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A new species of the Gondwanan genus *Cardiolaria* Munier-Chalmas in the Sandbian of northwestern Argentina: Paleobiogeographic considerations

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ABSTRACT

A new species of afghanodesmatid, *Cardiolaria benicioi*, is recorded from Sandbian strata of northwestern Argentina. This species confirms the strong paleobiogeographic relationships between the western Argentina basin and other peri-Gondwanan areas. The Mid-Late Ordovician distribution of bivalves fit well into the Mediterranean Province defined upon brachiopod and trilobite faunas. Similitudes between Tremadocian and Floian bivalves from the western Gondwana and the peri-Gondwanan areas indicate that such 'Mediterranean' paleobiogeographic patterns can be traced back well into the Early Ordovician.

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1. Introduction

Bivalves are uncommon in the Mid-Upper Ordovician successions of the northwestern Argentina basin. Mid Ordovician (Darriwilian-Sandbian) beds have yielded *Cadomia typa* de Tromelin, *Zaplaella capillaensis* Sánchez, and the new species *Cardiolaria benicioi*, described herein. These species are important paleobiogeographic markers and consequently are useful to elucidate faunal connections around Gondwana.

In this paper the new species *C. benicioi* is described on the basis of excellently preserved material recovered in the Sierra de Zapla of northwestern Argentina. In addition, the biogeogeographic distribution of Ordovician bivalves from western Gondwana is analyzed.

2. Geological setting and stratigraphy

Fossils come from the Capillas Formation (24°01′56″S–65°06-′17″W), a thin-bedded fine-grained, green to dark grey, fossil-rich, internally homogeneous and laterally continuous interval within a thick Ordovician section that outcrops in both flanks of the Zapla anticline (Nieniewski and Wleklinski, 1950), a major structure in the Sierras Subandinas, in northwest Argentina (Fig. 1). The Sierras Subandinas form a thin-skinned thrust and fold-belt in the present day foreland on northern Argentina and Bolivia (Kley et al., 1999). This abrupt region has a very dense green coverage. Due to the north–south trend of the main structures within the east propagating fold-belt, the Ordovician rocks crop out along east–west gorges, one of which is known as the Río Capillas, located ~25 km NW of the city of Jujuy (Fig. 1). Along this river there are excellent quality and relatively continuous exposures traversing the Sierra de Zapla (Fig. 1) that has allowed stratigraphic studies (Monaldi et al., 1986; Astini, 2003; Astini et al., 2003) and detailed sedimentological works on the Ordovician successions (Astini and Marengo, 2006). The ~450 m thick section displays an alternation of shallow-marine deltaic systems and estuarine environments, resulting from relative sea-level fluctuations (Fig. 2). Collections of invertebrate faunas as well as micropaleontological work have enhanced the importance of this locality (Sánchez et al., 2003; Waisfeld and Henry, 2003; Albanesi et al., 2007; Rubinstein et al., in press, among others). However, the recorded marginal marine settings with frequent subaerial exposure (Astini and Marengo, 2006), prevents proper biostratigraphic constraints of the complete sedimentary succession cropping along the Río Capillas. Middle Ordovician acritarchs and related marine algal forms, and spore-like microfossils were recently recorded from the Capillas Formation (Rubinstein et al., in press). Based on the palynological assemblages, a Dapingian age is interpreted for the upper Lagunillas Member of the underlying Labrado Formation (Fig. 2), whereas the lower part of the Capillas Formation is assigned to the Darriwilian (Fig. 2). Furthermore, conodont faunas recovered from some carbonate-rich lenses, in a section immediately to the north of this area, indicate an age not younger than late Darriwilian for the upper section of the unit (Albanesi et al., 2007), which can probably reach into the Sandbian (Astini et al., 2003). Both conodont faunas and facies analysis allow good correlation with other sections in the Cordillera Oriental (to the west, Fig. 1), allowing to trace this unique open-marine interval at a regional scale.

