

Revised conodont stratigraphy of the Cellon section (Silurian, Carnic Alps)

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The Cellon section, located in the Carnic Alps, is a reference section for the Silurian of the world. The conodont association of the section is revised according to the most recent taxonomy and the biostratigraphy updated in the basis of the recently published zonation schemes. Seventy taxa (species and sub-species) belonging to 23 genera have been identified, allowing the discrimination of 15 biozones from the upper Llandovery to the end of the Prídolí. However, some of the uppermost Llandovery and Wenlock biozones, corresponding to black shale intervals, have not been documented. □ *Biostratigraphy, Carnic Alps, Cellon section, Conodonts, Silurian.*

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The Cellon section, probably the most famous Silurian section in the world, is the reference section for many Silurian studies. It is located in the Austrian side of the Carnic Alps near Plöckenpass/ Passo di Monte Croce Carnico, a few hundred metres from the Italian/Austrian state border (Fig. 1). The conodont fauna from the section was studied and described by Walliser (1964), whose pioneering work on the section included the first proposed Silurian conodont zonation. Subsequent studies on the Cellon section have documented the composition and distribution of several fossil groups, micro-facies, isotope signatures, taphonomic and palaeoenvironmental indicators and eustatic sea-level changes. In all these studies, Walliser's (1964) conodont zonation was used as biostratigraphic framework, and the section was globally acknowledged as a Silurian reference section. In addition to papers comparing data from different regions with those from Cellon section, Kleffner (1989, 1995) chose it as a reference section for his Silurian chronostratigraphy-based on graphic correlation.

Since the Walliser's (1964) paper, conodont studies have proceeded all around the world; several new taxa have been discovered and described; conodont taxonomy has been revised and now is based on multi-element apparatuses. Also, many authors have proposed several new more detailed zonal schemes for selected time intervals or geographical regions

(Jeppsson 1997; Corradini & Serpagli 1999; Jeppsson *et al.* 2006; Männik 2007; Cramer *et al.* 2011; Corradini & Corriga 2012).

In this study, we present an updated Silurian conodont biostratigraphy of the Cellon section. The paper is based on restudy of Walliser's conodont collection, stored in Göttingen University. Also, several new samples were collected and processed from selected levels in the section.

Geological setting

The Carnic Alps are located across the Italian–Austrian border, and here is found one of the best-exposed and most complete Palaeozoic successions in the world, ranging from the Upper Ordovician to Upper Permian.

Silurian outcrops are irregularly distributed in the region. The main types of rocks exposed here include shallow water bioclastic limestones, nautiloid-bearing limestones, limestones interbedded with shales, and black graptolitic shales and cherts ('lydites'). The overall thickness of Silurian strata does not exceed 60 m. The Silurian transgression in the region started at the beginning of the Llandovery. The duration of the gap separating the Ordovician and Silurian successions is highly variable and a rock succession corresponding to several conodont zones of Llandovery or Llandovery to Early Wenlock



Fig. 1. Location of the Cellon section (star).

age is locally missing (Schönlaub & Histon 1999; Štorch & Schönlaub 2012).

Four main lithofacies, representing different depths and hydraulic conditions of deposition, have been described in the Silurian of the Carnic Alps (Wenzel 1997). The Wolayer facies is characterized by proximal sediments, the Bischofalm-facies by deep-water euxinic deposits; the Plöcken facies and the Findenig facies are intermediate between these two. In rough approximation, the four facies seem to replace each other from northwest to southeast in the western and central sectors of the Carnic Alps. The depositional features suggest an overall transgressive regime from Llandovery to Ludlow. The formation of uniform calcareous deposits in the Přídolí indicates that stable conditions were developed in the region at that time (Schönlaub 1997).

In terms of lithostratigraphical subdivision, a recently established (but still unpublished) scheme identifies three units that follow each other in succession in the proximal (calcareous) parts of the basin: the Kok Fm. (Llandovery–lower Ludlow), the Cardiola Fm. (Ludlow) and the Alticola Fm. (upper Ludlow–Přídolí). The last unit corresponds to the former Alticola Limestone and Megaerella Lime-

stone. All three units are represented mainly by ‘*Orthoceras* limestone’, a wackestone-packstone with high bioclastic content. The colour turns gradually from dark red and black in the lower Silurian to light grey-ochre in the Přídolí. Nautiloid cephalopods are very abundant; trilobites, bivalves and conodonts are common; crinoids, gastropods and rarer ostracods, brachiopods, chitinozoans are also present (Schönlaub 1997; Histon & Schönlaub 1999a; Schönlaub & Histon 2000; Corradini *et al.* 2010).

In the deeper part of the basin, the Silurian corresponds to the up to 60-m-thick Bischofalm Fm. It consists of black siliceous shales with interbeds of chert and clayish alum slate, mainly deposited in an euxinic environment. Graptolites are generally abundant in these rocks (Schönlaub 1997). Alternating black graptolitic shales, marls and limestones of the Nölbling Fm. were deposited in conditions intermediate between calcareous and shaley facies (Schönlaub 1997). Both the Bischofalm Fm. and the Nölbling Fm. range from the Llandovery to the Lochkovian.

The Cellon section

The Cellon section is located in the Carnic Alps in a narrow avalanche gorge on the eastern flank of Mt. Cellon, at an altitude of about 1500 m, at coordinates 46°36′32′ N, 12°56′31′ E (Figs 1, 2). It is reachable by a short walk from Plöcken Pass (Passo di Monte Croce Carnico).

The section represents the classical exposure of sediments of the Silurian ‘Plöcken facies’ and exposes rocks from the Upper Ordovician to the Lower Devonian. The Silurian is represented by more than 40 m of ‘*Orthoceras* limestone’. It belongs to four lithostratigraphic units: the Kok Fm., the Cardiola Fm. and the Alticola and Megaerella formations (as the new lithostratigraphical subdivision of the Variscan sequence of the Carnic Alps is still unpublished, in this study, we follow the previous scheme).

In more detail, the section has been subdivided into the following units (including the Upper Ordovician at the base and the Lower Devonian on top):

- 1 Uggwa Limestone (= Calcarei di Uqua in the Italian literature). Lithology: Greyish to brownish flaser limestone with layer of bioclastic debris. Thickness: 4.96 m. Age: Katian (Upper Ordovician), *Hamarodus ordovicicus* conodont Zone (beds 1–5).
- 2 Plöcken Formation. Lithology: Greyish siltstone intercalating with impure bioclastic limestone at the very base and grading into calcareous pyritic

