Faunal succession in the upper Cambrian (Furongian) *Leptoplastus* Superzone at Slemmestad, southern Norway

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The 'Middle' Cambrian–Tremadocian Alum Shale Formation is generally strongly tectonised in the Oslo area (southern Norway) and, as such, no complete succession through the Furongian exists in the area. The present paper presents a restored part of the Furongian interval through the *Leptoplastus* Superzone that has been measured and sampled at Slemmestad harbour. The limestone layers and nodule levels within the shale are preserved in the correct stratigraphic order with only limited repetition due to thrusting. Here the *Leptoplastus* Superzone is about 3.1 m thick. Within Scandinavia the superzone has previously been subdivided into the *Leptoplastus paucisegmentatus*, *L. raphidophorus*, *L. crassicornis*, *L. ovatus*, *L. angustatus* and *L. stenotus* zones, of which the *L. paucisegmentatus* Zone has not been recorded in the Oslo area. It may be truly absent or the interval may be devoid of fossiliferous limestone. It is alternatively possible that the index fossil is absent for ecological reasons. Variable first appearances of key taxa have somewhat confused the subdivision of the *Leptoplastus* Superzone. The order of appearance of *L. ovatus*, *L. crassicornis* and *L. angustatus* thus differs between Slemmestad and Andrarum in southern Sweden, and consequently the *L. ovatus* Zone is herein proposed abandoned as *L. ovatus* co-occurs with *L. crassicornis*. The *L. angustatus* Zone has also been proposed abandoned by recent authors. Based on detailed biostratigraphical data from Slemmestad and Andrarum, a combined *L. crassicornis*–*L. angustatus* Zone is defined; the lower boundary is characterised by the first appearance of *L. crassicornis*. The present study furthermore shows that *Protopeltura holtedahli* occurs in the *Parabolina spinulosa* Zone and that *Protopeltura broeggeri* is restricted to the upper part of the new *Leptoplastus crassicornis*–*L. angustatus* Zone. These *Protopeltura* species do not characterise separate zones or subzones as previously proposed. A lectotype of *Ctenopyge neglecta* var. *bornholmensis* Poulsen, 1923, now *Leptoplastus bornholmensis*, is designated and reillustrated.

Keywords: Cambrian, Furongian, Alum Shale, biostratigraphy, trilobites, Norway, Scandinavia, *Leptoplastus* Superzone

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Introduction

The 'Middle' Cambrian–Tremadocian Alum Shale Formation of Scandinavia consists of organic-rich, black and dark grey, finely laminated mudstones with a variable content of carbonate concretions and layers. The formation is very rich in trilobites and a detailed biostratigraphic framework comprising 27 zones and 6 superzones has been recognised for the Furongian interval (see Nielsen et al., 2014 for relevant references). The thinnest of these superzones is the *Leptoplastus* Superzone, which

is most complete in Scania, southernmost Sweden, and the Oslo area in southern Norway. The present study is based on sampling of an intra-Alum Shale anticline at Slemmestad near Oslo (Fig. 1). Here the *Leptoplastus* Superzone is preserved essentially intact and it is possible to reconstruct the succession of trilobites despite the structural overprinting. Henningsmoen (1957) outlined a Norwegian zonation, embracing the *Leptoplastus raphidophorus*, *L. crassicornis*, *L. ovatus*, *L. angustatus* and *L. stenotus* zones. The *L. paucisegmentatus* Zone, recognised in several districts in Sweden (Westergård, 1944, 1947; Ahlberg et al., 2006), has not been recorded in

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the Oslo area. However, the sequential order of the 'first appearance datum' (FAD) of the key species *L. crassicornis*, *L. ovatus* and *L. angustatus* differs between Slemmestad and Scania (Ahlberg et al., 2006 and present study), suggesting that the order of appearance reflects ecological control rather than chronostratigraphy. We also note that the potential index species *L. ovatus* and *L. crassicornis* appear at the same level in the investigated sections at Slemmestad. Hence, we suggest combining the *L. crassicornis*, *L. ovatus* and *L. angustatus* zones into just one zone, here referred to as the *L. crassicornis*–*L. angustatus* Zone. The reasons for doing so are detailed below.

Henningsmoen (1957) described *Protopeltura holtedahli* and *Protopeltura broeggeri* and inferred a likely derivation of these species from the lower part of the *Protopeltura praecursor* Zone (now *Protopeltura* Superzone, see Nielsen et al., 2014) and, although the zonal affiliation was uncertain, he named two separate subzones after these taxa, which in modern terminology would be treated as zones. The investigated outcrop shows that *P. holtedahli* co-occurs with *Protopeltura aciculata* and *P. pusilla* in the *Parabolina spinulosa* Zone, hence the *P. holtedahli* (Sub)Zone is rejected. *Protopeltura broeggeri* is relatively abundant in the upper part of the new *L. crassicornis*–*L. angustatus* Zone and no separate interval is characterised by this taxon. Hence, the *P. broeggeri* (Sub)Zone is also rejected. Neither of the (sub)zones have been recognised by recent authors. A preliminary report on the Slemmestad section was provided by Nielsen & Schovsbo (1999).

Geological setting

The Alum Shale was deposited in the mid to outer shelf areas of an extremely sediment starved epicontinental sea that covered Scandinavia from the 'mid' Cambrian to the Early Ordovician (Nielsen & Schovsbo, 2007). Two main facies types have been recognised based on the distribution of carbonate concretions and layers (Schovsbo, 2003). In the Oslo area, offshore Kattgat, Scania and Bornholm, as well as farther north within some successions in the Caledonian mountain chain, a relatively homogeneous shale with a comparatively low abundance of carbonates was deposited. This contrasts with the shale deposited in south central Sweden and on Öland that contains a high abundance of carbonates. The latter facies tends to be stratigraphically incomplete (cf., Martinsson, 1974).

The study area is situated in the distal part of the Caledonian foreland basin. The Lower Palaeozoic strata were folded and thrust during the Silurian and the Alum Shale Formation acted as décollement level and consequently it is strongly tectonised. During the Permian the area underwent downfaulting into the Oslo Graben, where it is preserved today. Intrusions occur locally in the Alum Shale; however, this is not the case in the investigated section. The Furongian in the Oslo region has an estimated thickness up to 45 m (Bjørlykke, 1974).

Figure 1. Map showing location of the studied sections. The site is marked with a star on the close-up of the Slemmestad industrial area.

However, the precise thickness is uncertain.

The Furongian part of the Alum Shale Formation is extremely fossiliferous, mostly trilobites but brachiopods (e.g., Westergård, 1922; Henningsmoen, 1958; Topper et al., 2013,) and various microfossils such as conodonts (e.g., Müller & Hinz-Schallreuter, 1998; Bagnoli & Stouge, 2014; Kleppe, 2014) also occur. Based on trilobites a sophisticated zonation has been established, for recent reviews see Terfelt et al. (2008) and Nielsen et al. (2014). Species turnover rates were high in the Furongian and the Scandinavian trilobite zones have an average duration of less than 500,000 yrs. Currently six superzones subdivided into 27 zones are recognised in the Furongian (Nielsen et al., 2014). Results based on the present study reduce the number of zones to 26 zones.

The *Leptoplastus* Superzone at Slemmestad

Only the mid-Furongian *Leptoplastus* Superzone is treated in the present paper. It was originally defined by Nathorst (1869); for a review of early works, see Westergård (1922). Strand (1929) recognised the *Leptoplastus/Eurycare* Zone (now *Leptoplastus* Superzone) in the Mjøsa district, but the Oslo region was not mentioned. Holtedahl (1910) described some of the most common olenid species from Norway. He believed that *L. ovatus* and *E. latum* are restricted to the Mjøsa district. However, Henningsmoen (1957) and this paper document these species from the Oslo region, thus dismissing Holtedahl's (1910) suspicions. Westergård (1942, 1944, 1947) recognised five subzones in the *Leptoplastus/Eurycare* Zone, in

ascending order: *L. paucisegmentatus*, *L. raphidophorus*, *L. ovatus*/*E. latum*, *E. angustatum* and *L. stenotus*. The interval was later divided into six subzones by Henningsmoen (1957), who renamed the *L. ovatus*/*E. latum* Subzone as the *L. ovatus* Subzone, allocated *angustatum* to *Leptoplastus* and inserted a *L. crassicornis* Subzone between the *L. raphidophorus* and the *L. ovatus* zones. Ahlberg (2003) reverted to five zones by leaving out the *L. crassicornis* Subzone, but subsequently Ahlberg et al. (2006) reinstated this subzone. Terfelt et al. (2008) abandoned the traditional zonation of the Furongian by elevating the subzones to zonal rank. They abandoned the *L. angustatus* Zone and subdivided the *Leptoplastus* interval into the *L. paucisegmentatus*, *L. raphidophorus*, *L. crassicornis*, *L. ovatus* and *L. stenotus* zones. Nielsen et al. (2014) ranked with minor amendments the traditional Furongian zones as superzones, including the *Leptoplastus* Superzone, and we follow this approach herein.

The trilobites of the *Leptoplastus* Superzone described here were sampled from both flanks of an anticline at Slemmestad (Fig. 1) by A.T. Nielsen and N.H. Schovsbo in 1998 (see Nielsen & Schovsbo, 1999). Supplementary sampling was undertaken in 2001. Bituminous limestone lenses and layers, so-called anthraconite, within the Alum Shale unit yielded numerous fossils. The layers appear to be in correct stratigraphical order despite the strong tectonic overprint, although small repetitions due to thrusting do occur. With few exceptions, no fossils were sampled from the interjacent shale, which is disturbed and smeared. Locally it does contain abundant trilobites.

The two flanks of the investigated anticline are referred to as section 1 (southwestern flank, oriented 92°/50°S) and section 2 (northeastern flank, oriented 80°/70°N), respectively. The flanks are 15 m apart at ground level. Some of the sampling was completed using a rope ladder. The two stratigraphic sections are similar, but exhibit minor differences in thickness due to tectonic disturbances. By combining the two sections (Figs. 2, 3), a composite section has been constructed (Fig. 4).

Parabolina spinulosa Zone

Thickness: >2.80 m in section 1 and >2.10 m in section 2; the lower boundary of the zone is not present in either of the investigated sections and the total zonal thickness cannot be established. The zone includes beds I, II, III and IV in section 1 and bed F in section 2 (Figs. 2, 3).

Remarks: The base of the zone is defined by the first appearance of *P. spinulosa* and the upper boundary is defined by the FAD of *Leptoplastus paucisegmentatus* (see Terfelt et al., 2008). However, *L. paucisegmentatus* does not occur in Norway and the *P. spinulosa* Zone is here directly overlain by the *Leptoplastus raphidophorus* Zone (see also remarks below on that zone). In the *P. spinulosa* Zone in the investigated sections the eponymous species co-occurs with *Protopeltura aciculata*, *P.*

pusilla and *P. holtedahli*. The co-occurrence of *P. pusilla* and *P. aciculata* has previously been recognised by Henningsmoen (1957), whereas the precise stratigraphic level of *P. holtedahli* has remained uncertain. Henningsmoen (1957) suspected that *P. holtedahli* occurred at the base of *Protopeltura praecursor* Zone, and even erected a separate *P. holtedahli* Subzone characterised by this taxon. Nielsen & Schovsbo (1999) disagreed and suggested that *P. holtedahli* may be a junior synonym of *P. aciculata*. The more detailed investigation of the material at hand indicates that *P. holtedahli* in fact occurs in the *Parabolina spinulosa* Zone, but exhibits consistent morphological differences, separating it from the associated *P. aciculata*. *Protopeltura aciculata* and *P. holtedahli* were only recorded in section 1.

