The element has three processes, two laterals and a posterior, all bearing denticles. Both lateral processes are curved downwards at an angle of 40° (Fig. 5H).

Remarks. Some of the recovered forms have degraded and darkened walls. These specimens presumably belong to older individuals within the species. Juvenile, mature and gerontic forms have been recovered.

Biostratigraphic significance

This work documents the first conodonts from the Alto del Cóndor Formation. The presence of *Baltoniodus*

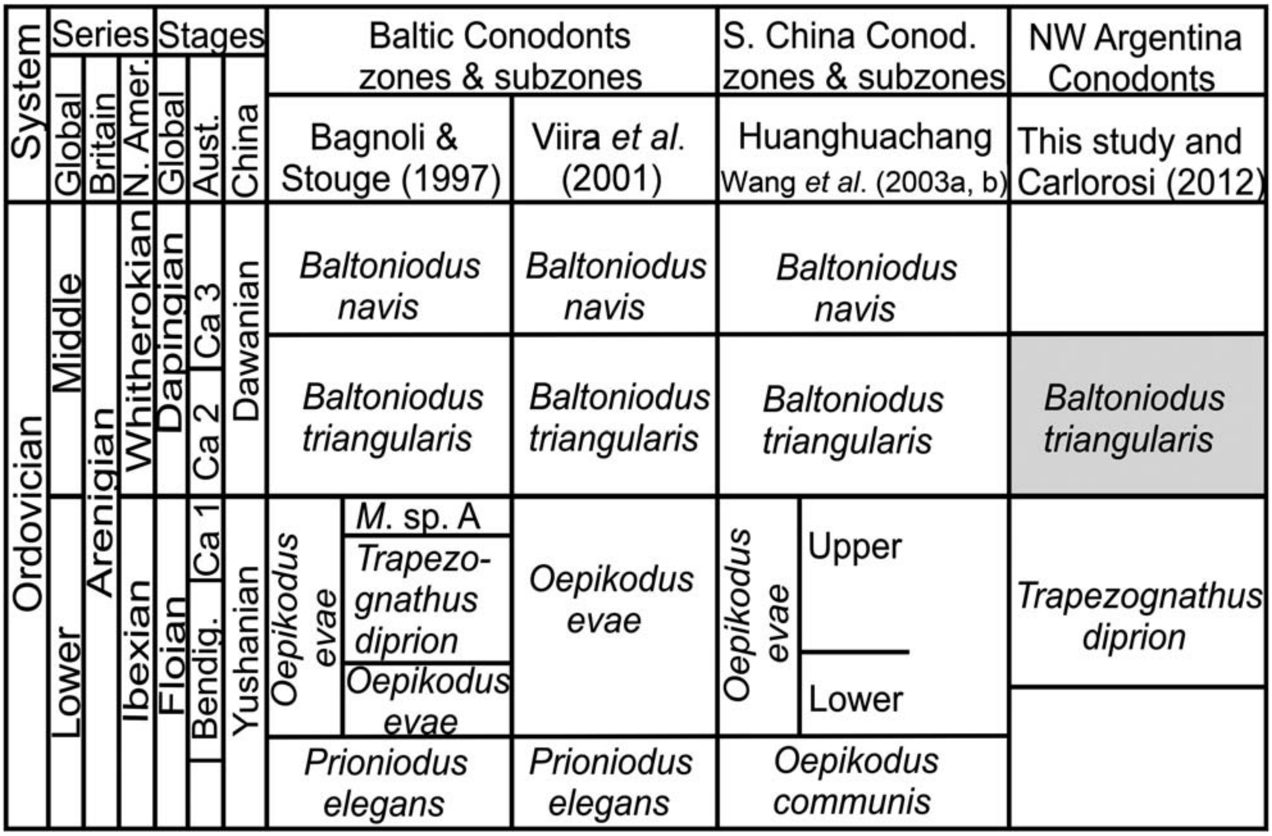

Fig. 6. Lower–Middle Ordovician biostratigraphical chart comparing conodont biozones from Baltica, South China and the Andean Basin.

triangularis in this unit allows assignment to the *B. triangularis* Zone, representing the first record of this zone in the lower Palaeozoic Central Andean Basin and in this part of Gondwana. This species occurs in both members of the unit, specifically in samples MI2 and MS1 to 4.

