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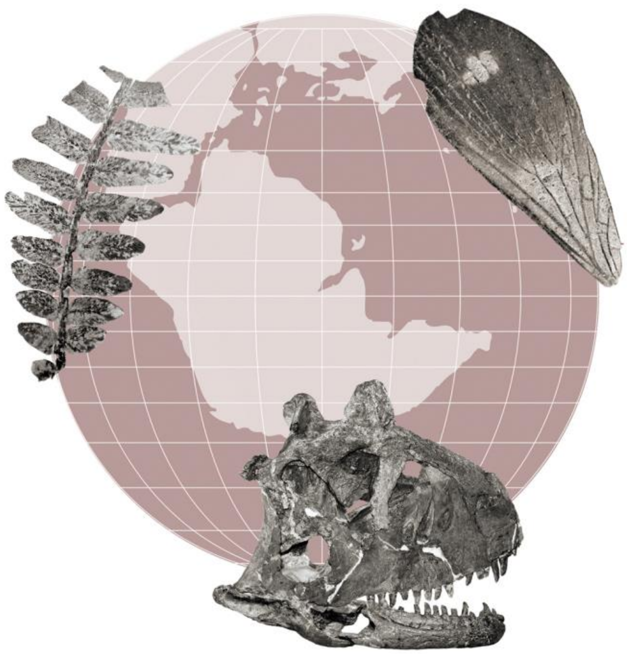



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# LATE ORDOVICIAN SCOLECODONTS FROM THE LA POLA AND DON BRAULIO FORMATIONS, VILLICUM RANGE, ARGENTINE PRECORDILLERA

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Short Description: Two assemblages of scolecodonts from the Upper Ordovician La Pola and Don Braulio formations exhibit diversity linked to geological events

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**Abstract.** Scolecodonts were particularly abundant during the Ordovician, with low extinction rates that experienced a slight increase in the Late Ordovician. In this work, we describe for the first time a Late Ordovician scolecodont fauna from La Pola creek, in the Sierra Villicum of the Eastern Precordillera. This fauna was collected from the upper part of the La Pola Formation and the lower members of the Don Braulio Formation. The recovery methodology included modifications to standard techniques to obtain complete forms without mechanical and/or chemical damage. Two distinctive scolecodont assemblages have been identified: The oldest assemblage, named AssemblageA, located in the La Pola Formation, is characterized by *Xanioprion* sp. 1, *Xanioprion* sp. 2, *Oenonites* aff. *eichwaldi* and *Oenonites* sp. The youngest assemblage, Assemblage B, located in the Fossiliferous Mudstones and Sandstones Member, includes *Andiprion paxtonae*, *Xanioprion* cf. *borealis*, *Kettnerites* sp., and forms of the Ramphoprionidae family.  Both assemblages span the Sandbian, Katian, and Hirnantian sequences. A significant difference in polychaete diversity has been observed between the two assemblages. This difference relates to geological events during the Katian–Hirnantian period, including tectonic activity, sea level changes, glaciation, and the potential for massive extinction (LOME).

**Keywords.** Late Ordovician. Scolecodonts. La Pola Formation. Don Braulio Formation. Villicum Range. Eastern Precordillera.

**Resumen.** ESCOLECODONTOS DEL ORDOVÍCICO TARDÍO DE LAS FORMACIONES LA POLA Y DON BRAULIO, SIERRA DE VILLICUM, PRECORDILLERA ARGENTINA. Los escolecodontos fueron particularmente abundantes durante el Ordovícico, con bajas tasas de extinción que experimentaron un ligero aumento en el Ordovícico Tardío. En este trabajo se describe por primera vez una fauna de escolecodontos del Ordovícico Tardío en la Quebrada La Pola, en la Sierra

Villicum de la Precordillera Oriental. Esta fauna se recolectó de la parte superior de la Formación La Pola y de los miembros inferiores de la Formación Don Braulio. La metodología utilizada para la recuperación incluyó modificaciones a las técnicas estándar, para poder obtener formas completas sin daños mecánicos y/o químicos. Se han identificado dos asociaciones distintivas de escolecodontos. La asociación más antigua, Asociación A, localizada en la Formación la Pola, está caracterizada por las especies *Xanioprion* sp. 1, *Xanioprion* sp. 2, *Oenonites* aff. *eichwaldi* y *Oenonites* sp. La asociación más joven, Asociación B, localizada en el Miembro de Fangolitas y Areniscas Fosilíferas incluye *Andiprion paxtonae*, *Xanioprion* cf. *borealis*, *Kettnerites* sp.y formas de la familia Ramphoprionidae. Ambas asociaciones son atribuidas al Sandbiense-Hirnantiense. Se ha observado una diferencia significativa en la diversidad de poliquetos entre ambas asociaciones. Esta diferencia se relaciona con los eventos geológicos durante el período Katiano-Hirnantiano, incluidos la actividad tectónica, los cambios en el nivel del mar, la glaciación y el potencial de extinción masiva. (LOME).

**Palabras clave.** Ordovícico Tardío. Escolecodontos. Formación La Pola. Formación Don Braulio. Sierra de Villicum. Precordillera Oriental.

SCOLECODONTS are the jaws of polychaete annelids belonging to the Order Eunicida. These have significant potential for stratigraphic application in Paleozoic strata. They are resistant to acids, oxidation, thermal alteration, and recrystallization of the carbonate matrix, just as other palynomorphs are (Jansonius and Craig, 1971). However, our understanding of these groups within the paraphyletic annelids remains limited (Parry *et al*., 2016).

Scolecodonts are particularly abundant in the Ordovician, Silurian, and Devonian periods and can be found globally (Hints, 2000; Hints *et al*., 2004; Hints and Eriksson, 2007; Whittle *et al*., 2008; Harper *et al*., 2020; Hints and Tonarová, 2023). These organisms thrived in shallow marine environments (Harper *et al*., 2020; Hints and Tonarová, 2023). Throughout the Ordovician Period, the extinction rates of polychaetes were low, with a slight increase occurring only in the latest part of the Late Ordovician (Hints and Eriksson, 2007).

The record of scolecodonts is limited in the Argentine Precordillera, with ages spanning the Middle to Late Ordovician (Ottone and Holfeltz, 1992; Eriksson *et al*., 2002; Gómez *et al*., 2024). Notable illustrated findings include a) the Gualcamayo Formation (Darriwillian), located in Potrerillos creek on the western slope of Cerro Perico, northeast of the city of Jáchal (Ottone and Holfeltz, 1992), and b) the San Juan Formation (Middle Ordovician), specifically the Talacasto section (Eriksson *et al*., 2002). Additionally, in northwestern Argentina, scolecodonts have been reported from the lower and upper sections of the Acoite Formation (Arenigian, today Floian) at Los Colorados creek (Tumbaya department) and its lower section at the Rio Cajas (Humahuaca department) by Ottone *et al*. (1992, see also Vergel *et al*. 2002), Cambro-Ordovician strata at the Angosto de Chucalezna (Aceñolaza *et al*., 2003), and the upper levels of the Casa Colorada Formation (Jujuy Province), as well as in Salta Province, the Pascha-Incamayo area (Toro *et al*., 2010) and the transitional interval between Zanjón and Labrado formations, Río Capilla section (Hints *et al*., 2017). No records from Ordovician Bolivia and Brazil were documented.

This paper aims to report, for the first time, scolecodont fauna from the late Katian? and Hirnantian La Pola and Don Braulio formations at La Pola creek in the Villicum Range of the Argentine Precordillera. This record offers new insights into the biostratigraphy of macro- and microfossil associations documented in these units.

**Institutional abbreviations.** Repository *Laboratorio de Palinoestratigrafía y Paleobotánica* (LPP), institutional acronym **CICYTTP-Pl** for palynologic collection (rocks, residues, and slides), and **CICYTTP-M** for SEM specimens. **Anatomical abbreviations. MIR- MIIR,** right maxillae I-II. **MIL- MIIRL,** left maxillae I-II.

