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Tremadocian and Floian (Ordovician) linguliformean brachiopods from the Stavelot–Venn Massif (Avalonia; Belgium and Germany)

YVES CANDELA

Department of Natural Sciences, National Museums Scotland, Chambers Street, Edinburgh EH1 1JF, United Kingdom; ***corresponding author****: y.candela@nms.ac.uk.*

BERNARD MOTTEQUIN

D.O. Terre et Histoire de la Vie, Institut royal des Sciences naturelles de Belgique, rue Vautier 29, B 1000 Brussels, Belgium; bmottequin@naturalsciences.be.

ABSTRACT

Lower Ordovician linguliformean brachiopods from the Stavelot–Venn Massif (Belgium and Germany) are described systematically for the first time. The material comprises specimens from the Jalhay (Solwaster Member) and Ottré (Les Plattes Member) formations of Tremadocian and Floian ages, respectively. The Solwaster Member yielded a relatively diverse assemblage of nine species of lingulide (e.g. *Lingulella lata*, *Lithobolus* sp., *Broeggeria* sp.) and acrotretide (*Acrotreta*? sp.) whereas only one siphonotretide species (*Celdobolus* sp.) is recognised from the base of the Les Plattes Member where it is associated with conodonts of the *Paroistodus proteus* Zone. The assemblage from the Solwaster Member, although not abundant, is much more diverse than that of the contemporaneous Chevlipont Formation in the Brabant Massif (Thyle Valley, Belgium). Some of the taxa identified in the Stavelot–Venn Massif represent some of the youngest occurrences and first occurrences documented in Avalonia.

KEYWORDS

Ordovician,
brachiopods,
Lingulida,
Acrotretida,
Siphonotretida,
Belgium,
Germany

Article history

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1. Introduction

The Lower Palaeozoic Stavelot–Venn Massif (or Inlier), which covers more than 1000 km^2 and extends on both sides of the border separating Belgium and Germany, is the second largest among the five Belgian Caledonian massifs (or inliers) (Figs 1-2). It was part of Avalonia during the early Palaeozoic (e.g. Cocks & Fortey, 2009; Herbosch et al., 2020). Fossils are extremely scarce in over 2.5 km-thick monotonous siliciclastic rocks (Cambrian–Middle Ordovician), except for the Cambrian ichnofossil *Oldhamia* (e.g. Herbosch & Verniers, 2011) and Tremadocian graptolites (e.g. Wang & Servais, 2015). These dendroid graptolites were the first fossils to be recognised (d'Omalius d'Halloy, 1828; Davreux, 1833; Dumont, 1847) and were subsequently discussed and/or illustrated by Malaise (1874a, 1874b, 1881). Nevertheless, most of the fossil reports (e.g. orthoconic cephalopods and trilobites) are still questionable due to the lack of illustration (e.g. Davreux, 1833; Crépin, 1873; Mourlon, 1873; Dewalque, 1874; Malaise, 1866, 1876, 1881; Forir, 1897).

Outside the Stavelot–Venn Massif, Cambrian–Tremadocian faunas are likewise extremely scarce in the other Caledonian massifs from Belgium and northern France (Fig. 1). The large-sized bivalves reported by Malaise (1910) and described by Fraipont (1910) from the middle Cambrian of the French part of the Rocroi Massif, were re-interpreted as pseudonodules by Babin (1994). Trilobites occur within the Tremadocian Chevlipont Formation of the Brabant Massif (Figs 1, 3) as indicated by Lecompte (1948), but need to be investigated. Up to now, linguliformean brachiopods are the only shelly faunas positively recognised in the Cambrian–Tremadocian succession of southern Belgium, more precisely in the Brabant and the Stavelot–Venn massifs (e.g. Charles, 1925; Roncart, 1925; Geukens, 1954, 1956, 1963; Schmidt & Geukens, 1959; Graulich, 1963; Geukens in Bulman, 1970; Vanguestaine & Rushton, 1979; Candela et al., 2021). Similar brachiopods were also recorded in the Tremadocian of the German part of the Stavelot–Venn Massif (Schmidt, 1954, 1956; Schmidt & Geukens, 1959; Geukens, 1957, 1963).

This paper is the first taxonomical study of the linguliformean brachiopods from the Tremadocian–Floian succession of the Stavelot–Venn Massif.

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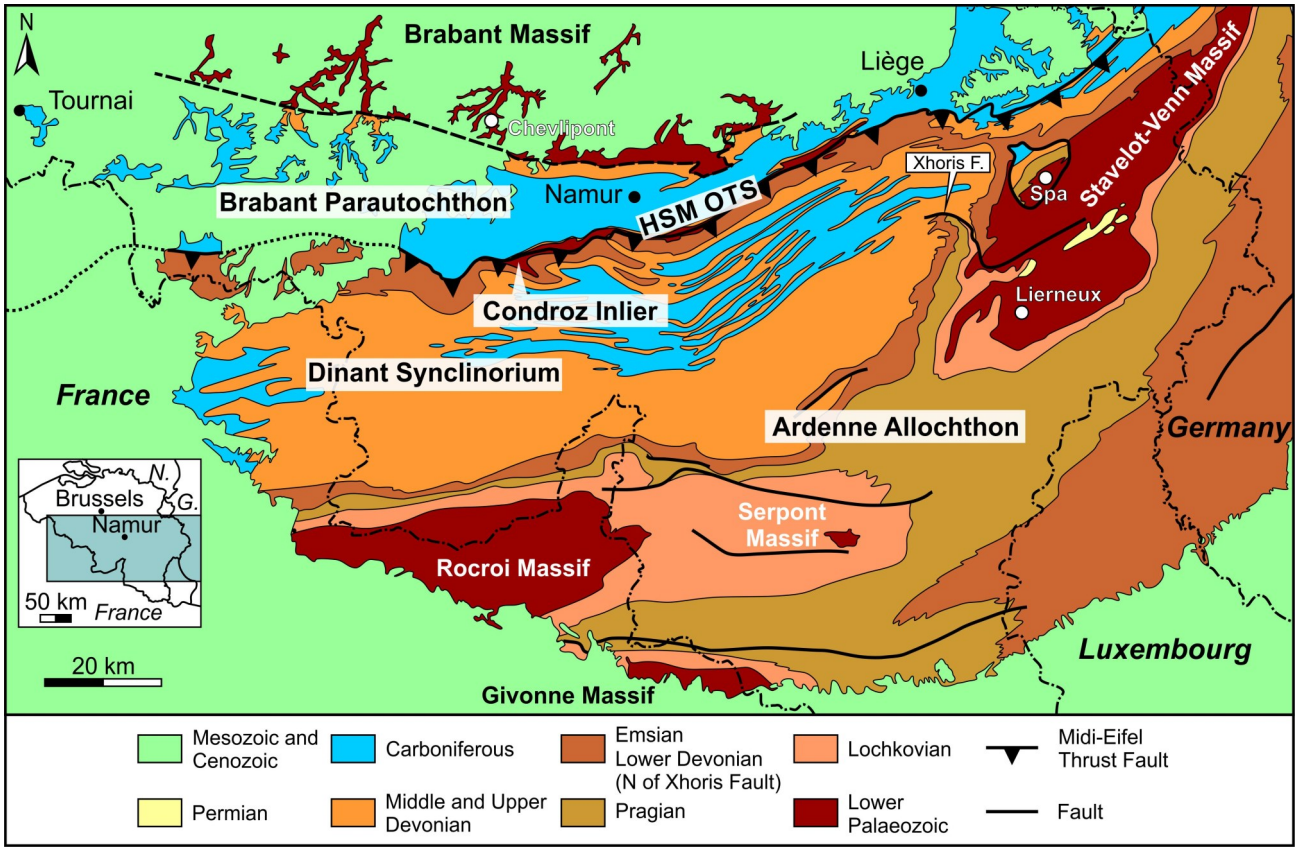

Figure 1. Location and schematic geological map of southern Belgium and adjacent countries (modified from de Béthune, 1954 and Mottequin, 2021). Abbreviations: F., fault; G., Germany; HSM OTS, Haine–Sambre–Meuse Overturned Thrust sheets (Belanger et al., 2012); N., the Netherlands.

2. Geological setting

2.1. General comments

The reader is referred to Geukens (1965, 1986, 1999) and Verniers et al. (2002) for the detailed description of the lithostratigraphy of the Stavelot–Venn Massif (Figs 1-2).