The base of the *B. triangularis* Zone marks the lower boundary of the Middle Ordovician (Floian to Dapingian boundary; Wang *et al.* 2003a, b, 2005, Bergström and Löfgren 2009, Wang *et al.* 2009, Li *et al.* 2010). The *Baltoniodus triangularis* Zone was first defined in Sweden by Lindström (1955), when proposing a conodont zonation for the Volkhovian stage. Later, Lindström (1971) divided the conodont succession into a general scheme for Northwest Europe, and that scheme has since been applied in Baltoscandia. Van Wamel (1974) introduced several modifications to this scheme, in which the *Baltoniodus triangularis* Zone would correspond to the middle *Microzarkodina flabellum* Zone. Other changes were proposed by Löfgren (1978, 1985, 1993, 1994, 1995) for central Sweden, where the *Baltoniodus triangularis* Zone is recognized. Subsequently, Stouge and Bagnoli (1990, 1999) and Bagnoli and Stouge (1997) determined the *Baltoniodus*? *triangularis* Zone at the base of Volkhovian stage (Fig. 6), which would correspond to the lower part of *B. triangularis* Zone of Löfgren (1993) and Lindström (1971).

The *Baltoniodus triangularis* Zone was also recorded in the stratotype section for the basal Dapingian at Huanghuachang, near Yichang (China; Wang *et al.* 2003a, b). This section is highly fossiliferous with abundant conodonts, graptolites, chitinozoans, acritarchs, brachiopods and trilobites, aiding correlation with other reference sections around the world. In this region, *O. evae*, *T. diprion*, *Baltoniodus* sp. cf. *B. triangularis*, *Baltoniodus triangularis* and *Baltoniodus navis* zones are recognized in a continuous succession across the Lower to Middle Ordovician boundary (Li *et al.* 2010). In the Los Colorados region, we recognized several of the same biozones, including the *T. diprion*, *Baltoniodus* sp. cf. *B. triangularis* and *Baltoniodus triangularis* zones in the outcrops of the Acoite and Alto del Cóndor formations (Carlorosi 2012; Fig. 6).

Bergström and Löfgren (2009) presented a list of the conodont species from the Baltic area and the Dapingian GSSP of China. When compared with the Chamarra Creek section, the number of shared species is low, but the importance of this section lies in the lineages that are present. *Baltoniodus* sp. cf. *B. triangularis* appears after the *Trapezognathus diprion* Zone and extends into the *B. triangularis* Zone. The presence of advanced forms of *T. diprion* in the *B. triangularis* Zone and the appearance of early forms of *T. quadrangulum* sharing the same sampled level constitutes an association that has not been recognized in Baltica or China. The discovery of primitive and advanced forms together in the *B. triangularis* Zone suggests the transition from one species to another.

Trapezognathus quadrangulum is recorded from the *Baltoniodus navis* Zone to the *L. antivariabilis* Subzone in South China and Baltica. Löfgren and Zhang (2003) determined that the stratigraphic record of *T. quadrangulum* is short, being restricted to zones and subzones of the Arenig (British Series). The record of *T. quadrangulum* in the Chamarra section favours placement of the FAD of this species in the *B. triangularis* Zone, thus representing the oldest record of this species.

Palaeobiogeography

An analysis of the conodont association recorded from the two members of the Alto del Cóndor Formation in the Los Colorados region suggests affinities of the lower Palaeozoic Central Andean Basin and faunal provinces in other regions of the world. The index species *Baltoniodus triangularis*, *Baltoniodus* sp. cf. *B. triangularis*, *Trapezognathus diprion* and *T. quadrangulum* are distributed in several classic sections of Baltica and South China, suggesting clear affinities of the Central Andean Basin fauna with the Shallow-Sea Realm of the Temperate-Cold Domain (Zhen and Percival 2003).

The presence of *Erraticodon patu* reveals a peculiar Australian Province affinity (Cooper 1981, Zhen *et al.* 2003), whereas the additional forms identified in the Alto del Cóndor Formation (*Gothodus costulatus*, *Drepanodus* sp., *Drepanoistodus basiovalis*, *Oistodus* sp. and *Triangulodus* sp.) have cosmopolitan distributions.

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