Leptoplastus paucisegmentatus Zone

Thickness: Not documented in the investigated sections; if the zone is developed in the non-fossiliferous shale facies, it may be between 0.23 and 0.62 m thick.

Remarks: This zone was recognised by Westergård (1942, 1944, 1947), but Henningsmoen (1957) did not record it in Norway. It is possible that no limestone beds occur in the *L. paucisegmentatus* Zone and that it is developed as shale in the investigated sections at Slemmestad, but in the absence of fossils this conjecture cannot be verified. It is alternatively possible that the zone is truly absent or it could even be speculated that the appearance of *L. paucisegmentatus* and *L. raphidophorus* was controlled by ecological conditions, similar to the appearances of *L. crassicornis*, *L. ovatus* and *L. angustatus*. The latter show variable FADs between Slemmestad and Andrarum (see discussion of biozonation below). The shale interval between beds IV and V was sampled in section 1 in order to investigate whether the shale was fossiliferous. The lower 5 cm contained several specimens of *Parabolina spinulosa* and *Protopeltura* sp. indicating that at least this part of the sections still represents the *Parabolina* Superzone. The upper main part of the shale contained no determinable trilobites.

Leptoplastus raphidophorus Zone

Thickness: 1.65 m in section 1 and 0.45 m in section 2. The zone includes beds V, VI and VII in section 1 and bed 9 in section 2 (Figs. 2, 3).

Remarks: The base of the zone is defined by the first appearance of *L. raphidophorus* and the upper boundary is defined by the FAD of *Leptoplastus crassicornis*, see discussion of biozones below. *Leptoplastus raphidophorus* occurs frequently in sections 1 and 2 and co-occurs in the former with *E. latum*, *L. norvegicus* and *E. brevicauda*. Such an assemblage has not been recorded previously; Terfelt et al. (2011) listed a FAD of the latter two species in the *Leptoplastus crassicornis* Zone (here *L. crassicornis*–*L. angustatus* Zone).

Figure 2. Log of the southwestern section (section 1).

Figure 3. Log of the northeastern section (section 2). Legend as in Fig. 2.

Leptoplastus crassicornis–*L. angustatus* Zone (new)

Basal stratotype: Andrarum, Caroli Shaft, Profile 6 sensu Westergaard (1922, p. 21), redescribed by Ahlberg et al. (2006, fig. 3).

Thickness: 2.25 m in section 1 and 2.35 m in section 2. The zone includes beds V, VI, VII, VIIIa, VIIIb, IX/X, XI, XII, XIII and XIV in section 1 and beds E, D2, D1, C, 8, 7.1 and 6 in section 2, see Figs. 2, 3.

Remarks: The *L. crassicornis* Subzone was defined by Henningsmoen (1957), and the subzone was reported

from Norway, Sweden and England. Henningsmoen (1957) also recorded the species *L. crassicornis* from Slemmestad. The present study shows that *Leptoplastus crassicornis* co-occurs with *E. brevicauda*, *E. explanatum*, *E. latum*, *L. ovatus* and *L. norvegicus*. Nielsen & Schovsbo (1999) proposed reverting to Westergaard's (1947) zonation, where the *L. crassicornis* interval is assigned to the *L. ovatus* Zone. In the present study we propose to recognise a combined *L. crassicornis*–*L. angustatus* Zone, defined by the FAD of *L. crassicornis*. This revised zonation is workable in the Oslo area as well as in Scania, despite a different local distribution of trilobite species in this part of the *Leptoplastus* Superzone.

Figure 4. Consensus log based on the two sections. It is constructed using the smallest thickness of zones seen in the respective sections, assuming that stacking due to overthrusting is the dominant tectonic disturbance. Legend as in Fig. 2.

Leptoplastus ovatus Zone (abandoned)

Remarks: The base of the zone was defined by the first appearance of the eponymous fossil and the upper boundary was defined by the FAD of *L. stenotus* (see Terfelt et al., 2008). *Leptoplastus ovatus* is quite abundant in the investigated sections at Slemmestad where it co-occurs with *E. brevicauda*, *E. explanatum*, *E. latum*, *L. norvegicus* and *L. crassicornis*. At Andrarum, the FAD of *L. ovatus* is later than the FAD of *L. angustatus*. At Slemmestad the FAD of *L. ovatus* is before that of *L. angustatus* and coinciding with the appearance of *L. crassicornis*. For this reason the *L. ovatus* Zone is replaced by the new *L. crassicornis*–*L. angustatus* Zone. By doing so, the different order of appearance of *L. ovatus*, *L. crassicornis* and *L. angustatus* in Scania and in the Oslo areas does not complicate the chronostratigraphic zonation.

Leptoplastus angustatus Zone (abandoned as an individual zone)

Remarks: The *Leptoplastus angustatus* Zone was established by Westergård (1942, 1944, 1947); see also Henningsmoen (1957), Nielsen & Schovsbo (1999), and Ahlberg (2003). Terfelt et al. (2008) abandoned this zone because the index fossil is coeval with *L. crassicornis* (see Ahlberg et al. 2006) and the latter was suggested to be a better zonal index fossil due to its short range. The amalgamation of the *L. crassicornis* and *L. angustatus* zones proposed here eliminates the confusion that arises from the different ranges shown by these species at Andrarum (see Ahlberg et al., 2006) and in Slemmestad (present study). The upper boundary of the new *L. crassicornis*–*L. angustatus* Zone is defined by the FAD of *L. stenotus*. *Leptoplastus angustatus* does not occur in bed XIV in section

1, although this layer is part of the *L. crassicornis*–*L. angustatus* Zone. Bed XIV is dominated mainly by *P. broeggeri* but a single specimen of *L. norvegicus* has also been recorded. *Leptoplastus angustatus* also co-occurs with *E. latum* (both sections) and *L. crassicornis* (section 1).

Leptoplastus stenotus Zone

Thickness: 0.80 m in section 1 and 0.28 m in section 2. The zone includes beds XV and XVI in section 1 and bed B in section 2; see Figs. 2, 3.

Remarks: The base of the zone is defined by the FAD of *L. stenotus*, see Terfelt et al. (2008). The upper boundary of the zone is defined by the FAD of *L. neglectus*, which defines the oldest zone of the *Protopeltura* Superzone. Within Scandinavia *L. stenotus* is known to co-occur with *L. bornholmensis* and *E. explanatum*. At Slemmestad, fossils are rare in the limestone concretions from this zone and *L. stenotus* occurs alone.

Leptoplastus neglectus Zone (*Protopeltura* Superzone)

Thickness: 0.17 m in section 1 and 0.42 m in section 2. The zone includes bed XVII and beds 2, 1 and A in section 2; see Figs. 2, 3.

Remarks: The base of the zone is defined by the FAD of *L. neglectus*, see Terfelt et al. (2008). The upper boundary is defined by the FAD of *Sphaerophthalmus postcurrens* (regarding generic assignment, see Høyberget & Bruton, 2012). The *L. neglectus* Zone is dominated by the eponymous species and is known to co-occur with *Protopeltura praecursor* in Scandinavia (see Terfelt et al., 2008). The base of the zone marks the upper boundary of the *Leptoplastus* Superzone.

Discussion and conclusions

The *Leptoplastus* Superzone is most complete in the Oslo region, southern Norway (Henningsmoen, 1957; present study), and Scania, southernmost Sweden, where the *Leptoplastus* Superzone at Andrarum was described in detail by Ahlberg et al. (2006). Terfelt et al. (2011) provided an updated list of species known from the superzone in Scandinavia.

The faunal successions at Andrarum and in the Oslo region are broadly similar (see Fig. 5), but with some important differences. At Andrarum, *Protopeltura aciculata* is the only *Protopeltura* species recorded from the *Parabolina spinulosa* Superzone, whereas *P. spinulosa* co-occurs with *P. aciculata*, *P. pusilla* and *P. holtedahli* at Slemmestad. It is surprising to find three morphologically similar *Protopeltura* species in the same horizon but the taxonomic differences, at least based on the material at hand, seem consistent.

The *Leptoplastus paucisegmentatus* Zone, the oldest zone recognised in the *Leptoplastus* Superzone, is well developed at Andrarum (Ahlberg et al., 2006) and elsewhere in Sweden (Westergård, 1947), but it appears to be absent at Slemmestad. This may be a consequence of the fact that the zone is represented by unfossiliferous shale rather than limestone in this region. If the *L. paucisegmentatus* Zone in fact is present at Slemmestad, it is relatively thin compared to Andrarum.

The *L. raphidophorus* (Sub)Zone was established by Westergård (1942, 1944, 1947). Only the eponymous species was recorded from this subzone by Henningsmoen (1957), but the present study shows that *L. raphidophorus* co-occurs with *E. latum*. *Leptoplastus abnormis* is present in the *Leptoplastus* Superzone at Andrarum (Ahlberg et al., 2006); this species has not been found at Slemmestad, neither by us nor by Henningsmoen (1957).

Henningsmoen (1957) erected a *L. crassicornis* Zone, which in turn was proposed abandoned by Nielsen & Schovsbo (1999) and Ahlberg (2003) but later reinstated by Ahlberg et al. (2006) and Terfelt et al. (2008). In the investigated sections the FAD of *L. crassicornis* coincides with that of *L. ovatus*. The latter species has a fairly short range, in theory making *L. ovatus* a better index fossil and the species is also widely distributed (Westergård 1922, 1944, 1947; Henningsmoen, 1957; Taylor & Rush-ton, 1972). However, the *L. ovatus* Zone is not workable for Andrarum (see Ahlberg et al., 2006) due to an overlap with *L. angustatus* (and *L. crassicornis*) and in this section the FAD of *L. angustatus* even predates that of *L. ovatus*, a problem not addressed by Ahlberg et al. (2006). In the investigated section at Slemmestad, *L. angustatus* appears significantly later (Figs. 2, 3) which seems to be the general pattern at most Scandinavian localities, except for Andrarum (e.g., Westergård, 1944).

