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Cambrian (Series 3 – Furongian) conodonts from the Alum Shale Formation at Slemmestad, Oslo Region, Norway

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Nine samples from the Alum Shale of Slemmestad, Oslo Region, were processed for conodonts. The limestone-rich interval extending from the mid Cambrian *Paradoxides paradoxissimus* trilobite Zone to the Lower Ordovician *Boeckaspis* trilobite Zone yielded a sparse conodont fauna. The fauna is dominated by the protoconodont species *Phakelodus elongatus* (Zhang in An et al., 1983) and *Phakelodus tenuis* Müller, 1959, the paraconodont species *Westergaardodina polymorpha* Müller & Hinz, 1991, *Westergaardodina ligula* Müller & Hinz, 1991, *Problematoconites perforatus* Müller, 1959 and *Trolmenia acies* Müller & Hinz, 1991; the euconodont species *Cordylodus proavus* Müller, 1959 is present in the *Acerocarina* Superzone. The presence of the cosmopolitan *Cordylodus proavus* Müller, 1956 at Slemmestad provides an important tie for regional and international correlation.

Keywords: Conodonts, Alum shale, upper Cambrian, Oslo Region, Norway

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Introduction

Records of Cambrian conodonts are rare in Norway, but also an unexplored topic relative to other Cambrian faunal components such as trilobites. The first mention of Furongian (late Cambrian) euconodonts from the Oslo Region was by Bruton et al. (1982; i.e., named *Cordylodus* sp.). Later, Bruton et al. (1988) described a conodont fauna composed of *Cordylodus proavus* Müller, 1959 and *Eoconodontus notchpeakensis* Miller, 1969, both recorded from the *Acerocare ecorne* trilobite Zone at the Nærnæs section near Slemmestad in the Oslo Region (Fig. 1). As the investigated interval concentrated on the Cambrian–Ordovician boundary, it is uncertain whether the presence of *C. proavus* in the *A. eocorne* Zone represented the first occurrence of the conodont taxa in the succession or if the first occurrence should be present at a lower trilobite horizon.

In 2006 and 2013, nine samples, five to seven kilos each, were collected representing the interval from the Middle Cambrian, and from the Upper Cambrian in Slemmestad, with the purpose to investigate the conodont faunal succession. All samples contained conodonts, although with a very low yield.

This paper presents and expands our knowledge of the distribution of Cambrian conodonts in the Oslo District. In addition, the first appearance of *Cordylodus proavus* in the late Cambrian of the Oslo Region (Bruton et al., 1988) is confirmed and the significance and precise match with the existing trilobite zonation is outlined.

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Alum Shale Formation

The Alum Shale Formation (the type section: Gislövshammar-2 core, southern Sweden; Andersson et al., 1985; Bergström & Gee, 1985; Buchardt et al., 1997) consists of bituminous brown to black shale and mudstone with alternating limestone and siltstone beds. Bituminous limestone concretions (antraconites) occur as discontinuous to semicontinuous lenses throughout the entire formation (Martinsson, 1974). The Alum Shale Formation is uniformly developed and covered an area extending from western Norway to St. Petersburg in the east and from Poland in the south to Finmark in northern Norway at its maximum extent (Bergström & Gee, 1985; Nielsen & Schovsbo, 2006). The high content of organic carbon suggests anoxic depositional conditions in a shallow-marine environment (Thickpenny, 1984, 1987; Buchardt et al., 1997) with sedimentation rates as low as 1 mm per 1000 years (Bjørlykke, 1974).

Due to the high content of carbon, the Alum Shale Formation is considered a good source rock (Buchardt et al., 1997); however, the deposits of the Alum Shale Formation in the Oslo Region have been exposed to high temperatures due to Permian intrusions and the source-rock potential is lost (Pedersen et al., 2006, 2007). The Alum Shale is also characterised by its high content of trace elements, mainly uranium and vanadium (Bergström & Gee, 1985).

The Alum Shale Formation is renowned for its rich fossil fauna of olenid, agnostoid and polymerid trilobites (Westergård, 1922, 1946, 1947; Henningsmoen, 1957; Ahlberg, 2003; Terfelt et al., 2008, 2011; Ahlberg & Terfelt, 2012; Nielsen et al., 2014). Trilobites are almost always absent in the shale, but present in the limestone nodules, sometimes in abundance and have been studied for many years (e.g., Brøgger, 1882; Westergård, 1922, 1946; Henningsmoen, 1957). Substantial work with respect to systematic description of the trilobite fauna, which through several stages of amendments (Ahlberg & Terfelt, 2012; Høyberget & Bruton, 2012; Terfelt et al., 2011), has resulted in the current accepted scheme (Nielsen et al., 2014). The Alum Shale Formation comprises the strata from mid Cambrian (Series 3) to close to the top of the Lower Ordovician Tremadocian Series (Westergård, 1922, 1947; Høyberget & Bruton, 2012).

In Scania, Sweden, and the Oslo Region, Norway, the Upper Cambrian *Acerocarina* Superzone is completely developed, whereas most or parts of this upper superzone are missing in other regions of Baltoscandia (Nielsen et al., 2014; Terfelt et al., 2014).

The Oslo Region

The Oslo Region is located within a graben structure, formed during the Carboniferous–Permian extensional rifting (Neumann et al., 2004). The width varies from 35 to 65 km and is bordered by major normal fault zones to the east (Neumann et al., 2004). The graben of the Oslo Region extends over a distance of about 200 km to the north and south of Oslo starting in the south from Langesundsfjorden to the northernmost part of the Mjøsa district (Fig. 1). The Oslo Region is well known for its variety of rocks comprising Lower Palaeozoic and Upper Carboniferous sedimentary rocks and Upper Carboniferous to Permian igneous rocks.

Due to the graben structure, the Lower Palaeozoic deposits are extensively preserved in the Oslo Region. Following the rifting, these deposits were covered by erosional material from the surrounding horst area and by volcanic and magmatic rocks (Andersen, 1998). The Lower Palaeozoic strata in the northern part of the Oslo Graben were strongly deformed and folded during the Scandian phase of the Caledonian orogeny (Bruton et al., 2010), while the southern part is strongly affected by Permian magmatism.