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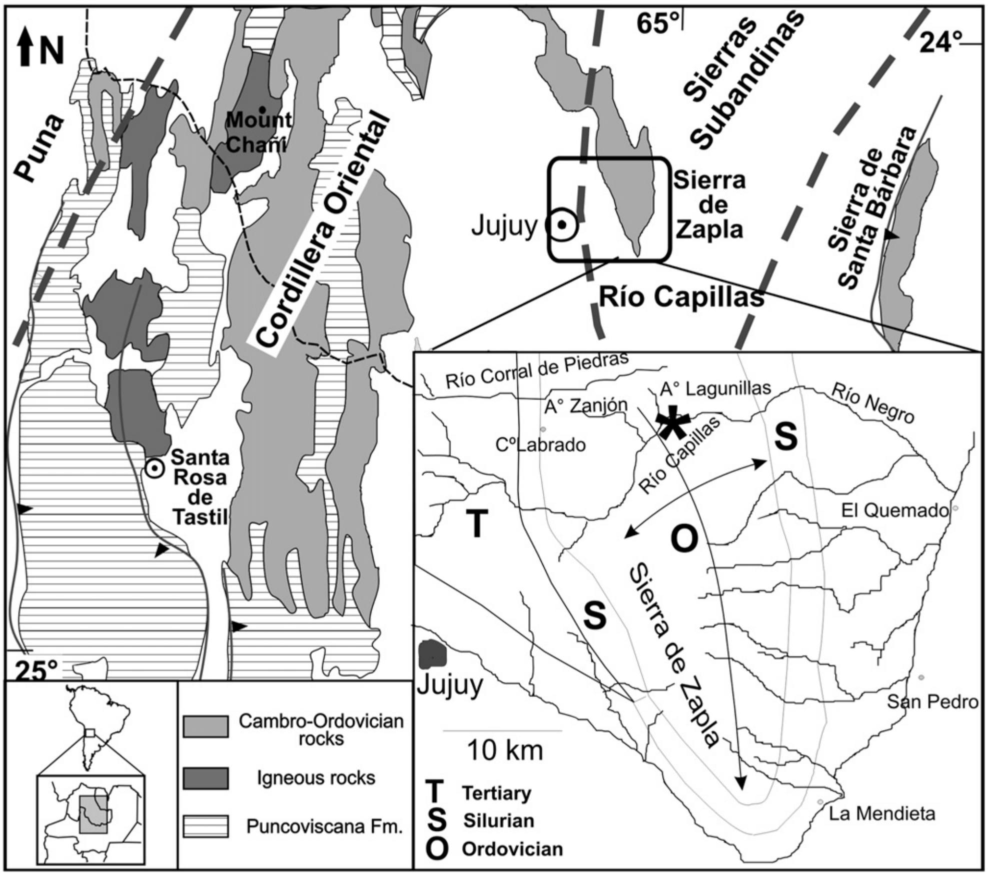

Fig. 1. Map of a part of the Sierras Subandinas showing location of the fossiliferous level.

Sharply overlying a composite sandy estuarine fill referred to the Labrado Formation (Fig. 2), the Capillas Formation is represented by a fossil-rich fine-grained laterally continuous fully marine interval, suggesting a rapid transgressive shift, compatible with development of a marine flooding surface. The Capillas Formation (~145 m) is a fine-grained shelfal facies association that gradually coarsens and thickens up. This unit contains the only truly marine shelly fauna that is not only embedded in the muddy facies within the middle section, but also concentrated in few calcareous storm beds, above the fine-grained interval that characterizes a maximum flooding stage. The lower section contains within the laminated black shales few thin-tabular gradded sandstones with parallel lamination and wavy tops. The middle section is gradually to pervasively homogenized with superposed bioturbation patterns, where *Phycodes* isp. belonging to the *Cruziana* ichnofacies appears to be outstanding. These silty mudstones contain abundant remains of bivalves and disarticulated trilobites. Shell beds are mostly composed by concentrations of well-preserved bivalves, few trilobites and large cephalopods. Internally, they vary from disorganised and poorly segregated to relatively organised, stacked and imbricated. Individual shell beds show common shelter structures and geopetal cements indicating their rapid burial. Fossil preservation is relatively good with weak fragmentation and scarce individual abrasion in shells. Altogether, these features indicate a parautochthonous origin, consistent with storm removal and nearby concentration in shallow-marine environments. Few well-preserved wave ripple trains above thin beds of laterally continuous sandstones allow inferring shallow subtidal environments.