We propose to use *L. crassicornis* as an index fossil for a zone, as this species is present at Slemmestad as well as in Scania. *Leptoplastus ovatus* turns up later than *L. crassicornis* at Andrarum (Ahlberg et al., 2006), which is why we prefer to use the former as an index species. *Leptoplastus crassicornis* co-occurs with *L. angustatus* at Andrarum, with the FAD of *L. angustatus* immediately above that of *L. crassicornis*. Higher up in the Andrarum section *L. angustatus* co-occurs with *L. ovatus*. Due to the long range of *L. Angustatus*, Terfelt et al. (2008) proposed to abandon the *L. angustatus* Zone and instead recognised a *L. crassicornis* Zone overlain by a *L. ovatus* Zone. Contrary to this pattern the *L. angustatus* Zone *sensu* Westergård (1947) is well defined at Slemmestad, but where the ranges of *L. crassicornis* and *L. ovatus* partially overlap. In order to reconcile the conflicting ranges of key taxa in different sections we propose to recognise a combined *L. crassicornis*–*L. angustatus* Zone between the *L. raphidophorus* and *L. stenotus* zones.

Eurycare explanatum occurs sporadically in the *L. crassicornis*–*L. angustatus* Zone at Slemmestad but has not been recorded at Andrarum (see, however, remarks on *Eurycare* species by Ahlberg et al., 2006, p. 105). *Leptoplastus norvegicus* ranges from the *L. raphidophorus* Zone into the *L. crassicornis*–*L. angustatus* Zone at Slemmestad but only a few specimens are recorded. According to Henningsmoen (1957), *L. norvegicus* occurs in the *L. crassicornis* Zone (now *L. crassicornis*–*L. angustatus* Zone) in Norway and Sweden, but *L. norvegicus* was not found at Andrarum by Ahlberg et al. (2006).

Protopeltura broeggeri is relatively abundant at Slemmestad in the upper part of the *L. crassicornis*–*L. angustatus* Zone. This is a slightly lower stratigraphic level for this species than inferred by Henningsmoen (1957). *P. broeggeri* was not recorded at Andrarum by Ahlberg et al. (2006). Due to its restricted geographical distribution it is not suitable as a zonal index fossil (cf., Henningsmoen, 1957).

Protopeltura holtedahli, another species of uncertain age (Henningsmoen, 1957), is here recorded from the *Parabolina spinulosa* Zone. The present investigation shows that this species does not characterise an individual zone as previously suggested (cf., Henningsmoen, 1957).

Systematic palaeontology

Family *Olenidae* Burmeister, 1843.

Genus *Eurycare* Angelin, 1854.

Type species (Subsequent designation, SD, Vogdes, 1925): *Eurycare brevicauda* Angelin, 1854.

Characteristics: A Leptoplastinae with slightly tapering or almost parallel-sided cephalic axis. The interocular cheeks are as wide as or wider than glabella at eye line. The postocular cheeks are as wide as or wider than occipital ring. The preglabellar field is short. The free cheeks have a long and coarse spine. Pygidium is subtriangular and possesses marginal spines. For full diagnosis, see Henningsmoen (1957).

Figure 5. Range chart of the Leptoplastus Superzone at Andrarum (eastern Scania), red lines, and Slemmestad (Oslo area), blue lines. Ranges based on Ahlberg et al. (2006) and the present study.

***Eurycare brevicauda* (Angelin, 1854)**

Fig. 6

- 1904 *Eurycare* sp. – Persson, p. 516, pl. 8, fig. 8 (fig. of axial shield).
 1922 *Eurycare brevicauda* Angelin – Westergård, p. 148, pl. IX, figs. 11, 12. (Description. Figs. of axial shield).
 1947 *Eurycare brevicauda* Angelin – Westergård, p. 24. (Occurrence in Sweden).
 1957 *Eurycare brevicauda* Angelin – Henningsmoen, p. 179, pl. 2, fig. 19; pl. 4. (Diagnosis and occurrence. Drawings of cranidium and pygidium).
 2006 *Eurycare brevicauda* Angelin – Ahlberg et al., fig. 5. (Fig. of dorsal shield).

Characteristics: An *Eurycare* species with interocular cheeks about as wide as glabella at eye line. Postocular cheeks about 1.5 times as wide as occipital ring. The free cheeks have a right genal angle and a strongly curved spine. Thorax consists of 14 segments; axial spine short.

Material: A few cranidia.

Occurrence: *Eurycare brevicauda* is characteristic for the *L. crassicornis*–*L. angustatus* Zone in Sweden and Norway (Westergård, 1922; Henningsmoen 1957). Henningsmoen (1957) did not, however, record *E. brevicauda* at Slemmestad. The species occurs in the investigated outcrop in bed VIII in section 1 and beds E and D2 in section 2, see Figs. 2, 3.

Comparison: *Eurycare brevicauda* resembles *E. latum*; for comparison, see remarks on the latter species. *Eurycare brevicauda* also strongly resembles *E. spinigerum* and they have identical cranidia and pygidia. However, *E. brevicauda* has a thorax with 14 segments whereas *E. spinigerum* has only 12–13 segments. *Eurycare spinigerum* has so far been reported only from Sweden, but without complete specimens at hand it is obviously impossible to identify this species with certainty and it may be mixed with *E. brevicauda*.

Remarks: Westergård (1922) described the postocular cheeks as 1.5 times as wide as the occipital ring, whereas Henningsmoen (1957) described the postocular cheeks in *E. brevicauda* to be only as wide as the occipital ring. However, the drawings and description in Henningsmoen (1957) are not matching and this must have been a mistake. The postocular cheeks are wider than the occipital ring in the available material. The free cheeks are poorly described in modern literature. Drawings published by Angelin (1854) of the free cheeks somewhat resemble those of *L. crassicornis* and *E. latum*. For the moment it is not possible to identify the free cheeks with certainty; if present in the material at hand they may have been mixed with *E. latum*.

***Eurycare explanatum* (Holtedahl, 1910)**

Fig. 6

- 1910 *Leptoplastus ovatus*, Angelin, var. *explanata*, nov. var. [partim] – Holtedahl, p. 10, pl. 1, fig. 10. (Description and fig. of cranidium).
 1922 *Leptoplastus ovatus explanatus* Holtedahl – Westergård, p. 110. (Remarks on Holtedahls material).
 1944 *Leptoplastus ovatus explanatus* Holtedahl – Westergård, p. 41. (Remarks).
 1957 *Eurycare explanatum* Holtedahl – Henningsmoen, pp. 179–180, pl. 16, figs. 3–5. (Diagnosis, description and occurrence. Drawings of cranidium and pygidium. Figs. of cranidia and pygidium).

Characteristics: An *Eurycare* species with cranidium 2½ times as wide as long, the glabella truncate at front and with subparallel sides. Preglabellar field present. Interocular cheeks as wide as glabella at eye line. Postocular cheeks 1½ times as wide as occipital ring. Free cheeks poorly known. Thorax unknown. Pygidium possibly belonging to this species with at least 4 pairs of marginal spines and 4 axial rings (2 fused end rings).

Material: Eight cranidia.

Occurrence: *Eurycare explanatum* is characteristic for the *L. crassicornis*–*L. angustatus* Zone in Sweden and Norway (Westergård, 1922; Henningsmoen 1957) and in England (Taylor & Rushton, 1972). Henningsmoen (1957) did not record *E. explanatum* at Slemmestad. The species occurs in the investigated outcrop in bed VIII in section 1; see Fig. 2.

Comparison: The species somewhat resembles *E. latum* and *E. brevicauda*. However, the fixed cheeks in *E. explanatum* are not as wide as in the cranidia of these species. The anterolateral corners of the cranidium are curved whereas the anterior corners in cranidia of *E. latum* and *E. brevicauda* are transverse. The free cheeks are poorly known, but the material from Holtedahl (1910) suggests that they resemble the free cheeks of *L. crassicornis*, but are more slender. The cranidium in *E. explanatum* is rather similar to that of *L. intermedius* (not treated in this paper), but the latter has interocular cheeks ¾ as wide as glabella at eye line.

Remarks: Cranidia of *E. explanatum* resemble several *Leptoplastus* species but most of them can be distinguished by having narrower fixed cheeks.

***Eurycare latum* (Boeck, 1838)**

Fig. 6

- 1904 *Eurycare latum* Boeck – Persson, p. 513, pl. 8, figs. 1–7. (Description, figs. of axial shield, all parts of dorsal shield and hypostoma).
- 1922 *Eurycare latum* (Boeck) – Westergård, p. 148, pl. IX, figs. 7–10. (Figs. of axial shield, free cheek and cranidia).
- 1923 *Eurycare latum* Boeck – Poulsen, pp. 32–33, pl. I, fig. 8 (Description and occurrence. Fig. of cranidium).
- 1944 *Eurycare latum* (Boeck) – Westergård, p. 41, pl. 2, figs. 11, 12. (Figs. of free cheek and axial shield).
- 1957 *Eurycare latum* (Boeck, 1838) – Henningsmoen, p. 181, pl. 16, figs. 6–9. (Diagnosis, description of type material and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidia).
- 2006 *Eurycare latum* Boeck – Ahlberg et al., p. 102, 105, figs. 4, 5, 8 (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shield and cranidium).

Characteristics: An *Eurycare* species with interocular cheeks from 1.2 to 1.5 times as wide as glabella at eye line. Postocular cheeks from 1.2 to 1.4 times as wide as occipital ring. Thorax with 16–17 segments and long axial spine from the 11th segment. Free cheeks are strongly

arched and provided with a long, wide and curved spine. Pygidium is triangular, twice as wide as long and carries three small marginal spines (Persson, 1904); axis consists of 4–5 segments.

Material: Several cranidia and free cheeks.

Occurrence: Henningsmoen (1957) described *E. latum* from the *L. crassicornis*–*L. angustatus* Zone in Norway and Sweden (Westergård, 1947; Ahlberg et al., 2006). It also occurs in the *Leptoplastus* Superzone on Bornholm, Denmark (Poulsen, 1923) and in England (Taylor & Rushton, 1972). The species occurs in the investigated outcrop in beds V, VI, VII, VIII, IX/X and XIII in section 1 and beds E, D2, 8 and 2 in section 2, see Figs. 2, 3.

Comparison: The wide fixed cheek in *E. latum* is highly characteristic for the species, but cranidia can resemble the cranidia of *E. breviceauda* and *E. spinigerum*. However, the interocular cheek in *E. breviceauda* and *E. spinigerum* is only as wide as glabella at eye line. The free cheek somewhat resembles those of *L. crassicornis* and *L. angustatus*; for remarks, see these taxa. It can be difficult to separate isolated genal spines from the long-spined *L. crassicornis* and *L. angustatus*, especially when the material is fragmentary. The genal spine in *L. crassicornis* is generally wider and flat whereas the genal spine in *L. angustatus* is slender and rounded.

Figure 6. Trilobites from the *Leptoplastus* Superzone at Slemmestad. All scale bars: 1 mm. (A) and (B) Cranidium and free cheek of *E. latum*, both from bed IX/X (PMO 228.191–228.192). (C) and (D) Cranidium and free cheek of *L. ovatus*, both from bed D2 (PMO 228.193–228.194). (E) Free cheek of *L. cf. norvegicus* from bed E (PMO 228.195). (F) Pygidium of *L. norvegicus* from bed VII (PMO 228.196), latex cast of pygidium, negative impression in limestone. (G) Cranidium of *E. breviceauda* from bed VI (PMO 228.197). (H) Cranidium of *E. explanatum* from bed VIIIa (PMO 228.198).