The Tremadocian material studied herein occurs in the Jalhay Formation (c. 400 m thick; base of the Salm Group) (Fig. 3), more precisely from its lower member known as the Solwaster Member (up to 150 m in thickness). It consists of dark green-blue silty slates (known as 'quartzophyllades' in the Belgian literature), black or green-blue slates, with at the base sandstone beds containing black shale fragments (Geukens, 1999; Verniers et al., 2002). The Jalhay Formation lies on the essentially black-coloured slates and silty slates ('quartzophyllades') of the upper Cambrian La Gleize Formation. According to Lamens (1985) and Lamens & Geukens (1985), the sedimentary succession that corresponds to the Jalhay Formation represents a transition from turbiditic to shallow-water sedimentation. They considered the Solwaster Member, including graptolitic mudstones and low-density turbidites, to be a relatively deep basin–plain association.

The youngest material is from the Ottré Formation (c. 150 m thick; Figs 3–4) that essentially consists of Fe- and Mn-rich red to purple pelitic rocks (e.g. Herbosch et al., 2016), and more particularly from the most basal part of the middle member of this lithostratigraphic unit, namely the Les Plattes Member, above the silty slates ('quartzophyllades') of the Meuville Member, with c. 3.5 m of an alternation of 0.1–0.2 m-thick coarse-grained siliciclastic beds (greywackes) with red shales and siltstones (Lamens, 1985; Lamens et al., 1986). Besides bioclasts (e.g. rare brachiopods and conodonts), the greywackes consist of quartz grains, rhodochrosite, hematite, phosphate and volcanic rock fragments in a hematite-rich matrix (Berger, 1965). The conodonts, studied by Vanguestaine et al. (2004), belong to the *Paroistodus proteus* Zone and, according to Herbosch et al. (2016, 2020, 2021), an early Floian age is likely for these fossiliferous beds. The rest of the Ottré Formation is locally characterised by the occurrence of coticule layers, this term designating a fine-grained metasedimentary yellowish rock mostly composed of quartz, garnet (spessartine) and mica (e.g. Lamens, 1985; Lamens et al., 1986; Herbosch et al., 2016). According to Herbosch et al. (2016), the coticule layers correspond to limy mud turbidites deposited in a deep oceanic basin.

2.1.1. Tremadocian localities

Several Belgian sections (Fig. 2) yielded the material investigated in Candela et al. (2021) and herein, but most of the specimens are only from two localities (Solwaster (Gospinal) and Targnon) and were collected by M. Vanguestaine. Two German outcrops yielded a very limited material from the NE extremity of the massif (Fig. 2) and were recovered by W. Schmidt and F. Geukens in the 1950s.

Grosshau (Großhau). One single specimen was collected by Schmidt (1956) in the disused Elise roof slate quarry, located west of the German village of Grosshau (see also Boscheinen, 1983).

Lake Gileppe. Roncart (1925) reported the presence of a lingulide that was subsequently identified by Maillieux (1926) as *Lingulella insons* Barrande var. *lata* Koliha (see Candela et al., 2021) in the section described by Dewalque (1881a) that exposes the Solwaster Member along the path situated on the right bank of the lake (Laloux et al., 1996), east of the dam. Geukens (1956) also mentioned the discovery of supplementary

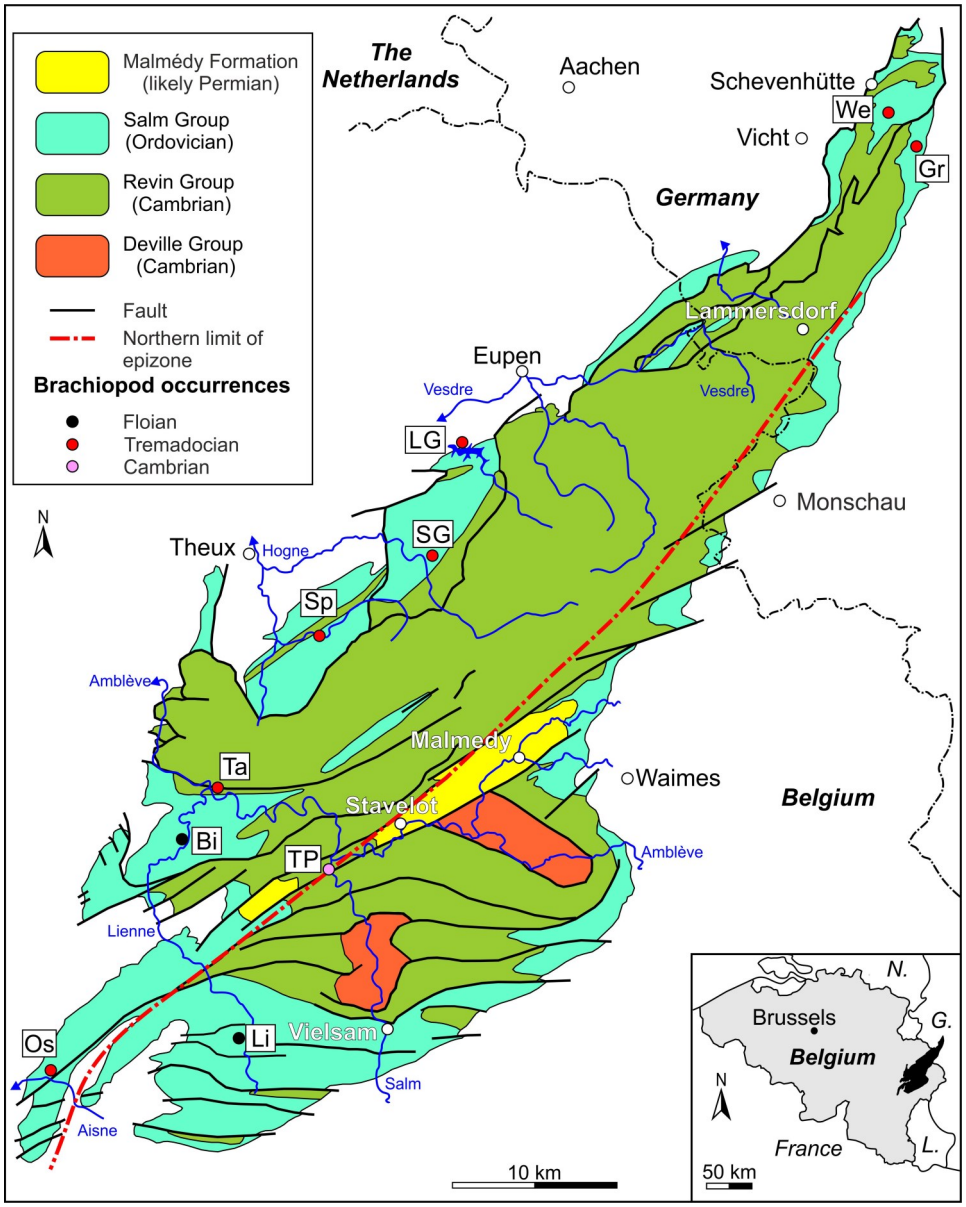

Figure 2. Geological map of the Stavelot–Venn Massif simplified from Geukens (1986, 1999) and Herbosch et al. (2020) with indication of the fossiliferous localities cited in text. Abbreviations: Bi, Bierleux; G., Germany; Gr, Grosshau (Groβhau); L., Luxembourg; LG, Lake Gileppe; Li, Lierneux; N., the Netherlands; Os, Oster; SG, Solwaster (Gospinal); Sp, Spa; Ta, Targnon 1 and 2; TP, Trois-Ponts; We, Rother Wehebach.

brachiopods in this area and Schmidt & Geukens (1959) reported a dorsal valve of *Acrotreta*. However, these specimens have not been traced (R. Speijer, pers. com., May 2021).

Oster. Geukens (1963) reported '*Obolus* (*Bröggeria*) *salteri* (Holl)' associated with '*Dictyonema flabelliforme sociale* (Salter)' as well as other unidentified organisms in the former tramway trench to the south of the village (see also Anten, 1926). The material has not been examined and the section is in poor condition.

Spa (route de Sart). This section, where A. Renier collected the largest Belgian specimen of *Broeggeria* known to-date (Candela et al., 2021, fig. 6.1), most probably corresponds to the long outcrop located along the N629 road, NE of Spa (Dewalque, 1881b; Graulich, 1949).

Solwaster (Gospinal). Graulich (1963) and Geukens (in Bulman, 1970) described this section located along the Sawe river, near the road linking the village of Solwaster to the Gospinal forest house (formerly Gospinal Farm; Renier, 1932). Graulich (1963) noted the presence of the genera *Lingulella* and *Obolus* and added that the material was entrusted to specialists for a detailed study, but no publication has resulted. The outcrop located along the road was briefly described by Renier (1932), Graulich (1949), and Geukens (1950).