3. Paleobiogeographic considerations

Cardiolaria is a Gondwanan and peri-Gondwanan genus common in Mid-Late Ordovician (Darriwillian-Sandbian) beds from the Armorican Massif, Iberia, Morocco, and NWA (Babin and Destombes, 1990; Babin and Gutiérrez-Marco, 1991; Gutiérrez-Marco and Babin, 1999; Sá, 2008). Also, *Cardiolaria* sp. has been reported by Gutiérrez-Marco et al. (1997) from the Early Ordovician (Floian) of Central Spain. In the Sandbian strata of the northwestern Argentina *Cardiolaria* co-occurs with *C. typa* de Tromelin, a Gondwanan species (Sánchez, 1986), and with the glyptarcidae *Z. capillaensis* Sánchez (Sánchez et al., 2003). Glyptarcids are common dwellers in the Ordovician Gondwanan and peri-Gondwanan shelves.

All the Capillas Formation bivalves show strong paleobiogeographic affinities with those from Gondwanan and peri-Gondwanan basins (Benedetto et al., 2009). Similar paleobiogeographic affinities have been documented by brachiopods and trilobites (Benedetto, 2003, and additional references therein), and by acritarchs from the lower part of the Capillas Formation (Rubinstein et al., in press). The paleogeographic reconstruction of Sandbian time by Cocks and Torsvik (2006) (Fig. 3) shows that the existence of nearly continuous peri-continental shelves around Gondwana promoted the dispersal of bivalves. It should be noted that the pattern of occurrences of bivalve assemblages along western Gondwana during the Mid-Late Ordovician coincides with the boundaries of the Mediterranean Province defined by Spjeldnaes (1961) and refined by Havlíček, 1989 on the basis of their brachiopod and trilobite assemblages.