Genus *Leptoplastus* Angelin, 1854.

Type species (SD Vogdes, 1890): *Leptoplastus stenotus* Angelin, 1854.

Characteristics: A Leptoplastinae with tapering or almost parallel-sided cephalic axis. Palbebral lobes are moderately sized. Interocular cheeks between $\frac{1}{4}$ to $\frac{3}{4}$ as wide as glabella at eye line. Postocular cheeks from slightly narrower to about 1.5 times as wide as occipital ring. Short or no preglabellar field. Free cheeks with a short to long, slender to coarse spine. Genal angle is acute to obtuse. Pygidium is subsemicircular to subtriangular. For full diagnosis, see Henningsmoen (1957).

Leptoplastus angustatus (Angelin, 1854)

Fig. 7

- 1904 *Eurycare angustatum* Angelin [partim] – Persson, p. 517, pl. 9, figs. 11–13. (Description. Figs. of axial shield, pygidium, free cheek and hypostoma.
- 1922 *Eurycare angustatum* Angelin – Westergård, p. 150, pl. X, figs. 4–9. (Remarks. Figs. of free cheek, cranidium, pygidium and axial shields).
- 1923 *Eurycare angustatum* Angelin – Poulsen, p. 34, pl. I, figs. 9, 10. (Description, occurrence. Figs. of cranidium and free cheek).
- 1944 *Eurycare angustatum* Angelin – Westergård, p. 41, pl. 2, figs. 5, 6. (Figs. of axial shield and free cheek).
- 1947 *Eurycare angustatum* Angelin – Westergård, p. 24. (Occurrence in Sweden).
- 1957 *Leptoplastus angustatus* Angelin – Henningsmoen, pp. 164–165, pl. 16, figs 10–13. (Diagnosis and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of axial shields and free cheeks).
- 2006 *Leptoplastus angustatus* Angelin – Ahlberg et al., 102, 105, figs. 4, 6, 7. (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shields and free cheek).
- 2008 *Leptoplastus angustatus* Angelin – Terfelt et al., p. 82. (Occurrence).

For further synonymy, see Henningsmoen (1957).

Characteristics: A *Leptoplastus* species with elongate cephalic axis somewhat longer than wide. Interocular cheeks about half as wide as glabella at eyeline. No preglabellar field. Postocular cheeks about as wide as occipital ring. Free cheeks with coarse, long spine and rounded posterior margin. Thorax with 12 segments, pleural regions slightly narrower than axis. No axial macrospine. Subtriangular pygidium with 3 pairs of marginal spines and 3–4 axial rings.

Material: Several cranidia and free cheeks, three pygidia.

Occurrence: *L. angustatus* is characteristic for the *L. crassicornis*–*L. angustatus* Zone in Norway and Sweden (Henningsmoen, 1957). It also occurs at this stratigraphic level in Denmark (Poulsen, 1923). The species occurs in the investigated outcrop in beds IX/X, XI, XII, XIII in section 1 and beds D1, C, 8, 7.1 and 6 in section 2, see Figs. 2, 3.

Comparison: For comparison with *L. crassicornis*, *L. ovatus*, *L. stenotus* and *E. latum*, see these taxa. In comparison with *L. norvegicus* the glabella in *L. angustatus* is wider and there is no preglabellar field. The postocular cheeks in *L. angustatus* are also about as wide as the occipital ring whereas the postocular cheeks in *L. norvegicus* are markedly wider than the occipital ring.

Leptoplastus bornholmensis (Poulsen, 1923)

Fig. 8

- 1923 *Leptoplastus neglectus*, Westergård var. *bornholmensis* – Poulsen, p. 37, pl. I, fig. 11. (Occurrence, comparison with *L. neglectus*, fig. of cranidium).
- 1957 *Leptoplastus bornholmensis* (Poulsen, 1923) – Henningsmoen p. 165. (Remarks).

Characteristics: A *Leptoplastus* species with postocular cheeks $1\frac{1}{2}$ to $1\frac{3}{4}$ times wider than occipital ring. Interocular cheeks slightly narrower, approx $\frac{3}{4}$, as wide as glabella at eyeline. Relatively well developed preglabellar field. Glabella is relatively vaulted. Free cheeks, thorax and pygidium are unknown.

Figure 7. *Leptoplastus angustatus* from the *Leptoplastus* Superzone at Slemmestad. All scale bars: 1 mm. (A) Cranidium from bed C (PMO 228.199). (B) Free cheek from bed C (PMO 228.200). Please note that the tip of the genal spine is broken off.

Figure 8. Lectotype cranium of *Leptoplastus bornholmensis* from Bornholm, Denmark. Scale bar: 1 mm. Previously illustrated by Poulsen (1923, pl. 1 fig. 11). MGUH 1964.

Material: A few cranidia housed in the collections of the Natural History Museum of Denmark.

Occurrence: *Leptoplastus bornholmensis* is known only from Bornholm.

Comparison: The cranium resembles that of *L. neglectus*, but the interocular cheeks in the latter are half as wide as glabella at eyeline, whereas the interocular cheeks are markedly wider in *L. bornholmensis*. The postocular cheeks are wider in *L. bornholmensis* than in the cranium of *L. neglectus*. *Leptoplastus bornholmensis* has wider postocular cheeks and occurs in a higher horizon in comparison with *L. intermedius* (not treated in this paper).

Remarks: The taxon was allocated to *Leptoplastus* by Henningsmoen (1957), who ranked it as an individual species. So far this form has been reported only from Bornholm. We here designate a lectotype cranium (MGUH 1964), which is refigured (Fig. 8).

Leptoplastus crassicornis (Westergård, 1944)

Fig. 9

- 1944 *Eurycare angustatum crassicorne* var. n. – Westergård, p. 41, pl. 2, figs. 2–4. (Comparison with *L. angustatus*. Figs. of dorsal shield, cranium and free cheek).
- 1947 *Eurycare angustatum crassicorne* Westergård – Westergård, p. 24. (Occurrence in Sweden).
- 1957 *Leptoplastus crassicorne* Westergård – Henningsmoen, p. 167, pl. 14, figs. 1–13. (Diagnosis and occurrence. Drawings of cranium, free cheeks and pygidium. Figs. of crania, free cheeks and pygidia).
- 1970 *Leptoplastus crassicornis* Westergård – Whitworth, pp 100–111, pl. 22–24 (Description. Figs. of crania, free cheeks, pygidia, hypostoma and axial shields).
- 2006 *Leptoplastus crassicornis* Westergård – Ahlberg et

al., p. 102, figs. 5, 7 (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of and dorsal shield with free cheek and free cheek).

2008 *Leptoplastus crassicornis*, Westergård – Terfelt et al., p. 82. (Occurrence).

Characteristics: A *Leptoplastus* species with elongate cephalic axis, interocular cheek about half as wide as glabella at eye line, postocular cheek about as wide as, or slightly wider than occipital ring. No or practically no preglabellar field. Free cheeks with very long and very thick spine, slightly acute or right-angled genal angle, and practically straight posterior margin. Thorax with 12 segments, pleural regions as wide as or slightly wider than axis, and no long axial spine. Pygidium subtriangular and with 4–5 axial rings and 3–4 pairs of marginal spines. See Henningsmoen (1957) for further description.

Material: Several cranidia and free cheeks. A few pygidia are tentatively assigned.

Occurrence: *Leptoplastus crassicornis* is characteristic for the lower part of the *L. crassicornis*–*L. angustatus* Zone in Scandinavia (Westergård, 1947; Henningsmoen, 1957;

Figure 9. *Leptoplastus crassicornis* from the *Leptoplastus Superzone* at Slemmestad. All scale bars: 1 mm. (A) Free cheek from bed VIIIa (PMO 228.201). (B) Cranium from bed IX/X (PMO 228.202).

Ahlberg et al., 2006; this paper) and in England (Taylor & Rushton, 1972). The species occurs in the investigated outcrop in beds VIIla and VIIlb in section 1 and bed D2 and D1 in section 2; see Figs. 2, 3.

Comparison: The free cheeks in *L. crassicornis* resemble those of *Eurycare latum* as both species have very robust, long spines, but which in *L. crassicornis* curve more than in *E. latum*. The genal field in *E. latum* is also more strongly vaulted than in *L. crassicornis*. In comparison with *L. angustatus*, that species has a more slender genal spine, and this is a key feature for separating the two species. The posterior margin of the free cheek is rounded in *L. angustatus* and *L. crassicornis*. The posterior margin is straight in *E. latum*. The cranium of *L. crassicornis* strongly resembles that of *L. angustatus* but the glabella in *L. crassicornis* is more elongated than in *L. angustatus*. The material at hand suggests that the anterolateral corners of the cranium in *L. crassicornis* are more laterally expanded than those of *L. angustatus*.

Remarks: Henningsmoen (1957) described a smaller variety of *L. crassicornis* from the *L. ovatus* Zone (now *L. crassicornis*–*L. angustatus* Zone) in the Hamar district, Norway. This variety possesses slender cheek spines.

Leptoplastus neglectus (Westergård, 1922)

Fig. 10

- 1910 *Leptoplastus Bröggeri*, nov. sp. [partim] – Holte-dahl, p. 18, pl. III, figs. 1, 3 and 11? (Description and figs. of cranium and free cheek).
 1922 *Ctenopyge neglecta* n. sp. [partim] – Westergård, p. 150, pl. X, figs. 10–17 (fig. 18 = *Sphaerophthalmus postcurrens*). (Description. Figs. of cranium, free cheeks, pygidium and hypostome).

- 1922 *Leptoplastus raphidophorus* Angelin [partim] – Westergård, p. 143, pl. X, fig. 2. (Fig. of dorsal shield).
 1944 *Ctenopyge neglecta* f.typ. – Westergård, p. 42. (Remarks).
 1947 *Ctenopyge neglecta* Westergård – Westergård, p. 24. (Occurrence in Sweden).
 1957 *Leptoplastus neglectus* Westergård – Henningsmoen, pp. 168–170, pl. 17, figs. 1–7. (Diagnosis and occurrence. Drawings of cranium, free cheek, pygidium and hypostoma. Figs of dorsal shield, free cheek and cranidia).
 2008 *Leptoplastus neglectus* Westergård – Terfelt et al., p. 82. (Occurrence).

Characteristics: A *Leptoplastus* species with elongate cephalic axis, bluntly rounded in front. Interocular cheeks about half as wide as glabella at eye line. Postocular cheeks markedly wider than occipital ring. Relatively well developed preglabellar field. Free cheeks with long, strong spine, straight posterior margin, and acute genal angle. Thorax with 12 segments, pleural regions about one and a half times as wide as axis, and long axial spine on one of the posterior segments. Pygidium with three pairs of marginal spines and three to four axial rings.

Material: Few cranidia and free cheeks. Five pygidia.

Occurrence: *Leptoplastus neglectus* is characteristic for *L. neglectus* Zone in Norway and Sweden (Henningsmoen, 1957). The species occurs in the investigated outcrop in beds XVII and between XVII/XVIII in section 1 and beds 2, 1 and A in section 2; see Figs. 2, 3.

