Glacial erratic boulders from Jutland, Denmark, feature an uppermost lower Cambrian fauna of the Lingulid Sandstone Member of Västergötland, Sweden

THOMAS WEIDNER, GERD GEYER, JAN OVE R. EBBESTAD & VOLKER VON SECKENDORFF

Reinvestigation of glacial erratic boulders from Jutland, Denmark, and from northern Germany, has revealed a moderately diverse fauna with the trilobites *Holmiella*? sp., *Epichalnipsus anartanus*, *Epichalnipsus* sp. A, *Epichalnipsus* sp. B, and *Berabichia erratica*, three species of lingulid brachiopods, one hyolith species, and trace fossils comparable to *Halopoa imbricata*. Comparison with faunas from the Cambrian of Scandinavia strongly suggested a biostratigraphic position equivalent to the uppermost part of the (revised) *Holmia kjerul i*–'*Ornamentaspis*' *linnarssoni* to lowermost *Comluella*?–*Ellipsocephalus lunatus* zones sensu Nielsen & Schovsbo (2011), or the lower to middle part of the traditional '*Ornamentaspis*' *linnarssoni* Zone, but probably a particular horizon and biofacies not yet discovered in Scandinavia. Considerations of glacial transport regimes and the distribution of comparable rock units, as well as a petrographical analysis of the material from the studied erratic boulders and rocks from outcrops in Sweden, indicate that the boulders were derived from the Lingulid Sandstone Member of the File Haidar Formation and the source area is situated in the vicinity of the present-day outcrops in the Halleberg–Hunneberg area, Västergötland, Sweden.

Thomas Weidner [to.we@paradis.dk], Ravnholtvej 23, Rårup, DK-7130 Juelsminde, Denmark. Gerd Geyer [gerd.geyer@uni-wuerzburg.de], Institut für Geographie und Geologie, Lehrstuhl für Geodynamik und Geomaterialforschung, Bayerische Julius-Maximilians-Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany. Jan Ove R. Ebbestad [jan-ove.ebbestad@em.uu.se], Museum of Evolution, Uppsala University, SE-75236 Uppsala, Sweden. Volker von Seckendorff [volker.von_seckendorff@uni-wuerzburg.de], Institut für Geographie und Geologie, Lehrstuhl für Geodynamik und Geomaterialforschung, Bayerische Julius-Maximilians-Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany.

Corresponding author: Gerd Geyer

Trilobite-bearing lower Cambrian strata (provisional Cambrian Series 2) in Sweden have been studied mainly at scattered localities in the south (Scania) and in numerous outcrops along the Caledonian mountain range (Jämtland, Ångermanland and Lapland), in both the autochthonous and allochthonous sequences (Fig. 1A). Rocks of early Cambrian age predominantly consist of siltstone and sandstone. Trilobites recorded from these strata of Baltica are fairly restricted by comparison to those from other Cambrian continents and belong to the olenelloid family Holmiidae (*Holmia*, *Holmiella*, *Kjerulfia* and *Schmidtiellus*), to the ptychoparioid family Ellipsocephalidae (with species assigned, or provisionally attributed to the genera *Comluella*, *Ellipsocephalus*, *Ornamentaspis* and *Strenuaeva*), and the eodiscid genera *Runcinodiscus*, *Calodiscus*, *Chelediscus* and *Neocobboldia*. The early Cambrian faunas and biostratigraphy of the Swedish regions are portrayed by Bergström (1973), Ahlberg & Bergström (1978, 1983, 1991), Ahlberg (1979, 1980, 1984a, 1984b, 1984c, 1985), Bergström & Ahlberg (1981), Ahlberg *et al.* (1986), Nielsen & Schovsbo (2006, 2011) and Høyberget *et al.* (2015). Studies during the last 15 years have increased our knowledge about these faunas, particularly of those from localities in the northern Caledonides (Moczydłowska *et al.* 2001; Axheimer *et al.* 2007; Cederström *et al.* 2009, 2011, 2012). Due to both outcrop conditions and depositional environments, polymerid trilobites are mostly fragmentary and often
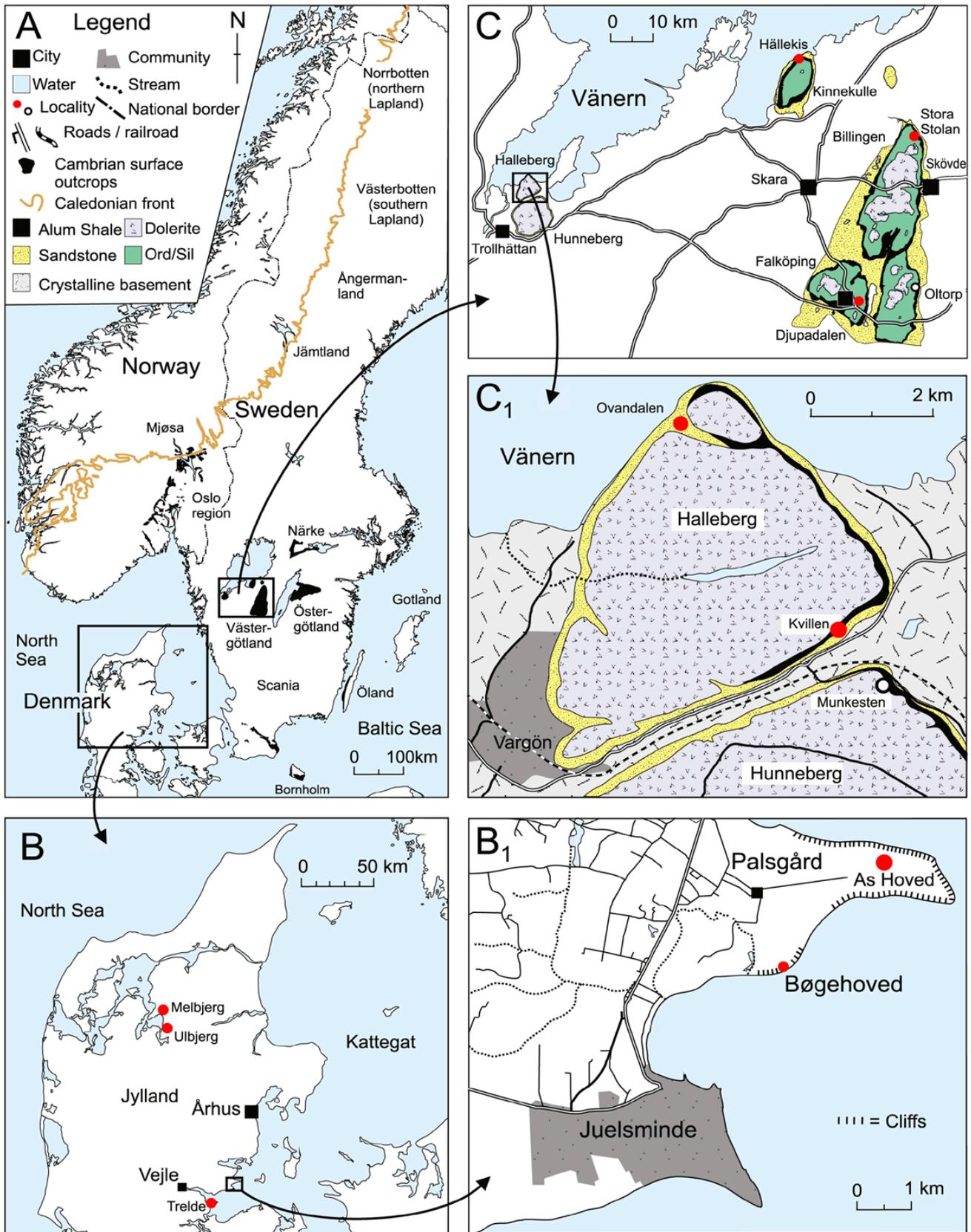
Fig. 1. A, map of Scandinavia showing outcrops of the Cambrian with inserts of the areas in Denmark and Sweden treated in the text; **B** and **B₁**, maps of Jutland, Denmark, with localities (red) yielding boulders of the fossil-bearing Lingulid Sandstone; **C**, map of Västergötland showing Lower Palaeozoic outcrops at Halleberg, Hunneberg, Kinnekulle, and Falbygden to the east with localities (red) yielding the fossil-bearing Lingulid Sandstone; **C₁**, detailed map of Halleberg with the localities Ovandalen and Kvillen (base map from Andersson *et al.* 1985).

do not permit a precise determination; they belong to genera or species endemic to Baltica and are of limited use for intercontinental or even global correlation, whereas correlation into other Cambrian continents is facilitated by the species of *Calodiscus* and *Chelediscus*. The lower Cambrian biostratigraphy of Scandinavia and Baltica in general has thus been in a state of preliminary subdivision and was recently revised by Nielsen & Schovsbo (2011) as shown in Fig. 2.