In Norway, the Cambrian deposits occur locally as autochthonous strata or in successions within nappes of the Caledonian Lower Allochthon (Bergström & Gee, 1985). The Alum Shale has functioned as a basal thrust plane for the lower nappe units and is overall deformed and thermally altered (Bruton & Owen, 1982; Bergström & Gee, 1985; Gabrielsen et al., 2005).

Stratigraphy

The Cambrian–Ordovician succession of the Oslo Region is composed mainly of clastic sedimentary rocks (Bruton et al., 2010). The mid Cambrian to earliest Ordovician deposition in the region was characterised by calm conditions and the sedimentary rocks are assigned to the Alum Shale Formation and Bjørkåsholmen Formation (Owen et al., 1990).

The Upper Cambrian trilobite zonation for the Oslo Region (Henningsmoen, 1957; Høyberget & Bruton, 2012) and now updated by Nielsen et al. (2014) is used as a reference for correlation (Fig. 2).

The Alum Shale Formation directly overlies the basement or an unnamed arkose unit. It consists of shale, siltstone and prominent limestone nodules with a high concentration of organic carbon. The Alum Shale ranges in thickness from about twenty to almost a hundred metres (Owen et al., 1990) in the Oslo Region, and the anthraconite concretions can be extremely fossiliferous, dominated by olenid trilobites (Henningsmoen, 1957; Høyberget & Bruton, 2012).

The Lower Ordovician Bjørkåsholmen Formation (formerly known as Ceratopyge shale and limestone)

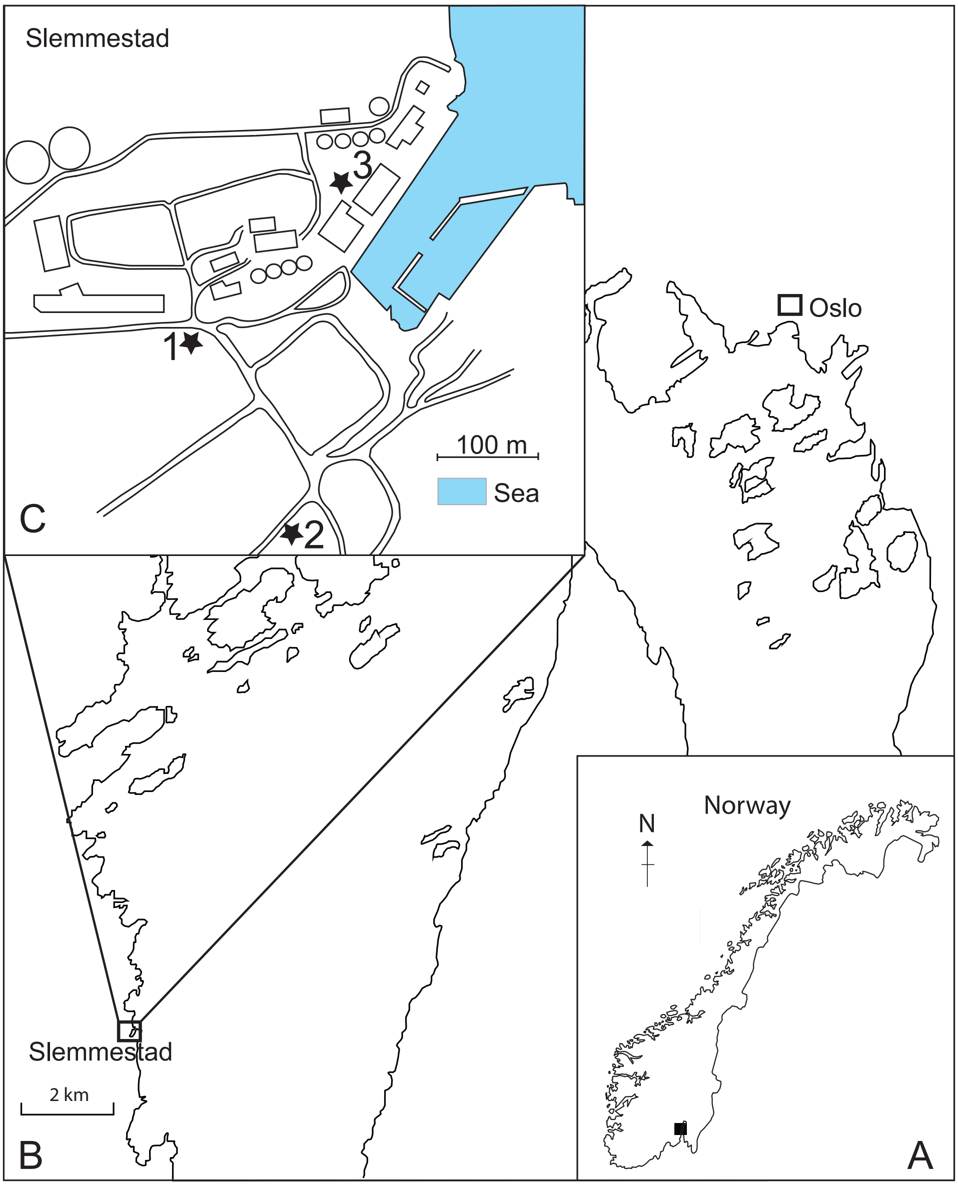

Figure 1. (A, B) Location map with geographical details of the Oslo Region. (C) Location of sample collection sites. 1 – PEL13, 2 – GIBB13, 3 – KAM1; 2, 4–7. Map modified from Rasmussen et al., 2015.

conformably overlies the Alum Shale Formation (Owen et al., 1990). The unit consists of dense to micritic limestone interbedded with shale; its thickness varies from 0.8 to 1.5 m (Ebbestad, 1999). The main faunal component is trilobites of the *Apatokephalus serratus* trilobite Zone (Ebbestad, 1999), and conodonts are referred to the *Paltodus deltifer* Zone. The unit is laterally extensive and present in much of Scandinavia.

Geology of the Slemmestad area

The Slemmestad area is located approximately 32 km southwest of Oslo. The sedimentary rocks are here preserved in the middle part of the Oslo Graben (Fig. 1), and the Lower Palaeozoic succession was strongly deformed and folded during the Caledonian orogeny. The Alum Shale Formation is exposed at several localities in the Slemmestad area (Fig. 1).