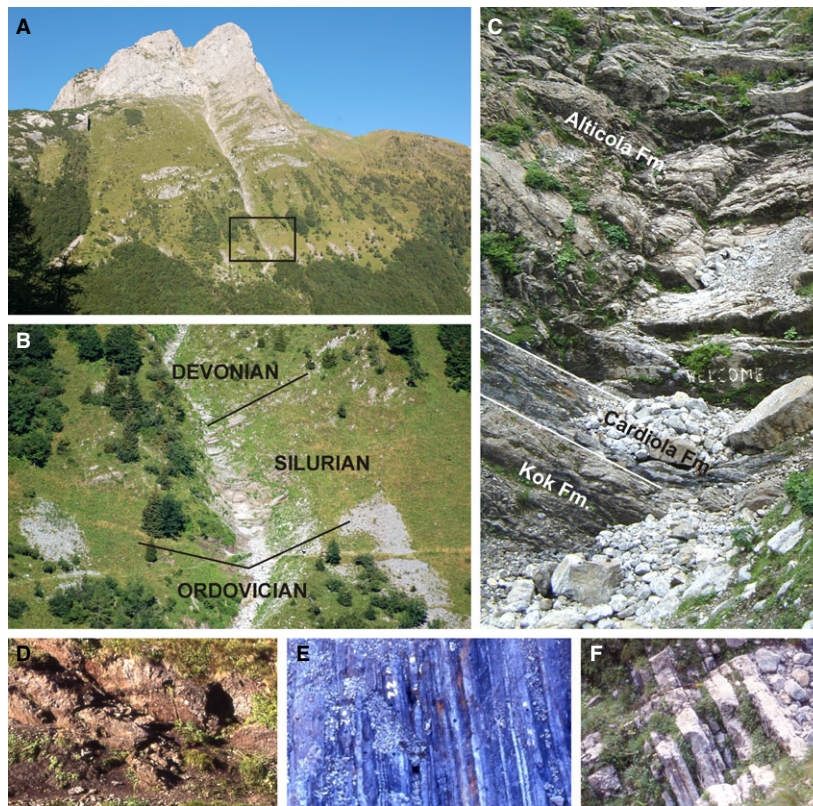


Fig. 2. Views of the Cellon section. A, panoramic view of Mt Cellon. Box indicates the studied section. B, close up view of the section. C, view of the central part of the Cellon section, with the lithostratigraphical units and their boundaries indicated. D, detail of the Kok Fm. E, detail of the Cardiola Fm. F, detail of the Alticola Fm.

- limestone and sandstone higher in the section. The lowermost strata in the formation are evidently of diamictite origin, the upper strata display contorted deformation structures, slumping, channel fillings and interbeds of fossil debris. Thickness: 6.17 m. Age: Hirnantian (Upper Ordovician), *Normalograptus persculptus* graptolite Zone (beds 6–8).
- 3 Kok Formation. Lithology: Well bedded brownish ferruginous nautiloid limestone, at the base alternating with black shale and marly interbeds. Thickness: 13.5 m. Age: Llandovery to Ludlow, *Pterospirifer celloni* SZ to *Ancoradella ploeckensis* conodont Zones (beds 9–19; Figs 4–5).
 - 4 Cardiola Formation. Lithology: Dark grey to black limestone with marly and shaly interbeds. Thickness: 3.5 m. Age: Ludlow, *A. ploeckensis* to *Polygnathoides siluricus* conodont Zone (beds 20–24A; Fig. 5).
 - 5 Alticola Formation. Lithology: Grey to reddish nautiloid limestone with some marly layers and coarse bioclastic interbeds. Thickness: 20 m. Age: Ludlow to Přídolí, *Pedavis latialata*–*Ozarkodina snajdri* IZ to ‘Oz.’ *eosteinhornensis* s.l. conodont Zone (beds 25–39A; Figs 5–6).

- 6 Megaerella Formation: Lithology: Greyish bioclastic limestone. Thickness: 8 m. Age: Přídolí–lowermost Lochkovian, ‘Oz.’ *eosteinhornensis* s.l. to *Icriodus hesperius* conodont Zone (beds 40–47B; Fig. 6).
- 7 Rauchkofel Limestone: Lithology: Blackish platy limestone with black marly interbeds. Thickness: 80–120 m. Age: Lochkovian (Lower Devonian), *Icriodus hesperius* conodont Zone (bed 47C and above; Fig. 6).

Previous studies in the Cellon section

The Cellon section is the stratotype for the Silurian in the eastern and southern Alps. Nowhere else in the Alps has a comparably good section been found. The section has been famous since the 1894 when, soon after the systematic mapping of the Carnic Alps by the Geological Survey of Austria had started, Geyer first described the rock succession exposed here, discriminating all the units that are now distinguished from Ordovician to Lower Devonian (Geyer 1894, 1895, 1899, 1902).

In 1903, the Cellon section was presented to 11 national and international experts during an excursion associated with the 9th International Geological Congress, which was held in Vienna (Geyer 1903).

A few years later Spitz (1909) confirmed the pioneering study of Geyer, published a detailed map and introduced the so-called Plöcken facies, which he distinguished from the contemporaneous but shallower 'Wolayer facies' farther to the west.

After World War One, a new scientific period started in which comprehensive fieldwork was carried out by von Gaertner (1927, 1931a,b) and palaeontological studies of nautiloids, bivalves, trilobites, brachiopods, gastropods, graptolites developed by Heritsch (1929) from both Austrian and Italian sides (Gortani and Vinassa de Regny) of the Carnic Alps. In particular, Gaertner focused his work on the Cellon section, where he described 11 lithostratigraphically defined units ('Formations'), which are partly still in use.

In the late 1950s, new techniques in macro- and micro-palaeontology were applied in studies in the Carnic Alps. After an initial work dated from 1957 (Walliser 1957), Walliser published his famous monograph on Silurian conodonts and conodont zonation, which was primarily based on data from the Cellon section (Walliser 1964). From the base to the top, Walliser processed 220 samples from nearly all limestone beds each weighing between 2 and 3 kg and he recovered almost 35 000 conodont elements. Based on this collection, he established 11 conodont zones for the Silurian. Although, in general, this zonation was recognized all over the world, it was subsequently updated and slightly revised. Nevertheless, the data from Cellon proved as a very successful tool for correlation of Silurian strata on a global scale.

In the following years, Walliser's study was complemented by the publication of new geological maps (Schönlaub 1985b), detailed lithological investigations to characterize the rock succession (Flügel 1965; Schönlaub 1985a; Dullo 1992; Kreuzer 1992) and, in particular, the recognition and interpretation of K-bentonites by Histon *et al.* (2007) followed by a sequence stratigraphical study of the Silurian succession of the Carnic Alps (including the Cellon section; Brett *et al.* 2009). Carbon isotopes were analysed from the Silurian part of the Cellon section. The signatures recorded were discussed in a wider context, the results compared with those from the Baltic Region, the Barandian, and some regions in Urals (Wenzel 1997), and for the Ludlow interval related to the Lau event along with data from Australia and Sardinia (Jeppsson *et al.* 2012).

At the same time, palaeontological research was re-started by studies on bivalves by Kříž (1974, 1979, 1999), brachiopods by Plodowski (1971, 1973) and Jaeger *et al.* (1975), nautiloids by Ristedt (1968, 1969), Gnoli & Histon (1998), Histon (1999, 2002, 2012), Histon & Schönlaub (1999b), Histon *et al.* (1999), graptolites by Jaeger (1975), Jaeger *et al.* (1975), Štorch & Schönlaub (2012), foraminifers by Langer (1969), Kristan-Tollmann (1971), ostracods by Schallreuter (1990), acritarchs by Martin (1978) and subsequently by Prielwaller (1987), chitinozoans by Prielwaller (1997, 1999, 2000), trilobites by Haas (1969) and Santel (2001) and corals by Pickett (2007). In addition, after Walliser (1964), Ferretti & Schönlaub (2001) studied the distribution of conodonts in the Hirnantian in the Cellon section. Results of detailed analyses focusing on the late Ordovician glaciation and its impact on the Carnic Alps with major emphasis on the Cellon section have been published in several papers (Schönlaub 1971, 1988; Schönlaub & Sheehan 2003; Hammarlund *et al.* 2012; Štorch & Schönlaub 2012).