Of particular interest is the upper lower Cambrian part of the succession, which provides distinct problems for correlation into other regions as emphasized in the discussions on the Cambrian Series 2–Series 3 and Stage 4–Stage 5 boundary (e.g., Geyer & Palmer 1995; Fletcher 2003; Geyer 2005; Sundberg *et al.* in press). The traditional subdivision and subsequent zonal schemes that recognize a *Holmia kjerulfi* group Zone, a *Proampyx* (or '*Ornamentaspis*') *linnarssoni* Zone, and a '*Protolenus*' Zone (Fig. 2) are equally unable to characterize the trilobite faunas, lack a recognizable evolutionary development of the trilobites, and are not even readily correlatable with the neighbouring regions of Baltica in northern Poland or the Holy Cross Mountains in southern Poland.

Geyer *et al.* (2004) described trilobites of the ellipsocephaloid genera *Epichalnipsus* and *Berabichia* from glacial erratic boulders collected at As Hoved and other localities in Denmark and northern Germany. These boulders of trilobite-bearing quartzitic sandstones were interpreted as being derived from the Lingulid Sandstone Member of Västergötland and to represent an unidentified stratigraphical interval. Based on close morphological affinities with ellipsocephaloid trilobites from the Moroccan Atlas ranges, Geyer *et al.* (2004) proposed a stratigraphic correlation with the *Sectigena* Zone of Morocco, West Gondwana. However, differences in lithology suggested that this type of Lingulid Sandstone was unknown in Sweden.

Lingulid Sandstone: distribution, lithology, and biostratigraphy

A key unit for the upper lower Cambrian is the Lingulid Sandstone which is generally treated as a member of the File Haidar Formation (Thorslund &

Fig. 2. Biostratigraphic chart of the Scandinavian classical lower Cambrian with the historic development of the lithostratigraphical units for Västergötland and Scania (left and right columns under Lithostratigraphy southern Sweden) and the tentative position of important fossil horizons mentioned in numerous publications (cited in the text) from southern and central Sweden, the Swedish Allochthon and Lapland, the Mjøsa District in Norway and the Digermul Peninsula, Finnmark, Norway. Stratigraphic interpretations that differ from the original concepts follow data in Nielsen & Schovsbo (2011). RM, Rispebjerg Member.

Westergård 1938; Thorslund 1960; Bergström & Gee 1985; Nielsen & Schovsbo 2006). The Lingulid Sandstone was first adequately recognized by Holm (in Holm & Munthe 1901) who separated Linnarsson's Fucoid Sandstone (see Wallin 1868) into a lower and an upper unit termed Mickwitzia and Lingulid Sandstone, respectively, based on differences in lithological characters and bedding thicknesses. It is generally regarded as a depositional tongue of the File Haidar Formation extending from the stratotype on Gotland (Thorslund & Westergård 1938; Bergström & Gee 1985) into Öland, Västergötland, Östergötland and Närke. The two units of the File Haidar Formation form the uppermost part of the traditional lower Cambrian succession, but their vertical extent shows an opposite trend. The Mickwitzia Sandstone Member increases in thickness eastward, whereas the Lingulid Sandstone Member has its maximum thickness in the west. In addition, the boundary between the two is locally (Lugnås, Billingen) marked by a conglomeratic or coarse-grained layer (Linnarsson 1871; Hadding 1927; Westergård 1931; Bergström & Gee 1985; Jensen 1997; Nielsen & Schovsbo 2006) which appears to indicate a hiatus of unknown extent between the units. The Lingulid Sandstone Member appears to testify a change in depositional regime and has been interpreted as a result of deposition in deeper water than the Mickwitzia Sandstone Member, and the sparse amount of fine-grained material has been understood as indication of increased wave action (Hadding 1927; Westergård 1931). Nevertheless, Martinsson (1974) advocated the differences to be a result of deposition at a later stage in the basin. Nielsen & Schovsbo (2011) interpreted both units as two sequences of a continuous depositional history.

Nielsen & Schovsbo (2006) selected the stratotype of the Lingulid Sandstone Member in the Bårstad-2 drill core in Östergötland, which has been described in detail by Eklund (1990).

The Lingulid Sandstone Member is widely distributed in Västergötland in narrow outcrops at the flanks of the renowned table mountains, where it is composed of light grey, moderately to poorly cemented fine-grained quartz sandstone. Its maximum thickness in Västergötland is 28.6 m in the DBH 15/73 core of southern Billingen (Nielsen & Schovsbo 2006).

Only three reports of trilobite findings exist for the Lingulid Sandstone Member of Västergötland (Ahlberg *et al.* 1986). The upper part of the member in the quarry at Stora Stolan, northern Billingen, yielded a large fragment of a cheek with a genal spine that was tentatively assigned to *Holmia grandis* Kiær 1917, a species otherwise known only from the lower part of the *Holmia kjerulfi* Zone of the Mjøsa area, Norway (Kiær 1917; Ebbestad *et al.* 2003). The other report is a

fragmentary pygidium identified as *Holmiella* sp. from the lower part of the Lingulid Sandstone Member in a quarry at Hällekis at Lake Vänern, Kinnekulle (Ahlberg *et al.* 1986). However, this specimen had originally been attributed to the Mickwitzia Sandstone (Bergström 1981; Ahlberg 1984c). This incomplete pygidium and numerous cranidial fragments from this locality were assigned to *Holmiella* sp. Both olenelloid taxa were assumed to indicate the *Holmia kjerulfi* Zone and are of little biostratigraphic significance, although Jensen (1997) emphasized the lithological equivalence of the host rocks with the Mickwitzia Sandstone. Furthermore, Jensen (1997) cited the discovery of a relatively complete trilobite by collector Holger Buentke in 1992, which has remained unpublished since and also is uncertain with respect to its precise stratigraphic position. Additional specimens of olenelloids were discovered at the eastern tip of Halleberg by Jan Johansson (personal communication to TW), and ellipsocephalid trilobites were collected by Frank Rudolph in erratic boulders in northern Germany (unpublished, examined by TW). Eponymous linguliform brachiopods are also known from several localities but have rarely found their way into collections. In summary, the fossil content of the Lingulid Sandstone appears to be far less sparse than commonly assumed, and the poor record is primarily an artefact of collecting and sampling.

This macrofossil record permits an unequivocal assignment to one of the established zones. Nielsen & Schovsbo's (2011) sequence stratigraphical approach placed the Lingulid Sandstone Member into the LC2–4 sequence of the newly established *Comluella*?–*Ellipsocephalus lunatus* Zone. This issue is discussed below (under 'Stratigraphy') in some detail.

Acritarchs from the File Haidar Formation were studied in some detail from drill cores obtained on Gotland, the Gotska Sandön and the southern Bothnian Sea (Hagenfeldt 1989a, 1989b; Hagenfeldt & Bjerkéus 1991), and from Östergötland (Eklund 1990). The recovered assemblages include the *Heliosphaeridium dissimilare–Skiagia ciliosa*, *Volkovia dentifera–Liepaina plana* and part of the *Eliasum–Cristallinium* assemblage zones, but are of little significance for a precise determination of the boundary between the members (see discussion in Landing *et al.* (2013) and Sundberg *et al.* in press).

The lithology of the Grötlingbo-1 core from Gotland was used by Hagenfeldt & Bjerkéus (1991) to introduce a subdivision of the File Haidar Formation into four units termed the Viklau Sandstone, Närr Shale, Närr Sandstone and Grötlingbo Siltstone, of which the Viklau Sandstone and the Grötlingbo Siltstone were ranked as formal members (Hagenfeldt 1994). The Närr Shale and Närr Sandstone, in contrast, have been regarded as subunits of a Närr Member but were subsequently classified as members in the Öland–

Gotland region by Nielsen & Schovsbo (2006), who subdivided the formation into the Viklau, När Shale, När Sandstone and Grötlingbo Members. Of these, the När Sandstone Member is regarded as more or less equivalent to the Lingulid Sandstone Member.