## GEOLOGICAL SETTING

The Precordillera is a geological province in western Argentina (Furque and Cuerda, 1979) and divided into three morpho-structural units: Western Precordillera (Baldis *et al*., 1982), Central Precordillera (Baldis and Chebli, 1969) and Eastern Precordillera (Ortiz and Zambrano, 1981), where La Pola creek is located, the object of this study (Fig. 1). In the Villicum range, an Ordovician-Silurian succession from base to top, is referred to the San Juan (Kobayashi, 1937; Furque, 1963), Gualcamayo (Furque, 1963), La Cantera (Baldis *et al*., 1982), La Pola (Astini, 2001a), Don Braulio (Baldis *et al*., 1982) and Rinconada (Amos, 1954) formations. This is the only section where sediments of the La Pola Formation have been recorded, making it the type locality (Astini, 2001a).

The Katian-Hirnantian succession is represented by the La Pola (Sandbian-Katian) and the Don Braulio (Hirnantian-Llandovery) formations directly associated with glacial and postglacial events of the Late Ordovician period (Benedetto, 1986; Peralta and Carter, 1990, 1999; Peralta and Baldis, 1992; Astini, 1993, 2001b; Astini and Buggish, 1993; Buggish and Astini, 1993; Peralta, 1993, 1998; Gómez *et al*., 2023a).

The La Pola Formation consists of various lithofacies, including block paraconglomerates, pebbly mudstones, bioclastic sandy conglomerates, graded or massive lenticular sandstones, thin rhythmites, and tabular silty-sandy mudstones. It is regarded by Astini (2001a) as a relic of the Hirnantian glaciation. The fossil content comprises notably well-preserved autochthonous and allochthonous specimens, including a diverse association of brachiopods, bivalves, gastropods, and trilobite fragments (Benedetto, 2003) and bryozoans (Ernst *et al*., 2022). Graptolites from the *Nemagraptus gracilis-Dicranograptus clingani* Zone (Brussa, 2000), as well as the conodont fauna of the *Amorphognathus tvaerensis* Zone, specifically the *Baltoniodus variabilis* Subzone (Heredia and Milana, 2010), constrain the age of this unit, Sandbian-Katian? (Brussa, 2000; Benedetto, 1998; 2003; Heredia and Milana, 2010). Palynomorphs are being studied to provide an independent age (Gómez *et al*., 2024).

The Don Braulio Formation is associated with the Hirnantian postglacial event (Figs. 2, 3). It has been divided into four members by Peralta (1993) and was deposited during three postglacial transgressive pulses throughout the Hirnantian (Gómez *et al*., 2023a). The Diamictitic Lower Member (first pulse) is a sequence composed of greenish-grey siltstone bearing clasts, conglomerates, channel-fill sandstones, and bioclastic remains. The channels extend laterally for tens of meters, and notably, the typical Hirnantian Fauna has been identified in these deposits (Peralta, 1993). The second pulse is represented by the Fossiliferous Mudstones and Sandstones Member, composed of greenish-grey mudstones and fine-medium grained sandstones, including calcareous lenses and fossiliferous remains of trilobites, brachiopods, graptolites, sponge spicules, bryozoans and gastropods (Levy and Nullo, 1975; Baldis and Blasco, 1975; Benedetto, 1986, 1990; Peralta and Baldis, 1990; Sánchez, 1985; Sánchez *et al*., 1991; Jiménez-Sánchez *et al*., 2014; Beresi and Gómez, 2023; Gómez *et al*., 2023b; Ferrari *et al*., 2024). Sánchez *et al*. (1991) suggest that this member developed on a marine platform with abundant fauna of low diversity.

The Ochre Mudstones represent the third pulse and consist of yellowish monotonous, massive, bioturbated mudstones with numerous tubular or irregular trace fossils that are either vertical or oblique to the stratification. According to Gómez *et al*. (2023b), these deposits have been interpreted as upwelling deposits containing poorly preserved biserial graptolite structures (Peralta and Carter, 1999) and palynomorphs (Gomez *et al*., 2023b, 2024). The Upper Iron Member, characterized by transgressive-regressive pulses, consists of reddish-brown iron-bearing sandstones and oolitic banks, intercalated with massive black to dark grey shales and siltstones (Peralta, 1985; Astini, 1992). This member also contains graptolites (Peralta, 1985) and palynomorphs (Volkheimer *et al*., 1980).

## MATERIAL AND METHODS

Sixteen samples were prepared for palynological analyses in the LPP at the CICYTTP. The productive samples come from the upper part of the La Pola Formation and the lower two members of the Don Braulio Formation (Figs. 2, 3).

The scolecodonts are part of the palynological material obtained using the methodology proposed by Gómez *et al*. (2024), which is modified from the standard laboratory technique employed in the LPP at the CICYTTP, as described by di Pasquo and Silvestri (2014). The process involves taking a sample of 20 to 30 grams, crushed into pieces not smaller than 2 cm to avoid fragmentation of larger palynomorphs. Hydrochloric acid (20%) and hydrofluoric acid (45%) are applied, and then the solution is washed with distilled water until it reaches neutrality. Residues are sieved carefully through 25 μm and 10 μm meshes to remove fine particles. The centrifuge is avoided. The scolecodonts were carefully selected from residues in Petri dishes, which were inspected under a stereomicroscope (Leica EC3) and photographed using a Leica 3 MP video camera. The manual concentration of scolecodonts involved using a fine needle or glass pipette. They were placed in temporary slides with water to be photographed using an optical microscope (Leica DM500), equipped with an Amscope 14 MP video camera and a fluorescence device (LED lamp with a filter block for fluorescein at approximately 450 nm, Leica Macrosystems, Wetzlar, Germany). Then, these specimens were carefully placed onto stubs to be imaged using a Scanning Electron Microscope (SEM), Jenck Phenom ProX (Phenom -World BV, Eindhoven, The Netherlands), under low vacuum, as it does not require metallization, according to di Pasquo and Vilá (2019). Additionally, residue drops were mounted in permanent slides using a mixture of 70% alcohol and Trabasil NR2. According to the corresponding collection, the materials were deposited under acronyms, i.e., CICYTTP-Pl for palynological preparations (Fig. 2) and CICYTTP-M for SEM specimens (indicated in the caption of scolecodonts' figure).

## RESULTS

The polychaete fauna from La Pola creek contains at least 16 scolecodonts attributed to 4 families, 5 genera and 3 species. Mostscolecodont specimens are moderately preserved, brown to black, deformed, flattened, and fragmented. Fewer ones are better preserved in three dimensions, showing original morphology. The degree of deformation and fragmentation depends on various physical, chemical, and biological factors (Eriksson *et al*., 2004). For example, the chemical composition of the scolecodonts and jaw morphology enhanced an easier or more frequent deformation of some taxa. Factors such as water energy, sediment composition, bioturbation, the presence of scavengers, postmortem transportation and burial, and weathering all influence the grade of preservation. Therefore, our laboratory treatment was intended to avoid fracturing the specimens. However, this proved neither easy nor successful, especially when the same specimen was manipulated to be illustrated under optical and SEM microscopes. The terminology is based on Jansonius and Craig (1971), Szaniawski (1996), and Eriksson *et al*. (2004).

## SYSTEMATIC PALEONTOLOGY

Family INCERTAE SEDIS

Genus ***Andiprion*** Hints, Tonarová & Eriksson, 2017

***Andiprion paxtonae*** Hints, Tonarová & Eriksson, 2017

Figure 4.1

**Referred material.** CICYTTP-Pl 2787 and CICYTTP-Pl 2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation, Fossiliferous Mudstones and Sandstones Member. Age: Hirnantian.