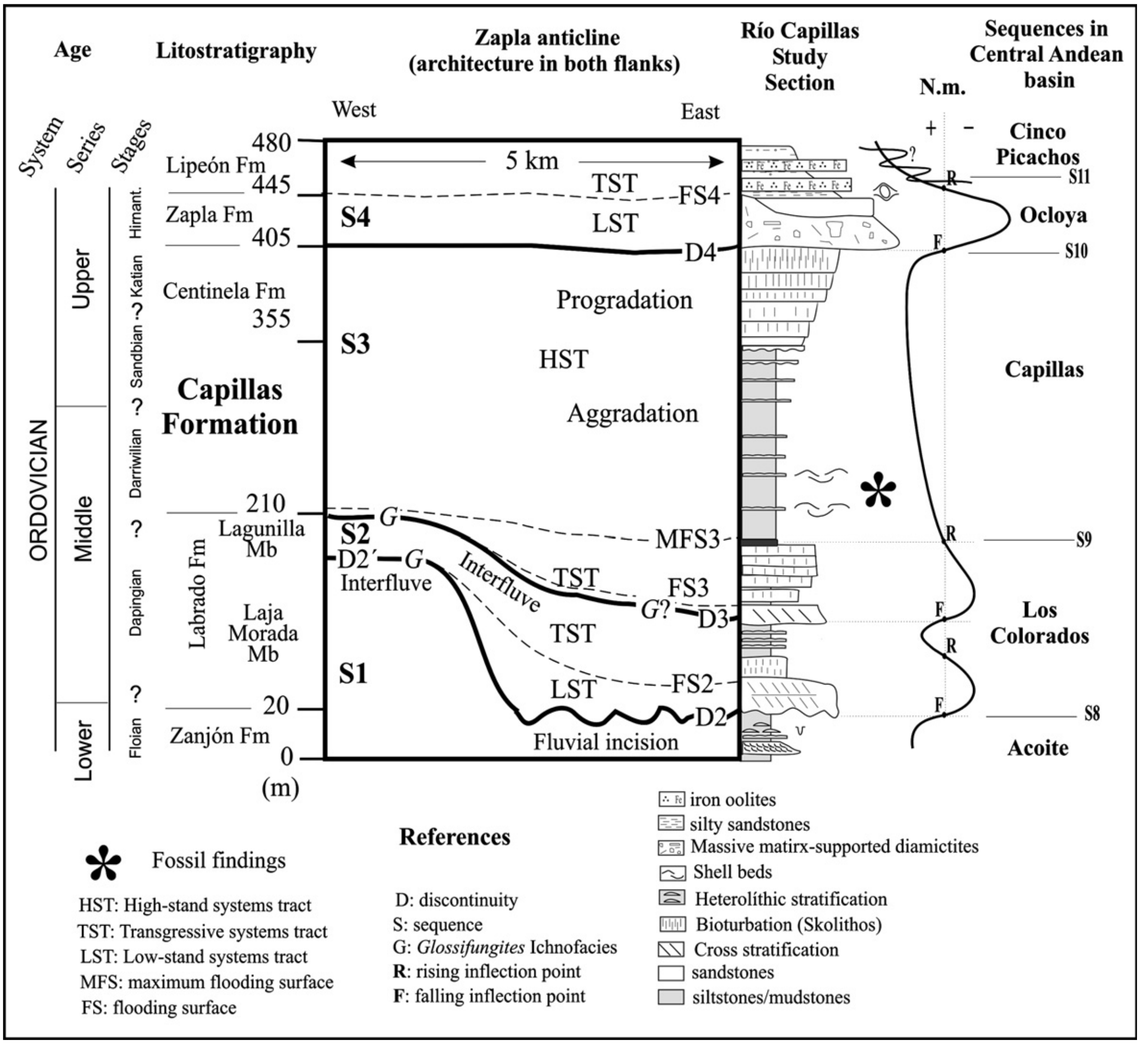

Fig. 2. Stratigraphy of the Capillas formation and location of fossiliferous level.

Glyptarcoids like *Glyptarca* Hicks, *Camnantia* Cope, and *Celtoconcha* Cope, were found in Floian beds from Wales (Cope, 2002). At that time, Avalonia rifted off from the northern extent of the South American margin of Gondwana from which it was separated by a narrow Rheic Sea (Cocks and Torsvik, 2006). The gradual widening of the Rheic Ocean through the Ordovician led to place Avalonia far away from Armorica but near Baltica by the end of the Ordovician after the closure of the Tornquist Ocean (Fig. 3). However, as Sánchez and Babin (2003) stated, the bivalves of Wales show closest paleobiogeographic affinities with Iberia and the Armorican Massif during the Sandbian. Genera like *Glyptarca*, *Praeleda* Pfab, *Myoplusia* Neumayr, and *Lyrodesma* Conrad, clearly show that some bivalves were able to disperse across the wide Rheic Ocean. Noticeably, *Lyrodesma*, recorded in Wales, has been reported also from Sandbian beds of Bolivia (Sánchez and Suárez-Soruco, 1996). According to Cope (2002) bivalve larvae were only capable to migrate around Gondwana during the Early Ordovician, and they were apparently not able to cross large oceans and to colonize other continental shelves before the Mid-Ordovician, when they expanded to extra Gondwanan areas. Most of Early Ordovician bivalves seem to have been stenotopic forms, without planctotrophic larvae, which probably prevented its geographic dispersion (Sánchez and Babin, 2003).