Localities

As Hoved locality

As Hoved is a *c.* 6 km long cliff-framed headland near Palsgård manor, situated 8 km north of Juelsminde (around 55°45′N, 10°04′E; Fig. 1B$_1$) at the east coast of Denmark, facing the Kattegat sea. This locality has an exceptional accumulation of glacial erratic boulders of Cambrian age. Along the shore thousands of boulders of lower Cambrian sandstones occur together with hundreds of boulders of middle Cambrian bituminous limestone (Swedish: orsten), limestone, conglomerate and alum shale, and thousands of boulders of Furongian bituminous limestone and shale (Fig. 3). Glacial erratic blocks of the middle Cambrian *Paradoxides paradoxissimus* Superzone act as index blocks which allow tracking their origin to Sweden, because the rocks of this superzone show particular characteristics for each province in southern and central Sweden (Scania, Öland, Västergötland, Östergötland and Närke). The foremost rock types at As Hoved that unmistakably point to Västergötland (Fig. 1C) as the source area of all the boulders are:

a. a phosphoritic sandstone conglomerate (Swedish: basalkonglomerat) with constituents of the Lingulid Sandstone. This unit marks the boundary between the lower Cambrian and the middle Cambrian sequence in Västergötland;

b. a greenish limestone of the *Triplagnostus gibbus* Zone with *Jincella munsteri* as found at Oltorp, Billingen (Westergård 1953, p. 12);

c. a greenish glauconitic limestone of the *Acidusus atavus* Zone occurring *in situ* at Oltorp and as loose boulders from other localities in southern and northern Billingen and on Mount Kinnekulle;

d. a highly fossiliferous, metamorphosed ('baked') bituminous limestone of the *Acidusus atavus*, *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones found *in situ* at Munkesten, Hunneberg;

e. the existence of a thin conglomeratic layer spanning the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones, discovered for the first time at As Hoved; eventually proven in Falbygden and on Mount Kinnekulle (Weidner *et al.* 2004);

f. countless blocks of dolerite that now cap the Lower Palaeozoic strata in Västergötland.

g. Houmark-Nielsen (1987, 1994, locality 92) demonstrated that the four Pleistocene glacial tills exposed at As Hoved cliff were derived from the north (Norway) and the north-east (Västergötland). The glacial erratic boulders transported from the north are dominated by rhomb porphyry and sedimentary rocks from the Danish subsurface, mostly of Palaeogene and Cretaceous age.

h. No index blocks from Scania (*Exsulans* Limestone) or Öland ("*Oelandicus* shales", "*Paradoxissimus* Sandstone") have been found at As Hoved.

Fig. 3. The cliff section at As Hoved near Palsgård, Jutland, with glacial erratic boulders along the beach.

Additional erratic boulders with Lingulid Sandstone lithology and equivalent fossils of *Epichalnipsus* faunal aspect have already been described from Ulbjerg and Melbjerg, Jutland, Denmark, and Sandesneben (Herzogtum Lauenburg county, Schleswig-Holstein), northern Germany, by Geyer *et al.* (2004). Other material has subsequently been collected from Damsdorf and Stocksee (both Segeberg county, Schleswig-Holstein), and Köhlen (Cuxhaven county, Niedersachsen), Germany.

Halleberg localities

Fossiliferous quarzitic sandstones have a wide geographical distribution in glacial deposits. In Denmark they are found, in addition to As Hoved, at other localities with Pleistocene moraines containing rocks characteristic of Västergötland (Bøgehoved, Trelde, Melbjerg, and Ulbjerg cliffs, Fig. 1). These sandstones are also scattered over the whole of northern Germany. However, they are unknown in Sweden, which prompted one of the authors (TW) to search for their source primarily in the Falbygden and Kinnekulle areas of Västergötland (Fig. 1), from where most of the middle Cambrian material from As Hoved has originated. Ten years of investigation in natural and man-made outcrops, as well as loose boulders in Västergötland, subsequently also in Östergötland and Närke, was unsuccessful. Only the regular Lingulid Sandstone was met in the field, with all boulders devoid of trilobite remains. In 2011, the search was extended to the Halleberg–Hunneberg outliers, two table mountains in the far west of Västergötland. Andersson *et al.* (1985, fig. 11) has shown that at certain parts of Halleberg and Hunneberg (Fig. 1C$_1$), a dolerite sill rests directly upon the Lingulid Sandstone or on a thin stratum of middle Cambrian alum shale and that the "diabase intrusion had baked the alum shale" Andersson *et al.* (1985, p. 19). Four exposures, a few metres long, and known since a long time in the literature (Hansen 1933), can be studied in the Ovandalen valley in the north-western corner of Halleberg where the public trail starts to descend from the dolerite platform down to Lake Vänern. Between 50 and 150 m north of the trail, three outcrops expose the dolerite sill where it is underlain (in descending order) by metamorphosed alum shale (*c.* 40 cm), metamorphosed bituminous limestone of the *Triplagnostus gibbus* Zone (*Paradoxides paradoxissimus* Superzone; *c.* 25 cm) and again by metamorphosed alum shale (*c.* 35 cm). The lower boundary of this alum shale bed is covered by debris of dolerite, soil and vegetation (Fig. 4). The foot of the approximately 10 m high slope is strewn with smaller blocks of quarzitic sandstone of a lithology quite similar to the erratic boulders known from As Hoved, but trilobite remains were not discovered

in the material. Another section *c.* 100 m to the south of the trail indicates that the alum shale pinches out, and the boundary between the dolerite sill and the
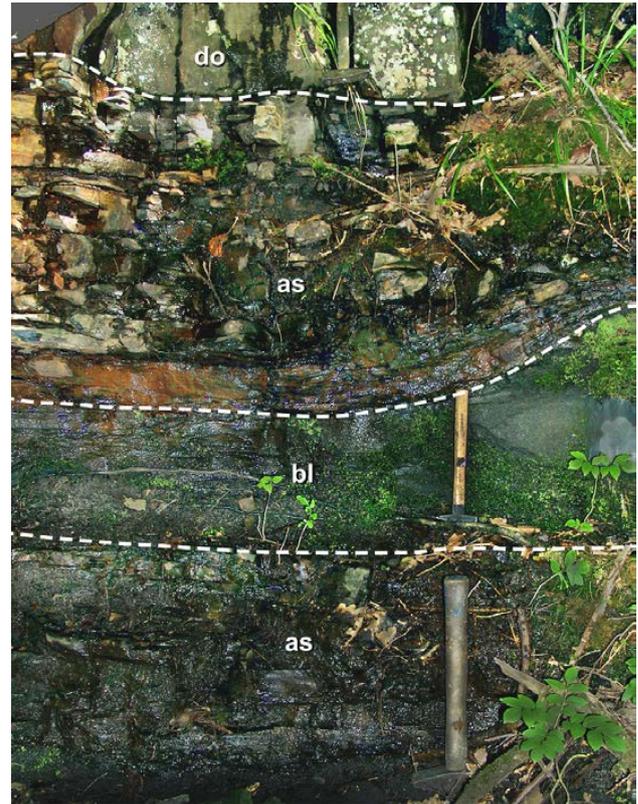
Fig. 4. Section 1 at Ovandalen on Halleberg, with the contact between a dolerite sill (do) overlying a strongly metamorphosed sequence comprising alum shale (as), a bituminous limestone bed of the *Triplagnostus gibbus* Zone (bl), and alum shale (as) the lower part of which is covered by soil. Length of hammer shaft 33 cm.

Fig. 5. Section 2 at Ovandalen on Halleberg, showing the boundary between the Lingulid Sandstone Member and the overlying dolerite sill (marked by the two hammers). Length of the right hammer shaft 33 cm.

underlying Lingulid Sandstone is visible (Fig. 5). This section lies 150 m from the nearest outcrop north of the trail. The same quartz-arenitic sandstones are also found as loose pebbles along the prehistoric shore-line at Kvillen close to the south-eastern corner of Halleberg. Trilobite remains from this locality were reported by Jan Johansson (personal communication 2002) but the material has not been published.

Karlsson (2001) demonstrated that the 90 m thick Permo–Carboniferous dolerite cap on Halleberg and Hunneberg, either resting directly on or only separated from the underlying sandstone by a thin cover of alum shales, has influenced the diagenetic development by hydrothermal overprint. This resulted in the regionally restricted occurrence of the quartzitic variety of the Lingulid Sandstone. In the east, at Billingen, in contrast, the dolerite cap attains only 45 m, and the dolerite is further separated by a thick Palaeozoic cover from the sandstone beneath. Therefore, the Lingulid Sandstone remained largely unaffected in the eastern areas of Västergötland.

Thus, we conclude that the quartzitic sandstones found in great quantity at As Hoved were derived from the Halleberg–Hunneberg area or another area where the dolerite was in close contact with the underlying sandstone, but in which the whole succession has been subject to denudation. Ovandalen is the only available outcrop on Halleberg–Hunneberg that reveals the boundary between the Cambrian rocks and the dolerite sill. Only the uppermost metre of the sandstone is exposed (the lower parts being concealed by large dolerite blocks), and therefore the exact position of this level within the Lingulid Sandstone Member of Västergötland remains uncertain.