Targnon. Charles (1925) reported brachiopods from the rocky spur situated south of the confluence between the Amblève and the Lienne rivers, NW of Targnon (= Targnon 1). These specimens reported as untraced by Candela et al. (2021) have since been recovered in the palaeontological collections of the Université de Liège. A second outcrop located near the bridge on the Amblève, along the road to Rahier (= Targnon 2) was formerly sampled by M. Vanguestaine and yielded some brachiopods.

Rother Wehebach. Two specimens were recovered by Schmidt & Geukens (1959) in the rubble of the trench dug on the eastern flank of the Rother Wehebach in Germany, during the Battle of Hurtgenwald (1944), which took place during World War II.

2.1.2. Floian localities

Bierleux. Few brachiopods were recovered from the greywackes occurring within the most basal part of the Les Plattes Member exposed in two disused quarries in which manganese ore was mined; the fossiliferous beds are located a few decimetres below the ore horizon (Vanguestaine et al., 2004). The quarries are situated on both flanks of the Lienne syncline (also known as

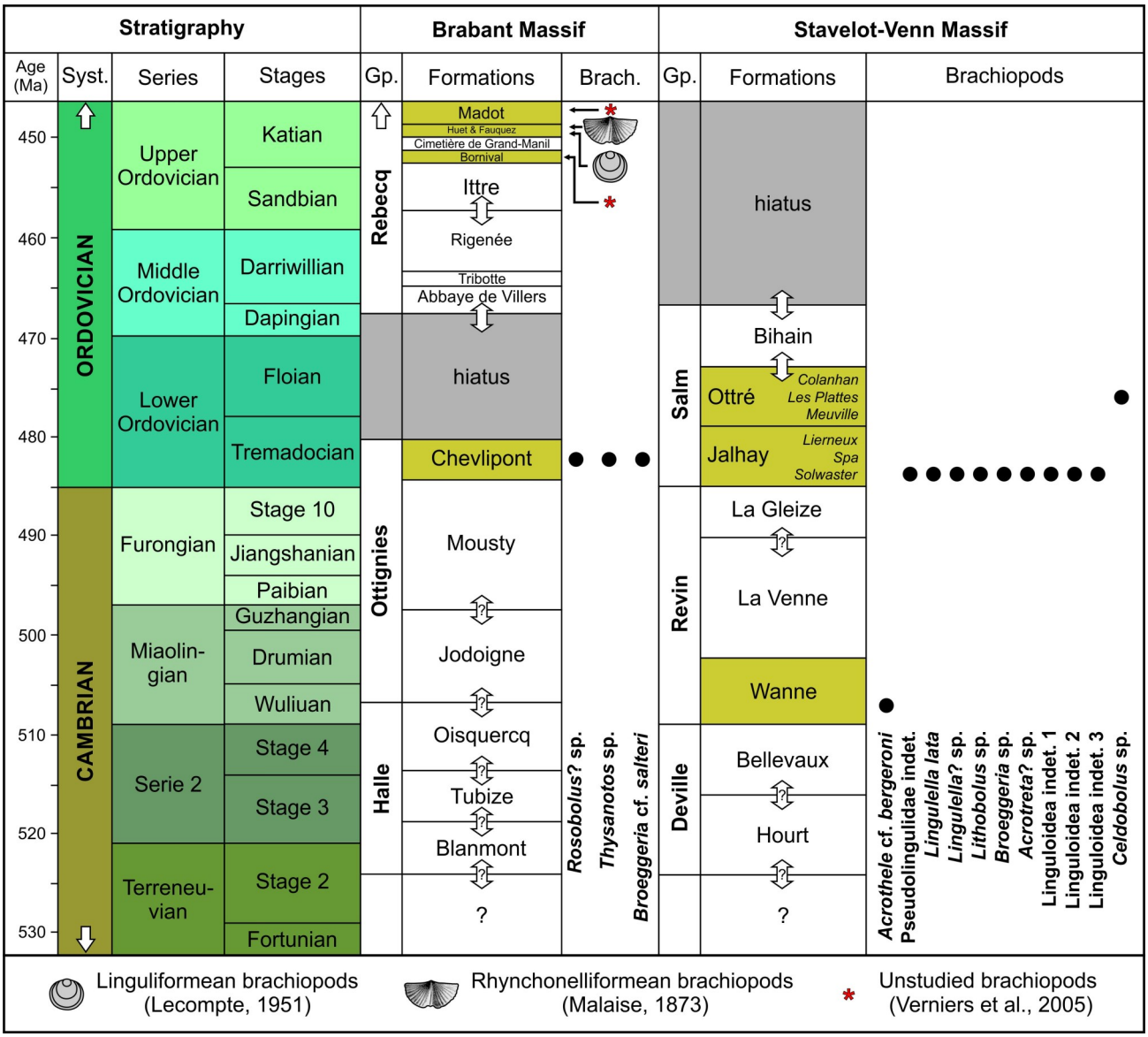

Figure 3. Chronostratigraphy and lithostratigraphy of the Brabant and Stavelot–Venn massifs (modified from Herbosch et al., 2020) with the distribution of the linguliformean brachiopods (modified from Candela et al., 2021). The double arrows indicate boundaries between formations of uncertain age. Abbreviations: Brach., brachiopods; Gp., Groups; Syst., Systems.

Chevron syncline), in the Lienne valley (Fig. 2). Lhoest (1935) reported the discovery of a single specimen identified as '*Lingulella* cf. *insons*' (identified by E. Maillieux) within the rubble of these excavations, but it was not traced in the collections of the Université de Liège.

Lierneux (?). Malaise's (1878a, b) reports of poorly preserved, but relatively abundant '*Lingula*' in the 'phyllades salmiens manganésifères' (Ottré Formation) from the Lierneux area, are possibly related to the material investigated herein from the Les Plattes Member. His specimens, which have not been traced, were submitted to Thomas Davidson (the doyen of 19th Century brachiopod researchers) for identification, who noted that the Cambrian *Lingulella primaeva* Hicks in Harkness & Hicks, 1871 displays somewhat the same outline. Of course, the absence of this material precludes further discussion.

2.2. Stratigraphic summary

The geographic and stratigraphic distributions of the Tremadocian and Floian brachiopods species across the Stavelot–Venn Massif are presented in Table 1 and Figure 3. The latter figure also presents Candela et al.'s (2021) data related to the Tremadocian Chevlipont Formation from the Brabant Massif.

3. Material and methods

The bulk of the studied material is part of the palaeontological collections of the Université de Liège (prefixed PA.ULg). Specimens from the Royal Belgian Institute of Natural Sciences (Brussels; prefixed RBINS) and the Geologischer Dienst Nordrhein-Westfalen (Krefeld; prefixed GD NRW) are also included in this study (Table 1). Specimens selected for scanning electron microscopy were imaged with an ESEM FEI Quanta 200, under low vacuum; specimens were uncoated. The material from the GD NRW was coated with ammonium chloride.

Species	JALHAY Formation							OTTRÉ Fm
	Belgium					Germany		Belgium
	Lake Gileppe	Oster	Spa	Solwaster (Gospinal)	Targnon	Grosshau	Rother Wehebach	Bierleux
Pseudolingulidae indet.				X				
Lingulella lata	X[1]							
Lingulella? sp.				X	X (T2)			
Lithobolus sp.				X				
Broeggeria sp.		?*	X	X	X (T2)	X	X	
Acrotreta? sp.	?[2]**			X				
Celdobolus sp.								X
Linguloidea indet. 1				X				
Linguloidea indet. 2				X				
Linguloidea indet. 3					X (T1)			
Collections	[1]RBINS [2]KUL?	KUL?	RBINS	ULg	ULg	GD NRW		ULg

Table 1. Ordovician lingulide, acrotretide and siphonotretide species in the Jalhay (Solwaster Member) and Ottré (basalmost part of the Les Plattes Member) formations in the Stavelot–Venn Massif. Geukens' material has not yet been traced in the KUL collections. Abbreviations: Fm, Formation; GD NRW, Geologischer Dienst Nordrhein-Westfalen; KUL, Katholieke Universiteit Leuven; RBINS, Royal Belgian Institute of Natural Sciences; T1 and T2, outcrops Targnon 1 and 2; ULg, Université de Liège, * = Geukens (1963); ** = Schmidt & Geukens (1959).