**Description.** The MI and dentary were recovered. The specimen measures 150 µm in width and 200 µm in maximum length. The anterolateral margin, extending from anterior to posterior, is convex, with the ramus slightly pointed and directed posteriorly into the jaw. The dentary is prominently bent towards the outer margin. It contains 9–10 denticles, which decrease in size towards the inner part of the dentary. Individual denticles show a slight inclination. Because it is a fragment of the upper part of the dorsal margin of the jaw, the end of the dentary, internal margin, angular ramus, and shank are not visible.

**Comparison.** The jaw fragment is similar to the MIR of the *Andiprion paxtonae* species, specifically in Fig. 2D, E, and I of Hints *et al*. (2017). However, the absence of a complete apparatus prevents a more specific description.

It is similar to the specimen of anterior maxillae MIIR described as Gen et sp. indet. 1 in Hints *et al*. (2015, plate II, 17) but differs in the denticles-ramus relationship, which is less pronounced or less convex than in *Andiprion paxtonae*. This same difference can be observed in the reconstruction of the jaw of *Ramphoprion* and *Kettnerites*, proposed by Hints *et al*. (2017, Figs. 4D and 2E, respectively), and in the dorsal view of the species *Xanioprion walliseri* Szaniawski and Wrona 1973, in Szaniawski (1996, Plate 2.D).

**Occurrence.** This species is recorded from the Dapingian of Argentina, in the upper part of the Zanjón Formation or its transition to the Laja Morada Member of the Labrado Formation in the Río Capillas area (Hints *et al*., 2017).

***Andiprion*** sp.

Figure 4.2

**Referred material.** CICYTTP-Pl 2785 and CICYTTP-Pl 2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation and the Diamictite Lower Member Fossiliferous Mudstones and Sandstones Member. Age: Hirnantian.

**Description.** Two fragments of the MIIL were recovered. The specimen measures 50-70 µm in width, 200-225 µm in maximum length, and 60 µm in depth. It corresponds to a pointed mandible; the ramus and the anterior margin are not observed. The posterolateral margin is straight or slightly inclined towards the anterolateral margin. The dentary has 5 to 6 denticles, with the size of the denticles decreasing toward the posterior margin. The denticles exhibit both erect and slanted forms.

**Comparison.** This form is similar to *Andiprion paxtonae* Hints *et al*. (2017, Fig. 3.D), and *Kalloprion* sp. A Hints (2000, Pl. 2.23, Right MI). However, it differs in the outer and anterior margins due to fragmentation. The genus *Paulinites* exhibits similar MII and MIII morphotypes (Szaniawski, 1996), as well as *Ramphoprion* cf. *deflexus* (Eller, 1942), noted in Hints (2000, Pl. 2.19, M2). Unfortunately, the fragmentation of our specimens hindered a more accurate comparison.

Family PAULINITIDAE Lange, 1947

Genus ***Kettnerites*** Žebera, 1935

***Kettnerites*** sp.

Figure 4. 9-10

**Referred material.** CICYTTP-Pl 2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation, Fossiliferous Mudstones and Sandstones Member. Age: Hirnantian.

**Description.** A fragment of the MIIR measures 240 µm in length and 75 µm in width. It is sharp-pointed toward the posterior margin, and its concave ventral margin. The distance from the base of the dentary to the ventral margin is 65 μm in depth. The dentary is complete and contains between 13 denticles. The upper denticles are the largest, measuring approximately 20 μm; they are erect and inclined toward the center. The lower denticles, located at the posterior margin, are flattened and are roughly half the size of the upper denticles.

**Comparison.** This form is assigned to the genus *Kettnerites*, following the description made by Tonarová *et al*. (2012, Fig. 6, AC), which shares features such as its elliptical shape, the characteristics of the denticles, and the shallow depression that separates the inner margin from the posterior part. However, due to the insufficient material for reconstructing the mandible, it is not possible to identify this specimen at the species level.

It also resembles *Kettnerites kosoviensis* Žebera in Tonarová (2008, Pl. 1, 3), but this specimen has a longer ramus. Other similar forms include Gen et sp. indet. 2 (right MI), described by Hints *et al*. (2015, Pl. 1, 12), which has fewer denticles and a wider ramus. Additionally, *Oenonites* spp., illustrated by Vandenbroucke *et al*. (2013, Fig. 5, G-I), also shares similarities; however, it features more denticles and a sharper depression between the internal and posterior margins.

**Occurrence.** *Kettnerites* spp. were documented in the Ordovician of the Prague Basin in the Czech Republic (Tonarová *et al*., 2023). The occurrence of *Kettnerites* sp. has been widely discussed since its original description, which is known from the Ordovician-Silurian transition (Khanna *et al*., 1985). Its range is extended from the Katian (Hints, 2000; Richmondian, Eriksson, 2003) through the Silurian (Snajdr, 1951; Martin, 1973; Bergman, 1989; Eriksson *et al*., 2004) and into the Devonian (Bharadwaj *et al*., 1973; Tonarová *et al*., 2017), as well as the Permian and Triassic (Zaslavski *et al*., 1992).

Family POLYCHAETASPIDAE Kielan-Jaworowska, 1966

Genus ***Oenonites*** Hinde, 1879

***Oenonites*** sp.

Figure 4.11

**Referred material.** CICYTTP-Pl 2781 and CICYTTP-Pl2787.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** La Pola Formation (upper part). Age: Sandbian-Katian?

Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** Two fragmented right maxillae (Basal Plate) were recovered. The better-preserved mandible measures 130 µm in length and 65 µm in width. The basal plate features a concave anterior margin that leads into a rectilinear cavity (sinus), forming an angle of approximately 35° with the baseline of the denticles. The dentary has six denticles erect with rounded edges. Notably, the first denticle does not resemble a fang. The ramus and posterior margin are fragmented, making it impossible to determine the proper size of the plate. Based on its position, the number of denticles, and the shape of the sinus, it is inferred that the plate does not exceed 200 µm in length.

**Comparison.** The recovered specimens are classified as *Oenonites* sp. C (Hints, 2000) due to morphological similarities, particularly in the anterior margin, dentary, and sinus shape. Other similar species have also been considered. Eriksson (2003) provided reconstruction diagrams of the mandibles of *Oenonites* sp. A. These diagrams included the standard shape of the Basal Plate; however, unlike the studied specimens, *Oenonites* sp. A feature a fang that is significantly larger than the denticles. The distinction between *Oenonites* sp. and the species described by Hints *et al*. (2015; Pl. 1, Fig. 11) lies in the inclination of the denticles.

There is also a resemblance to the Basal Plate of the genus *Labidognath*? (Hints *et al*., 2015; Pl. 1, Fig. 27), but it differs in the width between the basal line of the dentary and the ramus, which is broader in this species. Another comparable form is the MIIR of *Kettnerites kosoviensis* (Tonarová, 2008; Pl. 1, Fig. 3), but this species is notable for having a second denticle larger than the others.

**Occurrence.** *Oenonites* sp. (*Oenonites* sp. C) was reported from the Porkuni stage (Hirnantian) in Estonia (Hints, 2000).

***Oenonites aff. eichwaldi*** Eriksson, 1997

Figure 4.12

**Referred material.** CICYTTP-Pl 2781 and CICYTTP-Pl2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** La Pola Formation (upper part). Age: Sandbian-Katian?

Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** Two specimens have been recovered. A MIR from sample 2781 and a dentary fragment from sample 2788. MRI: The maxilla measures 200 µm in length and 105 µm in width. It has a narrow anterior and posterior margin, a characteristic that prevents the measurement and observation of the ligamentous scar. The ramus was not preserved due to fracturing. The dentary contains approximately 10 denticles. The first denticle is 2.5 times larger than the rest, similar to a cusp. The remaining denticles are broad at the base and have rounded ends toward the posterior margin, forming slanted denticles.