Localities

The investigated sections (59.780–59.783N 10.495–10.499E; Fig. 1) are composed of Alum Shale, c. 100 m thick, which overlies an arkose, usually less than 0.5 m thick and is the oldest strata around Slemmestad (Spjeldnæs, 1955, 1962). Locally, the arkose rests on a conglomerate with rare clasts of limestone and sandy to conglomeratic carbonaceous sediments. In some places there is also a conglomerate above the arkose with rare clasts of quartzite and conglomerate. The combined thickness of the arkose and conglomerate may be up to 1.5 m.

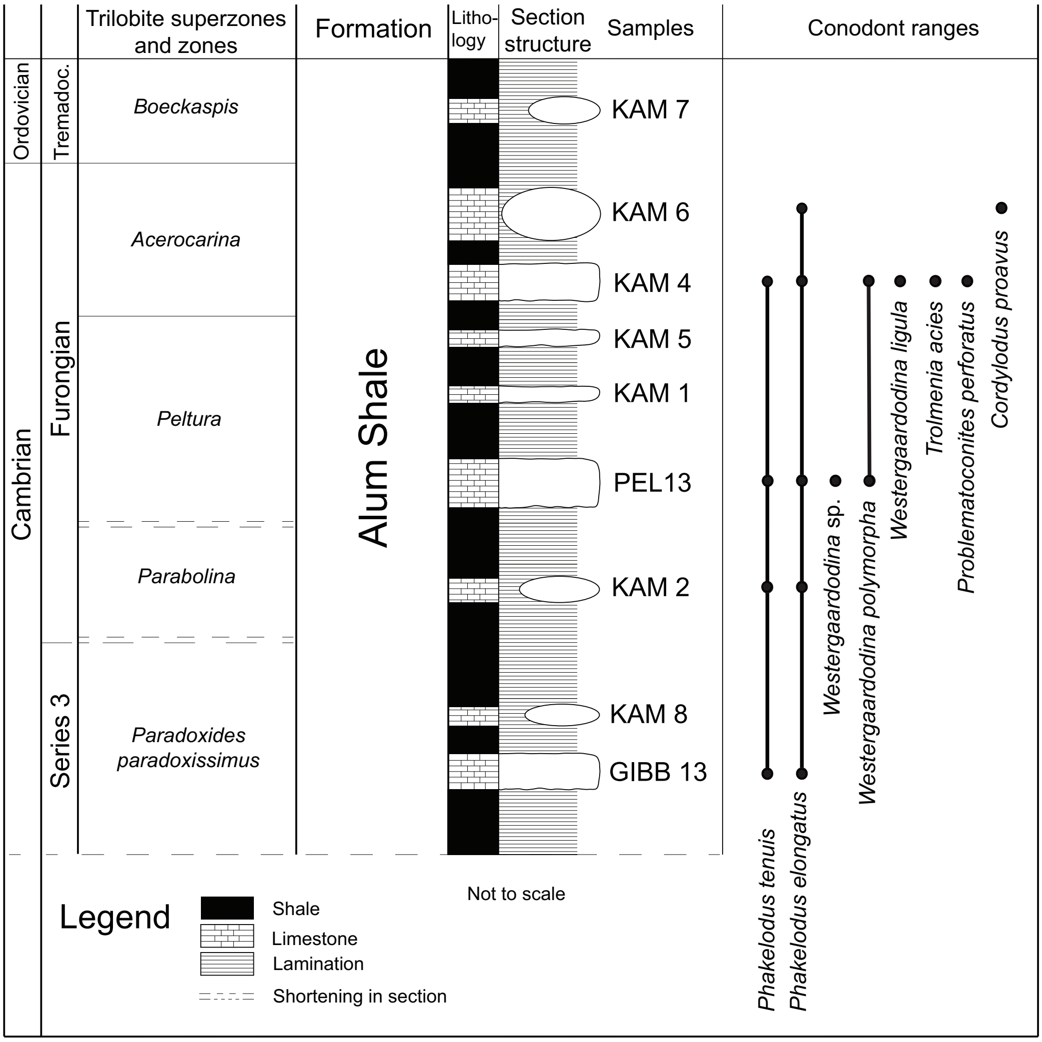

Figure 2. Composite section with samples and ranges of proto-, para- and euconodonts. Note that the section is not to scale, but arranged to conform with the order of the trilobite zones.

The Alum Shale succession extends from the *Paradoxides paradoxissimus* trilobite zone (mid Cambrian) to the Lower Ordovician (Tremadocian) *Boeckaspis* trilobite Zone.

Materials and methods

Material. – Nine samples, five to seven kilos each, collected from limestone-nodule rich levels with zonal trilobites (Fig. 2; Table 1).

Methods. – The samples were dissolved in diluted acetic acid (c. 10%) and five out of the nine samples yielded conodonts (Table 1). The acid-resistant residue from 63–500 µm was separated using heavy liquid in order to extract the euconodonts. The conodonts were hand-picked under stereomicroscope and the SEM was used for the illustration of the conodonts.

Conodont biostratigraphy

The Upper Cambrian trilobite zonation for the Oslo Region (Henningsmoen, 1957; Høyberget & Bruton, 2012) and now updated by Nielsen et al. (2014) is used as a reference for correlation (Fig. 2).

Conodont zones of northern Europe

The present acknowledged Furongian euconodont zonation of Baltoscandia comprises the *Proconodontus transitans, Proconodontus muelleri*, *Cordylodus andresi, Cordylodus proavus*, *C. caboti* and *C. intermedius* zones (Kaljo et al., 1986; Mens et al., 1996; Szaniawski & Bengtson, 1998; Bagnoli & Stouge, 2014; Terfelt et al., 2014; Fig. 3). These zones – or parts of them – are described and established from Estonia (Kaljo et al., 1986), western Russia (Popov et al., 1989), Lithuania and western Russia (Artyushkov et al., 2000), northern Poland

(Bednarczyk, 1979), Västergötland, central Sweden (Müller & Hinz, 1991; Szaniawski & Bengtson, 1998), Öland (Andres, 1981; Bagnoli & Stouge, 2014) and Skåne (Terfelt et al., 2014). The nominate taxa are recorded from the *Peltura scarabaeoides* trilobite Superzone (Szaniawski & Bengtson, 1998; Bagnoli & Stouge, 2014) with a possible extension into the lowermost *Acerocarina* Superzone (Andres, 1981; Nielsen et al., 2014). All these taxa, however, are older than the FO (First Occurrence) of *Cordylodus proavus* recorded by Bruton et al. (1982, 1988) and Terfelt et al. (2012) and in this study.