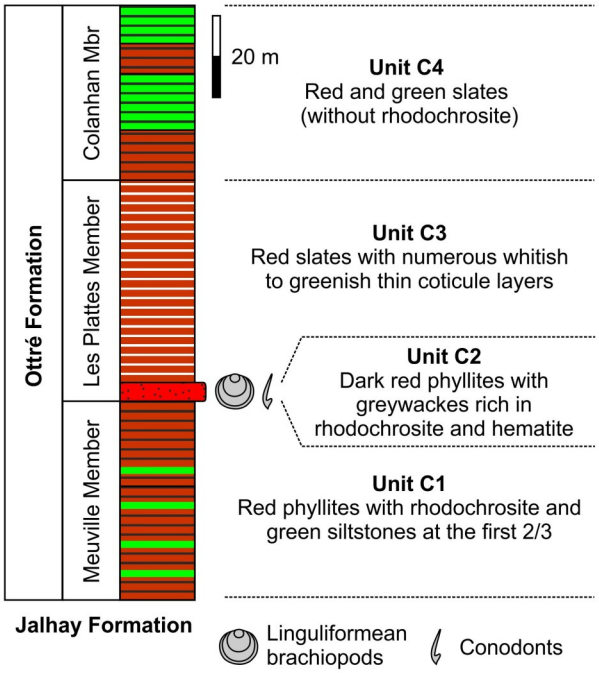

Figure 4. Lithology of the three members of the Ottré Formation in the Lienne Syncline (anchizonal area) (Lienne valley, Stavelot Massif) (modified from Lamens, 1985 and Herbosch et al., 2016). Abbreviation: Mbr, Member.

4. Systematic palaeontology

Subphylum Linguliformea Williams et al., 1996
Class Lingulata Gorjansky & Popov, 1985
Order Lingulida Waagen, 1885
Superfamily Linguloidea Menke, 1828
Family Pseudolingulidae Holmer, 1991

Pseudolingulidae indet.
(Fig. 5A-C)

v. 2021 Pseudolingulidae indet.; Candela et al., p. 392, fig. 6.4.

Material. A dorsal valve exterior; PA.ULg 2020.12.16/2, from the Solwaster Member of the Jalhay Formation, Solwaster (Gospinal) (Fig. 2).

Remarks. Valve subrectangular and elongate, with subparallel lateral margins. The limited morphological details are the only information to identify the specimen, and only to family level. The absence of internal morphological information prevents any further comparison beyond familial level.

Family Obolidae King, 1846
Subfamily Obolinae King, 1846
Genus *Lingulella* Salter, 1866

Type species. *Lingulella davisii* M'Coy, 1851, by subsequent designation of Dall (1870, p. 159); from the Ffestiniog Flags Formation (Furongian, upper Cambrian), near Tremadog, Caernarfonshire and Merionethshire, Wales.

Lingulella lata Koliha, 1924
(Fig. 5D-G)

*1924 *Lingulella insons* Barrande var. *lata* Koliha, p. 39, p. 56, pl. 2, figs 10, 11.
v. 1925 espèce très voisine de *Lingulella cedens* (Barrande); Roncart, p. B198.
v. 1926 *Lingulella insons* Barrande var. *lata* Koliha; Maillieux, p. 68.
v. 1933 *Lingulella insons*; Maillieux, p. 30.
v. 1954 *Lingulella insons* Barrande var. *lata* Koliha; Graulich, p. 22.
v. 1954 *Lingula insons* (Barrande); Geukens, p. 49.
v. 1959 *Lingulella insons* (Barrande); Schmidt & Geukens, p. 161.
1982 *Lingulella lata* Koliha; Havlíček, p. 42, pl. 3, figs 10-12.
1997 *Lingulella lata* Koliha; Mergl, p. 96, p. 98, fig. 2H-M.
2002 *Lingulella lata* Koliha; Mergl, p. 23, pl. 5, figs 1-7.
v. 2021 *Lingulella* sp.; Candela et al., p. 392, fig. 6.3.

Material. Ventral valve interior and exterior, RBINS a13490, from the Solwaster Member of the Jalhay Formation (Fig. 3), north shore of Lake Gileppe (Fig. 2).

Remarks. Ventral valve elongate, suboval; two marked

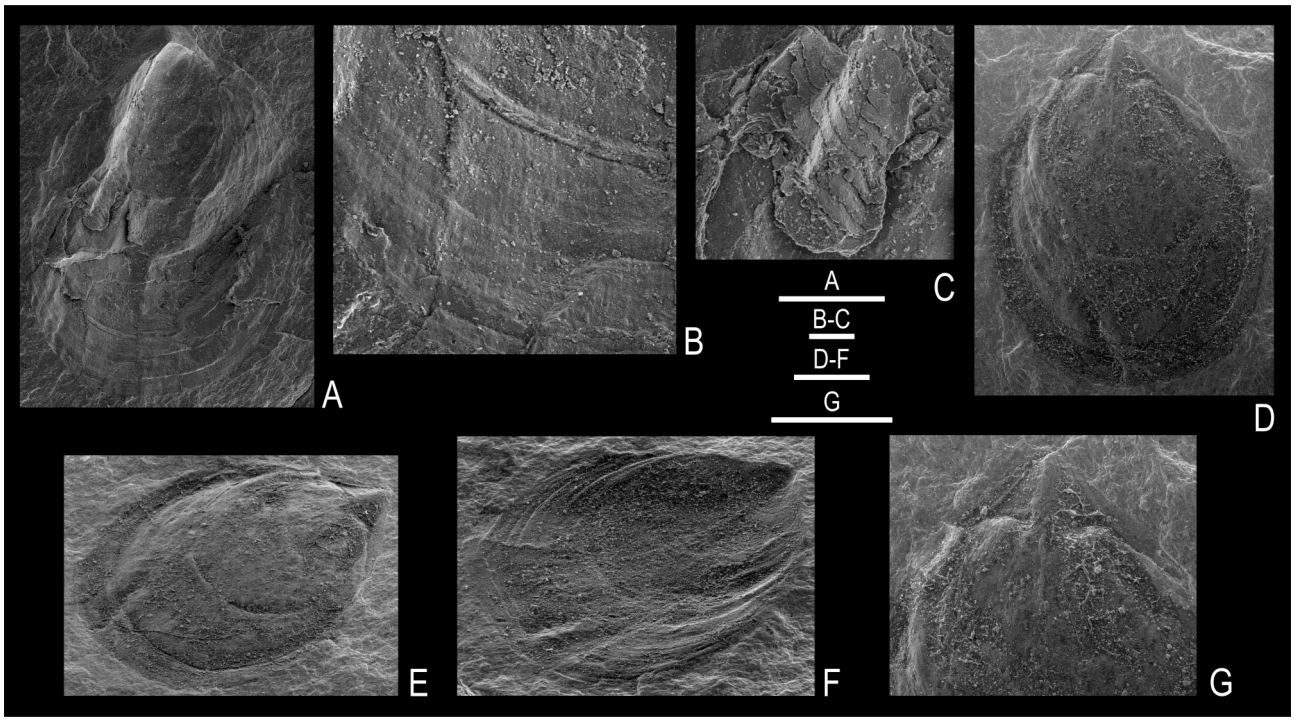

Figure 5. A-C. Pseudolingulidae indet., PA.ULg 2020.12.16/2 (Candela et al., 2021, fig. 6.4), dorsal valve exterior in dorsal view (A) and detail of the ornamentation (B, C), Solwaster (Gospinal). D-G. *Lingulella lata* Koliha, 1924, RBINS a13490 (Candela et al., 2021, fig. 6.3), ventral valve interior in ventral and oblique lateral views (D-E), ventral valve exterior in oblique lateral view (F), and detail of pseudointerarea (G), Lake Gileppe. All from the Jalhay Formation (Solwaster Member). All SEM. Scale bars: A, D-G = 1 mm; B-C = 0.1 mm.

circular growth lines, the anteriormost delimiting a wide anterior margin; orthocline pseudointerarea with narrow, triangular pedicle groove; propareas with well-developed flexure lines; visceral area weakly impressed.