**Comparison.** This form has been assigned to *Oenonites* aff. *eichwaldi*, as described by Hints and Tonarová (2023), due to its numerous morphological similarities, particularly in the shape of the dentary and the anterior margin. It differs from *Oenonites eichwaldi* in that it has a narrower anterior margin. It may also exhibit similarities to right MI *Oenonites* aff. *wyszogrodensis* (Kozłowski, 1956), imaged by Hints and Eriksson (2007) and Hints and Tonarová (2023). However, unlike our specimen, *Oenonites* aff. *wyszogrodensis* does not show such a pronounced curvature between the anterior margin and the first denticle. In contrast to *Oenonites marlenediesae* (Eller, 1942) (right MI, Eriksson, 2003; Hints and Tonarová, 2023) and *Oenonites zappae* Eriksson, 1997 (right MI, Hints and Tonarová, 2023), our specimen has more prominent denticles with a lesser inclination. Consequently, the denticles are closer to the posterior margin, aligned with the maxilla.

**Occurrence.** *Oenonites* aff. *eichwaldi* is part of the Katian-Hirnantian-Rhuddanian succession recorded by Hints and Tonarová (2023) from northern Estonia. Other records are from the Silurian of Sweden (Eriksson, 1997, 2000).

Family RAMPHOPRIONIDAE Kielan-Jaworowska, 1996

Figure 4. 3-8

**Referred material.** CICYTTP-Pl 2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation, Fossiliferous Mudstones and Sandstones Member. Age: Hirnantian.

**Description.** Four possible lateral teeth were recovered. The specimens measure approximately 55 µm in width and 155 µm in length. They exhibit a curve that can sometimes form either a closed or an open angle. The upper part of all the specimens is thin and pointed. One of the teeth has a wider base and features a small opening, measuring 2 µm, near the upper part.

**Comparison.** The examined forms show morphological similarities to the lateral tooth of the Ramphoprionidae family, as illustrated in form A (Text-Fig. 1-A, *Ramphoprion elongatus*) presented by Erickson (2002), as well as to the lateral tooth specimen of *Spitiprion khannai* Tonarová *et al*. (2024, Fig. 3-E). Additionally, they resemble the hook of *Ramphoprion bialatus* Hints, found by Hints (2000). However, these forms have been classified within the first-mentioned group due to their morphological features.

Other similar specimens are the lateral teeth illustrated by Hints and Nolvak (2006) as unidentified scolecodonts (Pl. 1, Figs. 14-15) and a labidognath polychaetaspid (Pl. 1, Fig. 14) in Hints *et al*. (2015). The examined forms exhibit morphological similarities to *Atraktoprion* sp. and the illustrated forms 1 to 3 (Plates 3.13, 15, 16, MI) presented by Hints *et al*. (2015), as well as to the specimen of *Atraktoprion* sp. shown in Szaniawski (1996, Plate 1.1-2).

**Occurrence.** The family Ramphoprionidae shows a wide distribution, ranging from the Middle Ordovician (Kielan-Jaworowska, 1962; Hints, 1998) to the Devonian, with works such as that of Suttner *et al.* (2010).

Family XANIOPRIONIDAE Kielan-Jaworowska, 1966

Genus ***Xanioprion*** Kielan-Jaworowska, 1966

***Xanioprion* cf. *borealis*** Kielan-Jaworowska 1966

Figure 4.13-14

**Referred material.** CICYTTP-Pl 2781 and CICYTTP-Pl2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** La Pola Formation (upper part). Age: Sandbian-Katian?

Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** Two fragments were recovered from the posterior part of the MIR. They are sub-rectangular in shape, measuring approximately 210 µm in length and 55 µm in width. These fragments correspond to the lower part of the MIR, which is why the anterior margin is missing in both specimens. The main ridge and four to five lateral denticles are visible. The dental pits consist of slanted denticles with pointed edges, while the posterior margin is rounded and convex.

**Comparison.** The studied form was assigned *Xanioprion* cf. *borealis*, recorded by Hints and Tonarová (2023), based on its characteristic morphology, including a posterior lower MIR. Additionally, another probably conspecific species is the indeterminate scolecodont illustrated by Aceñolaza *et al*. (2003, Fig. 5.18), which was documented in a lower Ordovician palynomorph assemblage from the Casa Colorada Formation in Quebrada de Moya, Northwest Argentina.

**Occurrence.** The species *Xanioprion* cf. *borealis* is reported for the Katian-Hirnantian-Llandovery succession from northern Estonia (Hints and Tonarová, 2023).

***Xanioprion*** sp. 1

Figure 4.15

**Referred material.** CICYTTP-Pl 2781.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** La Pola Formation (upper part). Age: Sandbian-Katian?

**Description.** Two forms corresponding to the upper part of the MIR were recovered. The best-preserved form measures 200 µm in length and 190 µm in width. This form represents the upper margin of the maxilla. The end of the ramus is not visible because the maxilla has fragmented at the pre-ramal slope. The inner margin is concave with a sharp, closed angle. Four pointed denticles are visible toward the posterior margin.

**Comparison.** Although the specimen is not complete, it differs from *X*. cf. *borealis* in Hints and Tonarová (2023, Fig. 2.D, anterior part of MI) and *X*. *walliseri* in Szaniawski (1996, MII right) from the Devonian of Poland due to its deeper curvature. A similar form is described as *Delosites* sp. in Jansonius and Craig (1971); however, our specimen is broken, making a more accurate designation difficult.

***Xanioprion*** **sp. 2**

Figure 4.16

**Referred material.** CICYTTP-Pl 2781 and CICYTTP-Pl 2788.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** La Pola Formation (upper part). Age: Sandbian-Katian?

Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** Two maxilla fragments were recovered, representing the middle part of an individual MI. Due to the absence of the anterior and posterior margins, it is impossible to determine whether the fragments are from the left or right side. The best-preserved fragment measures 250 µm in length and 80 µm in width. Additionally, a dentary with nine pointed denticles has been observed. The upper denticles are inclined toward the posterior margin, forming inclined denticles. Based on the width of the mandible, 50 µm, and the number of denticles present, it is estimated that the total number of denticles should be approximately 23 to 25.

**Comparison.** The specimen exhibits similarities to *Xanioprion* sp. as described by Hints and Tonarová (2023, Fig. 2.F, MI), as well as to specimens illustrated by Eriksson et al. (2002, Fig. 3.G-H). However, due to the fragmentation of both the anterior and posterior parts of our specimen, a more precise classification is not feasible. Additionally, features resembling those of *Xanioprion viivei* Hints and Nolvak (2006) and Mochtyellidae (Hints and Tonarová, 2023, Fig. 2.G-H, left MI) can be observed. Nonetheless, these specimens differ in shape, particularly in the anterior section, where they are narrower.

**Occurrence.** *Xanioprion* sp. (Hints and Tonarová, 2023) has been reported in the Katian-Rhuddanian palynological association of northern Estonia.

INCERTAE SEDIS

***Indeterminate*** form 1

Figure 4.17

**Referred material.** CICYTTP-Pl 2787.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** A fragmented conical shape measuring 260 µm in length and 95 µm in width was recovered. This specimen features an internal cavity that enables wall measurements: the thickest part measures 25 µm, while the thinnest part measures 15 µm. It features a beveled edge that gradually tapers toward the middle and a sharp, rounded apex.

**Comparison.** Due to its morphology, it could be considered a Lateral tooth, but without the upper part. Another possibility is that this form is regarded as a fragment of Shaft or Carrier, similar to *Pteropelta gladiata* Eisenack, 1939, in Hints and Eriksson (2010, Fig. 1.X-Y) and Szaniawski (1996, Text-Figure C).

***Indeterminate*** form 2

Figure 4.18

**Referred material.** CICYTTP-Pl 2787.

**Geographic occurrence.** La Pola Creek.

**Stratigraphic horizon.** Don Braulio Formation (Fossiliferous Mudstones and Sandstones Member). Age: Hirnantian.

**Description.** The recovered fragment is cone-shaped, measuring 40 µm at its base and tapering to a pointed apex. Its gentle curvature sets it apart from Indet. form 1 and the forms classified under the genus *Atraktoprion*. No beveled edges or denticles are present on the underside.