A hiatus is developed in central Sweden and the eastern Baltic area that covers the two or three lower trilobite zones of the *Acerocarina* Superzone (e.g., Martinsson, 1974; Mens & Pirrus, 1977; Szaniawski & Bengtson, 1998). Thus, the horizons with *Cordylodus proavus* recorded in Estonia and western Russia, the Oslo Region and in Scania, Sweden, are not represented in situ in central Sweden (Szaniawski & Bengtson, 1998; Löfgren & Viira, 2007). In addition, many records with *Cordylodus proavus* from Sweden and northern Germany are derived from loose blocks (Müller, 1959; Löfgren & Viira, 2007). The contained fauna recovered from the loose blocks commonly represents the *Cordylodus proavus* Zone, where *Cordylodus proavus* occurs together with *Eoconodontus notchpeakensis* in abundance (e.g., Löfgren & Viira, 2007). In addition, the species is also found in faunas where *Cordylodus proavus* occurs together with several younger species of *Cordylodus* (Löfgren, 1995). Van Wamel (1974) and Andres (1988) also reported *Cordylodus proavus* from antraconite nodules from the Lower Ordovician Djupvik Formation of the Alum Shale Formation.

In Scania, Sweden, the first record of the genus *Cordylodus* (listed as *Cordylodus* cf. *proavus*) is from the Södre Sandby section in the Alum Shale Formation. As in Norway, *Cordylodus proavus* occurs together with *Eoconodontus notchpeakensis* and thus the interval in the Södre Sandby section is largely coeval with sample KAM6 from Slemmestad. The first record of *Cordylodus proavus* is safely placed within the *Westergaardia* Zone in Scania (Terfelt et al., 2014).

In Estonia and the St. Petersburg region, the faunal succession *Cordylodus*? *andresi* Viira & Sergeyeva, 1987 (in Viira et al., 1987), *Cordylodus primitivus* Bagnoli et al., 1987, *Cordylodus proavus* followed by *Cordylodus caboti* Bagnoli et al., 1987 and *C. lindstromi* have been recorded in sandy deposits of the Kallavere Formation. There, and from its lateral equivalent deposits in the St. Petersburg area (Kaljo et al., 1986; Viira et al., 1987; Popov et al., 1989; Mens et al., 1996; Artyushkov et al., 2000), *Cordylodus proavus* is associated with common *Eoconodontus notchpeakensis*.

The *Cordylodus proavus* Zone has regional importance because it is chosen to mark the base of the Pakerort Regional Series (Kaljo et al., 1986). This implies that the base of the Pakerort Regional Series corresponds to the base of – or close to – the *Westergaardia* trilobite Zone of the *Acerocarina* Superzone of Scania, Sweden, and the Oslo Region, Norway.

The conodont fauna from the Slemmestad section

The conodont fauna from the Slemmestad section (Figs. 3–6) includes the protoconodonts *Phakelodus elongatus* (Zhang in An et al., 1983) and *Phakelodus tenuis* (Müller, 1959), the paraconodonts *Westergaardodina polymorpha* Müller & Hinz, 1991, *Westergaardodina ligula* Müller & Hinz, 1991, *Problematoconites perforatus*

Table 1. *Numerical distribution of conodont elements in the Slemmestad samples.*

Species	*GIBB13*	*KAM8*	*KAM2*	*PEL13*	*KAM1*	*KAM5*	*KAM4*	*KAM6*	*KAM7*	*Specimens total*
Sample weight (kg)	7	5	5	7	5	5	5	5	5	
Phakelodus elongatus	4		25			2		1		32
Phakelodus tenuis	1		12			2				15
Westergaardodina sp.			4							4
Westergaardodina polymorpha				2		7				9
Problematoconites perforatus						4				4
Trolmenia acies						1				1
Westergaardodina ligula						2				2
Cordylodus proavus								3		3
Sample total	5	0	41	2	0	18	0	4	0	70
Unidentified (fragments)				45		1				46

Müller, 1959 and *Trolmenia acies* Müller & Hinz, 1991. The euconodonts are all recorded from the uppermost *Acerocarina* Superzone and are referred to *Cordylodus proavus* Müller, 1959.

Kaljo et al. (1986), Popov et al. (1989), Szaniawski & Bengtson (1998) and Bagnoli & Stouge (2014) introduced para- and euconodont biozones for the Upper Cambrian (Furongian) and Lower Ordovician, which is used here as reference (Figs. 2 & 3).

The species from Slemmestad are all long-ranging taxa. At present, our knowledge of the distribution of paraconodonts is not yet ready for biozonation or detailed correlation (e.g., Müller & Hinz, 1991; Bagnoli & Stouge, 2014). However, similar paraconodont associations have been reported previously from most of the Upper Cambrian deposits in central Sweden and on Öland (Müller & Hinz, 1991; Szaniawski & Bengtson, 1998; Bagnoli & Stouge, 2014; Terfelt et al., 2014).

Bruton et al. (1982) and Bruton et al. (1988) recorded *Cordylodus proavus* together with a low diverse euconodont faunal assemblage from the Nærsnes section, close to Slemmestad. These authors focused on the Cambrian–Ordovician system boundary and thus investigated the interval ranging from the *Acerocare ecorne* Zone – the top zone of the *Acerocarina* Superzone – to the Lower Ordovician *Boeckaspis hirsuta* Zone. The conodont fauna from the uppermost *Acerocarina* trilobite Superzone includes the important euconodont species *Cordylodus proavus* and *Eoconodontus notchpeakensis,* and the conodont fauna was referred to the *Cordylodus proavus* conodont Zone *sensu* Kaljo et al. (1986).

The following anthraconite horizon with *Boekaspis hirsuta* yielded *Cordylodus proavus* and *Eoconodontus notchpeakensis* extending from below but now occurring together with *Cordylodus intermedius* Furnish, 1938, *Cordylodus lindstromi* Druce & Jones, 1971 and *Iapetognathus preaengensis* Landing in Fortey et al., 1982.