Roncart (1925) compared this single valve he collected to *Lingulella cedens* (Barrande, 1868) from the lowermost Ordovician of Bavaria. Barrande (1868) compared his specimen to *L. davisii* from Wales that Salter (1866) had figured. Moreover, the specimen illustrated by Barrande is a drawing of a valve exterior that shows little similarities to the present specimen. On the other hand, Maillieux (1926) has identified Roncart's (1925) specimen as belonging to *L. insons* Barrande var. *lata* Koliha, confirming a Tremadocian age for this horizon. Roncart's (1925) specimen was illustrated for the first time by Candela et al. (2021), and is figured here on Figure 5D-G. The mould of the ventral valve interior clearly shows well-developed flexure lines scarring the propareas, a narrow pedicle groove with subparallel sides and the presence of few marked concentric growth lines (two are present here on the internal mould and possibly four on the external mould). These features are diagnostic of the type specimens of *Lingulella lata* Koliha, 1924 as described by Koliha (1924, p. 30: "Stvolový žlábek není kuželovitě zaoblen, nýbrž válcovitě.", "Nejmladší okrajový vzrůstový prstenec tvoří široký lem." Translated into French on pp. 56, 57: "Le sillon du pédoncule n'est pas conique mais cylindrique; ses bords sont donc parallèles.", "Le dernier anneau d'accroissement forme une large bordure") and by Havlíček (1982, p. 42: "each "proparea" divided by a flexure line…"). Mergl (1997) also described new specimens assigned to *L. lata*, collected from a stratigraphically higher part of the Olešná Member of the Klabava Formation at Strašice, Prague Basin, and characterised by "Pedicle groove deep, narrow […], almost parallel sided", "Propareas distinctly bordered by flexure lines, […]" and "Shell surface covered by weak growth lines and several (four to five) slightly coarser growth lamellae." (p. 98). Although Mergl (2002, p. 23), who refigured Koliha's (1924) lectotype, indicated that *Lingulella lata* Koliha may belong to a new genus, the paucity of his, and of our material cannot justify the erection of a new taxon and these specimens are best identified as *L. lata* until more material is available. We follow Maillieux's (1926) identification of Roncart's (1925) specimen.

***Lingulella*? sp.**
(Fig. 6A-D)

Material. One ventral and three dorsal valve exteriors, from the Solwaster Member of the Jalhay Formation (Fig. 3), Solwaster (Gospinal) and Targnon 2 (Fig. 2).

Remarks. Shell biconvex, elongately oval, with ventral valve 150% as long as wide and dorsal valve 125% as long as wide. Ornament of concentric growth lines only. Interiors not preserved. Identification is tentative and is based only on exteriors and valve outline.

Candela et al. (2021) mentioned and figured a single specimen of *Lingulella* sp., now identified as *L. lata* Koliha, 1924 (see above), from the Solwaster Member of the Jalhay Formation collected at the Lake Gileppe. Based on the external moulds available these two collections may be conspecific (pending collection of internal moulds).

Genus *Lithobolus* Mergl, 1996

Type species. *Lithobolus plebeius* Mergl, 1996, by original designation; from the top of the Klabava Formation (Dapingian), Bukov, Ejpovice and Klabava, Czech Republic.

***Lithobolus* sp.**
(Fig. 6E-I)

Material. One ventral and one dorsal valves from the Solwaster Member of the Jalhay Formation, Solwaster

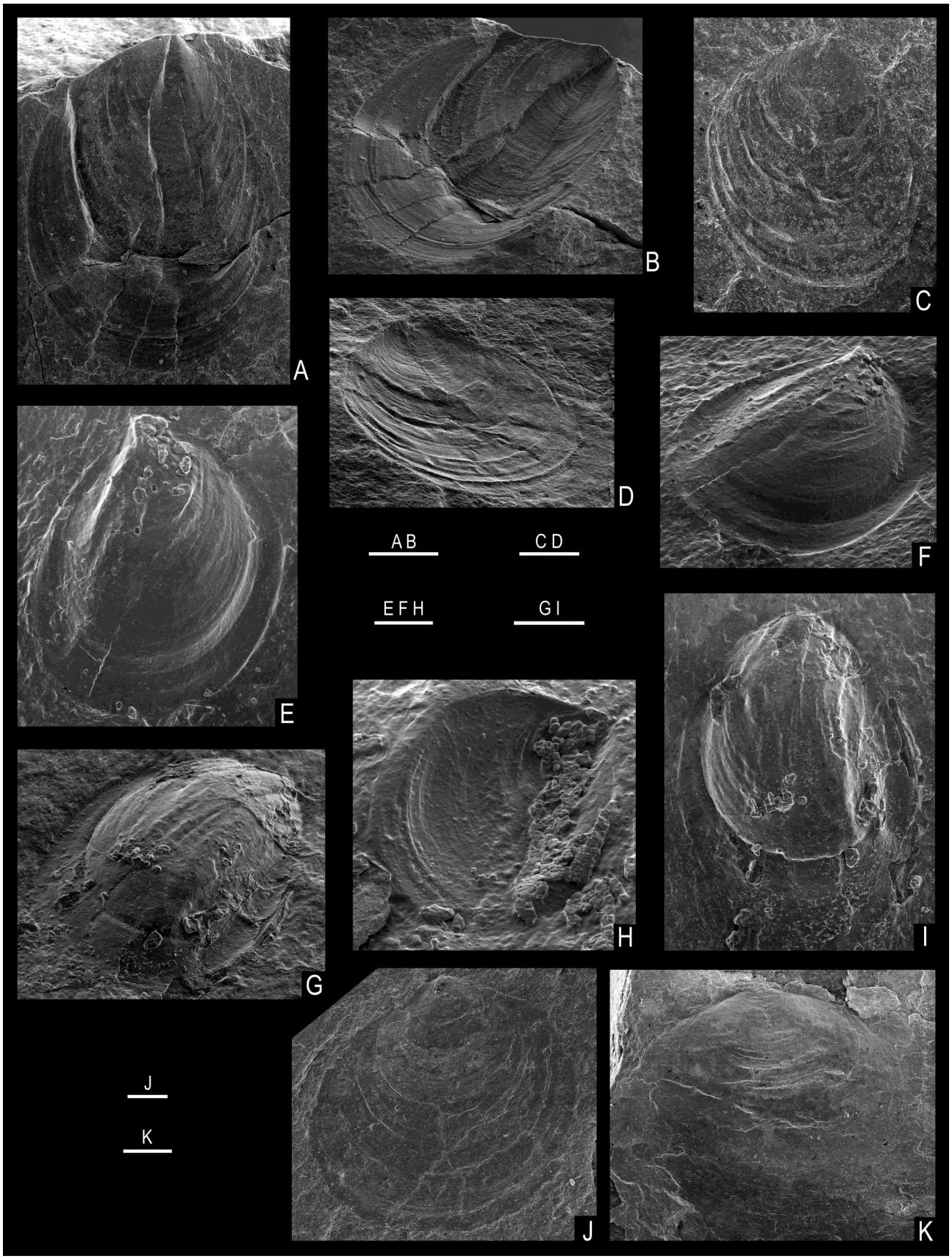

Figure 6. A-D. *Lingulella*? sp. A, B. PA.ULg 2021.08.19/1, a ventral valve exterior in ventral and oblique lateral views. C, D. PA.ULg 2021.08.19/2, a dorsal valve exterior in dorsal and oblique anterolateral views. E-I. *Lithobolus* sp. E-F, H. PA.ULg 2021.08.19/3, a ventral valve interior in ventral and oblique anterolateral views, and its external counterpart in oblique lateral view. G, I. PA.ULg 2021.08.19/4, a dorsal valve interior in oblique anterolateral and dorsal views. J, K. *Broeggeria* sp. J. PA.ULg 2021.08.19/5, a ventral valve exterior in ventral view. K. PA.ULg 2021.08.19/6, a dorsal valve exterior in antero-lateral view. All material from the Jalhay Formation (Solwaster Member); A, B, E-I from Solwaster (Gospinal); C, D, J, K from Targnon 2. All SEM. Scale bars: A-F, H = 1 mm; G, I-K = 0.5 mm.

(Gospinal) (Figs 2, 3).

Description. Ventral valve convex, elongate oval, 127% as long as wide, maximum width at mid-valve length; pseudointerarea short, flat, orthocline, extending anteriorly 12% of valve length, and 48% as wide as valve width; pedicle groove with sides diverging at about 40°, broadly triangular, 42% as wide as pseudointerarea and 24% as wide as valve width; anterior and posterolateral margins of the valve forming a flat limbus, 9% as wide as valve width.

Dorsal valve convex, elongate oval 127% as long as wide, maximum width at mid-valve length. Ventral interior with visceral area obscure. Dorsal interior with indistinct muscle scars.

Remarks. The identification of the two specimens is based on the presence of the wide limbus, the shape of the pedicle groove and the faint visceral areas on both valves, features which, according to Mergl (2002) distinguish *Lithobolus* from *Leptembolon* Mickwitz, 1896. The latter genus is known from the Floian of the Famatina Basin in western Argentina (Lavié & Benedetto, 2020) and the Dapingian of Bohemia (Mergl, 1996, 2002). Although slightly deformed, the Belgian specimens (e.g. see Fig. 6E) show an evenly rounded anterior and lateral commissure, a broad pedicle groove, a wide pseudointerarea comparable to the type species *Lithobolus plebeius* Mergl, 1996. On the other hand, *Lithobolus limbatum* Lavié & Benedetto, 2020 from Argentina is notably different, the shape of the valves having maximum width in the anterior third of the valve length, rather than around mid-valve. More material is needed to indicate whether the Belgian specimens are conspecific with the type species or belong to a different species.