**Comparison.** This specimen fragment is similar to Escolecodonte sp. A Ottone et al. (1992, Plate I, 8). Another similar form is represented by the hook of an MI of *Skalenoprion* sp. in Hints *et al*. (2006, Pl. II.21).

## DISCUSSION

### Age and stratigraphic distribution of taxa

The Sandbian-Katian-Hirnantian La Pola and Don Braulio formations are interpreted as a relatively continuous shallow-water succession, where tectonic and eustatic factors played an essential role (Peralta, 1993; Astini, 2001a; Benedetto *et al*., 2015).

Interbedded with the palynologic samples (Gómez *et al*., 2023b), *Hirnantian Fauna* (Benedetto, 1986), *Metabolograptus persculptus* (Peralta and Baldis, 1990), and spicules (Beresi and Gómez, 2023) support the age of the Don Braulio Formation (Fig. 3). Additionally, conodonts corresponding to the *Amorphognathus tvaerensis* Zone (Heredia and Milana, 2010; Kaufmann, 2019), brachiopods dating to an Early to Middle Caradoc age (Sandbian-Katian?, Benedetto, 2003) and graptolites from the *Nemagraptus gracilis-Dicranograptus clingani* Zone spanning the middle to upper Sandbian and lower Katian (Brussa, 2000) have been recorded in the La Pola Formation.

Two distinct scolecodont assemblages characterize these units (Fig. 5). Although the units display marked lithological differences, some species, such as *Xanioprion* sp. 2 and *Oenonites* aff. *eichwaldi* are common to both assemblages.

The oldest assemblage, Assemblage A (4 determinate and 4 indeterminate species), is represented by low-diverse scolecodonts with moderate preservation, including *Xanioprion* sp. 1, *Xanioprion* sp. 2, and *Oenonites* aff. *eichwaldi* and *Oenonites* sp. The Katian and Hirnantian previous records of *Oenonites* aff. *eichwaldi* (Hints, 2000; Hints and Tonarová, 2023) may reinforce the Katian age supported by the macrofauna found in the upper part of the La Pola Formation (Brussa, 2000; Benedetto, 2003; Heredia and Milana, 2010; Kaufmann, 2019).

The Assemblage B (12 determinate and 3 indeterminate species), composed of *Andiprion paxtonae*, *Xanioprion* cf. *borealis*, and *Kettnerites* sp. and ramphoprionids exhibits a higher diversity of genera and better-preserved specimens. The genera and species within this assemblage span a wide range, with occurrences dating from the

Middle Ordovician, Katian (Hints *et al*., 2017), to Early Silurian (Snajdr, 1951; Martin, 1973; Khanna *et al*., 1985; Eriksson, 2003; Eriksson *et al*., 2004; Hints and Tonarová, 2023). The Fossiliferous Mudstones and Sandstones Member of the Don Braulio Formation are well-known for their exceptional fossil record. Brachiopods from the Hirnantia Fauna (Benedetto, 1986, 1990), trilobites including the South American species of *Dalmanitina* Reed, and *Eohomalonotus villicunensis* Baldis and Blasco (Baldis and Blasco, 1975), the graptolite *Metabolograptus persculptus* Zone of lower-middle Hirnantian (Peralta and Baldis, 1990), and sponge spicules (Jiménez-Sánchez *et al*., 2014; Beresi and Gómez, 2023) are documented.

The discovery of *Andiprion paxtonae* Hints *et al*. (2017) from the Dapingian (Middle Ordovician) in the Capillas section of the Sierras Subandinas in northwestern Argentina marks a significant milestone in supporting the age of the AssemblageB. Given the older age range established for this species, its presence in the Hirnantian Don Braulio Formation suggests a broader age. *Xanioprion* cf. *borealis* is reported for the Katian-Hirnantian-Llandovery succession of Estonia (Hints and Tonarová, 2023). Therefore, despite being the first record of scolecodonts in this unit, the Hirnantian age of the lower-middle *M. persculptus* Zone supports their age. Moreover, the second transgressive pulse, described by Gómez et al. (2023a) in relation to the Fossiliferous Mudstones and Sandstones Member, indicates that reworking occurred laterally rather than temporally, which is consistent with our interpretation that indigenous species represent Assemblage B.

It is worth noting that a distinct turnover of polychaete fauna is observed between the two assemblages. This turnover may be attributed to various geological, mechanical, biological, and climatic events, including: a) tectonic activity that dominated during the Katian period (Astini, 1992); b) changes in sea level associated with the first and second transgressive pulses during the Hirnantian (Gómez *et al*., 2023a); c) a mass extinction event linked to paleoclimatic changes during the transition from the Katian to the Hirnantian, known as LOME1 (Melchin *et al*., 2013; Jones *et al*., 2017; Kozik *et al*., 2022; Gómez *et al*., 2023a; Sial *et al*., 2024); and d) local climatic fluctuations. However, a more comprehensive study that includes additional palynomorph and chemostratigraphic investigations is necessary to better understand the factors involved in the environment of the two units, as well as the gap and the nature of the contact between them (Figs. 2-5).

**Paleobiogeographic distribution of the documented taxa**

The presence of scolecodonts in palynomorph assemblage is barely common globally (Hints and Eriksson, 2007), which helps us better understand the temporal extent and spatial distribution of polychaethids during the Upper Ordovician. Therefore, we agree with Eriksson *et al*. (2004), who highlighted that continued taxonomic analyses, including studies of type collections and integration of historical single-element-based taxa, are crucial. Once the temporal and spatial distribution and the degree of facies dependence are known for all taxa, a scolecodont biozonation can be established, thereby avoiding ecological or reworked overprint bias. We expect that scolecodont diversity patterns can not only be correlated with the well-constrained, high-resolution conodont biostratigraphic framework in Precordillera and elsewhere in Argentina but also be tied to a sequence- and event-stratigraphic framework that is under development. Hints and Eriksson (2007) provide a detailed comparison of scolecodont fauna across various regions, including Laurentia, Baltica, Gondwana, and post-Gondwana terrains, such as Argentina, to explore their diversification and paleobiogeographic patterns. Hints and Eriksson (2007) also highlight that the presence of scolecodonts in the Argentine Precordillera, currently limited to those of Ottone *et al*.

(1992) for the Gualcamayo Formation and Eriksson *et al*. (2002) for the San Juan Formation, provoked controversy and differing opinions regarding whether the fauna is derived from Laurentia or is part of Gondwana.

AssemblageA and B exhibit some similarities with the faunas found in northwestern Argentina (Aceñolaza *et al*., 2003; Hints *et al*., 2017), where *Andiprion paxtonae* and *Xanioprion* cf. *borealis* are shared (Fig. 5).

At a global level, Assemblage A has a strong connection with Anticosti Island in eastern Canada (Hints *et al*., 2015), Estonia (Hints, 2000; Hints and Tonarová, 2023), and central Saudi Arabia (Hints *et al*., 2015). This connection is particularly highlighted by species such as *Kettnerites* sp., *Xanioprion* cf. *borealis*, *Oenonites* sp., and ramphoprionidsin these regions. Assemblage B has a close relationship with Estonia (Hints, 2000; Hints and Tonarová, 2023), primarily based on the records of *Xanioprion* sp. 2, *Oenonites* sp., and *Oenonites* aff. *eichwaldi*. Since the genera *Oenonites*, and *Kettnerites* are cosmopolitan and very abundant in Laurentia, Baltica, and Gondwana (Hints and Ericksson, 2007; Hints *et al*., 2015), a specific designation of their provenance cannot be made.

## CONCLUSIONS

A Late Ordovician scolecodont fauna is described for the first time from the La Pola and Don Braulio formations.

Two scolecodont assemblages have been identified:

- Assemblage A is characterized by the species *Xanioprion* sp. 1, *Xanioprion* sp. 2, *Oenonites* aff. *eichwaldi,* and *Oenonites* sp. This assemblage has been assigned to the Sandbian-Katian sequence.