Recent advances in Silurian conodont taxonomy

Since the publication of Walliser's masterpiece *Conodonten der Silurs* in 1964, conodont taxonomy has changed completely. The early 1970s was a '...time of transition from form-element to multi-element taxonomy' (Aldridge & von Bitter 2009, p. 13). Now, it is well known that a conodont had several elements of different morphology forming the 'conodont apparatus'. Hence, a conodont species yields elements of different morphology described earlier as separate taxa. Walliser (1964), although applying in his descriptions form-element taxonomy, had noticed general morphological similarities of elements of some of his taxa and proposed that, in reality, they might belong to the same species (apparatus). Based on such similarities and co-occurrences of elements, he described eight apparatuses, designated by letters ('Conodonten-Apparat A', 'Conodonten-Apparat B', etc). Since then, conodont taxonomy has been completely revised, and many new apparatus-based genera and species have been described following rules of the International Code of Zoological Nomenclature (Barrick & Klapper 1976; Barrick 1977; Miller & Aldrige 1993; Serpagli *et al.* 1997; Männik 1998; Serpagli & Corradini 1999; Murphy *et al.* 2004; Carls *et al.* 2005; Corradini 2008; Corradini & Corriga 2010).

History of Silurian conodont biozonation

The first conodont zonation for the Silurian was proposed by Walliser (1964), who based his scheme primarily on the succession of conodonts in Cellon section, but also including data from Bohemia and Spain. The author defined 12 successive first appearance zones spanning the Silurian and the lowermost Devonian. Several of these zones were widely recognized later, but the difficulties of applying the complete scheme in other regions of the world led to the development of many local zonations, mainly for the Llandovery which is not completely exposed in Cellon.

Aldridge & Schönlaub (1989), considering all the data then available, provided a new scheme, which was a 'step on the path to the development of a reference biozonation' (Aldridge & Schönlaub 1989, p. 275). Their global zonation was reported also in the Newsletter of the Subcommittee of Silurian Stratigraphy (*Silurian Times 1*, 1993). Two years later, a new Conodont Global Zonation chart was published (*Silurian Times 3*; Nowlan 1995). It differed significantly from previous zonations, but was never fully justified or discussed. This scheme contains several biases, such as the indication of two 'not zoned' intervals, and some zones in it are based on taxa with a limited geographical distribution.

Corradini & Serpagli (1998, 1999) proposed a new scheme, based on Sardinian data. However, due to the absence of lowermost Silurian carbonates in Sardinia, this scheme starts from the topmost Llandovery. The authors demonstrated that the Sardinian conodont zonation is usable worldwide and claimed that it is 'of practical use for Silurian biostratigraphy, and therefore more generally useful than extremely detailed schemes, sometimes based on not yet defined or endemic taxa' (Corradini & Serpagli 1999, p. 270). Following these considerations, the same authors (Corradini & Serpagli 2000) proposed their scheme as a Standard Silurian conodont zonation for the Wenlock–Přídolí time interval.

A totally different approach to the Standard conodont zonation was presented by Jeppsson (1997) and Jeppsson *et al.* (2006), who provided a detailed scheme of zones based on the latest Llandovery to latest Ludlow succession exposed on Gotland. Unfortunately, many of these zones are not applicable in other regions, either because they reflect the local environmental conditions on Gotland, or because some zonal markers are extremely rare taxa

(<0.1% of the fauna) or are endemic taxa to the Baltic area. Männik (2007) proposed a detailed zonation for the Llandovery, which is now widely accepted.

Ogg *et al.* (2008) published a zonation integrating those introduced by Nowlan (1995) and Corradini & Serpagli (1999), but some problems still remain, mainly the occurrence of a 'not zoned' interval and the unclear definition of a zone in the Ludlow.

More recently, following some taxonomic revisions of Late Silurian ozarkodinids, and detailed investigation of the upper Silurian in North Gondwana, the upper part of the Silurian zonation was updated by Corrigan & Corradini (2009) and Corradini & Corrigan (2012). These authors (Corrigan & Corradini 2009) renamed the former '*rem-scheidensis* interval Zone' as '*eosteinhornensis* s.l. interval Zone' without changing the meaning of the zone and the definition of its boundaries. This proposal was accepted by Cramer *et al.* (2011) in the most recent updating of the Silurian conodont zonation and included by Melchin *et al.* (2012) in their stratigraphical summary of the Silurian Period.

In this study, we follow mainly the zonation by Cramer *et al.* (2011), although some modifications of it are needed in order to apply it in the Carnic Alps and to incorporate new recently published data on conodont biostratigraphy (Corradini & Corrigan 2012; Slavík *et al.* 2012). These modifications include:

- The *Kockelella patula* Zone is recognized in the Wenlock; it corresponds to the central and upper parts of the *K. walliseri* Zone of Cramer *et al.* (2011). *K. walliseri* Zone cannot be identified because the nominal taxon of the zone has not been found in the Cellon section.
- In the Ludfordian, the *Ozarkodina snajdri* Interval Zone is here renamed the *Pedavis latialata*–*Oz. snajdri* interval Zone. The interval between the LAD of *Polygnathoides siluricus* and the FAD of *Oz. crispa* was often named *Oz. snajdri* Zone or *Oz. snajdri* Interval Zone (Aldridge & Schönlaub 1989; Cramer *et al.* 2011; Melchin *et al.* 2012). Other authors have subdivided this interval in two parts (Corradini & Serpagli 1999; Jeppsson *et al.* 2006): the lower one characterized by the icriodontid *Pe. latialata* and the upper one by *Oz. snajdri*. Also in the Cellon section, it is possible to subdivide this interval into two parts characterized by *Pe. latialata* and *Oz. snajdri*, respectively. However, in some regions in the world, *Pe. latialata* is very rare (e.g. in North America), whereas elsewhere it seems to have longer range and has been found also in the *Oz. crispa* Zone (Bohemia:

Slavík & Carls 2012), and the *Pe. latialata* and *Oz. snajdri* zones cannot be separated. Therefore, we have decided to rename the *Oz. snajdri* interval Zone after the names of the two more characteristic species to the *Pe. latialata*–*Oz. snajdri* interval Zone.

- The *Oz. crista* Zone extends into the lowermost Přídolí because its index taxon *Oz. crista* is present up to sample 33, above the occurrence of *Monograptus parultimus* Jaeger (the index taxon for the base of the Přídolí), found in the section just above sample 32 (Jaeger 1975).
- In the Přídolí, the *Oulodus elegans detortus* Zone is subdivided into a Lower *O. e. detortus* Zone and an Upper *O. e. detortus* Zone, as introduced by Corradini & Corrigan (2012).

Updated conodont data and biostratigraphy

The Walliser conodont collection from the Cellon section is stored in the Geoscience Centre of the Georg-August University of Göttingen, Germany, under repository number GZG 1613. It includes about 35 000 conodont elements from about 220 samples from the Upper Ordovician to the base of Devonian. It is well known that coniform elements from Walliser collections were sent to Dr. Klaus Müller (Berlin) to be studied and therefore are not present in the material stored in Göttingen. However, most of the samples in Göttingen include coniform elements, and some are very crowded of simple cones. This can be explained by the fact that Walliser collected samples from Cellon several times (in the collection, some beds are represented by two or three samples) and likely only coniforms from the first sampling are missing; therefore, it is possible to have a good database, even if not fully complete, of their occurrence in the section.

In this study, revised distribution data and zonation of conodonts from the Silurian part of the section are presented. Our information is based on the restudy of Walliser's collection and from several new samples collected from the section, mainly from its upper part. This additional material is stored in the Palaeontological and Geological museum 'Domenico Lovisato' of Cagliari University. Conodonts from a few samples stored in Lund University were also considered.

It should be noted that the biostratigraphy of the Upper Ordovician part of the section has been revised by Ferretti & Schönlaub (2001), and the

study of the Lochkovian part based on a new detailed sampling by M.G. Corrigan and C. Corradini is in progress.