Family Elkaniidae Walcott & Schuchert in Walcott, 1908
Genus *Broeggeria* Walcott, 1902

Type species. Obolella salteri Holl, 1865, by original designation; from the White-Leaved Oak Shale Formation (upper Cambrian), of the Malvern Hills, South Wales.

***Broeggeria* sp.**
(Fig. 7A-H)

1954 *Obolus* (*Bröggeria*) *salteri* (Holl); Schmidt, p. 83.
v. 1956 *Obolus* (*Bröggeria*) *salteri* (Holl); Schmidt, p. 16-17, pl. 2, fig. 1a-b.
v. 1959 *Obolus* (*bröggeria*) *salteri* (Höll) [sic]; Schmidt & Geukens, p. 160-161.
? 1963 *Obolus* (*Bröggeria*) *salteri* (Holl); Geukens, p. 39.
v. 2021 *Broeggeria* sp.; Candela et al., p. 392, fig. 6.1-2.

Material. Four ventral, two dorsal and 16 undetermined valves (total 22 valves) from the Solwaster Member of the Jalhay Formation (Fig. 3), Solwaster (Gospinal), Spa and Targnon in Belgium, and Grosshau and Rother Wehebach in Germany (Fig. 2).

Description. Ventral valve circular, gently convex in profile. Dorsal valve transversely subcircular, 90% as long as wide, gently convex in lateral profile. Ornament consisting of concentric rugellae, numbering 12–14 per mm. Ventral interior with a short orthocline pseudointerarea extending anteriorly for 7% of valve length and less than 40% as wide as valve width; pedicle groove triangular, 20% as wide as pseudointerarea, 12% as wide as valve width; pseudointerarea with well-defined flexure lines; impression of visceral area extending anteriorly for 20% of valve length, visible on one valve.

Remarks. In the Lower Ordovician (Tremadocian), *Broeggeria* is known from eastern Avalonia, Baltica, Kazakhstan and Bohemia (see Popov & Holmer, 1994). The genus has also been described from the Brabant Massif (*Broeggeria* cf. *salteri*; Chevlipont Formation) and has been recorded from Spa (*Broeggeria* sp.; Solwaster Member of the Jalhay Formation), in the Stavelot–Venn Massif (see Candela et al., 2021 for both Belgian occurrences). Schmidt (1956, pl. 2, fig. 1a-b) illustrated a specimen identified as *Broeggeria salteri* from the Jalhay Formation in the Hurtgenwald, i.e. in the German part of the Stavelot–Venn Massif. This species is also mentioned by Schmidt (1954) and Schmidt & Geukens (1959) from this area, but without illustration. The specimens mentioned in the latter are figured here on Figure 8A-C. The present material from Solwaster (Gospinal) (also from the Solwaster Member of the Jalhay Formation) complements the material from Spa and Solwaster (Gospinal) previously illustrated by Candela et al. (2021) and indicates that it may be conspecific. This is only based on external moulds; additional moulds especially internal ones need to be collected to undertake a meaningful comparison between the material from Spa and Solwaster (Gospinal), but also when comparing with the specimens from the Chevlipont Formation.

Order Acrotretida Kuhn, 1949
Superfamily Acrotretoidea Schuchert, 1893
Family Acrotretidae Schuchert, 1893
Genus *Acrotreta* Kutorga, 1848

Type species. Acrotreta subconica Kutorga, 1848, by subsequent designation of Davidson (1853, p. 133); from the Floian of Saint-Petersburg area, Russia.

***Acrotreta*? sp.**
(Fig. 7I-L)

Material. Dorsal valve interior and external counterpart: both are moulds of a single valve; Solwaster Member (Jalhay Formation), Solwaster (Gospinal) (Figs 2, 3).

Description. Valve subcircular, slightly wider than long, 90% as long as wide, gently convex, anterior commissure rectimarginate, maximum width slightly anterior to mid-valve length. Interior with short, anacline pseudointerarea, bisected by a concave, widely triangular median groove, deeper anteriorly than posteriorly; median buttress elevated; median septum triangular, gently elevated anteriorly, extending for 73% of valve length; root of median septum preserved as wide groove; anterocentral muscle scars flanking median groove extending for 65% of valve length; cardinal muscle scars large, deeply impressed, located posterolaterally extending anteriorly for almost 30% of valve length and 48% of valve width. Thickened brim developed anterior of median septum, 80% of valve length from umbo.

Remarks. This valve is characteristic of the genus *Acrotreta* in its median buttress and triangular median septum.

One dorsal valve of an undetermined species of the genus *Acrotreta* was previously reported by Schmidt & Geukens (1959) in the Solwaster Member in the Gileppe area. However, this specimen remains untraced in the palaeontological collections of the Catholic University of Leuven (R. Speijer, pers. com., May 2021).

Acrotreta is known in the Upper to Middle Ordovician from peri-Gondwana (Bohemia: upper Tremadocian to Dapingian; see Mergl, 2002), Baltica (Floian–Darriwilian; Holmer & Popov, 1994), South Urals (middle Tremadocian–lower Floian; Holmer & Popov, 1994; Popov & Holmer, 1994) and Laurentia (Darriwilian; Holmer & Popov, 1994, see also Cocks, 2008). Holmer & Popov (1994) reviewed the type species of *Acrotreta* as well as related species. The Belgian specimen is closer to *A. korynevskii* Holmer & Popov, 1994