- Assemblage B includes *Andiprion paxtonae*, *Xanioprion* cf. *borealis*, *Kettnerites* sp. and ramphoprionids. This group is recognized as part of a more diverse fauna from the Early to Middle Hirnantian.

A notable difference in the recovery of polychaete diversity has been observed between the two assemblages, related to geological events such as tectonic activity, sea level changes, glacial events, and mass extinctions (e.g., LOME1) across the Katian-Hirnantian.

This study, which is still preliminary, encourages us to continue looking for well-preserved specimens to identify species with accurate stratigraphic ranges and paleogeographic affinities and to determine the origin of the polychaete fauna of Precordillera Argentina.

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**Figure captions**

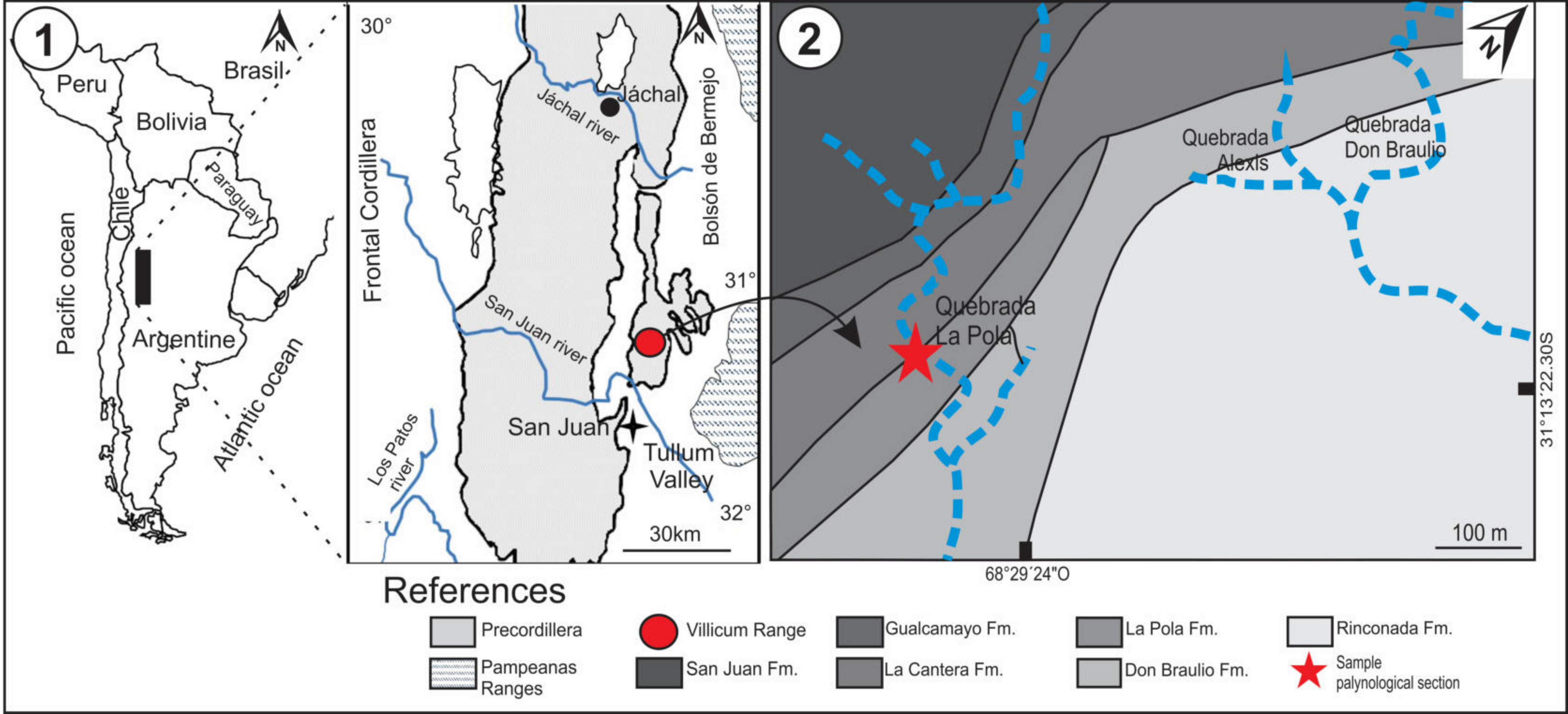
**Figure 1. 1,** Location of the study area. A. Map of the Argentine Precordillera showing the Villicum Range as the study location (Modified from Baldis et al., 1982, Gómez et al., 2024). **2,** Geological map of the Villicum Range indicating the coordinates of La Pola creek, where the Sandbian-Katian-Hirnantian succession under study is located.

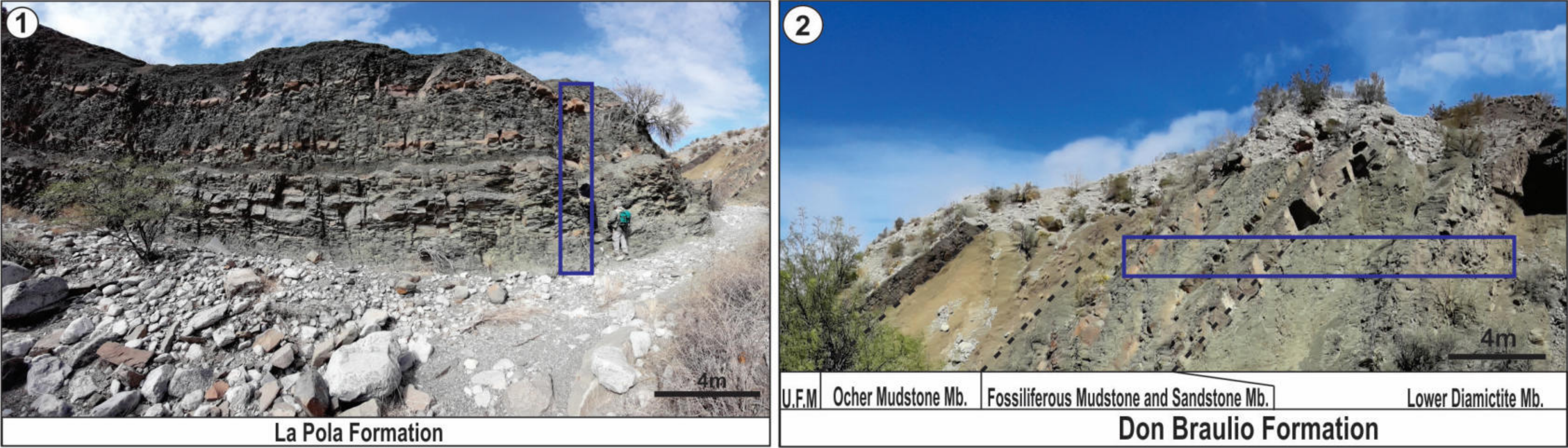
**Figure 2.** Panoramic photograph of the sampling area in the upper part of the La Pola Formation. (**1**) and of the Don Braulio Formation (**2**) indicating the sampling area. Mb, Member. U.F.M., Upper Ferriferous Member**.**