In terms of diversity, Walliser (1964) paper reported the occurrence of 83 morphospecies from the Silurian part of the section; our revision now demonstrates the presence of 70 taxa (species and sub-species) belonging to 23 genera: *Ancoradella*, *Apsidognathus*, *Aspelundia?*, *Aulacognathus*, *Belodella*, *Coryssognathus*, *Dapsilodus*, *Decoriconus*, *Distomodus*, *Dvorakia*, *Kockelella*, *Oulodus*, *Ozarkodina*, *Panderodus*, *Pedavis*, *Pelekysgnathus*, *Polygnathoides*, *Pseudolonchodina?*, *Pseudooneotodus*, *Pterospathodus*, *Walliserodus*, *Wurmiella*, *Zieglerodina*. The occurrence of all these taxa is shown in Figures 4–6.

Conodont zones in the Cellon section

The conodont fauna allows the discrimination of 15 biozones from the upper Llandovery to the end of the Přídolí (Figs 3–6). However, some of the uppermost Llandovery and Wenlock biozones, most probably corresponding to unsampled black shale intervals, have not been documented (Fig. 3).

The conodont zones now recognized in the Cellon section are briefly discussed below. For each zone, its original definition, interval in the Cellon section, occurrence of the most characteristic taxa and a few comments, if necessary, are provided. The complete conodont distribution data are provided in Figures 4–6.

Pterospathodus celloni Superzone, Männik (2007)

The superzone corresponds to the interval between the first appearance datum (FAD) of *Pt. amorphognathoides angulatus* below and *Pt. a. amorphognathoides* above and evidently correlates with the interval of total range of *Pt. celloni* (Männik 2007). In the Cellon section, *Pt. celloni* appears in sample W735 (10allg.) evidently marking the lower boundary of the *Pt. celloni* Superzone (SZ) (Fig. 4). However, as there are no data from strata over a thickness of several metres (from beds 8 and 9) and the next sample below comes from bed 7 (yielding elements of an Ordovician conodont *Amorphognathus* sp., Walliser 1964), the lower boundary of the *Pt. celloni* SZ can only be drawn just below sample 10allg. tentatively. In reality, it could be at any level between the probable Ordovician–Silurian boundary at the base of bed 9 below (Walliser 1964) and

EPOCH AGE	Walliser (1964)	Aldridge & Schönlaub (1989)	Nowlan (1995)	Corradini & Serpagli (1999)	Jeppsson et al. (2006)	Ogg et al. (2008)	Cramer et al. (2011)	CELLON (this paper)	
Pridoli	"Oz. steinhorn. eosteinhorn."	<i>I. w. woschmidti</i>	<i>Oz. east. - O. e. det.</i>	<i>O. e. detortus</i>		<i>O. e. detortus</i>	<i>O. e. detortus</i>	Upper <i>O. e. det.</i>	
		<i>Oz. remscheid. eosteinhorn.</i>	<i>Oz. remscheid. IZ</i>			<i>Oz. remscheid. IZ</i>	<i>Oz. eosteinhorn. IZ</i>	Lower <i>O. e. detortus</i>	
									<i>Oz. eosteinhorn. IZ</i>
Ludlow	" <i>S. crispus</i> "	<i>Oz. crispera</i>	<i>Oz. crispera</i>	<i>Oz. crispera</i>	<i>Oz. crispera</i>	<i>Oz. crispera - Oz. snajdri IZ</i>	<i>Oz. crispera</i>	<i>Oz. crispera</i>	
	" <i>I. latialatus</i> "	<i>Oz. snajdri</i>	<i>Oz. snajdri IZ</i>	<i>Oz. snajdri</i>	<i>Oz. snajdri</i>		<i>Oz. snajdri IZ</i>	<i>Pe. latialata - Oz. snajdri IZ</i>	
	" <i>P. siluricus</i> "	<i>P. siluricus</i>	<i>P. siluricus</i>	<i>P. siluricus</i>	<i>P. siluricus</i>		<i>P. siluricus</i>	<i>P. siluricus</i>	
	"A. ploeckensis"	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	<i>A. ploeckensis</i>	
			NOT ZONED	<i>Oz. exc. hamata</i>	<i>K. v. variabilis</i> <i>Oz. exc. hamata</i>	NOT ZONED	<i>K. variabilis IZ</i>	<i>K. variabilis IZ</i>	
	" <i>Oz. crassa</i> "		<i>K. stauros</i>	<i>K. variabilis IZ</i> <i>K. crassa</i>	<i>Oz. excavata n.sp.S</i> <i>K. crassa</i>	<i>K. stauros</i>	<i>K. crassa</i>	<i>K. crassa</i>	
	Wenlock	"S. sagitta"	<i>Oz. bohémica bohémica</i>	<i>Oz. bohémica</i>	<i>Oz. bohémica</i>	UNZONED	<i>Oz. bohémica</i>	<i>K. ortus absidata</i>	Grey interval
						<i>C. murchisoni</i> <i>K. o. absidata</i>		<i>Oz. bohémica longa</i>	
						<i>Oz. s. sagitta</i>		<i>Oz. s. sagitta</i>	<i>Oz. s. sagitta</i>
		K. patula	<i>Oz. sagitta sagitta</i>	<i>Oz. s. rhenana - K. patula</i>	<i>Oz. s. rhenana</i>	<i>Oz. s. rhenana</i>	<i>K. o. ortus</i> 1	<i>Oz. s. rhenana</i>	<i>K. o. ortus</i>
<i>K. patula</i> 2							<i>K. walliseri</i>		<i>K. patula</i>
	<i>Oz. sagitta rhenana</i>	<i>K. ranuliformis IZ</i>	<i>K. ranuliformis IZ</i>	<i>K. ranuliform. SZ</i> <i>Pt. p. procerus SZ</i>	<i>Pt. s. rhen. 3</i>	<i>K. ranuliformis IZ</i>	<i>K. ranuliform. SZ.</i> <i>Pt. p. procerus SZ</i>	Grey interval	
				<i>Ps. bicornis SZ</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>		
	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	<i>Pt. amorphognath.</i>	
Llandovery	<i>Pt. celloni</i>	<i>Pt. celloni</i>	<i>Pt. celloni</i>			<i>Pt. celloni</i>	<i>Pt. am. lith.</i> <i>Pt. am. lennarti</i> <i>Pt. am. angulatus</i>	<i>Pt. am. lith. - Pt. am. lennarti</i> <i>Pt. am. angulatus</i>	
		<i>D. staurogath.</i>	<i>Pr. tenuis - D. staurogath.</i>			<i>Pt. eopennatus</i>	<i>Pt. eopennatus</i>	Grey interval	
		<i>D. kentuckyensis</i>	<i>D. kentuckyensis</i>			<i>D. staurogath.</i>	<i>D. staurogath.</i>		
						<i>Pr. tenuis</i>	<i>Pr. tenuis</i> <i>Asp.? expansa</i>		
			<i>O. nathani</i>			<i>D. kentuckyensis</i>	<i>D. kentuckyensis</i>		
						<i>O. nathani</i>			

Fig. 3. Comparison of the main Silurian zonal schemes published earlier with the zonation recognized in the Cellon section. For discussion, see the text. Grey intervals correspond to zones not recognized in the Cellon section. 1 – *K. o. ortus* SZ; 2 – Upper *K. walliseri* SZ; 3 – *O. s. rhenana* SZ. Abbreviations: IZ – Interval Zone; SZ – Superzone; A. – *Ancoradella*; am. – *amorphognathoides*; amorphognath. – *amorphognathoides*; Asp. – *Aspelundia*; C. – *Ctenognathodus*; det. – *detortus*; D. – *Distomodus*; e. – *elegans*; eosteinhorn. – *eosteinhornensis*; exc. – *excavata*; I. – *Icriodus*; K. – *Kockelella*; lith. – *lithuanicus*; O. – *Oulodus*; o. – *ortus*; Oz. – *Ozarkodina*; P. – *Polygnathoides*; Pe. – *Pedavis*; p. – *pennatus*; Pr. – *Pranognathus*; Ps. – *Pseudooneotodus*; Pt. – *Pterospathodus*; ranuliform. – *ranuliformis*; remscheid. – *remscheidensis*; rhen. – *rhenana*; s. – *sagitta*; S. – *Spathognathodus*; staurogath. – *staurogathoides*; steinhorn. – *steinhornensis*; v. – *variabilis*; w. – *woschmidti*.