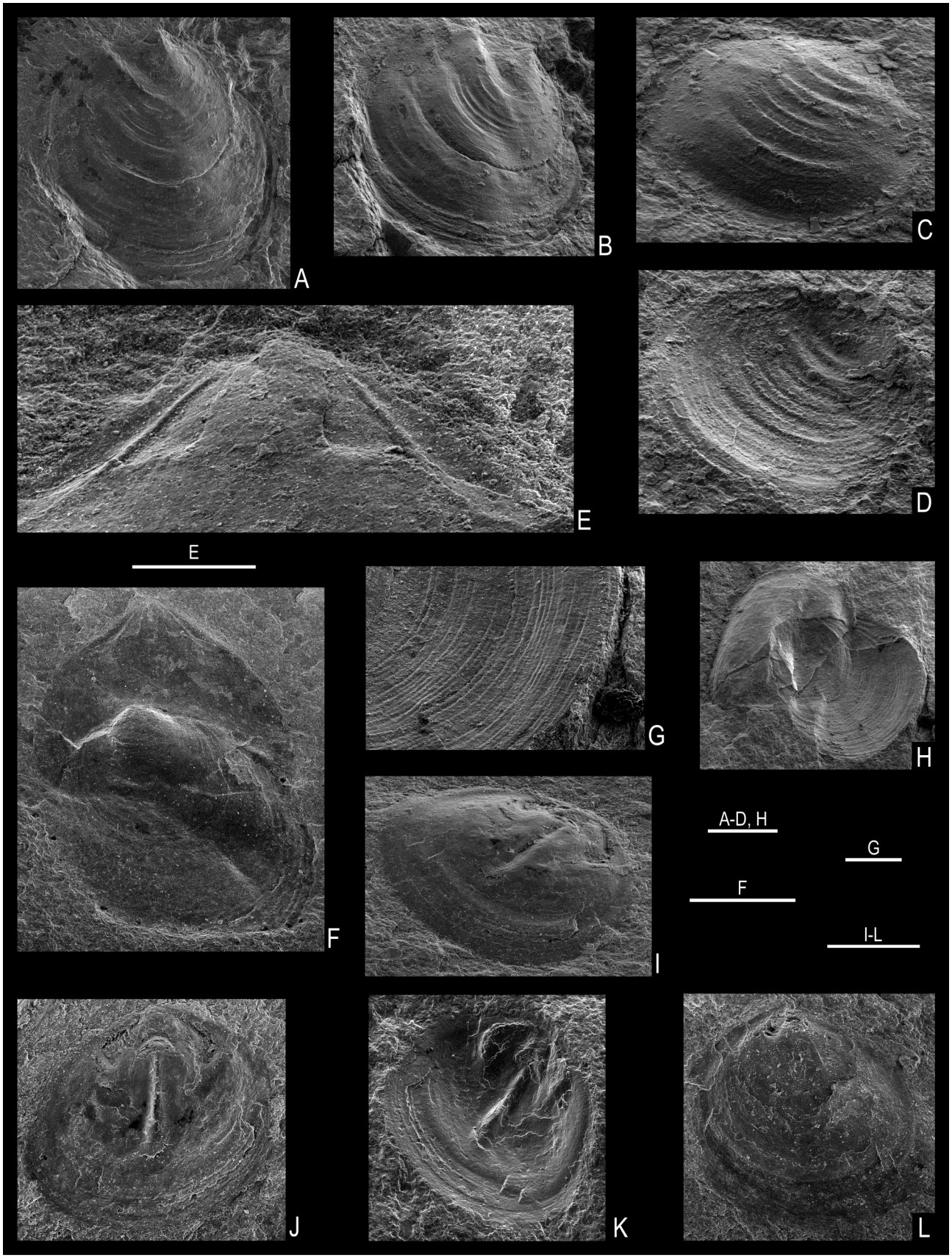

Figure 7. A-H. *Broeggeria* sp. A, B. PA.ULg 2021.08.19/7, a dorsal valve exterior in dorsal and oblique lateral views. C, D. PA.ULg 2021.08.19/8, a ventral valve exterior (part and counterpart) in oblique lateral view. E, F. PA.ULg 2021.08.19/9, detail of ventral pseudointerarea and view of disarticulated ventral valve (showing internal features) and dorsal valve (showing external ornament). G, H. PA.ULg 2021.08.19/10, a ventral valve exterior [H] and detail of ornament [G] in oblique lateral view. I-L. *Acrotreta*? sp. PA.ULg 2021.08.19/11, a dorsal valve interior in oblique anterolateral and dorsal views, latex cast of valve interior in lateral view (tilt of 30°), and a dorsal valve exterior (counterpart) in dorsal view. All material from the Jalhay Formation (Solwaster Member), Solwaster (Gospinal). All SEM. Scale bars: A-D, F, H = 1 mm; E, G = 0.25 mm; I-L = 0.5 mm.

from the Ural Mountains, Kazakhstan, on account of similar median septum length relative to valve length, similar short and narrow dorsal pseudointerarea, a convex dorsal valve and a very faint sulcus (almost lacking). However, based on a single specimen, the comparison is not significant. Moreover, the Kazakh species differs from the Belgian specimen in a poorly developed median buttress, wider cardinal and faint anterocentral muscle scars and a less circular dorsal valve.

Since Holmer & Popov (1994), new species have been described or reassigned to the genus: in particular Ghobadi Pour et al. (2011) reassigned *Spondylotreta dissimilis* Biernat, 1973 to *Acrotreta*. This species is recorded from the middle Tremadocian (*peltifer* Conodont Zone) of the Holy Cross Mountains (Poland) (Biernat, 1973) and the Eastern Alborz Mountains (Iran) (Ghobadi Pour et al., 2011), and is regarded as the earliest occurrence of the genus. This species is different from the Belgian specimen in its cardinal muscle scars (more narrowly developed and extending anteriorly further in *dissimilis*), the poorly defined median buttress, and a wider, thicker base for the dorsal median septum.

The shape of the median buttress, and the triangular median septum indicate *Acrotreta.* The paucity of the Belgian material does not permit confident identification, and therefore the specimen is identified as *Acrotreta*? sp. Nevertheless, this represents a coeval occurrence to the specimens described by Sutton et al. (2000) as *Acrotreta*? from the Lower Tremadocian of Wales, and if confirmed would be the earliest occurrences of the genus *Acrotreta*.

Order Siphonotretida Kuhn, 1949
Superfamily Siphonotretoidea Kutorga, 1848
Family Siphonotretidae Kutorga, 1848
Genus *Celdobolus* Havlíček, 1982

Type species. *Obolus complexus* Barrande, 1879, by original designation; from the Klabava Formation (Floian) of Medový Újezd, Czech Republic.

***Celdobolus* sp.**
(Fig. 8D-J)

? 1935 *Lingulella* cf. *insons*; Maillieux in Lhoest, p. B151.
v. 2004 lingulid brachiopod, phosphatic brachiopod; Vanguestaine et al., pl. 1, figs 17, 19, 20.
v. 2021 Linguliformea indet.; Candela et al., fig. 2.

Material. Three dorsal valves (external and internal moulds) and three indeterminate valves; from the Ottré Formation (basalmost part of the Les Plattes Member), Bierleux (Figs 2, 3).

Description. Dorsal valves convex and oval, slightly elongate; concentric growth line characterised by absence of spines; spine bases are developed as tubercules arranged into concentric, staggered rows; tubercule diameter 50 µm; pseudointerarea seems damaged but appears orthocline. Interior with broad median septum; central muscle scars oval, subparallel; *vascular lateralia* arcuate.

Remarks. The unidentified brachiopod specimens figured by Vanguestaine et al. (2004) on pl. 1, figs 17, 19 and 20, have been partly located and re-identified here as *Celdobolus* sp. The specimen on pl. 1, fig. 17 is identified as PA.ULg 2021.08.19/13 (Fig. 8F); specimen on pl. 1, fig 19 is identified as PA.ULg 2021.08.19/12 (Fig. 8D-E); whereas specimen on pl. 1 fig. 20 has not been traced. It is possible that the specimens identified as *Lingulella* cf. *insons* by Maillieux (in Lhoest, 1935) are identical to those investigated here, but these have not yet been located in the collections of the Université de Liège, where they were deposited. Unfortunately, no description of the specimen was presented in Lhoest's (1935) note.

The genus *Celdobolus* is, in the Floian, typical of Bohemia. Havlíček (1982) recorded there three species, *C. complexus* (Barrande, 1879), *C. mirandus* (Barrande, 1879) and *C. punctatus* (Klouček, 1924), but Mergl (2002) synonymised the first and last, and extensively described and discussed *C. complexus* and *C. mirandus.* Havlíček (1982) also listed a possible occurrence of the genus in the upper Tremadocian of the Holy Cross Mountains in Poland with *C.* cf. *complexus*. Lastly, a new occurrence in the *Araneograptus murrayi* Zone of the Fezouata Shale (upper Tremadocian) is under study by one of us (YC) and colleagues (David A.T. Harper and Michal Mergl). Comparison of the Belgian material described with any known species is difficult because of the lack of whole material. However, one specimen (PA.ULg 2021.08.19/14; Fig. 8G) displays the internal morphology of a dorsal valve laterally and almost up to the anterior commissure. No tubercules can be seen around the shell margin, which, as demonstrated by Mergl (2002, p. 59), would indicate *C. complexus* rather than *C. mirandus*. Therefore, the Belgian specimens may have a closer affinity with *C. mirandus*. More material is nevertheless required to validate this hypothesis, and until then, the specimens are best left under open nomenclature. Nevertheless, this constitutes the first occurrence of the genus in Avalonia.

Miscellaneous undetermined valves

Three additional valves from the Solwaster Member (Jalhay Formation), belonging to the superfamily Linguloidea, are figured and briefly discussed in the study, but their state of preservation does not permit identification beyond family level. Both Linguloidea indet. 1 and indet. 2 were collected from Solwaster (Gospinal), whereas Linguloidea indet. 3 was collected from Targnon 1.

Linguloidea indet. 1 (Fig. 8K-L) is a subcircular dorsal valve interior and exterior: the specimens show wrinkles but these seem to have developed post-mortem and do not represent morphological features. The valve is characterised by concentric growth lines.

Linguloidea indet. 2 (Fig. 8M-N) is an elongated valve (possibly dorsal), internal features are not visible.

Linguloidea indet. 3 (Fig. 8O-P) is an external mould of a subcircular valve with finely developed growth lines. It is one of the two specimens mentioned by Charles (1925) that he identified as 'lingule' from the outcrop Targnon 1 located at the confluence of the rivers Lienne and Amblève, few hundreds of metres NW of the town of (Fig. 2), in the western part of the Stavelot–Venn Massif. These specimens were brought to his attention by students during a fieldtrip. They were not figured in the short note where the occurrence is recorded. The specimen does not show any internal features, but it shows some similarities to the genus *Broeggeria*. Externally, it is superficially similar to the specimens of *Broeggeria* sp. from Solwaster (Gospinal) illustrated here on Figure 7A-H, and the specimens could be conspecific. Nevertheless, since no internal features are shown, we cannot identify the specimen at the generic level, and it is therefore identified to the superfamily level only. Comparison with *Broeggeria* cf. *salteri* from the Chevlipont Formation in the Brabant Massif (Candela et al., 2021) is also difficult to undertake as the present material only shows external morphology.