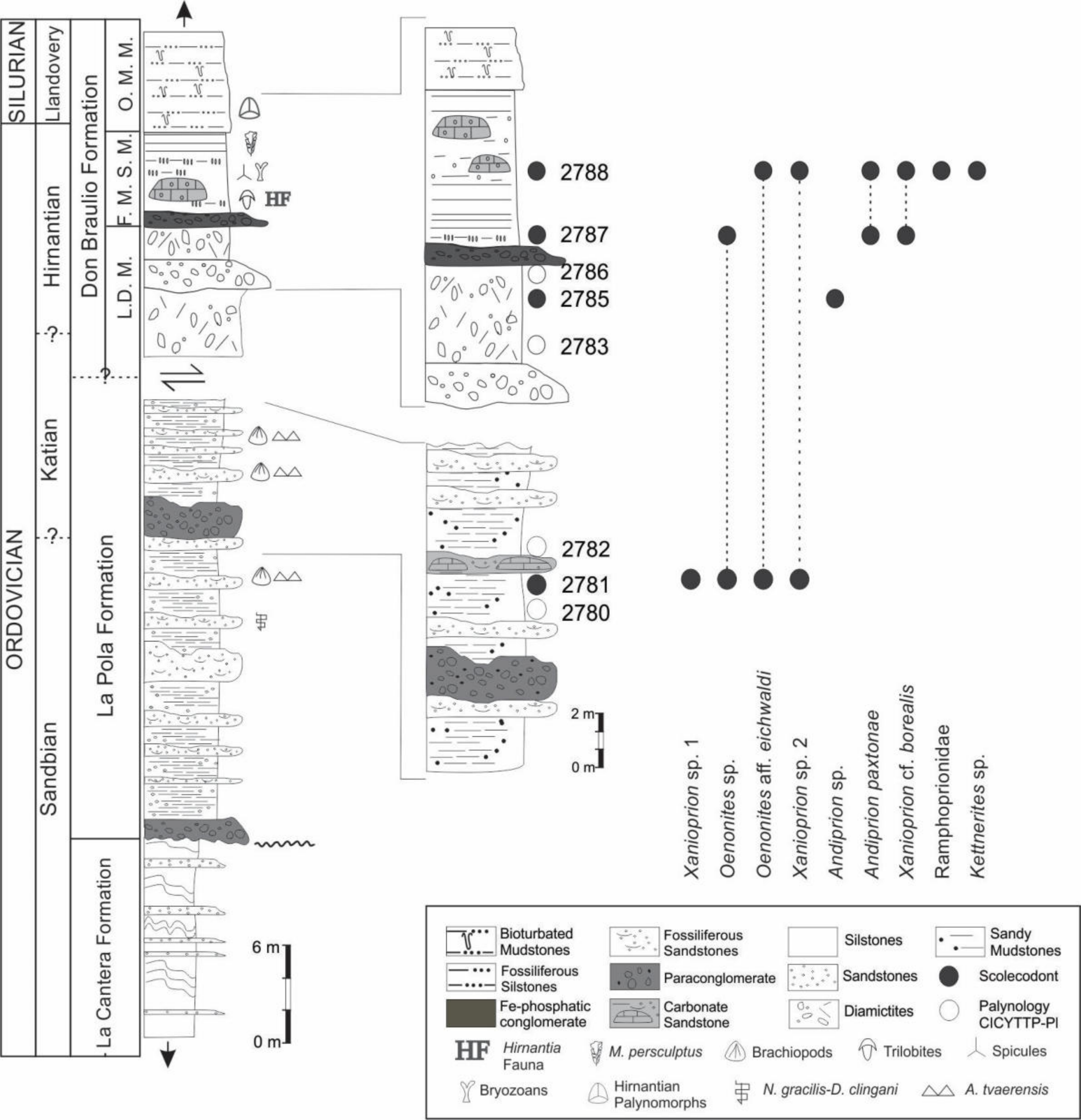
**Figure 3.** Stratigraphy of the sampled section and distribution of scolecodonts in the Sandbian-Katian-Hirnantian succession in the Villicum Range. The sample number indicated corresponds to the acronym of the palynologic collection (CICYTTP-Pl). Abbreviations: D.L.M, Diamictite Lower Member; F.M.S.M, Fossiliferous Mudstones and Sandstones Member; O.M.M, Ochre Mudstones Member.

**Figure 4.** Selected latest Katian and Hirnantian scolecodonts from the La Pola and Don Braulio formations, La Pola creek, Villicum Range. **1,** *Andiprion paxtonae*, MIR, CICYTTP-Pl 2788; **2,** *Andiprion* sp., MIIL, CICYTTP-Pl 2785; **3-8** ramphoprionids, lateral tooth, CICYTTP-Pl 2788, **4,** SEM image, CICYTTP-M553, **6,** SEM image, CICYTTP-M554, **8,** SEM image, CICYTTP-M555; **9 and 10,** *Kettnerites* sp., MIIR, CICYTTP-Pl 2788, **10,** SEM image, CICYTTP-M556; **11**, *Oenonites* sp., Basal Plate, CICYTTP-Pl 2781; **12,** *Oenonites* aff. *eichwaldi*, MIR, CICYTTP-Pl 2781; **13 and 14,** *Xanioprion* cf. *borealis*, MIR, CICYTTP-Pl 2787-2788; **15,** *Xanioprion* sp. 1, MIR, CICYTTP-Pl 2781; **16,** *Xanioprion* sp. 2, MI, CICYTTP-Pl 2781; **17,** Indet. form 1, SEM image, Shaft, CICYTTP-M557, CICYTTP-Pl 2787; **18,** Indet. form 2, CICYTTP-Pl 2787. 1, 9, and 15 are stereomicroscope pictures. Scale bars equal 100 μm. Abbreviations: **MIR-MIIR,** right maxillae I-II; **MIL-MIIL,** left maxillae I-II.

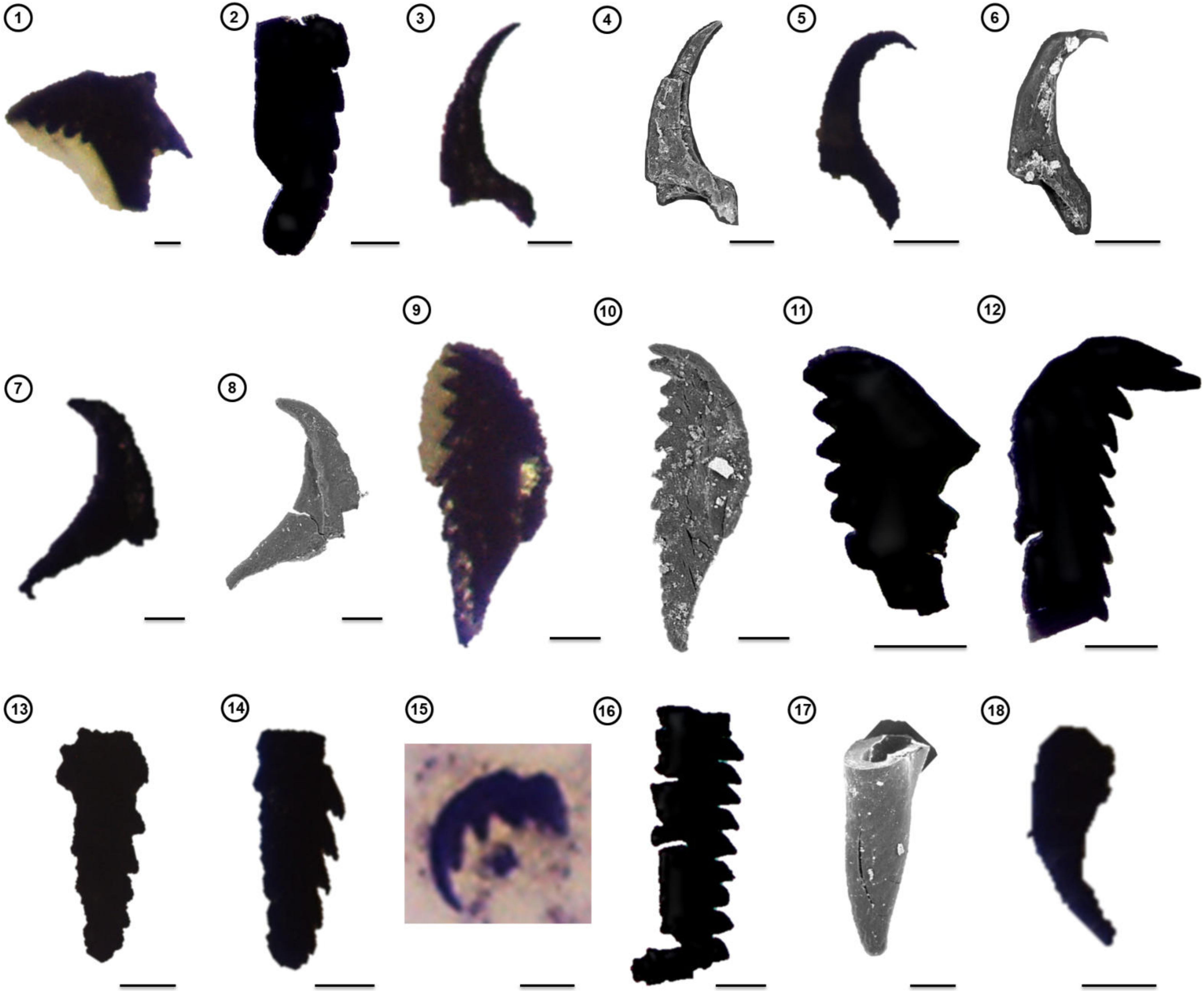
**Figure 5.** An overview of the taxonomic diversity in polychaetids within the two associations, highlighted in green (Assemblages A) and red (Assemblage B), along with the stratigraphic ranges of species. The gray area indicates a lack of information, primarily due to the absence of a rock interval.