sample 10allg. above. The lowermost *Pt. a. amorphognathoides* in the section has been found in sample Wa1709 (10J). In reality, two samples, Wa1709 (dominated by specimens of *Pt. a. amorphognathoides*) and W740 [in Walliser (1964) indicated as sample 10J, dominated by *Pt. celloni*] were processed from the bed 10J. It is evident that one of them (W740) comes from the lower part of the bed

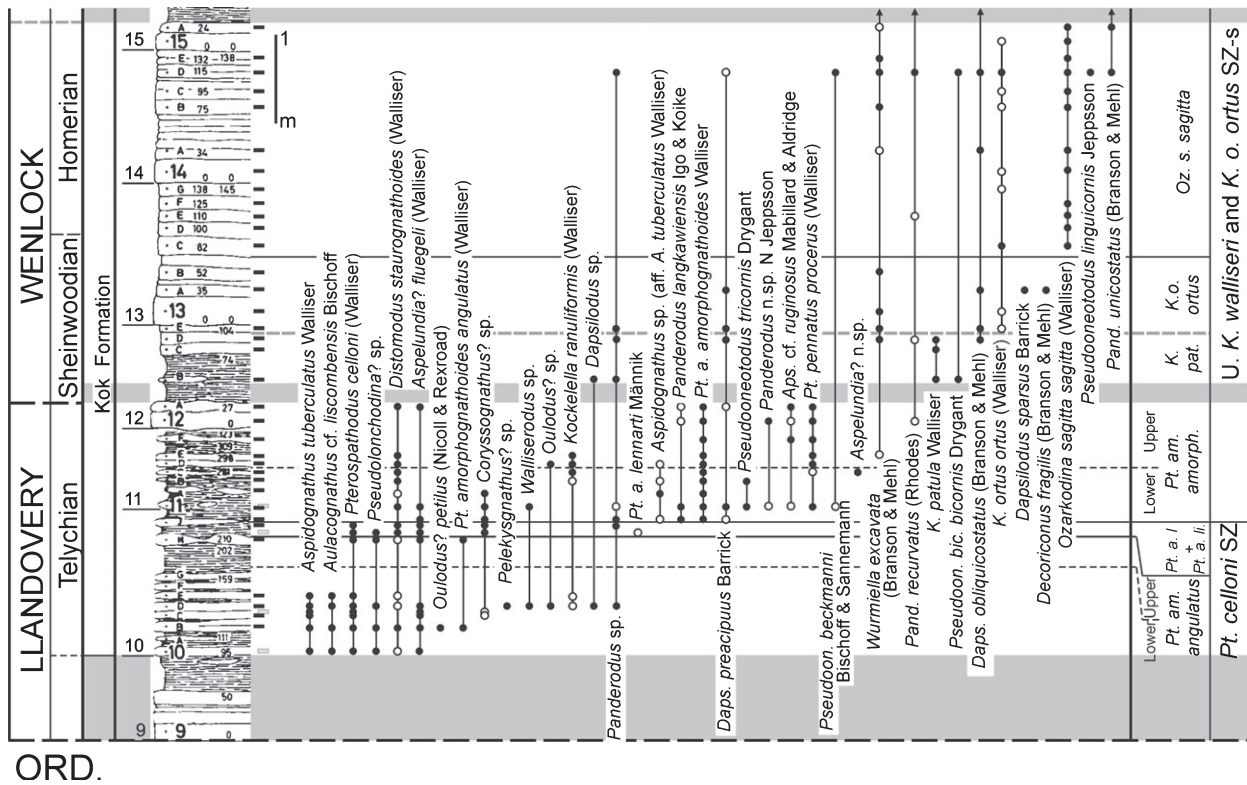


Fig. 4. Distribution of conodonts in the Llandoverly and Wenlock parts of the Cellon section. From left to right: series, stage, formation, bed numbers, lithological log (after the original drawing by Walliser 1964), samples (grey squares indicate samples for which the precise position in the section is not known), distribution of taxa (white dots indicate problematic identifications), sub-zones, zones, superzones. Arrows at the end of distribution lines indicate that the taxon also occurs above the illustrated interval. Horizontal lines mark boundaries of chrono-/litho-/biostratigraphical units: dashed line – position of the boundary is probable. Horizontal grey belts – strata not dated, several biostratigraphic units have not been identified.

and the other one (Wa1709) from the upper part of it. Hence, the boundary between the *Pt. celloni* SZ and the *Pt. a. amorphognathoides* Zone lies in bed 10J.

Three zones, *Pt. a. angulatus*, *Pt. a. lennarti* and *Pt. a. lithuanicus*, correspond to the *Pt. celloni* SZ (Männik 2007).

Pterospathodus amorphognathoides angulatus Zone, Männik (2007)

The *Pt. a. angulatus* Zone corresponds to the interval of the total range of the nominal species (Männik 2007). *Pt. a. angulatus* dominates in the inner shelf carbonate-terrigenous facies, but is sporadic in distal graptolite-bearing facies, where *Dapsilodus* is common and *Pt. celloni* appears and occurs together with *Pt. a. angulatus*. In the Cellon section, the appearance of *Pt. a. angulatus* in sample (bed) 10B indicates that this level lies already in the *Pt. a. angulatus* Zone, the appearance of *Pt. celloni* at a lower level, in sample 10allg., indicates that the lower boundary of the zone should be looked for below that sample (see above).

Two sub-zones, the Lower and Upper *P. a. angulatus* sub-zones, were distinguished in the *P. a. angulatus* Zone. The boundary between these sub-zones was drawn at the level of the appearance of *Ozarkodina* sp. n. (Männik 2007). Additionally, *Apsidognathus* disappears temporarily (reappears in the lowermost *Pt. a. amorphognathoides* Zone) at this level and *Pelekysgnathus?* sp. occurs in the Lower *Pt. a. angulatus* Sub-zone. No *Ozarkodina* has been found in this interval in the Cellon section, but the continuous occurrence of *Apsidognathus tuberculatus* in beds 10allg.–10E, and of *Pelekysgnathus?* sp. in bed 10D, evidently suggest that this interval corresponds to the Lower *Pt. a. angulatus* Sub-zone and the boundary between the Lower and Upper *Pt. a. angulatus* sub-zones lies between samples 10E and 10H (Fig. 4).

Pterospathodus amorphognathoides lennarti and *Pterospathodus amorphognathoides lithuanicus* zones, Männik (2007)

The *Pt. a. lennarti* Zone corresponds to the interval of the total range of *Pt. a. lennarti* (Männik 2007).