This younger conodont fauna is here referred to the *Cordylodus lindstromi* conodont Zone of Kaljo et al. (1986). Bruton et al. (1988) and Cooper et al. (1998) recorded and described the Early Ordovician graptolite succession starting from *Rhabdinopora praeparabola* (Bruton et al., 1982) to *Rhabdinopora parabola* (Bulman, 1954) from the shale just above the *Boekaspis*-yielding limestone nodule.

The latest Cambrian low diverse fauna from the Slemmestad section with the appearance of *Cordylodus proavus* in sample KAM6 is referred to the *Cordylodus proavus* Zone (*sensu* Kaljo et al., 1986; i.e., Furongian Series, uppermost Cambrian; Fig. 3). Unfortunately, the investigated sample KAM7 from the *Boeckaspis hirsuta* trilobite Zone was barren and thus no new data can be added to those already given by Bruton et al. (1988) from this trilobite zone.

SYSTEM	SERIES	STAGES	FORMATION	TRILOBITE SUPERZONES AND ZONES			CONODONT ZONES: NORWAY	SWEDEN		ESTONIA	Baltoscandia	
							Oslo Region	Västergötland Öland	Scania	North Estonia	Stage	Series
				Nielsen *et al.* 2014			Bruton *et al.* 1982 This study	Szaniawski & Bengtson 1998 Bagnoli & Stouge 2014	Terfelt *et al.* 2012	Kaljo *et al.* 1986 Viira *et al.* 1987 Mens *et al.* 1993		
ORDOVICIAN	Lower	Tremadocian	Alum Shale	*Boeckaspis*			*Cordylodus lindstromi s.l.*	Hiatus (reworked fauna)	not zoned	*Cordylodus lindstromi*	Pakertortian	Oelandian
CAMBRIAN	Furongian	Stage 10		*Trilobagnostus holmi*	*Acerocarina*	*Acerocare eocorne*	not recorded			*Cordylodus intermedius*		
							Cordylodus proavus		*Cordylodus proavus*	*Cordylodus proavus*		
						Westergaardia scanica	not recorded		not recorded	*Cordylodus andresi*		
						Peltura costata		*Cordylodus* aff. *C. andresi*		Hiatus		

Figure 3. *Correlation of the Slemmestad euconodont fauna. Conodont zones of the Baltoscadian Region (from Kaljo et al., 1986; Viira et al., 1987; Mens et al., 1993; Szaniawski & Bengtson, 1998; Bagnoli & Stouge, 2014). The trilobite zones are from Nielsen et al. (2014).*

Conclusions

The conodont fauna recorded from the Slemmestad section is composed of proto-, para- and euconodonts. The protoconodont succession begins in the lowermost sample, GIBB13, correlating with the *Paradoxides paradoxissimus* trilobite Superzone; it includes the species given in Table 1 and Fig. 3. *Phakelodus tenuis* has its upper range in sample KAM5, correlating to the *Peltura* Superzone, while *Phakelodus elongatus* is present in all the conodont-bearing samples (Fig. 3). In Scandinavia, *Phakelodus tenuis* and *Phakelodus elongatus* have been reported from older and age-equivalent deposits (Miller, 1984; Müller & Hinz, 1991, Bagnoli & Stouge, 2014; Terfelt et al., 2014).

The paraconodonts are present in three of the five conodont-bearing samples (Fig. 3; Table 1). The succession of the paraconodonts begins in sample KAM2 with one unidentifiable species of the genus *Westergaardodina* in the *Parabolina* Superzone. *Westergaardodina polymorpha* is present in samples PEL13 and KAM5, both representing the *Peltura* Superzone. The conodont fauna changes in sample KAM5 with a diverse fauna compared with the other samples (Fig. 3; Table 1). Here, *Westergaardodina ligula*, *Trolmenia acies* and *Problematoconites perforatus* are present. The paraconodont succession has its last occurrence in sample KAM5 within the *Peltura* Superzone, but the paraconodont species are long-ranging taxa and are reported from older as well as age-coeval deposits from Sweden (see Müller & Hinz, 1991; Bagnoli & Stouge, 2014, Terfelt et al., 2014).

The sample KAM6 yielded *Cordylodus proavus,* a species that is ranging from the *Westergaardia* to the *Acerocare* trilobite zones of the *Acerocarina* Superzone. Thus, the investigated sample of the *Cordylodus proavus* Zone may be referred to the *Westergaardia* trilobite Zone and/or the *Acerocare ecorne* trilobite Zone, as previously reported from the Oslo Region (i.e., Bruton et al., 1988).

The current study has provided new information on the distribution of conodonts in the Oslo Region and supported previous studies, as well as filling in faunal gaps in the Slemmestad section.

Taxonomical remarks

The small number of specimens recorded in this study does not provide any new significant information on the taxa already fully described by Müller & Hinz (1991) and Bagnoli & Stouge (2014); however, a few remarks on the material are presented here.

Repository. – Figured material is deposited in the palaeontological collection of the Natural History Museum, University of Oslo (collection acronym PMO).

Synonymy. – The synonymy presented here is representative for the northern European occurrences.

Phylum CHAETOGNATHA Leuckart, 1854

Order PROTOCONODONTIDA Landing, 1995

Genus *Phakelodus* Miller, 1980

Type species. – *Oneotodus tenuis* Müller, 1959.

Phakelodus elongatus Zhang in An et al., 1983

Fig. 4A, D, F, H, J–M

1983 *Proconodontus elongatus* n. sp. Zhang, F. in An et al., p. 125, pl. 5, figs. 4, 5.
1991 *Phakelodus elongatus* (Zhang, F. in An et al., 1983) – Müller & Hinz, pp. 32–33 (*cum syn.*).
1998 *Phakelodus elongatus* (Zhang, F. in An et al., 1983) – Müller & Hinz, pp. 99, fig. 6.3–6.5.

Remarks. – This taxon is fully described by Müller & Hinz (1991). The specimens at hand are slender, gently recurved, simple cones, which are rounded anteriorly and keeled posteriorly. The cross-section is tear-shaped at the base. A few semiclusters are also present but not illustrated.

Material. – 45 specimens.