Lithology and petrology of samples from the As Hoved cliff and the Lingulid Sandstone of Västergötland

The sandstone of the glacial erratic boulders from As Hoved and bedrock samples from Västergötland were studied to allow a reliable comparison of lithological characters. The As Hoved samples and two samples from the Kvillen section, Halleberg, and the Djupadalen locality were examined petrographically in thin sections. See Appendix 1 for systematic comparisons.

The studied sandstone of the As Hoved cliff displays a variety of lithological characteristics. The sandstones are either platy (most frequently separating into slabs with thicknesses of 1–2 cm) or massive blocks with bed thicknesses of up to 30 cm. The general colour is light grey, occasionally with a yellowish, greenish or reddish stain. The sand grains are generally fine-grained, with nearly even sizes, and relatively pure, indicating a high maturity.

Thin sections (Fig. 6A–D) indicate a pore volume of c. 1–5 vol.%. Quartz grains constitute c. 94 vol.% of the rock and range from 0.03 to 0.3 mm in diameter, with the prevalence of a slight longitudinal shape. They show high compaction and cementation as suggested by inconspicuous concave–convex and saturated grain contacts, and syntaxial overgrowths. Ferritic/limonitic coats are rarely present. Feldspar accounts for c. 1 vol.%, mica for c. 2 vol.%, glauconite for c. 2 vol.%, and zircon and tourmaline together for c. 0.5 vol.%. Alkali feldspar as well as plagioclase grains are fairly fresh and present as slightly rounded cleavage fragments (up to 0.3 mm in size, but generally around 0.1 mm and less). Mica consists nearly exclusively of white mica; only a few flakes of dark mica are present. Glauconite grains are generally around 0.1 mm in size and slightly rounded, mostly compacted and partly show a pale brown crust. The argillaceous-chloritic and illitic porous cement is restricted to minute interporous spaces. A secondary diffuse film of rust is occasionally visible between the quartz grains.

Sedimentary structures are usually inconspicuous. Most samples show a fine, nearly parallel bedding or a very low angle cross-stratification, which becomes obvious after splitting.

A sample of typical thick-bedded sandstone of the Lingulid Sandstone Member from the Kvillen section, Halleberg (sample 09/05), shows remarkable similarity to the As Hoved sample. Thin sections (Fig. 6E, F) indicate the same amount of pore space of c. 1–5 vol.%, which is in accordance with the results of Karlsson (2001), who determined a porosity of 3–6 vol.% for samples collected at Hunneberg (with a resulting permeability of 0 mD). The quartz grains constitute c. 90 vol.% of the rock and are from 0.04 to 0.15 mm in size, with the prevalence of slightly longitudinal grains. Ferritic coats are rarely observed. Feldspar accounts for c. 1 vol.%, mica for c. 3 vol.%, glauconite for c. 5 vol.%, and zircon and tourmaline together for c. 0.5 vol.%. Alkali feldspar and plagioclase grains are fairly fresh and present as cleavage fragments. Glauconite grains are generally about 0.1 mm in size and slightly rounded, mostly compacted and partly show a pale brown crust. Mica consists predominantly of white mica, with a minor amount of biotite present. The minute interporous spaces are filled with an argillaceous-chloritic and illitic cement.

Sample 3 of the typical sandstone of the Lingulid Sandstone Member from the Djupadalen locality shows a similar composition as the sandstones from

As Hoved and Halleberg, but differs in a number of minor aspects (Fig. 6G, H). Thin sections of the quartz arenite indicate a distinctly higher pore space of *c.* 10–15 vol.%, which is clearly filled with argillaceous-ferritic cement (illite + goethite) and distinct syntaxial quartz overgrowths. The quartz grains constitute *c.* 97 vol.% of the rock and range from 0.05 to 0.3 mm in size, with slightly rounded grains of low sphericity, and distinctly platy grains with frequent ferritic coats. Feldspar and mica account together for *c.* 1 vol.%, glauconite for *c.* 1 vol.%, and zircon and tourmaline together for *c.* 0.5 vol.%. Alkali feldspar as well as plagioclase grains are fairly fresh, but alkali feldspar grains commonly show a fringe altered to illite or white mica. Glauconite grains are generally around 0.1 mm in size, rounded, and mostly compacted, but are devoid of external crusts. Mica is present as white mica, but also as biotite (partly altered to chlorite).

It should be emphasized that the samples from the Lingulid Sandstone Member of Västergötland studied by Karlsson (2001) have a feldspar content between 2.3 and 6 vol.%, with some samples having a distinct content of rock fragments up to 5.6 vol.%. However, the samples described by Karlsson (2001) are all devoid of any notable amounts of Fe-hydroxide.

Fossils

Fossils occur predominantly in platy sandstone and occur as external moulds. They are often poorly preserved as fairly eroded imprints due to perennial wave transport on the present-day shoreline. The
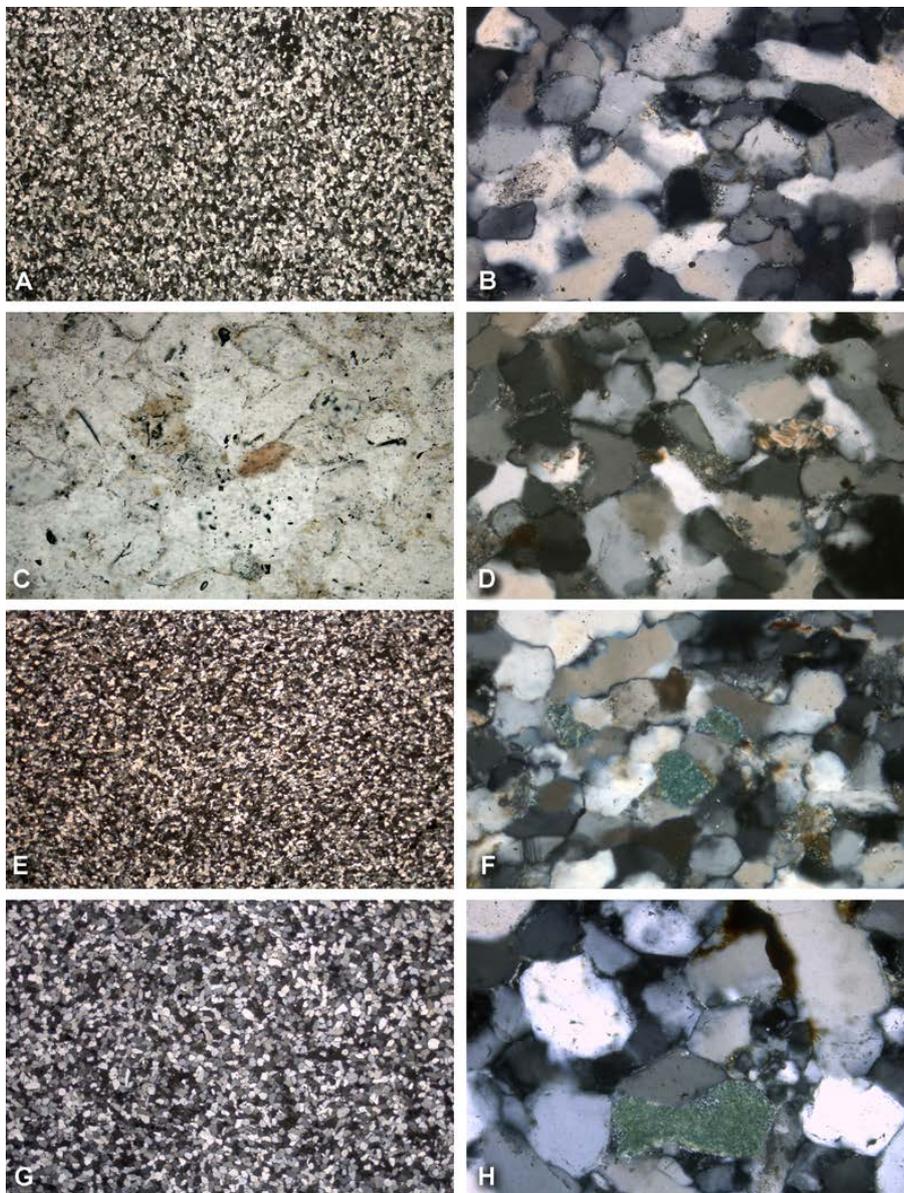
Fig. 6. Thin sections. **A–D**, sandstone from erratic boulder at the As Hoved Cliff near Palsgård, Jutland, Denmark (sample PMU 28676). **A**, overview under crossed polarizers, width of image 7.2 mm; **B**, detail with chloritized contact zone, view under crossed polarizers, width of image 0.6 mm; **C**, detail of typical composition with relatively large quartz grains, width of image 0.6 mm; **D**, detail with illitic pore cement, view under crossed polarizers, width of image 0.6 mm. **E–F**, sandstone representing the typical thick-bedded sandstone of the Lingulid Sandstone Member in the Kvillen section, Halleberg, Sweden (sample PMU 28677). **E**, overview under crossed polarizers, width of image 7.2 mm; **F**, detail with glauconite grains near centre, view under crossed polarizers, width of image 0.6 mm. **G–H**, quartz arenite from the Lingulid Sandstone Member, Djupadalen, Falbygden, Sweden (sample PMU 28678). **G**, overview under crossed polarizers, width of image 7.2 mm; **H**, detail with large glauconite grain below centre, view under crossed polarizers, width of image 0.6 mm.

best preserved fossil remains come from the larger, massive blocks, in which scattered trilobite remains occur, but unfortunately are often destroyed during splitting of the rock. Internal and external moulds, typical for preservation in sandstone, rarely display the characteristics necessary to determine the species (Table 1). Only cranidia of *Epichalnipsus* and *Berabichia* are preserved fairly completely. Other trilobite remains are fragmentary. Holmiid trilobites were found in the As Hoved boulders only as a genal fragment (Fig. 7A). Due to the prevalence of *Epichalnipsus* in the assemblage, it is here termed the *Epichalnipsus* fauna.