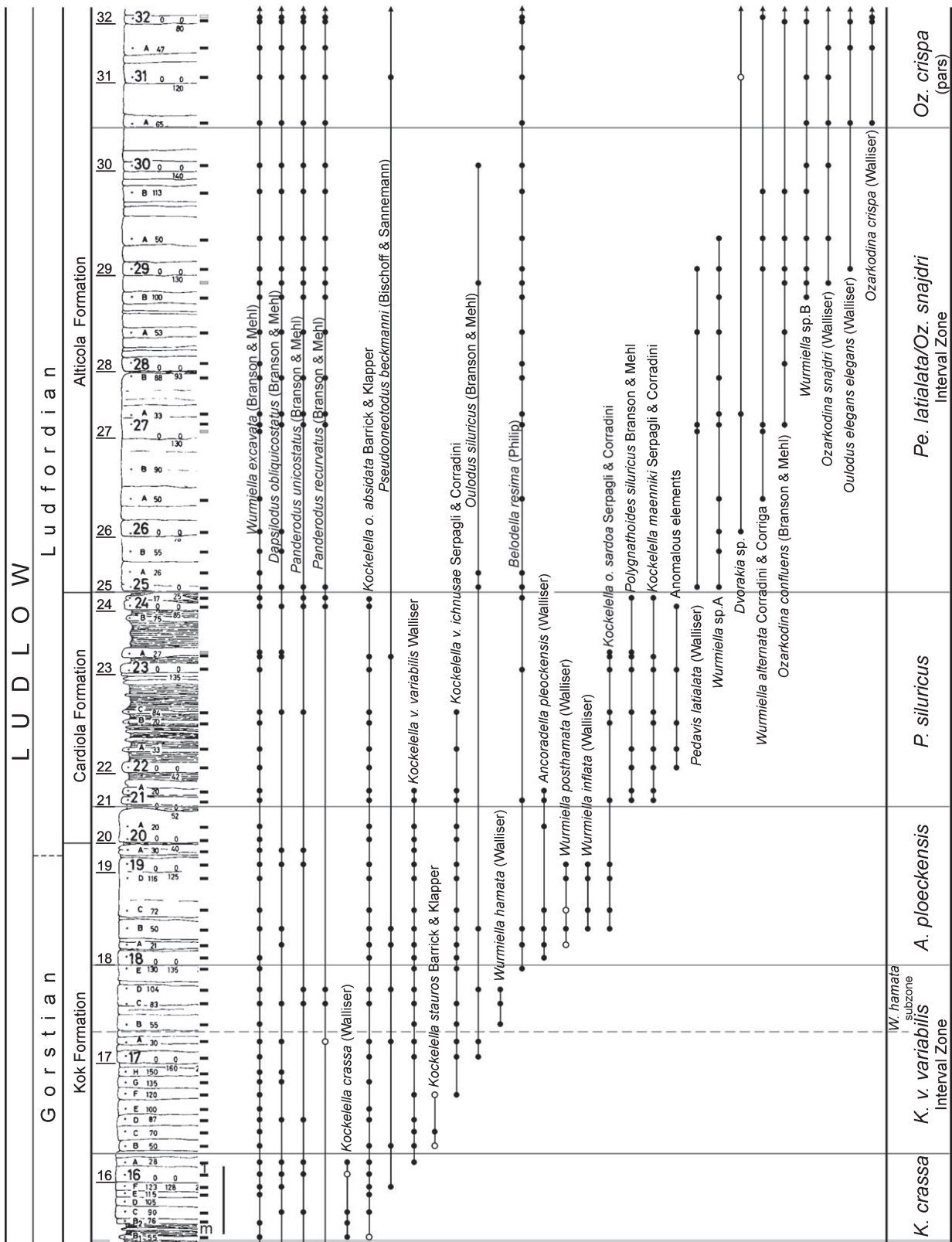


Fig. 5. Distribution of conodonts in the Ludlow part of the Cella section. From left to right: series, stage, formation, bed numbers, lithological log (after the original drawing by Walliser 1964), samples (grey squares indicate samples which precise position in the section is not known), distribution of taxa (white dots indicate problematic identifications), zones. Arrows at the end of distribution lines indicate that the taxon also occurs above/below the illustrated interval. Horizontal lines mark boundaries of chrono-/litho-/biostratigraphical units.

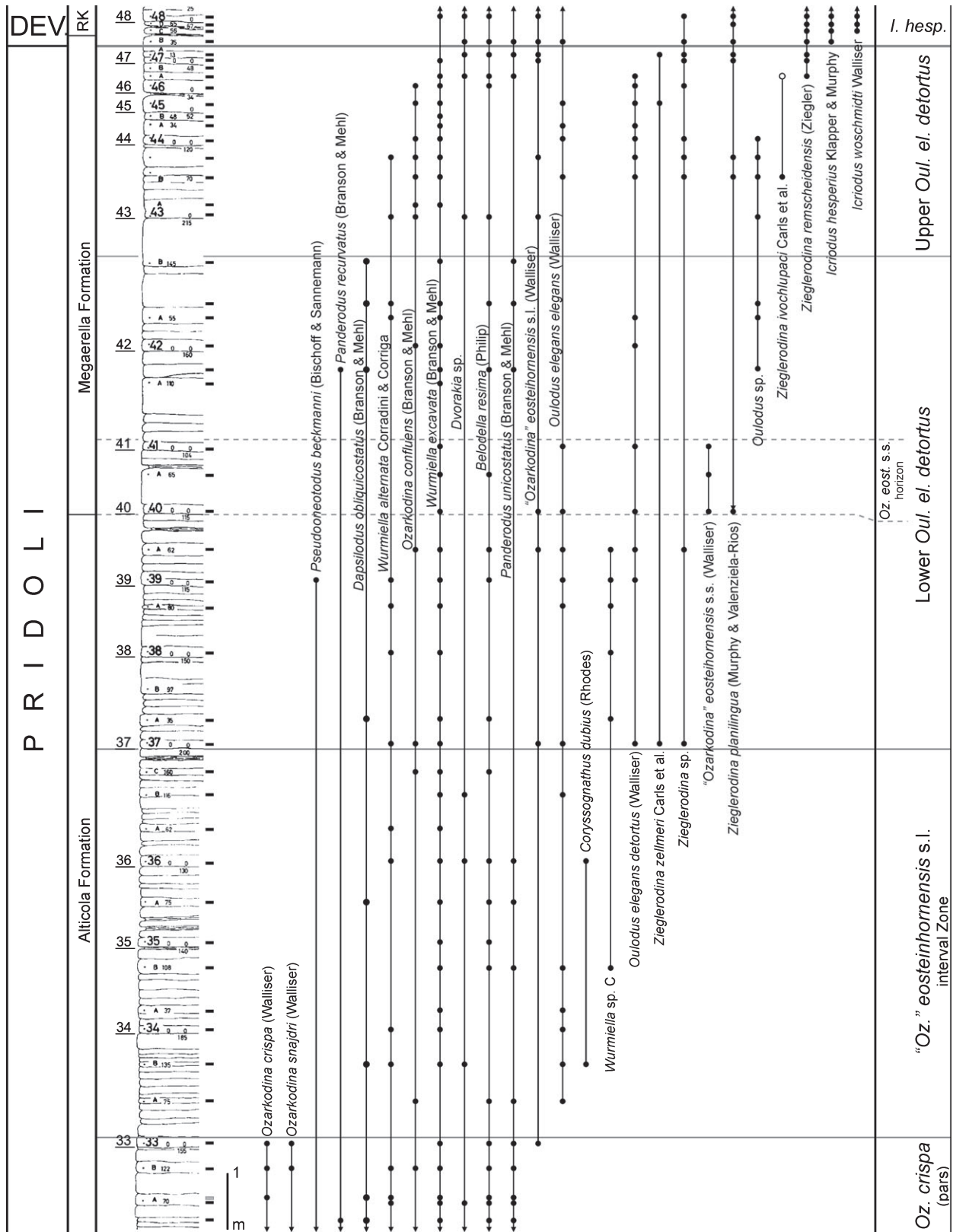


Fig. 6. Distribution of conodonts in the Prídolí part of the Cellon section. From left to right: series, formation, bed numbers, lithological log (after the original drawing by Walliser 1964), samples (grey squares indicate samples which precise position in the section is not known), distribution of taxa (white dots indicate problematic identifications), zones. Arrows at the end of distribution lines indicate that the taxon also occurs above/below the illustrated interval. Horizontal lines mark boundaries of chrono-/litho-/biostratigraphical units.