Occurrence. – GIBB13 (4 specimens), KAM2 (25 specimens), PEL13 (13 specimens), KAM5 (2 specimens), KAM6 (1 specimen), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Paradoxides paradoxissimus* Superzone to the *Acerocarina* Superzone, mid to upper Furongian Series, Cambrian.

Phakelodus tenuis (Müller, 1959)

Fig. 4B, C, E, G, I

1959 *Oneotodus tenuis* n. sp. Müller, p. 457, pl. 13, figs. 13, 14, 20.
1991 *Phakelodus tenuis* (Müller, 1959) – Müller & Hinz, pp. 33–34 (*cum syn.*), pl. 1, figs. 6, 10, 11, 15–21, 23, pl. 2, figs. 1–24.
2009 *Phakelodus tenuis* (Müller, 1959) – Szaniawski, fig. 3B.
2014 *Phakelodus tenuis* (Müller, 1959) – Terfelt et al., ?fig. 6A.

Figure 4. (A, D, F, H, J–M) Phakelodus elongatus *Zhang in An et al., 1983. (A) PMO 221.739/40, lateral view; sample KAM5. (D) PMO 221.748/1, lateral view; sample PEL13. (F) PMO 221.737/5, lateral view; sample KAM2. (H) PMO 221.746/56, incomplete cluster; sample KAM2. (J) PMO 221.737/5, lateral view; sample KAM6. (K) PMO 221.746/22, postero-lateral view; sample KAM2. (L) PMO 227.742/25, lateral view; sample PEL13. (M) PMO 221.746/19, lateral view; sample KAM2. (B, C, E, G, I)* Phakelodus tenuis *(Müller, 1959). (B) PMO 221.742/40, lateral view; sample PEL13. (C), PMO 221.742/44, lateral view; sample PEL13. (E) PMO 221.737/5, posterior lateral view; sample KAM6. (G) PMO 221.746/17, incomplete cluster; sampleKAM2. (I) PMO 221.742/63, lateral view; sample PEL13. Scalebar represents 500 µm.*

Remarks. – The Slemmestad material consists of slender, gently recurved, simple cone elements, which are rounded anteriorly and posteriorly; the cross-section of the base is oval.

Material. – 47 specimens.

Occurrence. – GIBB13 (1 specimen), KAM2 (12 specimens), PEL13 (32 specimens), KAM5 (2 specimens), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Paradoxides paradoxissimus* Superzone to *Acerocarina* Superzone, mid to upper Furongian Series, Cambrian.

Phylum CHORDATA Bateson, 1886
Class CONODONTA Pander, 1856
(Class CONODONTA Eichenberg, 1930)

Order PARACONODONTIDA Müller, 1962

Genus *Problematoconites* Müller, 1959

Type species. – *Problematoconites perforata* Müller, 1959.