Comparison: The cranium resembles that of *L. stenotus*, but the interocular cheeks in the latter are less than half

Figure 10. Trilobites from the Protopenetula Superzone at Slemmestad. All scale bars: 1 mm. (A) and (B) Cranidium and pygidium of *P. praecursor*, both from bed 1 (PMO 228.203–228.204). (C) Free cheek of *P. praecursor* from bed A (PMO 228.205). (D) Cranidium of *L. neglectus* from bed A (PMO 228.206). (E) Free cheek of *L. neglectus* from bed 1 (PMO 228.207).

as wide as glabella at eye line, whereas the interocular cheeks are about half as wide as glabella at eye line in *L. neglectus*. The postocular cheeks are wider in *L. neglectus* than in the cranidium of *L. stenotus*. In comparison with *Sphaerophthalmus postcurrens*, having a cranidium with interocular cheeks that are about as wide as glabella at eye line, the interocular cheeks in *L. neglectus* are half as wide as glabella at eye line. The preglabellar field in *S. postcurrens* is described as absent or very short by Henningsmoen (1957), but Westergård (1922) and the illustrations shown by Henningsmoen (1957) indicate the presence of a preglabellar field. This feature thus cannot distinguish the two species. The free cheeks in *S. postcurrens* also resemble those of *L. neglectus*, but the free cheeks in the former have a right-angled genal angle and a shorter genal spine. For comparison with *P. broeggeri*, see that taxon.

Remarks: Overall the free cheeks in *L. neglectus* resemble a species of the genus *Eurycare* rather than a typical representative of *Leptoplastus*.

Leptoplastus norvegicus (Holtedahl, 1910)

Fig. 6

- 1910 *Eurycare angustatum*, Angelin var. *norvegicum*, nov. var. [partim] – Holtedahl, p. 5, pl. 1, fig. 1 (Description, fig. of axial shield).
- 1910 *Leptoplastus longispinus*, nov. sp. – Holtedahl, pp. 11–13, pl. III, figs. 12–14. (Description. Figs. of free cheeks, cranidium and pygidium).
- 1922 *Eurycare angustatum norvegicum* Holtedahl – Westergård, p. 150. (Short comparison with *L. raphidophorus*).
- 1922 *Leptoplastus longispinus* Holtedahl – Westergård, p. 110. (Short remark).
- 1957 *Leptoplastus norvegicus* Holtedahl – Henningsmoen, pp. 170–172, pl. 15, figs. 1–10 and pl. 16, figs. 1–2 (Diagnosis and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidium, free cheeks, pygidium and dorsal shield).

Characteristics: *Leptoplastus* species with elongate cephalic axis. Interocular cheeks 0.5–0.7 times as wide as glabella at eye line. Postocular cheeks markedly wider than occipital ring. Short preglabellar field. Free cheeks with long spine, right-angled to obtuse genal angle and virtually straight posterior margin. Thorax with 12 segments, pleural regions about one and a half times as wide as axis, slender relatively long pleural spines, and probably a long axial spine on 11th segment. Subtriangular pygidium with 5 pairs of marginal spines and 4–6 axial rings.

Material: Two cranidia. Besides, two free cheeks and one pygidium are tentatively assigned.

Occurrence: *Leptoplastus norvegicus* occurs in the *L. crassicornis*–*L. angustatus* Zone in Norway and Sweden (Henningsmoen, 1957). The species occurs in the investi-

gated outcrop in beds VIII and XIV in section 1 and bed E and D2 in section 2; see Figs. 2, 3.

Comparison: *Leptoplastus norvegicus* can easily be separated from the co-occurring species because of the markedly narrower fixed cheeks in the cranidium. The glabella is more elongate in *L. norvegicus* and which also has preglabellar field unlike *L. crassicornis*. For comparison with *L. raphidophorus*, *L. angustatus* and *L. ovatus*, see these taxa.

Remarks: The present study shows that *L. norvegicus* ranges from the *L. raphidophorus* Zone and into the *L. crassicornis*–*L. angustatus* Zone. Holtedahl (1910) described a great variation of glabella, but he included material of several species when describing *L. norvegicus*.

Leptoplastus ovatus (Angelin, 1854)

Fig. 6

- 1904 *Leptoplastus ovatus* Angelin – Persson, p. 520, pl. 9, figs. 17–23. (Description. Figs. of cranidia, free cheek and dorsal shields).
- 1910 *Leptoplastus ovatus* Angelin, var. *norvegicum*, nov. var. [partim] – Holtedahl, pp. 10–11, pl. I, figs. 11, 12. (Description and figs. of free cheeks and pygidium).
- 1922 *Leptoplastus ovatus* Angelin – Westergård, p. 145, pl. VIII, figs. 18–21. (Remarks, figs. of free cheeks and two incomplete dorsal shields).
- 1923 *Leptoplastus ovatus* Angelin – Poulsen, p. 35 (Description, occurrence).
- 1947 *Leptoplastus ovatus* Angelin – Westergård, p. 24. (Occurrence in Sweden).
- 1957 *Leptoplastus ovatus* Angelin – Henningsmoen, pp. 173–174, pl. 13, figs. 8–10. (Diagnosis, remarks and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidia and free cheek).
- 2006 *Leptoplastus ovatus* Angelin – Ahlberg et al., p. 102, 106, figs. 4, 6, 7. (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shields).
- 2008 *Leptoplastus ovatus* Angelin – Terfelt et al., p. 82. (Occurrence).

Characteristics: A *Leptoplastus* species with about as long as wide cephalic axis. Interocular cheeks about one-fourth as wide as glabella at eye line. Postocular cheeks somewhat narrower than occipital ring. No preglabellar field. Free cheeks with relatively short spine, straight posterior margin and obtuse genal angle. Thorax with 12 segments, no long axial spine, and pleural regions about three-quarters as wide as the axis. Subsemicircular pygidium with 3 pairs of marginal spines and 3 axial rings.

Material: Several cranidia and free cheeks.

Occurrence: *Leptoplastus ovatus* is characteristic for the *L. crassicornis*–*L. angustatus* Zone in Scandinavia

(Westergård, 1942, 1944; Ahlberg et al., 2006; this paper). It also occurs in the England (Taylor & Rushton, 1972) and possibly eastern Canada (same horizon), Henningsmoen (1957). The species occur in the investigated outcrop in bed VIII in section 1 and beds E and D2 in section 2; see Figs. 2, 3.

Comparison: *Leptoplastus ovatus* resembles *L. norvegicus*, but the interocular cheek is narrower and the genal spine is shorter in *L. ovatus*. Furthermore, *L. norvegicus* has a more elongated and tapering glabella. The free cheek in *L. ovatus* resembles that of *L. angustatus*, but in the latter the genal spine is positioned closer to the middle of the posterior margin. In *L. ovatus* the cephalic axis is nearly as long as wide, in *L. angustatus* and *L. raphidophorus* the cephalic axis is markedly elongate. In comparison with *L. crassicornis*, the cranidium of *L. ovatus* has narrower interocular cheeks.

Leptoplastus paucisegmentatus (Westergård, 1922)

- 1922 *Leptoplastus paucisegmentatus* n. sp. – Westergård, p. 146, pl. VIII, figs. 22–24. (Short description. Figs. of axial shield, cranidium and free cheeks).
- 1922 *Leptoplastus minor* n. sp. – Westergård, p. 144, pl. VIII, figs. 25–29. (Description. Figs. of cranidia, free cheek and pygidia).
- Non 1929 *Leptoplastus minor* Wgd. – Strand, p. 358. (Remarks).
- 1944 *Leptoplastus paucisegmentatus* Westergård – Westergård, p. 40, pl. 1 figs. 20–22. (Remarks. Figs. of axial shield, dorsal shield, and free cheek).
- 1947 *Leptoplastus paucisegmentatus* Wgård. – Westergård, p. 24. (Distribution in Sweden).
- ?1952 *Leptoplastus minor* Westergård – Hutchinson, p. 85, pl. IV, figs. 3–5, 6? (Description. Figs. of cranidia, free cheek and conspecific? pygidium).
- 1957 *Leptoplastus paucisegmentatus* – Henningsmoen, p. 174, pl. 4. (Description and occurrence. Drawings of cranidium, free cheek and pygidium).
- 2006 *Leptoplastus paucisegmentatus* Westergård – Ahlberg et al., p. 102, figs. 5, 7 (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shields).
- 2008 *Leptoplastus paucisegmentatus* Westergård – Terfelt et al., p. 81. (Occurrence).

Characteristics: A *Leptoplastus* species with elongate cephalic axis, interocular cheeks less than half as wide as glabella at eyeline. Postocular cheeks about as wide as occipital ring. No or very short preglabellar field. Free cheeks with relatively short spine, obtuse genal angle, and straight posterior margin. Thorax with 10 segments. Subsemicircular pygidium with 2–3 axial rings and 2–3 pairs of marginal spines.

Occurrence: The species is characteristic for the *L. paucisegmentatus* Zone in Sweden (Westergård, 1922; Henningsmoen, 1957; Terfelt et al., 2008), England (Taylor

& Rushton, 1972) and possibly Nova Scotia, Canada (Hutchinson, 1952).

Comparison: For comparison with *L. raphidophorus*, see that taxon.

Leptoplastus raphidophorus (Angelin, 1854)

Fig. 11

- 1910 *Leptoplastus ovatus*, Angelin – Høltedahl, p. 8, pl. 1, figs. 4–9.
- 1922 *Leptoplastus raphidophorus* Angelin [*partim*] – Westergård, p. 143, pl. VIII, figs. 13–17; pl. X, fig. 3 (Description, figs. of dorsal shield and all parts of dorsal shield). (Non Pl. X, fig. 2 = *L. neglectus*).
- 1947 *Leptoplastus raphidophorus* Angelin – Westergård, p. 24. (Occurrence in Sweden).
- 1957 *Leptoplastus raphidophorus* Angelin – Henningsmoen, pp. 157–177, pl. 13, fig. 17. (Diagnosis and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidia and free cheeks).
- 2006 *Leptoplastus raphidophorus* Angelin – Ahlberg et al., p. 102, figs. 4, 5, 7 (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shields).
- 2008 *Leptoplastus raphidophorus*, Angelin – Terfelt et al., p. 82. (Occurrence).

For further synonymy, see Henningsmoen (1957).

Characteristics: A *Leptoplastus* species with cephalic axis markedly longer than wide. Interocular cheeks between half and one-third as wide as glabella at eye line. Postocular cheeks slightly to markedly wider than occipital ring. Short preglabellar field. Free cheeks with long spine, straight posterior margin, and slightly obtuse genal angle. Thorax with 12 segments, pleural regions slightly to markedly wider than axis, and long axial spine on 11th segment. Pygidium rounded subtriangular with 3 pairs of marginal spines and 3 axial rings. For a more detailed description, see Westergård (1922) and Henningsmoen (1957).