In the Cellon section, only one fragment of *Pt. a. lennarti* has been found (in sample 10H/J). Its precise position in the section is not known to us, but H/J might indicate that this sample yields (rock) material from both beds 10H and 10J (in Fig. 4 this sample is indicated between these two beds). *Pt. a. lennarti* was not found in sample 10J (bed 10J). Accordingly, it is most probable that the boundary between the *Pt. a. angulatus* and *Pt. a. lennarti* Zones lies in bed 10H or in the shale between beds 10H and 10J.

As noted above, the lower boundary of the *Pt. a. amorphognathoides* Zone in the section occurs in bed 10J. The sample just below this boundary, from the lower part of bed 10J, is dominated by elements of *Pt. celloni*. No specimens of *Pt. amorphognathoides* were found. As it is known from elsewhere, the uppermost part of the *Pt. celloni* SZ corresponds to the *Pt. a. lithuanicus* Zone (Männik 2007). *Pt. a. lithuanicus* has not been found in the Cellon section. This might have two reasons: (1) *Pt. a. lithuanicus* is missing due to ecological conditions (*Pt. a. lithuanicus* is very rare in distal graptolite-bearing environments; Männik 2007); or (2) the strata corresponding to this zone are missing in the section. Additional sampling is needed to find out which explanation is correct. Tentatively, in Figure 4, the interval from the sample 10H/J up to the lower boundary of the *Pt. a. amorphognathoides* Zone above is correlated with the *Pt. a. lennarti* and *Pt. a. lithuanicus* zones.

Pterospathodus amorphognathoides amorphognathoides Zone, Walliser (1964)

According to Jeppsson (1997), the *Pt. a. amorphognathoides* Zone forms the lower (main) part of the *Pt. a. amorphognathoides* Zonal group. The zonal group corresponds to the total range interval of *Pt. a. amorphognathoides*. In its uppermost part, the Lower and Upper *Pseudooneotodus bicornis* zones were separated. The *Pt. a. amorphognathoides* Zone corresponds to the interval between the appearance of *Pt. a. amorphognathoides* below and Datum 1 of the Ireviken Event (the level of disappearance of *Nudibelodina sensitiva* Jeppsson) above. At or very close to the lower boundary of the zone *Apsidognathus*, which is missing in the upper half of the *Pt. celloni* SZ, is known to reappear (Männik 2007). In the *Pt. a. amorphognathoides* Zone, this genus is usually represented by *A. walmsleyi* Aldridge and *A. ruginosus*. In the Cellon section, *Pt. a. amorphognathoides* appears in the upper part of bed 10J (in sample Wa1709) and its uppermost specimens in the section come from bed 12A (Fig. 4). Together

with *Pt. a. amorphognathoides*, poorly preserved specimens of *Apsidognathus* appear and are identified here as *Apsidognathus* sp. (aff. *A. tuberculatus*), somewhat higher in the section *A. cf. ruginosus* and *Pt. pennatus procerus* are also present. However, as *N. sensitiva* has not been found in this section, the level of the upper boundary of the *Pt. a. amorphognathoides* Zone remains problematic here. It may lie in the upper (most) part of the *Pt. a. amorphognathoides* range or higher in the section, in the unsampled shales between beds 12A and 12B. As the uppermost sample with *Pt. a. amorphognathoides* also yields *Apsidognathus* (*A. cf. ruginosus*), it is evident that this sample comes from an interval below Datum 2 of the Ireviken Event (marked by the disappearance of *Apsidognathus* together with some other taxa and corresponding to the boundary between the Lower and Upper *Ps. bicornis* zones, Jeppsson 1997).

Aspelundia fluegeli, common in the *Pt. celloni* SZ, disappears in the basal part of the *P. a. amorphognathoides* Zone. It reappears briefly in the middle part of the zone (in the Cellon section in bed 11C) where it is represented by another species, *Aspelundia?* n. sp. (Fig. 4; Männik 2007). The level of disappearance of this taxon corresponds to the boundary between the Lower and Upper Sub-zones of the *P. a. amorphognathoides* Zone. Elsewhere, *Aspelundia* has not been found above this level. The occurrence of *A. fluegeli* in a sample from bed 12A in the Cellon section is unusual and difficult to explain: either this is real occurrence and *Aspelundia* reappears in the uppermost *Pt. a. amorphognathoides* Zone or this presents some mistreatment during sample processing in laboratory.

Kockella patula Zone, Walliser (1964)

The zone corresponds to the total range of *K. patula* (Jeppsson 1997); in the Cellon section to beds 12B–12D. In this interval, the fauna is dominated by *K. patula*. According to Jeppsson (1997), *K. patula* Zone forms the middle part of the Upper *K. walliseri* SZ; in Cramer *et al.* (2011), it is considered to be an equivalent of the central and upper parts of the *K. walliseri* Zone. Other zones of the Upper *K. walliseri* SZ *sensu* Jeppsson (1997) and other intervals lying below (*Ozarkodina sagitta rhenana*, *K. ranuliformis*, *Pt. p. procerus* and *Ps. bicornis* superzones) known from elsewhere were not recognized in the Cellon section (Figs 3, 4). They might correspond to a gap or, at least some of them, to the unsampled interval of shales between beds 12A and 12B. *K. walliseri* has not been found in the Cellon section.

Kockelella ortus ortus Zone, Jeppsson (1997)

This zone corresponds to the interval between the FAD of *K. o. ortus* below and that of *Oz. s. sagitta* above. According to Jeppsson (1997), the zone forms the middle part of the *K. o. ortus* SZ. In the Cellon section, the *K. o. ortus* Zone seems to overlie directly the *K. patula* Zone indicating that the uppermost Upper *K. walliseri* SZ and the lowermost *K. o. ortus* SZ might be missing here (Figs 3, 4).

Ozarkodina sagitta sagitta Zone, Aldridge & Schönlaub (1989)

The zone corresponds to the interval of total range of *Oz. s. sagitta* (Jeppsson 1997; Jeppsson & Calner 2002). In the Cellon section, the zone is discriminated in beds 13C-15A by the occurrence of *Oz. s. sagitta* in the samples from these beds (Fig. 4). In this part of the section, the diversity of conodonts is very low, and many samples yielded only a monospecific association represented by *Oz. s. sagitta*. *Ps. linguicornis* Jeppsson has its only occurrence within this zone (in bed 14D), as documented also in other areas (Männik & Małkowski 1998; Männik 2003; Corradini 2008).

Kockelella crassa Zone, Walliser (1964)

The *K. crassa* Zone corresponds to the interval of the total range of the marker *K. crassa* (Corradini & Serpagli 1999). In the Cellon section, the zone is discriminated in beds 15B1-16A. The base of this zone coincides with the base of the Ludlow series (Cramer *et al.* 2011). *Kockelella v. variabilis* Walliser enters in the upper part of this Zone.

Two zones, *Oz. bohemicus longa* and *K. o. absidata*, corresponding to the main part of Homerian have been recognized between the *Oz. s. sagitta* and *K. crassa* zones (Cramer *et al.* 2011; Fig. 3). Both of them seem to be missing in the Cellon section. They correspond to a gap in the section or lie in the narrow interval of shales between samples 15A and 15B1 (Figs 4, 5).

Kockelella variabilis variabilis Interval Zone, Cramer *et al.* (2011)

The *K. v. variabilis* Interval Zone is recognized in beds 16B-17E. The lower boundary is marked by the last occurrence of *K. crassa* and the upper boundary by the entry of *Ancoradella ploeckensis*. Rare specimens of *K. stauros* occur in the lower part of the Zone. *K. variabilis ichnusae* Serpagli & Corradini has its first occurrence in the lower part of the zone.