Lingulid brachiopods are eponymous for the Lingulid Sandstone of Sweden and occur as well fairly frequently in the collected erratic boulders (Fig. 7B, C, E–I), but are mostly too poorly preserved to be determinable even to the genus. The only well-known genus and species reported from the Lingulid Sandstone of Sweden is *Glyptias favosa* (Linnarsson 1869), which is also represented in the As Hoved samples (Fig. 7I). A rare and relatively surprising constituent of the fauna is an orthothecid hyolith conch (Fig. 7D) found in unequivocally the same type of erratic boulders at Damsdorf in Germany.

Some of the boulders include large-scale trace fossils with a rather peculiar preservation, probably caused in part as a result of specific weathering processes (Fig. 8). Some specimens appear to record different layers of the original trace as shown in Fig. 8B and 8D. Sören Jensen (personal communication to GG) suggested similarities with *Halopoa*, particularly *H. imbricata* Torell 1870, recorded from lower and middle Cambrian sandstones in Scandinavia, particularly the Mickwitzia Sandstone Member; a genus which has been synonymized with *Palaeophycus* in Jensen (1997).

The fauna described derives from 35 blocks of a

collection of 50 units. Of these, 43 units are from As Hoved and seven from other localities in Denmark and northern Germany. All figured and listed specimens in this paper are deposited in the Museum of Evolution, Uppsala University, Sweden (PMU).

Systematic palaeontology

Superfamily Olenelloidea Walcott 1890

Family Holmiidae Hupé 1953

Genus *Holmiella* Fritz 1972

Type species. *Holmiella preancora* Fritz 1972; by original designation.

Holmiella? sp. A
Fig. 7A

Material. Single gena, PMU 28679, from As Hoved, Palsgård area, Denmark.

Discussion. The single fragmentary gena has a moderately and evenly curved lateral border that proceeds into a long, moderately tapering genal spine with elliptical cross section. The genal field ("ocular platform") is relatively narrow (tr.), weakly convex. The lateral border and border furrow are obsolescent and the posterior librigenal margin has a distinct, large indentation so that the margin defines a broad curvature towards the genal angle.

The specimen is fairly abraded on the cobble so that the recognizable characters do not permit a confident determination, but it matches the morphology known from *Holmiella*. The specimen is tentatively assigned to *Holmiella*.

Superfamily Ellipsocephaloidea Matthew 1887

Family Ellipsocephalidae Matthew 1887

The family Ellipsocephalidae is a notoriously difficult taxon. It includes numerous genera, which are often not only difficult to demarcate from other genera with a similar morphology, but may also pose difficulties in the recognition of species if not based on well-preserved material. Geyer (1990) attempted a reappraisal of the group with strong focus on material from the Moroccan Atlas ranges, but emphasized that a large number of taxa described from Baltica are in need of careful revision.

Table 1. List of the fossil material collected from the As Hoved locality

Trilobita	Material
Holmiella? sp. A	1 gena
Epichalnipsus anartanus	>100 cranidia, 3 librigenae, 3 thoracic segments
Epichalnipsus sp. A	3 cranidia
Epichalnipsus sp. B	2 cranidia
Berabichia erratica	8 cranidia, 3 tentatively assigned librigenae
Brachiopoda	
Lingulid gen. and sp. A	8 valves
Lingulid gen. and sp. B	2 valves
cf. *Glyptias favosa*	1 ventral valve
Hyolitha	
Orthothecida gen. and sp. incert. A	1 conch

The difficulty in the study of ellipsocephalid trilobites arises from the coincidence of three particular problems:

Firstly, there is an evolutionary tendency towards a progressive effacement of the cephalic relief that commonly masks important morphological characters. This trend during evolutionary development contributes to the need of well-preserved specimens to permit a confident determination. This trend is also seen during ontogeny of species from the later phase of this development such as *Kingaspioides sanctacrucensis* (Czarnocki 1927) from the Holy Cross Mountains, southern Poland (see Żylińska & Masiak 2007), or *Kingaspidoides frankenwaldensis* (Wurm 1925) from the Franconian Forest, Germany, where the cephalic relief becomes largely effaced in large mature individuals.

Secondly, morphologic trends during the phylogenetic history are decipherable in different lineages so that a strong development of morphological convergence can be recorded. Careful biostratigraphic
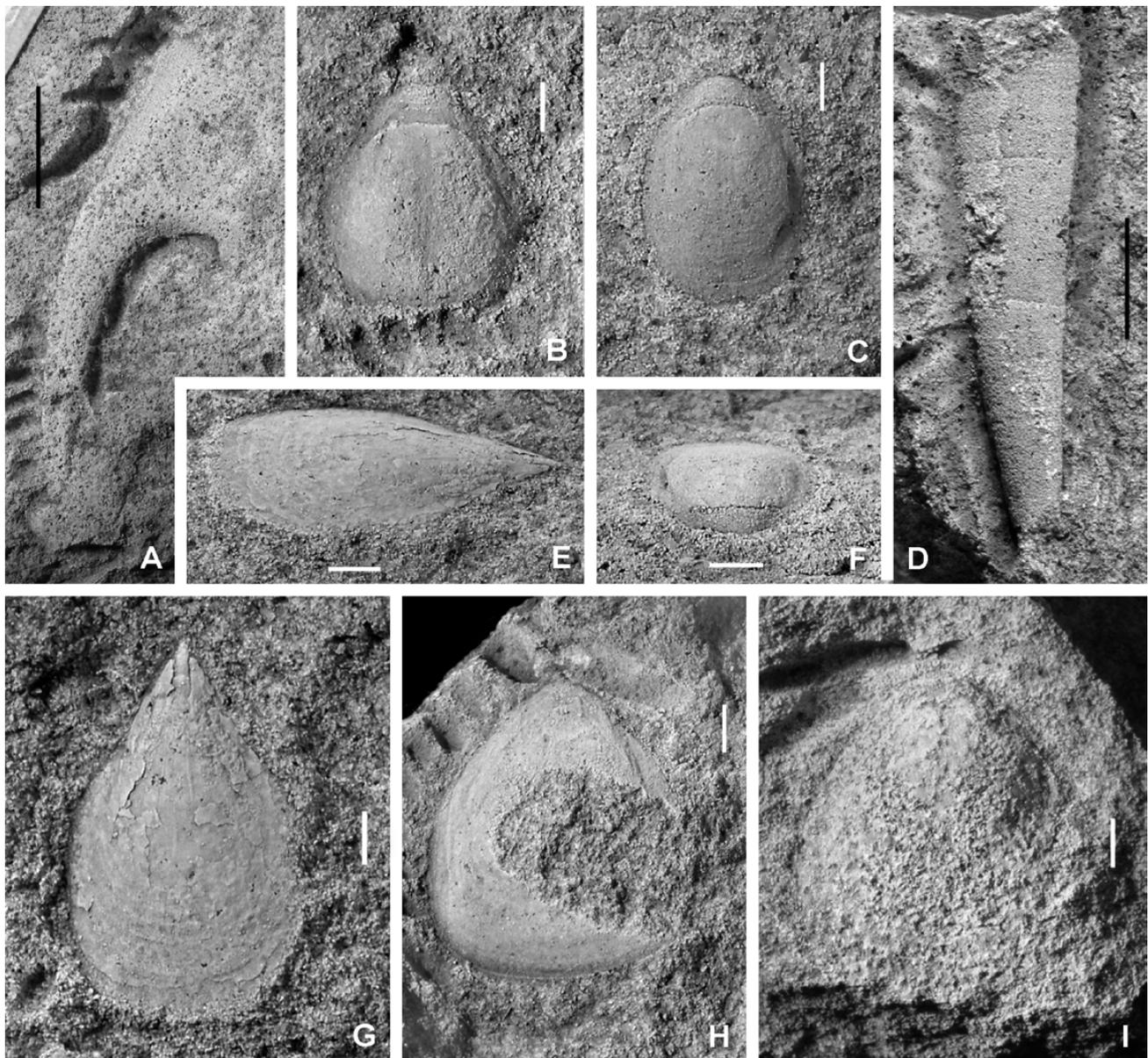
Fig. 7. *Holmiella*? sp. and examples of non-trilobitic body fossils from the erratic boulders at As Hoved, Jutland, Denmark (except for D). **A**, *Holmiella*? sp. A, PMU 28679, incomplete gena **B**, **C**, **E**–**G**, Lingulid gen. and sp. A; **B**, PMU 28680/1, ventral valve; **C**, **F**, 28681, ventral valve, ventral and anterior views; **E**, **G**, PMU 28682/1, dorsal valve, lateral and dorsal views; **D**, Orthothecida gen. and sp. incert., PMU 28683, incomplete conch; from erratic boulder probably from the Lingulid Sandstone collected near Damsdorf, Germany; **H**, Lingulid gen. and sp. B, PMU 28680/2, dorsal valve; **I**, cf. *Glyptias favosa* (Linnarsson 1869), PMU 28684, ventral valve. White scale bars equal 1 mm, black scale bars equal 5 mm.