Material: Several cranidia and free cheeks. Two pygidia.

Occurrence: *Leptoplastus raphidophorus* is characteristic for the *Leptoplastus raphidophorus* Zone in Norway, Sweden and England (Westergård, 1922; Henningsmoen, 1957; Taylor & Rushton, 1972). The species occurs in the investigated outcrop in beds V, VI and VII in section 1 and bed 9 in section 2; see Figs. 2, 3.

Comparison: *Leptoplastus raphidophorus* to some extent resembles *L. paucisegmentatus*. Both species thus have an elongated cephalic axis, but the glabella in *L. raphidophorus* is, however, significantly longer than wide. Postocular cheeks are about as wide as the occipital ring in *L. paucisegmentatus*, and wider than the occipital ring in *L. raphidophorus*. Preglabellar field is short in *L. raphidophorus*, and very short or absent in *L. paucisegmentatus*.

Figure 11. *Leptoplastus raphidophorus* from the *Leptoplastus* Superzone at Slemmestad, all from bed V, All scale bars: 1 mm. (A) and (C) Free cheeks (PMO 228.208–228.209). (B) Cranidium (PMO 228.210).

tus. Genal spine is longer in *L. raphidophorus* than in *L. paucisegmentatus*.

In comparison with *L. norvegicus* the interocular cheeks in *L. raphidophorus* are between $\frac{1}{3}$ and $\frac{1}{2}$ as wide as glabella at eye line whereas the interocular cheeks in *L. norvegicus* are between 0.5 and 0.7 as wide as glabella at eye line. Genal angle in *L. raphidophorus* is slightly obtuse, and right to acute in *L. norvegicus*. For comparison with *L. stenotus*, see that taxon.

Leptoplastus stenotus (Angelin, 1854)

Fig. 12

- 1904 *Leptoplastus stenotus* Angelin – Persson, p. 552, pl. 9, figs. 14–16. (Description. Figs. of free cheeks and axial shield).
- 1922 *Leptoplastus stenotus* Angelin – Westergård, p. 146, pl. IX, figs. 1–6. (Remarks. Figs. of dorsal shield and all parts of the dorsal shield).
- 1923 *Leptoplastus stenotus* Angelin – Poulsen, pp. 36–37, 58, figs. 13, 14, 21 (Description, occurrence, figs. of dorsal shield, free cheek and juvenile cranidium).
- 1947 *Leptoplastus stenotus* Ang. – Westergård, p. 24. (Occurrence in Sweden).
- 1957 *Leptoplastus stenotus* Angelin – Henningsmoen, pp. 177–178, pl. 2, fig. 16; pl. 4. (Diagnosis and occurrence. Drawings of cranidium, free cheek, pygidium and dorsal shield with free cheek).
- 2006 *Leptoplastus stenotus* Angelin – Terfelt, p. 1343, pl. 3 figs. 8–10. (Remarks. Fig. of cranidia, pygidia, free cheeks and dorsal shield).
- 2006 *Leptoplastus stenotus* Angelin – Ahlberg et al., p. 105, figs. 4, 6, 7. (Occurrence. Drawing of dorsal shield with free cheeks. Figs. of dorsal shield, free cheek).
- 2008 *Leptoplastus stenotus* Angelin – Terfelt et al., p. 82. (Occurrence).

For further synonymy, see Terfelt (2006).

Characteristics: A *Leptoplastus* species with elongated cephalic axis, truncate in front. Short preglabellar field. Interocular cheeks somewhat less than half as wide as glabella at eye line. Postocular cheeks almost as wide as glabella at the occipital ring. Free cheeks with slender spine, obtuse genal angle and straight posterior margin. Entire pygidium (or with small marginal points) with evenly rounded margin and 3–4 axial rings.

Material: Several cranidia and free cheeks. One pygidium.

Occurrence: *Leptoplastus stenotus* is characteristic for the eponymous zone in Norway, Sweden and Denmark (Henningsmoen, 1957). The species occurs in the investigated outcrop in beds XV and XVI in section 1 and bed B in section 2; see Figs. 2, 3.

Comparison: The cranidium of *L. stenotus* resembles that of *L. raphidophorus*, but in the latter the interocular cheeks are $\frac{1}{3}$ – $\frac{1}{2}$ as wide as glabella at eye line whereas they are nearly half as wide as glabella at eye line in *L. stenotus*. The postocular cheeks in *L. raphidophorus* are wider than the occipital ring and about as wide as the occipital ring in *L. stenotus*. *Leptoplastus stenotus* has a more slender and shorter genal spine compared to *L. raphidophorus*. The pygidium is rounded subtriangular in *L. raphidophorus* and evenly rounded in *L. stenotus*. The cranidium in *L. stenotus* also somewhat resembles that of *L. angustatus*, but the latter has no preglabellar field and the glabella is slightly tapering. The interocular cheeks in *L. angustatus* varies from more than half as wide as glabella at eye line to slightly less than half as wide. The interocular cheeks in *L. stenotus* are somewhat less than half as wide as the glabella at eye line. The cranidium of *L. stenotus* is rather similar to that of *L. raphidophorus* in many features, but the two species are readily distinguished by their free cheeks.

Remarks: *Leptoplastus stenotus* is the only species in this outcrop which occurs alone in its own zone.

Genus *Parabolina* Salter, 1849.

Type species (by monotypy): *Entomostracites spinulosus* Wahlenberg, 1818.

Characteristics: Oleninae with subparallel or converging facial sutures. Preglabellar field variably developed and may be absent. Free cheeks with spine continuous with lateral margin or slightly diverging outwards. Transversely subelliptical to subsemicircular pygidium with or without marginal spines. For full diagnosis, see Henningsmoen (1957).

***Parabolina spinulosa* (Wahlenberg, 1818)**

Fig. 13

- 1904 *Parabolina spinulosa* Wahlenberg – Persson, p. 513, pl. IX, fig. 24. (Fig. of juvenile pygidium).
 1910 *Parabolina spinulosa*, Wahlenberg – Høltedahl, p. 5, pl. II, fig. 13. (Fig. of hypostoma).
 1922 *Parabolina spinulosa* (Wahlenberg) – Westergård, p. 134, pl. VI, figs. 14–20. (Description, figs. of dorsal shield, pygidium, free cheek, hypostoma and axial shield of juvenile specimen).
 1923 *Parabolina spinulosa* Wahlenberg – Poulsen, pp. 29–31. (Description, occurrence).
 1947 *Parabolina spinulosa* (Wahlenberg) – Westergård, p. 24. (Occurrence).
 1957 *Parabolina spinulosa* (Wahlenberg) – Henningsmoen, p. 126, pl. 1, 3, text fig. 12. (Description and occurrence. Drawings of cranidium, free cheek, pygidium, hypostoma and dorsal shield).
 1997 *Parabolina spinulosa* 1997 (Wahlenberg) – Clarkson et al., pp. 69–89, figs. 1–17. (Description and diagnosis of protaspids. Drawings and figs. of cranidia, free cheeks, pygidia, hypostomae, dorsal shields and growth stages).
 2006 *Parabolina spinulosa* Wahlenberg – Ahlberg et al., p. 101, figs. 5, 8 (Occurrence. Drawing of dorsal shield and free cheeks. Figs. of cranidia and pygidium).
 2008 *Parabolina spinulosa* Wahlenberg – Terfelt et al., p. 81. (Occurrence).

For further synonymy, see Henningsmoen (1957) and Clarkson et al. (1997).

Characteristics: A *Parabolina* species with moderately wide pleural regions and fixed cheeks. No or practically no prelabellar field, small palpebral lobes far forwards and close to glabella. Free cheeks with about right-angled inner spine angle. 12 thoracic segments, pleural spines progressively longer from anterior segments (short spines) to posterior segments (long spines). Pygidium with 5–6 axial rings and 3–5 pairs of marginal spines, all but the inner pair long. For a more detailed description, see Westergård (1922, p. 134) and Henningsmoen (1957, p. 126).

Material: Few cranidia and free cheeks. Four pygidia.

Occurrence: The species is characteristic for the *Parabolina spinulosa* Zone but it also ranges into the *Leptoplastus paucisegmentatus* Zone in Sweden (Westergård, 1947). It occurs in Norway, Denmark, Poland, England and Canada (Westergård, 1922; Poulsen, 1923; Henningsmoen 1957; Taylor & Rushton, 1972; Żylińska 2002). The species occurs in the investigated outcrop in beds I, II, III and IV in section 1 and bed F in section 2; see Figs. 2, 3.

Comparison: According to Westergård (1922, p. 135) this species cannot be confused with other species except *P. brevispina* (occurring in the lower part of the *Parabolina* Superzone). The postocular cheeks in *P. spinulosa* are wider than the glabella at eye line than in *P. brevispina*. The free cheeks of *P. brevispina* are slender and the length of the spine is shorter than the free cheek itself. The pygidium of *P. spinulosa* has significantly longer marginal spines than the pygidium of *P. brevispina*.

Figure 12. *Leptoplastus stenotus* from the *Leptoplastus* Superzone at Slemmestad, all from bed B. All scale bars: 1 mm. (A) Cranidium. (B) Pygidium. (C) Free cheek (PMO 228.211–228.212–228.213).

Genus *Protopeltura* Brøgger, 1882.

Type species (SD Westergård, 1922): *Peltura praecursor* Westergård, 1922.

Characteristics: A Pelturinae with a rounded glabella or truncated in front, short or no preglabellar field. Fixed cheeks from about $\frac{1}{2}$ to $\frac{3}{4}$ as wide as occipital ring. Free cheeks with spine deviating slightly outwards from lateral margin, straight posterior margin. Subtriangular to subsemicircular pygidium with or without marginal spines. For full diagnosis, see Henningsmoen (1957).

***Protopeltura aciculata* (Angelin, 1854)**

Fig. 13

- 1854 *Olenus aciculatus*. n. sp. – Angelin, p. 44, pl. XXV, fig. 6. (Brief diagnosis. Crude, partly incorrect figure of dorsal shield).
- 1922 *Protopeltura aciculata* (Angelin) – Westergård, p. 169, pl. XIV, figs. 3–13. (Description. Figs. of axial shield, cranidia, free cheeks, fragments of thorax, pygidia and hypostoma).
- 1947 *Protopeltura aciculata* (Ang.) – Westergård, p. 26. (Distribution in Sweden).
- 1957 *Protopeltura aciculata* (Angelin) – Henningsmoen, p. 222, pl. 3. (Description, remark and occurrence. Drawings of cranidium, free cheek, pygidium and hypostoma).
- 2002 *Protopeltura aciculata* (Angelin) – Żylińska, p. 225. (Occurrence).
- 2012 *Protopeltura aciculata* (Ang.) – Månsson & Clarkson, p. 889, figs. 2–6. (Description and remarks. Drawings of cranidia, dorsal shields and growth stages. Figs. of cranidia, pygidia, free cheeks, hypostoma and dorsal shields).