5. Discussion

The assemblage collected from the Tremadocian Solwaster Member of the Jalhay Formation, although not abundant, is more diverse (four genera identified and additional specimens

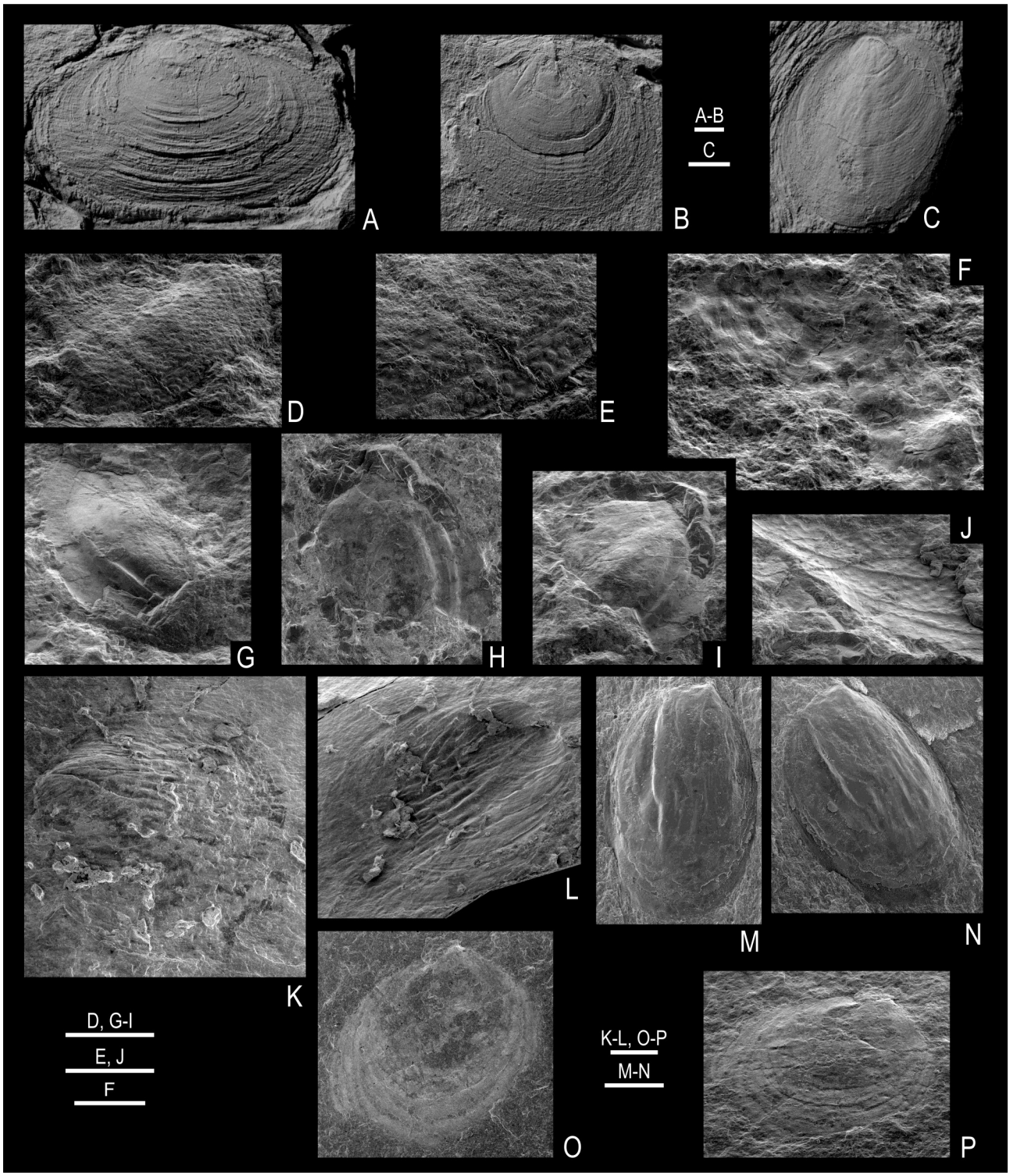

Figure 8. A-C. *Broeggeria* sp., specimens reported by Schmidt (1956) and Schmidt & Geukens (1959) from the German part of the Stavelot–Venn Massif; Jalhay Formation (Solwaster Member). A. GD NRW/Or2, a ventral valve exterior, eastern side of the Rother Wehebach valley. B. GD NRW/Or1 (Schmidt, 1956, pl. 2, fig. 1a–b), a ventral valve interior, disused Elise slate quarry, Grosshau (Groβhau). C. GD NRW/Or3, a dorsal valve exterior, eastern side of the Rother Wehebach valley. D-J. *Celdobolus* sp., Ottré Formation (Les Plattes Member), Bierleux. D-E. PA.ULg 2021.08.19/12 (Vanguestaine et al., 2004, pl. 2, fig. 19), fragment of undeterminable valve exterior. F. PA.ULg 2021.08.19/13 (Vanguestaine et al., 2004, pl. 2, fig. 17), a dorsal valve exterior. G. PA.ULg 2021.08.19/14, a ventral (?) valve interior. H-I. PA.ULg 2021.08.19/15, a ventral valve interior. J. PA.ULg 2021.08.19/16, part of undeterminable valve exterior. K-L. Linguloidea indet. 1, PA.ULg 2021.08.19/17, a dorsal valve interior and its exterior counterpart, Jalhay Formation (Solwaster Member), Solwaster (Gospinal). M-N. Linguloidea indet. 2, PA.ULg 2021.08.19/18, a ventral valve interior, Jalhay Formation (Solwaster Member), Solwaster (Gospinal). O-P. Linguloidea indet. 3, PA.ULg 2021.08.19/19, a ventral (?) valve exterior, Jalhay Formation (Solwaster Member), Targnon 1. All SEM except A-C. Scale bars: A-D, F-I, K-L, O-P = 1 mm; E, J, M-N = 0.5 mm.

identified to only the family level) than the assemblage described from the coeval Chevlipont Formation (see Candela et al., 2021), where three genera were identified (Fig. 3). It is also very different taxonomically, *Broeggeria* being the sole common taxon. Additionally, a single taxon was identified from the basalmost part of the Les Plattes Member of the Ottré Formation (Floian), *Celdobolus*, which constitutes the first occurrence of this genus in Avalonia.

Although taxonomically different, the assemblage from the Solwaster Member may represent the equivalent to the assemblage found in the Chevlipont Formation, the differences being controlled by the substrate. Both are characteristic of relatively deep-water environment. The presence of *Celdobolus* in the Les Plattes Member may indicate a deepening of the environment in the Floian (see discussion in Herbosch et al., 2020).

The assemblages from Belgium (both from the Brabant Massif and the Stavelot–Venn Inlier) exhibit some of the earliest occurrences of a taxon (e.g. *Thysanotos*, see Candela et al., 2021), but also some of the earliest occurrences of taxa expanding their geographic distribution (e.g. *Celdobolus*, *Acrotreta* and possibly *Lithobolus*). The presence in the Lower Ordovician of the siphonotretide *Celdobolus* in high-latitude Gondwana and peri-Gondwana mirrors the proliferation of spinose siphonotretides in the Furongian–lower Tremadocian (see Popov et al., 2009, 2013).

The material from the Les Plattes Member may represent the youngest occurrence of brachiopods within the Stavelot–Venn Inlier as the dark bioturbated siltstones of the younger Bihain Formation (Fig. 3) seem to be devoid of shelly fauna. Therefore, only linguliformean brachiopods have been recovered so far from this area. The situation is different in the Brabant Massif. Besides the poorly diverse assemblage known from the Chevlipont Formation (Candela et al., 2021) in which graptolites (Wang & Servais, 2015) and trilobites (Lecompte, 1948) were found, it is worthwhile to stress on the linguliformeans mentioned, but not illustrated, by Lecompte (1951) within the dark mudstones of the Katian Fauquez Formation (Herbosch & Verniers, 2014) (Fig. 3). This author identified five species, including large-sized '*Lingula*', associated to graptolites (Bulman in Lecompte, 1951; Maletz & Servais, 1998) that need to be re-investigated. Astonishingly, according to the literature related to the Brabant Massif, rhynchonelliformean brachiopods occurred for the first time only within the Katian Huet Formation (Malaise, 1873), where they are associated to a rich macrofauna (e.g. cephalopods and trilobites). This striking absence could be related to unsuitable conditions (e.g. graptolitic facies) during a large part of the Ordovician and/or sampling biases. So far, the oldest representatives of rhynchonelliformeans recognised in the Belgian inliers are from the Condroz Inlier, namely the orthides illustrated by Maillieux (1939) from the upper Darriwillian–upper Katian Sart-Bernard Formation (Owens & Servais, 2007) and the unstudied material from the Oxhe Formation (e.g. Dean, 1991) of late Sandbian to earliest Katian age. Verniers et al. (2005) reported brachiopods from member 1 of the Bornival Formation (Katian) (Fig. 3); these may include rhynchonelliformeans, but are still unstudied.

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Author contribution

Both authors contributed equally to the data acquisition, their interpretation and the writing of this article.

Data availability

All studied specimens are housed in official repositories guaranteeing their long-term safekeeping and availability to other researchers for future studies.

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