1
N
Peru
Brasil
Bolivia
Paraguay
Chile
Pacific ocean
Argentine
Atlantic ocean
30°
N
Jáchal
Jáchal river
Frontal Cordillera
Bolsón de Bermejo
31°
San Juan river
San Juan
Tullum Valley
Los Patos river
32°
30km
2
Quebrada Alexis
Quebrada Don Braulio
Quebrada La Pola
31°13´22.30S
100 m
68°29´24"O
References
Precordillera
Pampeanas Ranges
Villicum Range
San Juan Fm.
Gualcamayo Fm.
La Cantera Fm.
La Pola Fm.
Don Braulio Fm.
Rinconada Fm.
Sample palynological section


1
4m
La Pola Formation
2
4m
U.F.M
Ocher Mudstone Mb.
Fossiliferous Mudstone and Sandstone Mb.
Lower Diamictite Mb.
Don Braulio Formation



SILURIAN
Llandovery
ORDOVICIAN
Hirnantian
Katian
Sandbian
Don Braulio Formation
La Pola Formation
La Cantera Formation
O. M. M.
F. M. S. M.
L.D. M.
HF
6 m
0 m
2 m
0 m
2788
2787
2786
2785
2783
2782
2781
2780
Xanioprion sp. 1
Oenonites sp.
Oenonites aff. eichwaldi
Xanioprion sp. 2
Andiprion sp.
Andiprion paxtonae
Xanioprion cf. borealis
Ramphoprionidae
Kettnerites sp.
Bioturbated Mudstones
Fossiliferous Silstones
Fe-phosphatic conglomerate
Fossiliferous Sandstones
Paraconglomerate
Carbonate Sandstone
Silstones
Sandstones
Diamictites
Sandy Mudstones
Scolecodont
Palynology CICYTTP-PI
Hirnantia Fauna
M. persculptus
Brachiopods
Trilobites
Spicules
Bryozoans
Hirnantian Palynomorphs
N. gracilis-D. clingani
A. tvaerensis


1
2
3
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5
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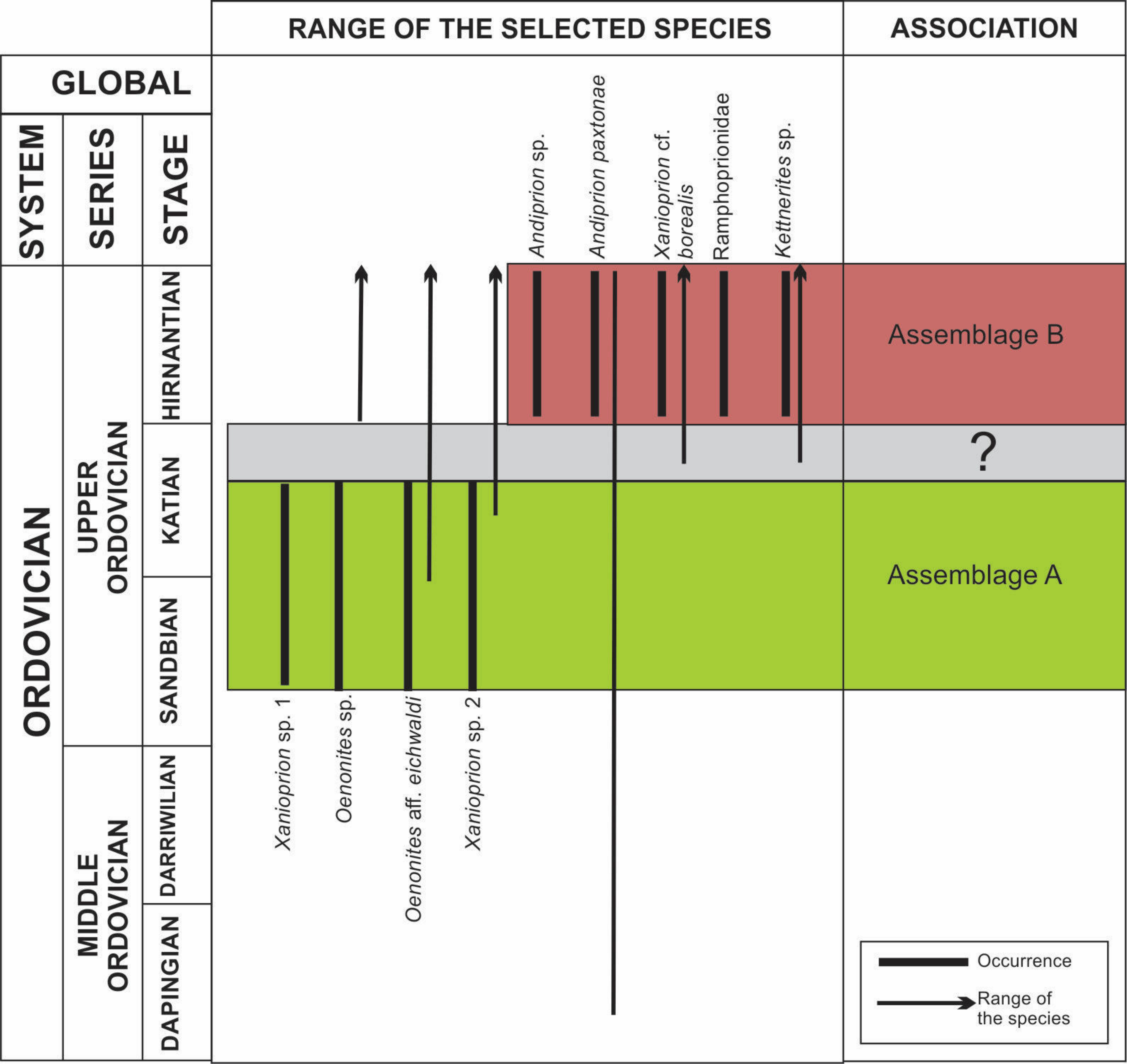
RANGE OF THE SELECTED SPECIES
ASSOCIATION
GLOBAL
SYSTEM
SERIES
STAGE
ORDOVICIAN
UPPER ORDOVICIAN
MIDDLE ORDOVICIAN
HIRNANTIAN
KATIAN
SANDBIAN
DARRIWILIAN
DAPINGIAN
Andiprion sp.
Andiprion paxtonae
Xanioprion cf. borealis
Ramphoprionidae
Kettnerites sp.
Xanioprion sp. 1
Oenonites sp.
Oenonites aff. eichwaldi
Xanioprion sp. 2
Assemblage B
?
Assemblage A
Occurrence
Range of the species