Characteristics: A *Protopeltura* species with cephalic axis well rounded at front, relatively long preglabellar field. S1 and S2 distinct. Interocular cheeks about half as wide as glabella at eye line, postocular cheeks about as wide as the occipital ring; free cheeks with slightly acute to slightly obtuse inner spine angle. 12 thoracic segments, pygidium subsemicircular, entire or with one pair of small marginal spines. For a more detailed description, see Månsson & Clarkson (2012).

Material: One cranidium and two pygidia.

Occurrence: *Protopeltura aciculata* is characteristic for the *Parabolina spinulosa* Zone in Sweden, Norway, Denmark and Poland (Henningsmoen, 1957; Żylińska, 2002). The species occurs in the investigated outcrop in beds I, II, III and IV in section 1; see Figs. 2, 3.

Comparison: For comparison with *P. holtedahli*, *P. intermedia*, *P. pusilla* and *P. praecursor*, see these taxa.

***Protopeltura broeggeri* (Holtedahl, 1910)**

Fig. 14

- 1910 *Leptoplastus Brøggeri*, nov. sp. – Holtedahl, p. 18, pl. III, figs. 2, 4, 10. (Description. Figs. of a part of cranidium, part of thorax, pygidium, hypostoma, juvenile axial shield, juvenile cranidium and juvenile pygidium).
- 1922 *Leptoplastus Brøggeri* Holtedahl – Westergård, pp. 110, 111, 151. (Remarks).
- 1957 *Protopeltura broeggeri* Holtedahl – Henningsmoen, pp. 225–226, pl. 23, figs. 7–15. (Diagnosis, description and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidia, free cheeks, hypostoma, pygidium and dorsal shield).

Figure 13. Trilobites from the *Parabolina Superzone* at Slemmestad. All scale bars: 1 mm. (A) Pygidium of *P. spinulosa* from bed I (PMO 228.214). (B) and (C) Cranidium and pygidium of *P. pusilla*, both from bed I (PMO 228.215–228.216). (D) and (E) Pygidium and cranidium of *P. aciculata*, from beds II and I, respectively (PMO 228.217–228.218). (F) Cranidium of *P. holtedahli* from bed II (PMO 228.219).

Characteristics: A *Protopeltura* species with relatively long preglabellar field. S1 and S2 distinct. Interocular cheeks about half as wide as glabella at eye line. Postocular cheeks slightly wider than the occipital ring. Widest pleurae up to 1.5 times as wide as axis. With entire, rounded subtriangular pygidium with 3 axial rings and end lobe. Number of thoracic segments unknown (probably 12).

Material: Several cranidia and free cheeks. One pygidium.

Occurrence: *Protopeltura broeggeri* occurs in the upper part of the *L. crassicornis*–*L. angustatus* Zone in Norway. The species has been found in the investigated outcrop in bed XIV in section 1 and beds 7.1 and 6 in section 2, see Figs. 2, 3.

Comparison: The cranidium of *P. broeggeri* somewhat resembles that of *L. neglectus* but the postocular cheeks in the latter are wider compared to the occipital ring. The glabella in *L. neglectus* is more slender than in *P. broeggeri*. The interocular cheeks are about half as wide as the glabella at eye line in both *P. broeggeri* and *L. neglectus*.

Remarks: The cranidium in *P. broeggeri* to some extent resembles *Leptoplastus* representatives and the features are not typically Pelturid-like.

Protopeltura holtedahli (Henningsmoen, 1957)

Fig. 13

1910 *Peltura praecursor*, Westergård – Høltedahl, p. 14, pl. II, figs. 3, 4, 6–10. (Figs. of thoracic segments with attached pygidium, young free cheek, pygidium and cranidia).

1957 *Protopeltura holtedahli* n. sp. Henningsmoen – Henningsmoen, p. 227, pl 6; pl 23 figs. 16–22. (Description and occurrence, Drawings of cranidium, free cheek, hypostoma and pygidium. Figs. of cranidia, free cheeks, hypostoma and postcephalic dorsal shield).

Characteristics: A *Protopeltura* species with short preglabellar field S1 and S2 distinct. Postocular cheeks $\frac{3}{4}$ as wide as occipital ring. Interocular cheeks about $\frac{1}{4}$ as

wide as the glabella at eye line. Free cheeks with relatively wide border and long spine. Thorax apparently with 10 segments. Subsemicircular pygidium without marginal spines, but slightly undulating. For a more detailed description, see Henningsmoen (1957).

Material: Six cranidia.

Occurrence: *Protopeltura holtedahli* occurs in the *P. spinulosa* Zone in Norway (present paper). The species has been recorded in the investigated outcrop in beds I, II, and III in section 1, see Figs. 2, 3.

Comparison: *Protopeltura holtedahli* resembles *P. aciculata* and *P. pusilla*, but the interocular cheeks are about half as wide as the glabella at eye line in *P. aciculata* and *P. pusilla* whereas the interocular cheek in *P. holtedahli* is about one fourth as wide as the glabella at eye line. The postocular cheeks are of the same width as the occipital ring in *P. aciculata* and *P. pusilla* whereas the postocular cheeks in *P. holtedahli* are three-quarters as wide as the occipital ring. *Protopeltura aciculata* has a pygidium without or only a pair of rudimentary marginal spines and when such rudimentary spines are present it can be differentiated from the pygidium of *P. holtedahli*. The axis constitutes one third of the total pygidial width measured anteriorly at *P. aciculata* and *P. pusilla*, at *P. holtedahli* the axis occupies $\frac{3}{7}$ of the total width of the pygidium. The cranidium of *P. holtedahli* resembles that of *P. intermedia*, but the latter species has a shorter preglabellar field and a tapering glabella. The pygidium of *P. intermedia* is subsemicircular in outline whereas *P. holtedahli* has a subtriangular pygidium. For comparison with *P. praecursor*, see that taxon.

Remarks: *Protopeltura holtedahli* occurred without associated species in the museum material Henningsmoen (1957) had at his disposal and he could not identify with certainty from which level the species originated. He suspected that it may derive from the base of the *Protopeltura praecursor* Zone, now *Protopeltura* Superzone, and even erected a separate subzone, assumed characterised by *P. holtedahli*. However, the new material demonstrates that the species is from the older *P. spinulosa* Zone. It resembles the coeval *P. aciculata* in many ways (see above), but they cannot be separated just as subspecies

Figure 14. *Protopeltura broeggeri* from the *Leptoplastus* Superzone at Slemmestad, all from bed XIV. All scale bars: 1 mm. (A) Pygidium, (B) Free cheek and (C) Cranidium (PMO 228.220–228.221–228.226).

since they co-occur. It is peculiar that three rather similarly looking taxa, *P. holtedahli*, *P. aciculata* and *P. pusilla*, occur together in the *P. spinulosa* Zone. In the material at hand they appear distinguishable, but a larger material should be investigated in order to analyse morphological variation (overlap?) of these taxa.

Protopeltura intermedia (Westergård, 1922)

1922 *Protopeltura intermedia* n. sp. – Westergård, p. 171, pl. XIV, figs. 18–22. (Description. Figs. of cranidia, free cheek and pygidia).

1947 *Protopeltura intermedia*, Westergård – Westergård, p. 26. (Occurrence in Sweden).

1957 *Protopeltura intermedia*, Westergård – Henningsmoen, p. 228, pl. 4. (Distribution in Sweden and description. Drawings of cranidium, free cheek and pygidium).

Characteristics: A *Protopeltura* species with very short preglabellar field, glabella bluntly rounded in front and eyes rather close to the glabella. Postocular cheeks slightly more than half as wide as the occipital ring. Free cheeks with short and slender spine. Pygidium subsemicircular, entire. Thorax unknown.

Occurrence: *Protopeltura intermedia* occurs in the *Lep-
toplastus* Superzone in Sweden (Westergård, 1922; Henningsmoen, 1957).

Comparison: The cranidium to some extent resembles the cranidia of *P. holtedahli*, *P. praecursor*, *P. pusilla* and *P. aciculata*. *Protopeltura intermedia* differs from these species by having wider postocular cheeks and the eyes closer to the glabella. The pygidium of *P. intermedia* resembles *P. aciculata*, but *P. intermedia* does not have minor marginal spines. However, as *P. aciculata* only sometimes has minor marginal spines, the pygidia of these forms can be difficult to differentiate. For comparison with *P. holtedahli*, see that taxon.

Protopeltura praecursor (Westergård, 1909)

Fig. 10

1909 *Peltura praecursor* n.sp. – Westergård, p. 48. (Remarks).

1910 *Peltura praecursor*, Westergård [partim] – Holtedahli, p. 14, pl. II, figs. 1, 2 and 5? (Figs. of cranidium, free cheek and hypostoma. Non figs. 3, 4, 6–10 = *Protopeltura holtedahli*).

1922 *Protopeltura praecursor* (Westergård) – Westergård, p. 171, pl. XIV, figs. 23–29, 31; pl. XV, fig. 1. (Description. Figs. of dorsal shield, cranidia, free cheek, pygidium and hypostoma).

1947 *Protopeltura praecursor* Westergård – Westergård, p. 26. (Occurrence in Sweden).

1957 *Protopeltura praecursor* Westergård – Henningsmoen, pp. 229–230, pl. 24, figs. 1–5. (Diagnosis and occurrence. Drawings of cranidium, free

cheek, hypostoma, pygidium and dorsal shield. Figs. of cranidium, free cheek, hypostoma, pygidium and dorsal shield).

For further synonymy, see Henningsmoen (1957).

Characteristics: A *Protopeltura* species with very short or practically no preglabellar field. The interocular cheeks are about $\frac{1}{3}$ as wide as glabella at eye line. Postocular cheeks somewhat more than half as wide as the occipital ring. The palpebral lobes are situated in front and close to the glabella. The postocular margin is highly convex. The free cheek possesses a slender spine. Pygidium with 2–4 pairs of marginal spines and 3–4 axial rings.

Material: Few cranidia, several free cheeks.

Occurrence: The species occurs in several horizons of *Protopeltura* Superzone in Norway and Sweden (cf., Henningsmoen, 1957; Terfelt et al., 2008). The species occurs in the investigated outcrop in beds XVII and between XVII/XVIII in section 1 and beds 2 and 1 in section 2; see Figs. 2, 3.

Comparison: The cranidium of *P. praecursor* possesses typical Pelturid features and in comparison with the cranidia of *P. aciculata*, *P. pusilla* and *P. holtedahli* a preglabellar field is absent. The interocular cheek in *P. praecursor* is $\frac{1}{3}$ as wide as the glabella at eye line; in *P. aciculata* and *P. pusilla* it is only half as wide as glabella and in *P. holtedahli* the interocular cheek is $\frac{1}{4}$ as wide as the glabella. The postocular cheeks in *P. praecursor* are somewhat more than half as wide as the occipital ring; in *P. aciculata* and *P. pusilla* the postocular cheeks are about as wide as the occipital ring and in *P. holtedahli* the postocular cheeks are about $\frac{3}{4}$ as wide as the occipital ring. The free cheeks of the discussed species are readily separated. For comparison with *P. intermedia*, see that taxon.