Problematoconites perforatus Müller, 1959

Fig. 6A–D

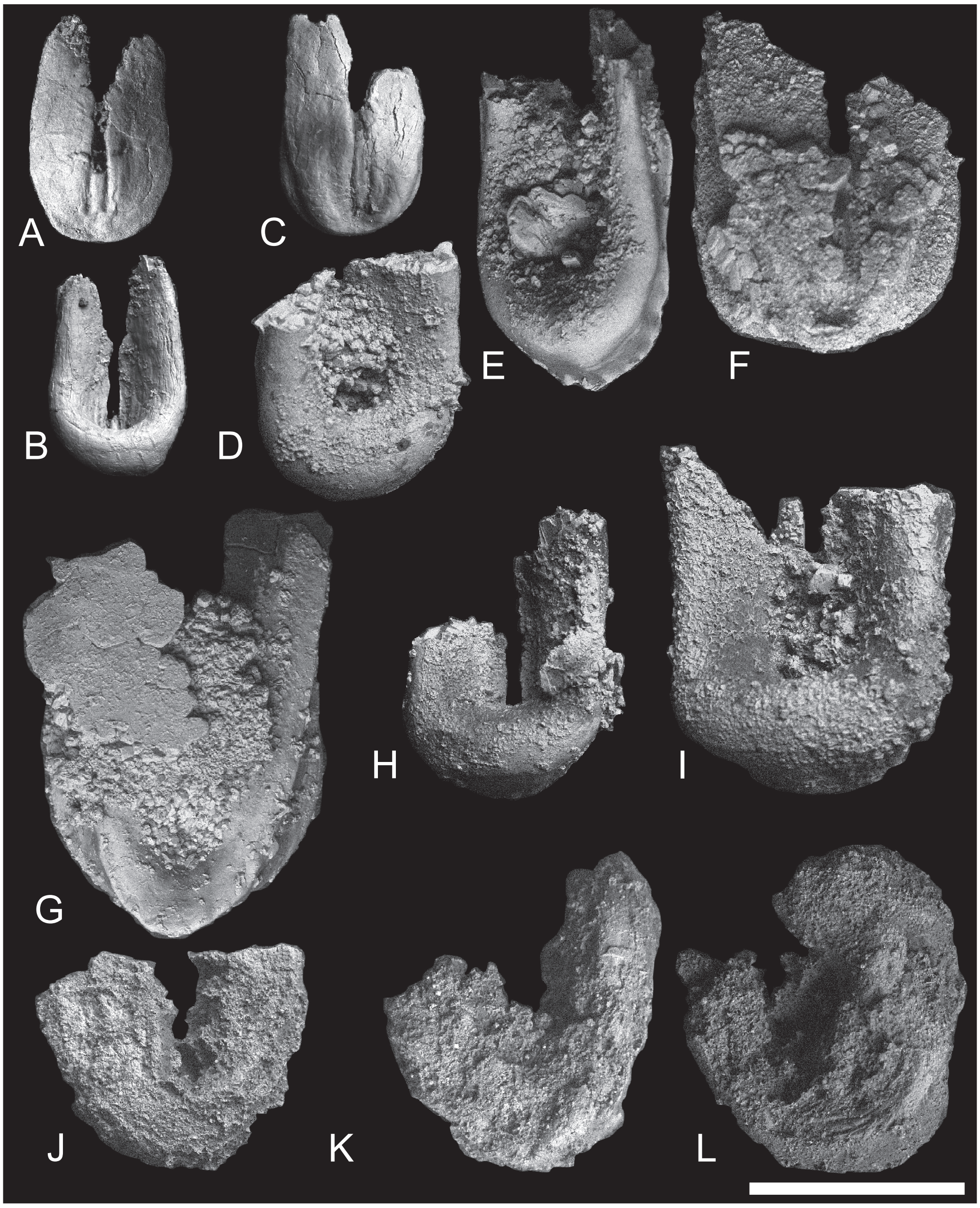

Figure 5. *(A–C, F–I)* Westergaardodina polymorpha *Müller & Hinz, 1991. (A) PMO 221.742/1, anterior view; sample PEL13. (B) PMO 221.742/2, posterior view; sample PEL13. (C) PMO 221.742/2, anterior view; sample PEL13. (F) PMO 221.739/17, posterior view; sample KAM5. (G) PMO 221.739/18, posterior view; sample KAM5. (H) PMO 221.739/17, anterior view; sample KAM5. (I) PMO 221.739/21, partly covered speciment, posterior view; sample KAM5. (D, E)* Westergaardodina ligula *Müller & Hinz, 1991. (D) PMO 221.739/2, posterior view; sample KAM5. (E) PMO 221.739/1, posterior view; sample KAM5. (J–L)* Westergaardodina *sp. (J) PMO 221.746/28, posterior view, fragment; sample KAM2. (K) PMO 221.746/46, anterior(?) view, fragment; sample KAM2. (L) PMO 221.746/47, posterior view, fragment; sample KAM2. Scalebar represents 500 µm.*

1959 *Problematoconites perforata* n. sp. Müller, p. 471, pl. 15, fig. 17.
1991 *Problematoconites perforatus* Müller, 1959 – Müller & Hinz, pp. 36, 37 (*cum syn.*), pl. 23, 1–10, 14, 15, 18–20, 22.
1998 *Problematoconites perforatus* Müller, 1959 – Müller & Hinz, 99–101, figs. 7.1–7.4.
2014 *Problematoconites perforatus* Müller, 1959 – Terfelt et al., fig. 6F.
2014 *Problematoconites perforatus* Müller, 1959 – Bagnoli & Stouge, fig. 8K.

Remarks. – The Slemmestad specimens are recurved with a large basal opening, and rounded tip. The cross section is oval at the base.

Material. – 4 specimens.

Occurrence. – KAM5 (4 specimens), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Peltura* Superzone, Stage 10, Furongian Series, Cambrian.

Genus *Trolmenia* Müller & Hinz, 1991

Type species. – *Trolmenia acies* Müller & Hinz, 1991.

Trolmenia acies Müller & Hinz, 1991

Fig. 5E

1991 *Trolmenia acies* n. sp. Müller & Hinz, pp. 39, 40, pl. 26, 1–9, fig. 16A–C.
1998 *Trolmenia acies* Muller & Hinz, 1991 – Müller & Hinz, p. 101, fig. 8.2.
2014 *Trolmenia acies* Müller & Hinz, 1991 – Bagnoli & Stouge, fig. 8S, T.

Material. – 1 specimen.

Occurrence. – KAM5 (1 specimen), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Peltura* Superzone, Stage 10, Furongian Series, Cambrian.

Genus *Westergaardodina* Müller, 1959

Type species. – *Westergaardodina bicuspicata* Müller, 1959.

Westergaardodina ligula Müller & Hinz, 1991

Fig. 5D, E

1991 *Westergaardodina ligula* n. sp. Müller & Hinz, p. 46 (*cum syn.*), pl. 28, figs. 1–14.
2014 *Westergaardodina ligula* Müller & Hinz, 1991 – Bagnoli & Stouge, fig. 9R.

Remarks. – These tricuspidate elements have a small median projection. The anterior side
is strongly convex. The posterior side is deeply excavated giving it a spoon-like appearance.

Material. – 3 specimens.

Occurrence. – KAM5 (3 specimens), Alum Shale Forma tion, Slemmestad, Norway.

Stratigraphic distribution. – *Peltura* Superzone, Stage 10, Furongian Series, Cambrian.

Westergaardodina polymorpha Müller & Hinz, 1991

Fig. 6A–C, F–I

1991 *Westergaardodina polymorpha* n. sp. Müller & Hinz, pp. 48, 49 (*cum syn.*), pl. 31, figs. 1–21.
1998 *Westergaardodina polymorpha* Müller & Hinz, 1991 – Müller & Hinz, fig. 15.1–15.3.
2014 *Westergaardodina polymorpha* Müller & Hinz, 1991 – Bagnoli & Stouge, fig. 9S–V.

Remarks. – Gently recurved bicuspidate elements with a much larger posterior side than anterior side. The profile is rather flat and the median projection is very small, or absent. The lateral projections diverge increasingly during growth. The posterior side is commonly enlarged in the basal part.

Material. – 9 specimens.

Occurrence. – PEL13 (2 specimens), KAM5 (7 specimens), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Peltura* Superzone, Stage 10, Furongian Series, Cambrian.

Order CONODONTOPHORIDA Eichenberg, 1930
Superfamily CORDYLODONTACEA Lindström, 1970
Family CORDYLODONTIDAE Lindström, 1970

Genus *Cordylodus* Pander, 1856

Type species. – *Cordylodus angulatus* Pander, 1856.

Cordylodus proavus Müller, 1959

Fig. 6F–H

1959 *Cordylodus proavus* Müller, p. 448, pl. 15, figs. 11, 12, 18; fig. 3B.
1974 *Cordylodus angulatus* Pander, 1856 – van Wamel, pp. 58, 59, pl. 1, fig. 5 (only).
cf. 1987 *Cordylodus proavus* Müller, 1959 – Olgun, pp. 47, 48, pl. 5, figs. R, ?S. ?T, U, V, ?X, Z.
1987 *Cordylodus proavus* Müller, 1959 – Viira et al., pp. 149–151, pl. 2, figs. 1–6, pl. 3, figs. 3, 8, 12; text-fig. 2: 1–3, 6–9, 19–21, 23–29; text-fig. 3: 3, 6, 7, 10, 11, 16, 17, 22; text-fig. 4: 6–27.
1996 *Cordylodus proavus* Müller, 1959 – Mens et al., pl. 2, figs. 1–3, *non* pl. 1, fig. 9 (=*Cordylodus primitivus* Bagnoli et al., 1987).
non 1988 *Cordylodus proavus* Müller, 1959 – Andres, p. 129, figs. 26–34, pl. 13, figs. 1, 2 (=*Cordylodus andresi* Viira et al. in Kaljo et al., 1986).
1988 *Cordylodus proavus* Müller, 1959 – Bruton et al., fig. 4f.