It is possible to discriminate an interval characterized by *Wurmiella hamata* (Walliser) in the upper part of the zone. This interval was considered as a zone by Corradini & Serpagli (1999) on the basis of the occurrence of the nominal taxon in North Gondwana, Laurentia (Nevada) and Baltica (Gotland). However, as the index taxon is not reported from many other regions and, even if present, it is rare, it looks more appropriate to consider this interval as a sub-zone in the upper part of the *K. variabilis* Interval Zone (Fig. 5).

Ancoradella ploeckensis Zone, Walliser (1964)

The *A. ploeckensis* Zone is discriminated in samples 18–20A. The lower boundary is marked by the entry of *Ancoradella ploeckensis* and the upper boundary by the first occurrence of *Polygnathoides siluricus*. In the Cellon section, *Wurmiella posthamata* and *W. inflata* occur only in this zone, whereas elsewhere the latter taxon appears already in older strata (Corradini & Serpagli 1999; Corrigan *et al.* 2009). *Kockelella ortus sardoa* has its first occurrence in the central part of the zone.

Polygnathoides siluricus Zone, Walliser (1964)

This zone corresponds to the interval of total range of *P. siluricus* and is one of the zones with widest distribution in the Silurian: it has been indicated in all published zonal schemes and everywhere its boundaries are defined on the same criteria (Fig. 3). In the Cellon section, this zone is recognized in beds 20–24A and includes most of the *Cardiola* Fm. *A. ploeckensis* is still present in the lower part of the zone and genus *Kockelella* disappears within it but various species of the genus have different last occurrences: *K. v. variabilis* and *K. v. ichnusae* occur only in the lower part of the zone, *K. o. sardoa* reaches its upper part, while *K. o. absidata* and *K. maenniki* are present up to the top of the zone. The last species occurs only in this zone (Serpagli & Corradini 1999), but it usually does not reach its upper boundary. However, it should be noted that, as suggested by the presence of a hard ground just above sample 24A at the top of the *Cardiola* Fm., a short hiatus may occur, and likely the upper(most) part of the *P. siluricus* Zone is missing in the Cellon section.

Within this zone, a few anomalous elements, represented mainly by ramiforms with branched processes, are present. Such specimens are documented in various intervals in the Silurian and Lower Devonian, but are particularly abundant in the *P. siluricus*

Zone (Corradini *et al.* 1996; Slavík *et al.* 2010; Corrigan *et al.* 2014b).

Pedavis latialata – Ozarkodina snajdri Interval Zone

This zone corresponds to the interval of beds 25–30. Its lower boundary is defined by the last occurrence of *Polygnathoides siluricus* and the upper boundary by the first occurrence of *Ozarkodina crisa* (Walliser). For the reasons discussed above, we indicate this interval using names of the two most characteristic species occurring here: *Pe. latialata* (Walliser) and *Oz. snajdri* (Walliser). In the Cellon section, *Pe. latialata* occurs in the lower part of the zone, and *Oz. snajdri* appears in its upper part. The ranges of these two taxa overlap in a short interval (samples 28B–29).

Wurmiella sp. A, characterized by an asymmetrical P₁ element, occurs only in this zone; *W. alternata* and *Oz. confluens* appear in the lower part, and *Oulodus elegans elegans* and *Wurmiella* sp. B in the upper part of the zone. The latter species is characterized by a distinct enlargement of the blade of P₁ element, just below the insertion of denticles.

Ozarkodina crisa Zone, Walliser (1964)

The *Oz. crisa* Zone corresponds to the interval of total range of *Oz. crisa*, in the Cellon section to beds 30A–33. *Oz. eosteinhornensis* s.l. enters in the uppermost part of the zone, while *Oz. snajdri* became extinct at the top of the zone.

It should be noted that the last occurrence of *Oz. crisa* was often used to approximate the Ludlow/Prídoli boundary. However, the presence of *Monograptus parultimus* Jaeger just above sample 32 (Jaeger 1975) indicates that this zone spans the boundary and includes also the lowermost part of the Prídoli.

‘Ozarkodina’ eosteinhornensis s.l. Interval Zone, Corrigan & Corradini (2009)

The ‘Oz.’ *eosteinhornensis* s.l. Interval Zone is discriminated in beds 33A–36C. The lower boundary of the zone is defined by the last occurrence of *Oz. crisa* and the upper boundary by the first occurrence of *O. e. detortus* (Corradini & Corrigan 2012). *Corysognathus dubius* has its only occurrence at Cellon section within this zone; *O. e. elegans* appears at the base of the zone and *Wurmiella* sp. C (characterized by strongly reclined denticles on the P₁ element), in the central part of it.

Lower Oulodus elegans detortus Zone, Corradini & Corrigan (2012)

The lower boundary of the Lower *O. e. detortus* Zone is defined by the first occurrence of *O. e. detortus* and the upper boundary by the last occurrence of *Dapsilodus obliquicostatus* (Corradini & Corrigan 2012). In the Cellon section, the zone has been discriminated in beds 37–42B. The occurrence of ‘Oz.’ *eosteinhornensis* s.s. in the central part of the zone marks a well-defined horizon, about one metre thick (beds 40–41), that can be used for correlations (see discussion in Corradini & Corrigan 2012, p. 647). *Zieglerodina planilingua* enters within this horizon and ranges up to the Devonian, as also in other regions (i.e. Morocco, Corrigan *et al.* 2014a,b; Sardinia, Corrigan *et al.* 2009; Corradini & Corrigan 2012). *Wurmiella* sp. C is present in the lower part of the zone, below the ‘Oz.’ *eosteinornensis* s.s. horizon. Rare specimens of *Z. zellmeri*, and some other still undescribed species of *Zieglerodina*, appear at the base of the zone.

Upper Oulodus elegans detortus Zone, Corradini & Corrigan (2012)

The Upper *O. e. detortus* Zone has been discriminated in beds 43–47A. Its lower boundary is marked by the last occurrence of *Daps. obliquicostatus* and the upper boundary by the first occurrence of *Icriodus hesperius* (Corradini & Corrigan 2012). Rare specimens of *Z. ivochlupachi* occur within the zone. *W. alternata* disappears within the zone, and *Oz. confluens* in the upper part of the zone, just below the level of the first occurrence of *Z. remscheidensis*, which enters just below the upper boundary. *Z. zellmeri* is present up to the top of the zone.

The occurrence of *I. hesperius* in bed 47 B marks the base of the *I. hesperius* Zone. This level coincides with the base of the Devonian (Carls *et al.* 2007; Corradini & Corrigan 2012).

Conclusions

The main results of this study can be summarized as follows:

- The conodont association from the Silurian of Cellon section has been revised. Seventy taxa (species and sub-species) belonging to 23 genera were recognized.
- The conodont fauna allows the discrimination of 15 biozones in the interval from the upper Llanoverly to the end of the Prídoli. However, some

of the zones known from the uppermost Llandovery and Wenlock have not been documented. Most probably, they correspond to the unsampled intervals of black shale.

In terms of biostratigraphy, the zonation applied in this study differs from the recently published zonation in that:

- To incorporate recently published data on conodont biostratigraphy, the interval between the last occurrence of *Polygnathoides siluricus* and the first occurrence of *Ozarkodina crispa* is dealt as the *Pe. latialata*–*Oz. snajdri* Interval Zone;
- It appears that the uppermost part of the *Oz. crispa* Zone corresponds to the lowermost Přídolí; *Oz. crispa* has been found above the first occurrence of *Monograptus parultimus* Jaeger (the index taxon for the base of the Přídolí).

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