analysis indicates that these trends partly occur at different phases. This is particularly adverse because biostratigraphically reliable index fossils occur sparsely in the stratigraphic interval in which the ellipsocephalids possessed their acme. This, in turn, either helped to obscure biostratigraphic significance or led to erroneous correlations.

Thirdly, the major stratigraphic interval in which the ellipsocephalids occurred in Earth history coincides with the lower–middle Cambrian boundary interval, which is affected on most Cambrian continents and particularly in their major area in the Acadobaltic faunal realm by sea-level fluctuations. These were responsible not only for an unusually large amount of siliciclastic sediments that were deposited during this interval and which are often unsuitable for favourable preservation of trilobites, but also created gaps that further restrict the amount of available material.

The majority of ellipsocephalid trilobites are known only from cranidia, although it is obvious that pygidia provide important additional information necessary to reveal systematic relations. An example of lumping of species into 'morphotaxa' is the genus *Ellipsocephalus* Zenker 1833, which is used since decades to furnish species with a similar effaced cranidium, regardless of a distinctly differing pygidial morphology as illustrated by *Ellipsocephalus hoffi* Schlotheim 1823, *Germaropyge germari* (Barrande 1852), and *Ellipsostrenua gripi* Kautsky 1945.

It is beyond the scope of this article to discuss the taxonomy of the elllipsocephalid species from Scandinavia. However, it is necessary to emphasize that most generic assignments of the ellipsocephalids from Sweden and Norway are in strong need of a revision. None of the species described from the upper to uppermost lower Cambrian strata of Scandinavia can be assigned correctly to *Ellipsocephalus*, *Proampyx*, and *Ornamentaspis*, although the latter has been suggested by Geyer (1990) to be used as a nickname for the index species *Strenuella linnarssoni* Kiær 1917, to avoid the completely inappropriate assignment to the late middle Cambrian genus *Proampyx* Frech 1897. Recently, Høyberget *et al.* (2015) placed the species in *Ellipsocephalus* although its pygidia differ distinctly from those of typical species of *Ellipsocephalus* such as *E. hoffi* or *E. lejostracus*. Another species dealt with as *Ellipsocephalus lunatus* and used as an index fossil of the *Comluella?–Ellipsocephalus lunatus* Zone is cer-
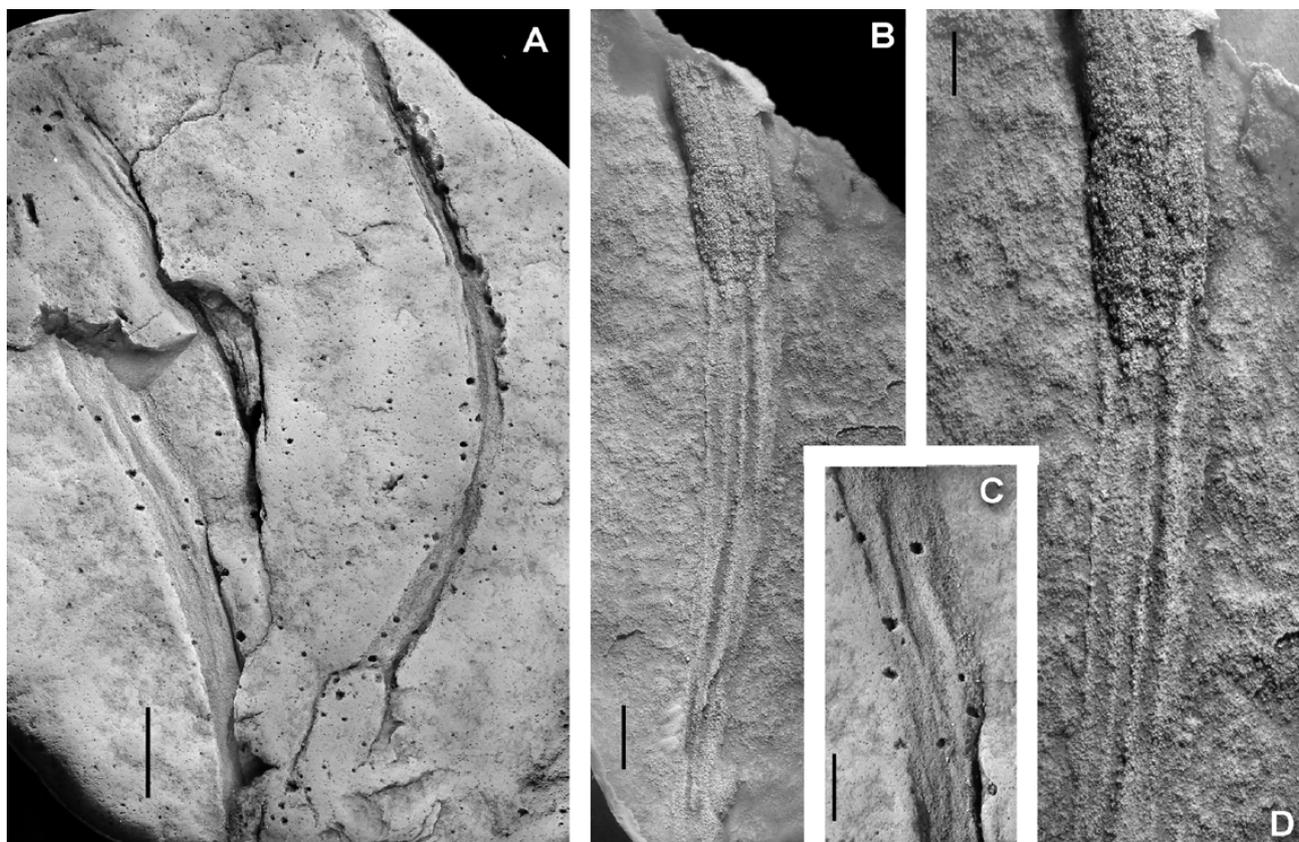
Fig. 8. Trace fossil (cf. *Halopoa imbricata* Torell 1870) from the erratic boulders at As Hoved, Jutland, Denmark. **A**, PMU 28685, several specimens preserved as negative hyporelief; length of figured view *c.* 7 cm; **C**, detail; **B**, **D**, latex cast of PMU 28685, illustrating coating with grains on the wall. All scale bars equal 5 mm.

tainly not a true species of the genus. It is probably more closely related to species of *Kingaspidoides* and (pending future studies) it is termed *"Ellipsocephalus"* *lunatus* herein, awaiting a careful revision.

The subdivision of the family into the subfamilies Antatlasiinae, Ellipsocephalinae, Protoleninae, and

Strenuellinae appears to be appropriate to date. The subfamily Kingaspidinae is a junior synonym of the Ellipsocephalinae.