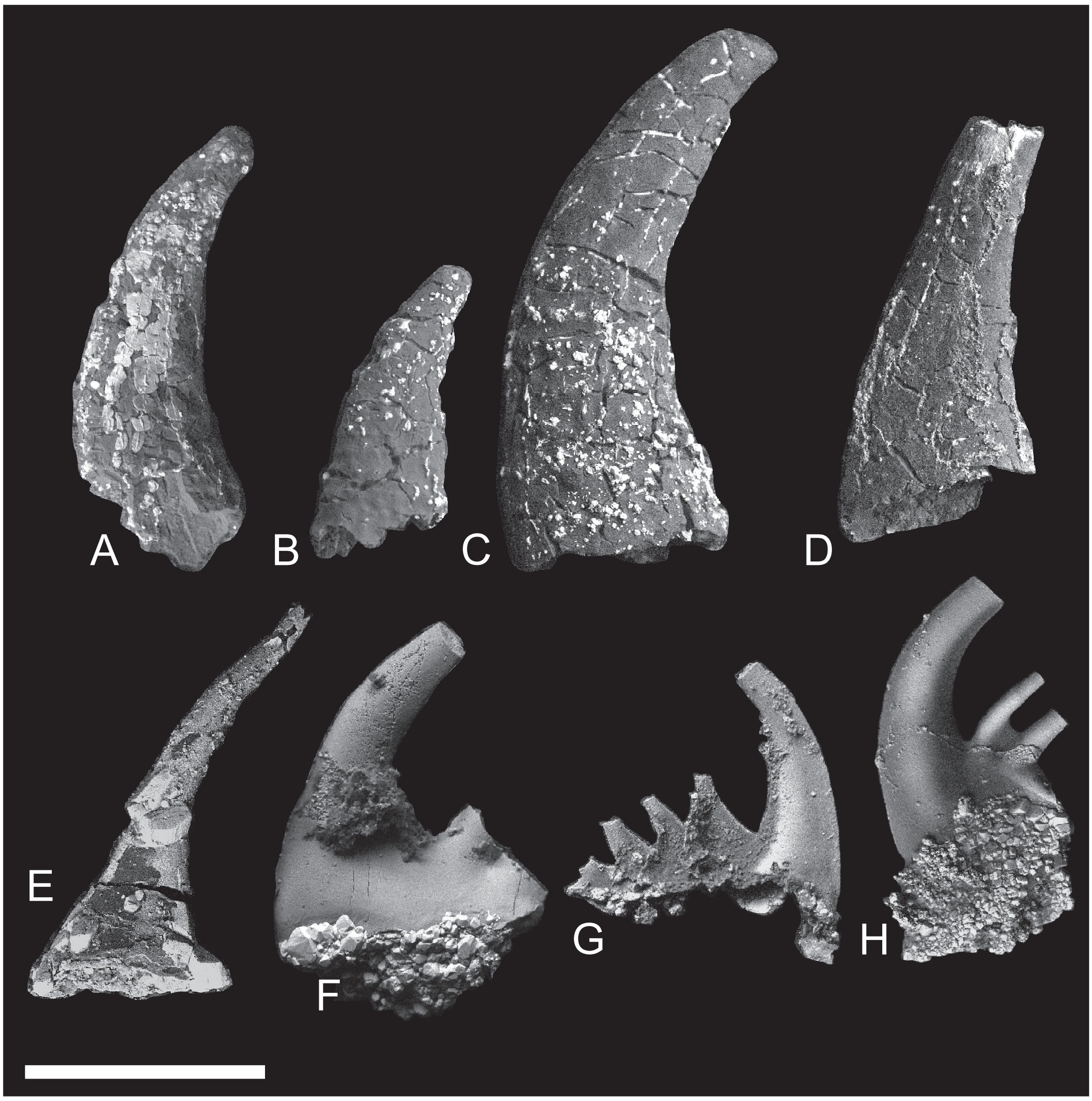

Figure 6. (A–D) Problematoconites perforatus *Müller, 1959. (A) PMO 221.740/20, lateral view; sample KAM5. (B) PMO 221.740/17, lateral view; sample KAM5. (C) PMO 221.741/11, lateral view; sample KAM5. (D) PMO 221.741/12, lateral view; sample KAM5. (E)* Trolmenia acies *Müller & Hinz, 1991. (E) PMO 221.741/2, lateral view; sample KAM5. (F–H)* Cordylodus proavus *Müller, 1959. (F) PMO221.737/2, rounded, slightly laterally deflected element, lateral view; sample KAM6, (G) PMO221.737/1, compressed element, inner lateral view; sample KAM6. (H) PMO221.737/3, rounded symmetrical element, lateral view; sample KAM6. Scalebar for Fig. 6E, F equals 250 µm; for Fig. 6A–D, G, H it represents 500 µm.*

2014 *Cordylodus proavus* Müller, 1959 – Terfelt et al., figs. 5A–E, 7T, U.

Comments to synonymy – The specimens illustrated by Olgun (1987) did not show the diagnostic basal cavity and the specimens are tentatively referred to this species. The specimens marked with a question mark probably represent *Cordylodus primitivus* Bagnoli et al., 1987. *Cordylodus proavus sensu* Andres is *Cordylodus* cf. *C. andresi* (see Szaniawski & Bengtson, 1998, p. 16).

Remarks. – The dolobrate elements are recurved; the deep basal cavity extends up to about 1/3 of the length of the cusp. The denticles and the cusp above the tip of the basal cavity are albid. The material includes a rounded, compressed and twisted element.

Material. – 3 specimens.

Occurrence. – KAM6 (3 specimens), Alum Shale Formation, Slemmestad, Norway.

Stratigraphic distribution. – *Acerocarina* Superzone, Stage 10, Furongian Series, Cambrian.

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