It is interesting to note that though the Mediterranean Province was recognized by Sandbian times, occurrences of Early Ordovician bivalves from Gondwanan and peri-Gondwanan localities display a similar distribution. There is enough evidence supporting that the South American basins were closely related to the Mediterranean Province since the Early Ordovician (e.g. Babin and Branisa, 1987; Benedetto and Sánchez, 1996; Sánchez and Babin, 2005). By the Floian, the northwestern region of Argentina shared with the Mediterranean region the genera *Redonia* Rouault and *Coxiconchia* Babin, and closely related forms such as the cycloconchids *Cienagomya* Sánchez and *Fortowensia* Cope. Gutiérrez-Marco et al. (2004) reported *Suria* Sánchez from late Floian strata of Peru, a genus originally described from nearly coeval beds from the Sierra de Famatina, western Argentina (Sánchez, 1997). In conclusion, according to the bivalve evidence, a western Gondwana corridor was established since the Floian and was active during most of the Ordovician.

4. Sistematic paleontology (by T.M. Sánchez)

Material used in this study is housed in the paleontological collections of the Centro de Investigaciones Paleobiológicas,

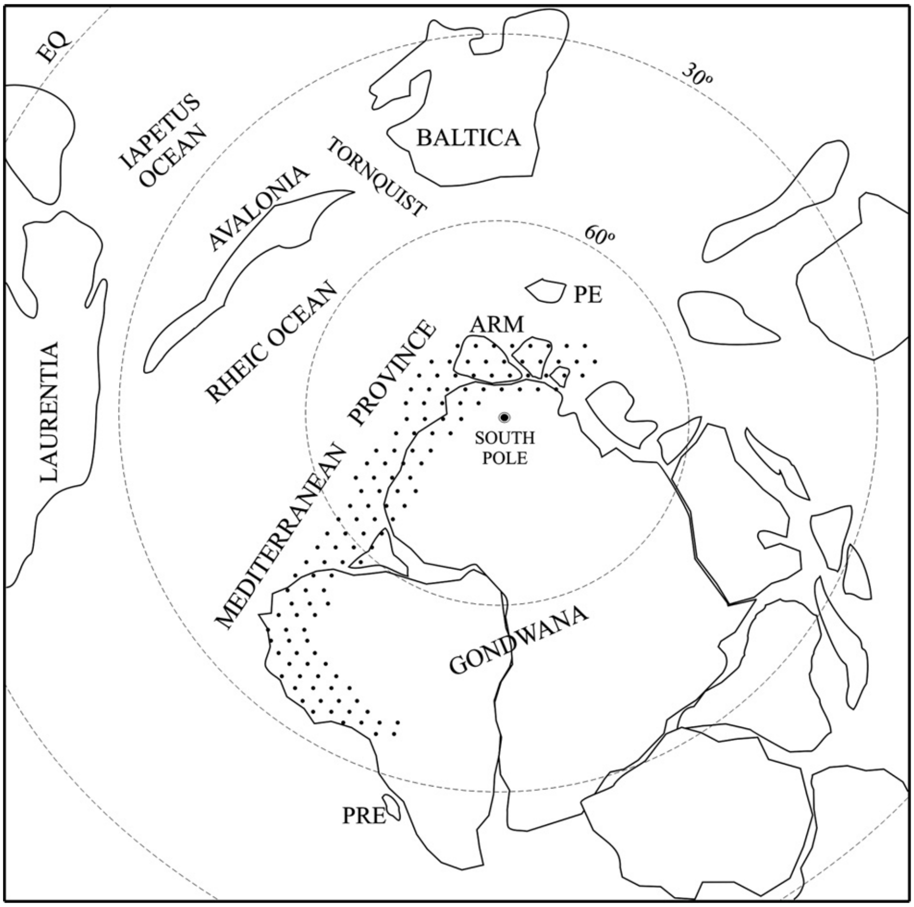

Fig. 3. Paleogeographic reconstruction for the Sandbian simplified from Cocks and Torsvik (2006). ARM, Armorique, PE, Perunica, PRE, Precordillera.

Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, prefix CEGH-UNC.

Family AFGHANODESMATIDAE Scarlato and Starobogatov, 1979

Genus *Cardiolaria* Munier-Chalmas, 1876

Type species: *Cardiolaria barrandei* Munier-Chalmas, 1876

C. benicioi nov. sp.

2003. *Cardiolaria* sp. Sánchez, Pl 4, Fig. 1.