Subfamily Antatlasiinae Hupé 1953

Discussion. The Antatlasiinae are the oldest ellipsocephaline trilobites and thus ancestral to all other ellipsocephaloideans. They are unequivocally derived from bigotinid trilobites. Species of *Berabichia* have a relatively general body plan, although the genus *Antatlasia* predates *Berabichia*. A phylogenetic lineage leads towards late early Cambrian genera such as *Sectigena* and *Issafeniella*. The Siberian genera *Chorbusulina* Lazarenko 1962 and *Charaulaspis* Lazarenko 1962 are closely related to *Berabichia* Geyer 1990, although the general similarity in the morphology of the genae is obviously an independent, parallel development in geographically disjunct genera because they can be differentiated by several other characters as discussed in Geyer *et al.* (2004).

Despite of caveats mentioned in Geyer *et al.* (2004), *Strenuaeva* Richter & Richter 1940 is also a genus of the Antatlasiinae. However, species of this genus only include the type species *S. primaeva* (Brøgger 1879) from Norway, *S. inflata* Ahlberg & Bergström 1978 from the Lake Torneträsk area, Sweden (see Cederström *et al.* 2012), *S. baltica* (Wiman 1905) from erratic material of the Gävle Bay, east-central Sweden, *S. nefanda* Geyer 1990 from the western Anti-Atlas of Morocco, and an unnamed species listed as *S. nefanda* from south-eastern Newfoundland (Fletcher 2003, 2006). Other species, previously assigned to *Strenuaeva*, belong to *Issafeniella* Geyer 1990, including *I. orlowinensis* (Samsonowicz 1959) and *I. trifida* (Orłowski 1985), both from the Ociesęki and Kamieniec formations of the Holy Cross Mountains, Poland (Żylińska & Masiak 2007; Żylińska & Szczepanik 2009), and the Spanish species *I. sampelayoi* (Richter & Richter 1940) and *I. melendezi* (Gil Cid 1972).

Genus *Epichalnipsus* Geyer, Popp, Weidner & Förster 2004

Type species. *Epichalnipsus anartanus* Geyer, Popp,

Weidner & Förster 2004; by original designation.

Additional species included: *Berabichia inopinata* Geyer 1990, from the lower Cambrian *Sectigena* Zone of Morocco.

Emended diagnosis. Antatlasiine genus with shallow furrows and a generalized overall convexity in transverse section; frontal area convex in sagittal section, distinctly separated from glabella; glabella somewhat raised above shallow dorsal furrows, genae sloping ventrally from dorsal furrows; glabella tapering forward, frontal lobe subacute or with low curvature in dorsal view.

Discussion. Epichalnipsus has been introduced by Geyer *et al.* (2004) for species of the *Berabichia* clade that are characterized primarily by a subquadrate cephalon with a well-rounded to faintly subarcuate anterior margin, with a subequal overall convexity in transverse section, and a glabella that is slightly to moderately raised above the genae. The fixigenae themselves are weakly convex in transverse section, without a transverse or diagonal depression, and gently slope abaxially from the axial furrows. The axial furrows are moderately wide and weakly defined from the fixigenae.

As noted by Geyer (1990), the type species of *Berabichia* Geyer 1990, *B. vertumnia*, *B. stenometopa* Geyer 1990, and four of the forms described in open nomenclature are characterized by a cephalon in which the different cranidial regions (such as the glabella, fixigenae, palpebral lobes, and frontal area) have individual convexities so that these different parts are generally well defined by distinct furrows. In turn, *Berabichia inopinata* Geyer 1990 differs in having a cephalon with a rather homogenous overall convexity, at least in a transverse section across the glabella, the fixigenae and the palpebral lobes. This species, provisionally assigned to *Berabichia* in Geyer (1990), has the typical convexities shown by *Epichalnipsus anartanus* and was thus transferred to *Epichalnipsus*.

A specimen of the type species from the erratic boulders was first described by one of the authors (Popp 1999) under the name *Proampyx*? cf. *rotundatus*

◄ **Fig. 9. A–V, W?, X?**, *Epichalnipsus anartanus* Geyer, Popp, Weidner & Förster 2004. **A**, **E**, **H**, PMU 28686, cranidium, occipital ring partly exfoliated, composite mould, dorsal, lateral and anterior views; **B**, **F**, **I**, PMU 28687, cranidium, composite mould, dorsal, lateral and anterior views; **C**, **L**, PMU 28688, librigena, internal mould, dorsal and left lateral views; **D**, **G**, **K**, PMU 28689, incomplete cranidium, internal mould, dorsal, lateral and anterior views; **J**, **P**, PMU 28690, librigena, internal mould, oblique posterior and dorsal views; **M**, **Q**, **T**, PMU 28691, cranidium of small individual, internal mould, dorsal, lateral and anterior views; **N**, **R**, **U**, PMU 28692a, incomplete cranidium, latex cast of external mould, dorsal, anterior and lateral views; **O**, **S**, **V**, PMU 28693/1, incomplete immature cranidium, internal mould, dorsal, lateral and anterior views, scale bars 1 mm; **W**, PMU 28694, fragment of thoracic segment, dorsal view; **X**, PMU 28693/2, partial thoracic segment, dorsal view. All specimens from the As Hoved locality, Jutland, Denmark. Scale bars equal 5 mm except where otherwise noted.

and *Proampyx* cf. *rotundatus*, respectively. The species described under the name *Proampyx rotundatus* (Kiær 1917) bears indeed a great resemblance in respect to proportions, convexity of the preglabellar field and the pattern of lateral glabellar furrows with species of *Epichalnipsus*. However, this species has a tapering glabella and a generally strong convexity in the cranidium. Although the exact convexities of the shell exterior are unknown, it appears to share most characters with *Berabichia* (see below).

Epichalnipsus anartanus Geyer, Popp, Weidner & Förster 2004
Fig. 9A–V, W?, X?

v 1999 *Proampyx*? cf. *rotundatus* (Kiær 1917), Popp, p. 3.
v 1999 *Proampyx* cf. *rotundatus* (Kiær 1917), Popp, pp. 4–7, figs. 1–2.
v 2004 *Epichalnipsus anartanus* n. gen., n. sp., Geyer *et al.*, pp. 131, 133–134, figs. 3, 4.1, 4.3–4.15.

Material. More than one hundred cranidia or cranidial fragments, mostly incomplete internal moulds, 13 cranidia studied in detail (in repository: PMU 28686, PMU 28687, PMU 28689, PMU 28691, PMU 28692a, b (part and counterpart), PMU 28693/1, PMU 28695/1, PMU 28696), three librigena (in repository: PMU 28688, PMU 28690), three fragments of thoracic segments attributed to the species (in repository: PMU 28694, PMU
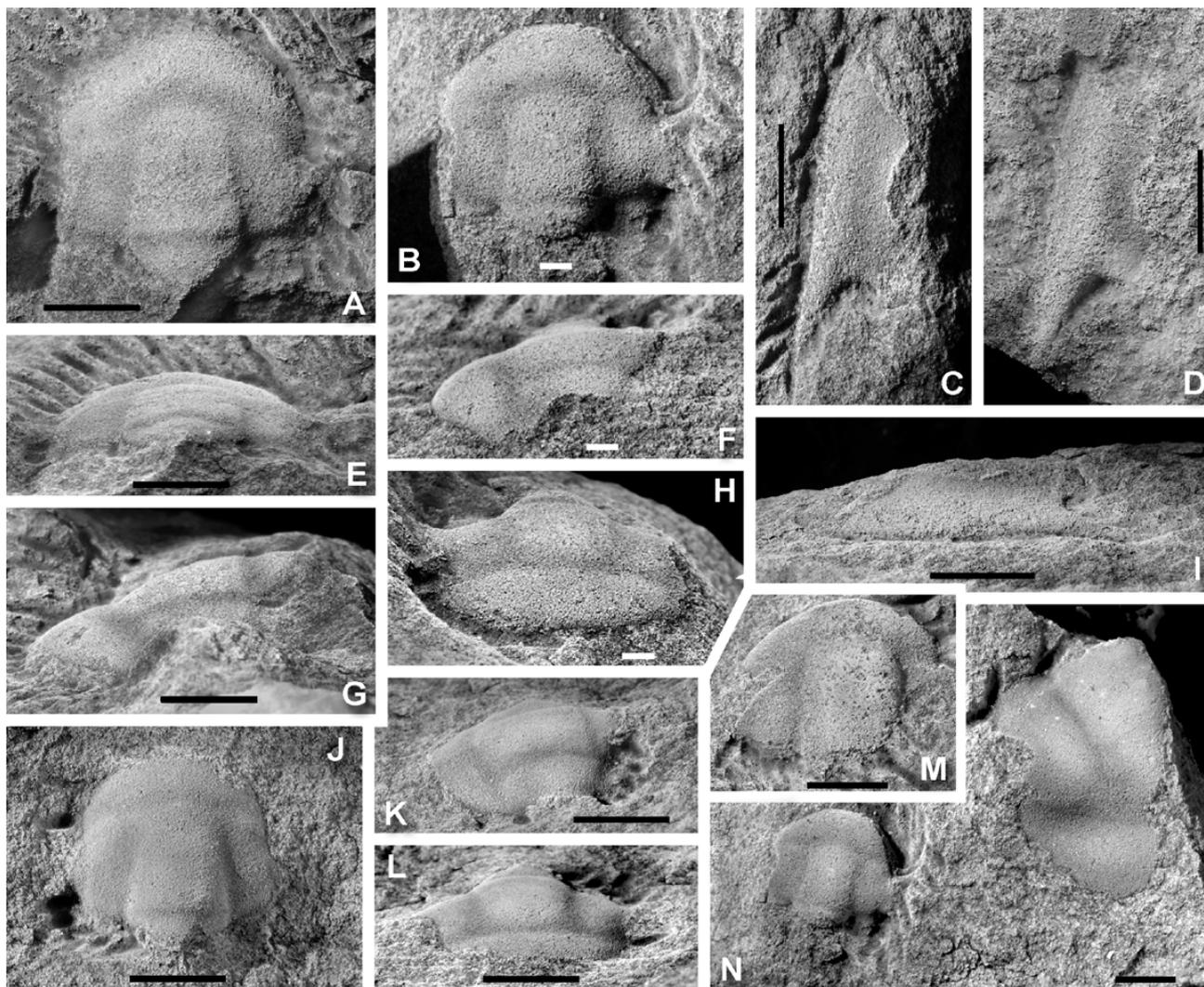
Fig. 10. A, **B**, **E**, **F**, **G**, **H**, **N**, *Epichalnipsus* sp. A. **A**, **E**, **G**, PMU 28697, incomplete cranidium, internal mould, dorsal, posterior and lateral views; **B**, **F**, **H**, PMU 28698/1, incomplete cranidium, composite mould, dorsal, lateral and anterior views, scale bar 1 mm; **N**, slab with PMU 28698/1 and PMU 28698/2 illustrating differences in size.
C, **D**, **I**, *Berabichia erratica* Geyer, Popp, Weidner & Förster 2004?; **C**, **I**, PMU 28701, librigena, dorsal and lateral views; **D**, PMU 28702, incomplete librigena, dorsal views.
J–L, **M?**, *Epichalnipsus* sp. B; **J–L**, PMU 28699, cranidium, dorsal, lateral and anterior views; **M**, PMU 28700, partial cranidium, dorsal views. All specimens from the As Hoved locality, Jutland, Denmark. Scale bars equal 5 mm except where otherwise noted.