Protopeltura pusilla (Westergård, 1922)

Fig. 13

1922 *Protopeltura aciculata pusilla* Norwegian variant – Westergård, pl. XIV, p. 171, figs. 14–17. (Diagnosis. Figs. of cranidium, free cheeks and pygidium).

1947 *Protopeltura aciculata pusilla* Westergård – Westergård, p. 26. (Occurrence in Sweden).

1957 *Protopeltura aciculata pusilla* Westergård – Henningsmoen, p. 223, pl. 3; pl. 23, figs. 1–6. (Diagnosis, remarks and occurrence. Drawings of cranidium, free cheek and pygidium. Figs. of cranidia, free cheek hypostoma, dorsal and axial shields).

Characteristics: A *Protopeltura* species with a subrectangular cranidium. Truncated glabella front. The posterior part of the glabella has parallel sides and is tapering towards the front. The fixed cheeks have a curved margin and the interocular cheeks are about half as wide as the glabella at eye line, postocular cheeks about as wide as the occipital ring. Free cheeks with a curved lateral

border and a slightly curved posterior margin. Relatively short and slender spine with a right or slightly obtuse genal angle. Wide, subtriangular and entire pygidium, without marginal spines. For a more detailed description, see Westergård (1922) and Henningsmoen (1957).

Material: Few cranidia, one free cheek and one pygidium.

Occurrence: The species is characteristic for the *Parabolina spinulosa* Zone in Norway and it is known from several localities including Røyken (Slemmestad) (Henningsmoen, 1957). Żylińska (2002) reported *P. aciculata* from the lower part of the *Parabolina brevispina* Zone in Poland. The species occurs in the investigated outcrop in beds I, II, III and IV in section 1 and bed F in section 2; see Figs. 2, 3.

Comparison: *Protopeltura pusilla* resembles *P. aciculata* but is smaller and has a subrectangular truncated glabella. The free cheeks are also wider and carry a shorter spine. For comparison with *P. holtedahli* and *P. praecursor*, see these taxa.

Remarks: *Protopeltura pusilla* has previously been ranked as a subspecies of *P. aciculata*, but in the investigated outcrops *P. pusilla* and *P. aciculata* co-occur and are, accordingly, separated at species level.

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References

- Ahlberg, P. 2003: Trilobites and intercontinental tie points in the Upper Cambrian of Scandinavia. *Geologica Acta* 1, 127–134.
- Ahlberg, P., Månsson, K., Clarkson, E.N.K. & Taylor, C.M. 2006: Faunal turnovers and trilobite morphologies in the upper Cambrian *Leptoplastus* Zone at Andrarum, southern Sweden. *Lethaia* 39, 97–110.
- Angelin, N.P. 1854: *Palaeontologia Scandinavica. I: Crustacea formationis transitionis* 2. T.O. Weigel, Leipzig, pp. 21–92.
- Bagnoli, G. & Stouge, S. 2014: Upper Furongian (Cambrian) conodonts from the Degerhamn quarry road section, southern Öland, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar* 136, 436–458.
- Bjørlykke, K. 1974: Depositional history and geochemical composition of Lower Palaeozoic epicontinental sediments from the Oslo region. *Norges geologiske undersøkelse* 305, 1–81.
- Boeck, C. 1838: Uebersicht der bisher in Norwegen gefundenen Formen der Trilobiten. In Keilhau, B.M. (ed.): *Gaea Norvegica*, Johan Dahl, Christiania (Oslo), pp. 138–145.
- Brøgger, W.C. 1882: *Die silurischen Etagen 2 und 3 im Kristianiagebiet und auf Eker, ihre Gliederung, Fossilien, Schichtenstörung und Contactmetamorphosen*. Universitätsprogramm für 2. Sem 1882, Kristiania, viii, 376 pp., 12 pls.
- Burmeister, H. 1843: *Die Organisation der Trilobiten aus ihren lebenden Verwandten entwickelt: nebst einer systematischen Uebersicht aller zeither beschriebenen Arten*. Georg Reimer, Berlin, 148 pp., pl. I–VI.
- Clarkson, E.N.K., Taylor, C.M. & Ahlberg, P. 1997: Ontogeny of the trilobite *Parabolina spinulosa* (Wahlenberg, 1818) from the upper Cambrian Alum Shales of Sweden. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 88, 69–89.
- Henningsmoen, G. 1957: *The trilobite family Olenidae*. Skrifter Utgitt av det Norske Videnskaps-Akademi i Oslo, I Matematisk naturvidenskapelig Klasse 1, pp. 1–303.
- Henningsmoen, G. 1958: The Upper Cambrian faunas of Norway. *Norsk Geologisk Tidsskrift* 38, 179–196.
- Holtedahli, O. 1910: Über einige norwegischen Oleniden. *Norsk Geologisk Tidsskrift* 2, 1–24.
- Hutchinson, R.D. 1952: The stratigraphy and trilobite faunas of the Cambrian sedimentary rocks of Cape Breton Island, Nova Scotia. *Geological Survey of Canada, Memoir* 263, 1–124.
- Høyberget, M. & Bruton, D.L. 2012: Revision of the trilobite genus *Sphaerophthalmus* and relatives from the Furongian (Cambrian) Alum Shale Formation, Oslo Region, Norway. *Norwegian Journal of Geology* 92, 433–450.
- Kleppe, K.S. 2014: *Conodonts and depositional environment of the Middle and Upper Cambrian Alum Shale, Slemmestad, Oslo Region*. MSc thesis, University of Oslo, pp. 1–110.
- Martinsson, A. 1974: The Cambrian of Norden. In Holland, C.H. (ed.): *Lower Palaeozoic rocks of the world, Volume 2, Cambrian of the British Isles, Norden, and Spitsbergen*, Wiley-Interscience, London, pp. 185–283.
- Müller, K.J. & Hinz-Schallreuter, I. 1998: Internal structures of Cambrian conodonts. *Journal of Paleontology* 72, 91–112.
- Månsson, K. & Clarkson, E.N.K. 2012: Ontogeny of the upper Cambrian (Furongian) Olenid trilobite *Protopeltura aciculata* (Angelin, 1854) from Skåne and Västergötland, Sweden. *Palaeontology* 55, 887–901.
- Nathorst, A.G. 1869: Om lagerföljden inom Cambriska formationen vid Andrarum i Skåne. *Öfversigt af Kongliga Vetenskaps-Akademiens Förhandlingar* 1869, 61–65.
- Nielsen, A.T. & Schovsbo, N.H. 1999: The *Leptoplastus* Zone (Upper Cambrian) at Slemmestad, Norway. In Eriksson, M. (ed.): *Lundagarna i Historisk Geologi och Paleontologi VI, Abstracts*, Lund Publications in Geology 144, p. 22.
- Nielsen, A.T. & Schovsbo, N.H. 2007: Cambrian to basal Ordovician lithostratigraphy in southern Scandinavia. *Bulletin of the Geological Society of Denmark* 53, 47–92.
- Nielsen, A.T., Weidner, T., Terfelt, F. & Høyberget, M. 2014: Upper Cambrian (Furongian) biostratigraphy in Scandinavia revisited: definition of superzones. *Geologiska Föreningens i Stockholm Förhandlingar* 136, 193–197.
- Persson, E. 1904: Till kännedomen om oleniderna i "zonen med *Eurycare* och *Leptoplastus*" vid Andrarum. I. *Geologiska Föreningens i Stockholm Förhandlingar* 26, 507–528.
- Poulsen, C. 1923: Bornholms Olenuslag og deres fauna. *Danmarks geologiske Undersøgelse* 2, række 40, 1–83.
- Salter, J.W. 1849: Figures and descriptions illustrative of British organic remains, Decade 2. *Memoirs of the Geological Survey of the United Kingdom*, 38 pp., 10 pls.
- Schovsbo, N.H. 2003: The geochemistry of Lower Palaeozoic sediments deposited on the margin of Baltica. *Bulletin of the Geological Society of Denmark* 50, 11–27.
- Strand, T. 1929: The Cambrian beds of the Mjøsen District in Norway. *Norsk geologisk tidsskrift* 10, 307–365, pls. I–II.
- Taylor, K. & Rushton, A.W.A. 1972 [dated 1971]: The pre-Westphalian geology of the Warwickshire Coalfield. *Bulletin of the Geological Survey of Great Britain* 35, 1–152.
- Terfelt, F. 2006: Review of uppermost Furongian trilobites from Scania, southern Sweden, based on type material. *Palaeontology* 49, 1339–1355.

- Terfelt, F., Eriksson, M.E., Ahlberg, P. & Babcock, L.E. 2008: Furongian Series (Cambrian) biostratigraphy of Scandinavia — a revision. *Norwegian Journal of Geology* 88, 73–87.
- Terfelt, F., Ahlberg, P. & Eriksson, M.E. 2011: Complete record of Furongian polymerid trilobites and agnostoids of Scandinavia — a biostratigraphical scheme. *Lethaia* 44, 8–14.
- Topper, T.P., Skovsted, C.B., Harper, D.A., & Ahlberg, P. (2013): A bradoriid and brachiopod dominated shelly fauna from the Furongian (Cambrian) of Västergötland, Sweden. *Journal of Paleontology* 87, 69–83.
- Vogdes, A.W. 1890: A bibliography of Paleozoic Crustacea from 1698 to 1889 including a list of North American species and a systematic arrangement of genera. *Bulletin of the United States Geological Survey* 63, 177 pp.
- Vogdes, A.W. 1925: Paleozoic Crustacea. Parts I–III. *Transactions of the San Diego Society of Natural History* IV, pp. 1–154.
- Wahlenberg, G. 1818: Petrificata telluris svecanae. *Nova Acta Regiae Societatis Scientiarum Upsaliensis* 8, 1–116.
- Westergård, A.H. 1909: Studier öfver Dictyograptusskiffern och dess gränslager med särskild hänsyn till i Skåne förekommande bildningar. *Lunds Universitets Årsskrift, N.F.* 2, 1–79, pls. 1–5.
- Westergård, A.H. 1922: Sveriges olenidskiffer. *Sveriges Geologiska Undersökning Ca* 18, 1–205.
- Westergård, A.H. 1942: Stratigraphic results of the borings through the Alum Shales of Scania made in 1941–1942. *Meddelanden Från Lunds Geologisk-Mineralogiska Institution* 100, 1–20.
- Westergård, A.H. 1944: Borrningar genom Skånes alunskiffer 1941–42. *Sveriges Geologiska Undersökning C* 459, 1–45.
- Westergård, A.H. 1947: Supplementary notes on the Upper Cambrian trilobites of Sweden. *Sveriges Geologiska Undersökning C* 489, 1–34.
- Whitworth, P. H. 1970: Ontogeny of the upper Cambrian trilobite *Leptoplastus crassicornis* (Westergaard) from Sweden. *Palaeontology* 13, 100–111, pls. 22–23.
- Żylińska, A. 2002: Stratigraphic and biogeographic significance of Late Cambrian trilobites from Łysogóry (Holy Cross Mountains, central Poland). *Acta Geologica Polonica* 52, 217–238.