Derivation of name: From my grandson Benicio.

Holotype: The holotype is an internal mould of a left valve with the posterior extremity incomplete, CEGH-UNC24072.

Paratypes: Six internal molds of left and right valves, CEGH-UNC21078, and 24,073 to 24,077.

Type locality and age: Capillas Formation, northwestern Argentina, Darriwilian.

Diagnosis. *Cardiolaria* with elongate shell outline and with anterior and posterior teeth of similar size.

4.1. *Description*

Shell outline ovate, posteriorly elongated and moderately convex. Maximal high placed at the subumbonal region. Prosogyrous beak placed in the anterior third of the valve. Eight anterior teeth and 15–20 posterior teeth. The posterior teeth are similar in size to those of the anterior one but some of the posterior series decrease abruptly in size below the umbo. These smaller posterior teeth overlap the anterior teeth sub-umbonally. A small edentulous space below the umbo separates both dental series. Anterior teeth not chevroned; anterior subumbonal teeth diverging from the dorsal to the ventral part of the valve (Fig. 4, ,4). Posterior teeth with ample chevron angles; most distal posterior teeth in zig-zag (Fig. 4, 3 and 6). Adductor anterior muscle scar fringed on its internal margin by a myophoric butress. Posterior adductor scars smaller than the anterior ones but deeply impressed. In the absence of well-preserved external moulds, there is no evidence of the shell ornament, but some poorly preserved external moulds show only growth lines. Shell length ranges from 8 to 22 mm.

4.2. *Discussion*

C. benicioi nov. sp. is distinguished from *Cardiolaria beirensis* (Sharpe, 1853) and the type species by its elongated outline shell and the size of the anterior teeth with regard to the posterior ones. *C. barrandei* described and illustrated by MacAlester (1968) has a strongly inflated, rounded outline shell, and preserve three large anterior teeth and several smaller posterior teeth. MacAlester (1968) stated that the subumbonal dentition is not preserved in this material. However, Babin (in Babin and Gutiérrez-Marco, 1991) noted that a single specimen from the type locality shows an edentulous space beneath the umbo between the two dental series. *C. benicioi* differs from *C. barrandei* in the shell outline, in the less inflated shell, and in the number and relative size of the anterior teeth. Moreover, impressions of adductor muscles in *C. barrandei* are stronger than those of the *C. benicioi*. *C. beirensis*, described and figured by Bradshaw (1970) and Babin and Gutiérrez-Marco (1991) clearly differs from *C. benicioi* in its rounded shell outline and both

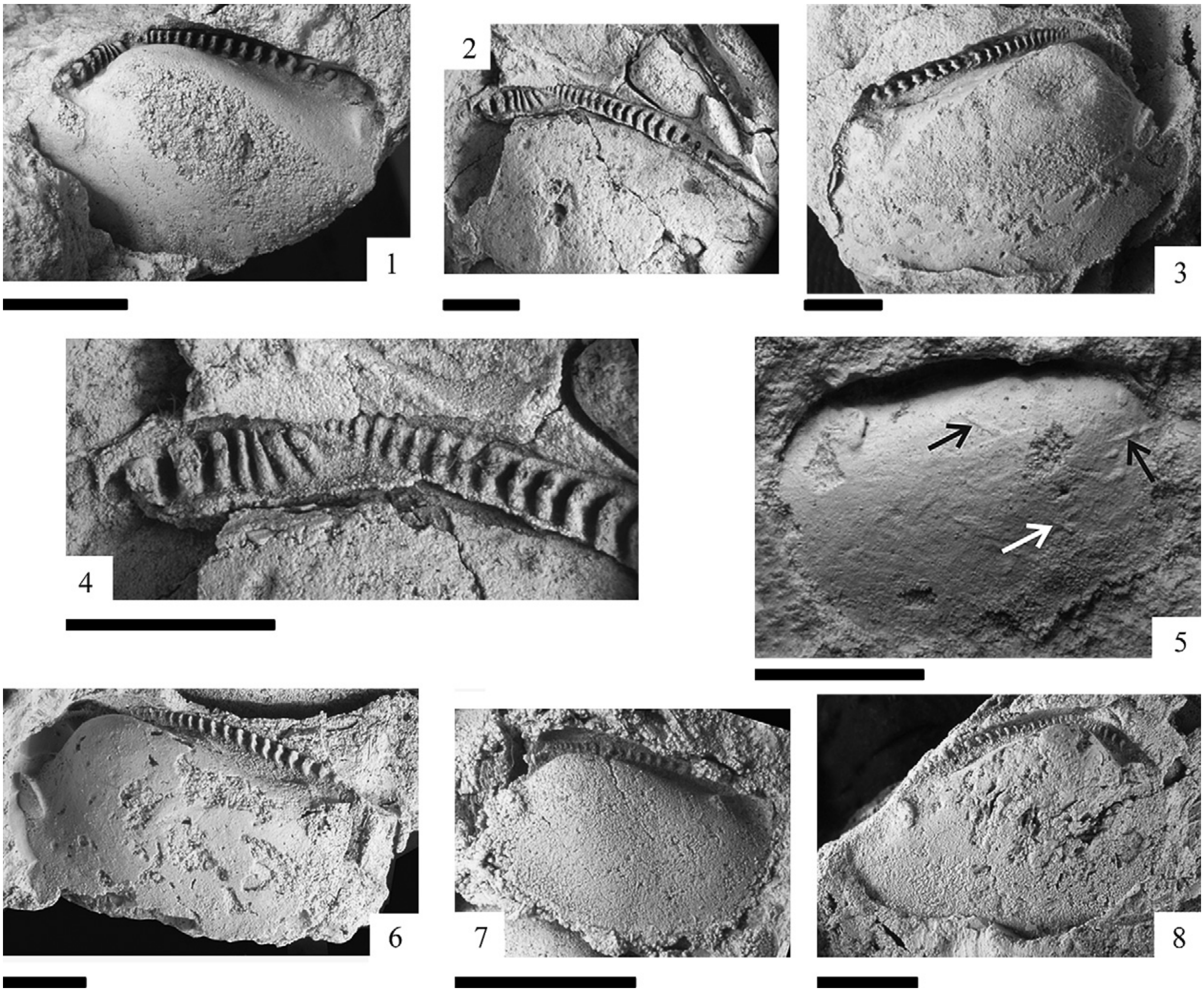

Fig. 4. *Cardiolaria benicioi* nov. sp. 1. Left valve, Holotype, CEGH-UNC24072. 2. Incomplete left valve, CEGH-UNC21078. 3. Right valve, CEGH-UNC24075. 4. Detail of dentition, same specimen of the Fig. 2. 5. Right valve, CEGH-UNC24073. Arrows indicate the traces possibly made by *Vermiforichnus*. 6. Left valve, CEGH-UNC24074. 7. Left valve, CEGH-UNC24076. 8. Right valve, CEGH-UNC24077. Scale bars: 5 mm.

the size and form of the anterior and posterior teeth. Bradshaw (1970) suggested that differences in shell outline cannot be diagnostic for species identification because this feature is the little value in distorted faunas. It is important to note that although the specimens of *C. benicioi* show a chaotic position and are densely packed, shells are not deformed.

5. Additional comments

The specimen CEGH-UNC24073 (Fig. 4, 5) shows some trace fossils preserved as epirelief on the internal mould. Although there are few records of similar trace fossils in the Ordovician, their form and size resemble those formed by annelids whose most common Paleozoic trace is *Vermiforichnus*, Cameron (1969) to which can be tentatively assigned. The traces on the *C. benicioi* specimen are short, almost straight, unbranched epirelief tubules, displayed along the, and parallel to the surface of internal moulds. Because neither external moulds nor shells are preserved there is not evidence of shell borings.

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