28693/2, PMU 28695/2). All specimens from As Hoved, Palsgård area, Denmark, except for PMU 28695/1 and PMU 28695/2 from Damsdorf, Germany.

Emended diagnosis. Species of *Epichalnipsus* with frontal area distinctly inflated that forms a conspicuous platform in lateral view; glabella including occipital ring of *c.* 65–70 % cephalic length; occipital ring with small, subterminal spine; palpebral lobes of about 25 % cephalic length.

Description. Cephalon with strongly curved to well-rounded to faintly subarcuate anterior margin, ranging from 4.0 to 27 mm in the studied specimens. Glabella including occipital ring in adult individuals of 63 to 72 % cephalic length, maximum width across L1 *c.* 45 % maximum cranidial width across centre of palpebral lobes (slightly less in juveniles); tapers forward to anterolateral corners of frontal lobe to *c.* 80 to 85 % width across L1; sides weakly curved. Glabella with three pairs of shallow lateral glabellar furrows, which are fairly well visible on internal moulds, but faint to obsolescent on the shell exterior; S1 moderately long, curved backward; S2 and S3 comparatively shorter, S2 directed slightly backward, S3 almost normal to axis; front terminates in a subacute tip that is usually well visible on internal moulds, but less well developed on the shell exterior. Occipital furrow relatively broad (sag.) and normal to axis in the middle part. Occipital ring sagittally about 14–19 % cephalic length, extreme lateral parts narrow, with moderately long spine in subterminal position.

Fixigenae close to dorsal furrows of about 40 % cephalic length or slightly less, genal width across centre of palpebral lobes *c.* 43 to 49 % maximum glabellar width (across L1); with slightly extended posterior limb. Eye ridge weakly defined on exterior, weakly to moderately well developed on internal moulds, faintly connected with anterolateral corners of glabella; tends to bifid (or perhaps even trifid; Geyer *et al.* 2004, fig. 4.13, also suggested in Fig. 9D, 9M) at dorsal furrows, the anterior thread-like branch of which form an almost obsolete, rarely visible parafrontal line. Palpebral lobes moderately long (exsagittally 22 to 27 % maximum cephalic length in adult individuals), posterior tip located opposite anterior portion of L1 or at about S1, anterior tip opposite L3, faintly oblique to axis.

Preglabellar field long, distinctly convex to slightly inflated, fused medially with anterior border to form an anterior unit of up to more than 30 % cephalic length in adult individuals, distinctly shorter in juveniles. Anterior border narrow, obsolescent, occasionally faintly indicated close to the sutures. Posterior border with straight adaxial part, weakly sigmoidally curved distally and bent forward to palpebral lobes. Posterior border furrow well defined, narrow adaxially, broadening abaxially.

Anterior branches of facial suture diverge from anterior ends of the palpebral lobes to border furrow, with strong inward curvature anteriorly. Posterior branches diverge markedly from posterior ends of palpebral lobes.

Librigena with moderately and evenly curved lateral border that defines a fairly long, moderately tapering genal spine with elliptical cross-section. Librigenal field ('ocular platform') relatively narrow (tr.), weakly convex, grades into distinctly upturned ocular socle. Lateral librigenal border and border furrow obsolescent. Posterior librigenal margin slightly forward directed to narrow curved genal angle.

Rostral plate and hypostome unknown.

Thorax known only from three fragmentary segments assigned to *E. anartanus* (Fig. 9W, X). Axial ring moderately convex in transverse section, without median node or spine, but with faint lateral swelling adjacent to the axial furrow. Transverse furrow shallow to moderately well impressed. Articulating half-ring lenticular in dorsal view, with distinctly curved anterior margin, moderately elevated. Pleurae directed slightly backward, short in comparison to the transverse width of the axial rings. Pleural furrow fairly shallow adaxially, better impressed toward pleural tips, divides pleura into narrow, lenticular anterior strip and a broader transversely triangular posterior section of about double exsag. width near axial furrow; commences at axial furrow close to the anterior margin, directed obliquely to the axis almost straight to the acute pleural tip.

Pygidium unknown.

Discussion. Epichalnipsus anartanus is distinguished from *E. inopinatus* (Geyer 1990) from the *Sectigena* Zone of the Atlas Ranges in Morocco by a strongly inflated frontal area which forms a platform in front of the glabella, whereas the frontal area in the Moroccan species slopes from the glabellar front. Furthermore, *E. anartanus* has slightly shorter palpebral lobes and an occipital ring with a small, subterminal spine rather than a minute node as in *E. inopinatus*.

Epichalnipsus sp. A
Fig. 10A, B, E, F, G, H, N

Material. Three cranidia (PMU 28697, PMU 28698/1, PMU 28698/2). Specimens from As Hoved, Palsgård area, Denmark.

Description. Cephalon with strongly bowed anterior margin. Glabella including occipital ring of slightly less than 70 % cephalic length, maximum width across L1 slightly more than 40 % maximum cranidial width across centre of palpebral lobes; tapering forward

or apparently with subparallel sides due to slightly extended anterolateral corners of frontal lobe; sides faintly curved; three pairs of shallow, faint to obsolescent lateral glabellar furrows; S1 moderately long, curved backward; S2 and S3 short and indistinct; frontal lobe with weak curvature anteriorly. Occipital furrow relatively broad (sag.) and normal to axis in the middle part, slightly more distinct laterally. Occipital ring sagittally of 16–18 % cephalic length, reduced to particularly narrow extreme lateral parts, with distinctly curved posterior margin.

Fixigenae close to dorsal furrows of *c.* 40 % cephalic length or slightly less, genal width across centre of palpebral lobes *c.* 60 % maximum glabellar width (across L1). Eye ridge weakly defined. Palpebral lobes moderately long (exsagittally 26 to 33 % maximum cephalic length in the studied specimens), faintly oblique to axis.

Preglabellar field long, distinctly convex, fused medially with anterior border to form an anterior unit of up to 30 % cephalic length. Anterior border obsolescent. Posterior border with straight adaxial part, weakly sigmoidally curved distally and bent forward to palpebral lobes. Posterior border furrow well defined, narrow adaxially, widens abaxially.

Anterior branches of facial suture diverge from anterior ends of the palpebral lobes to border furrow, with strong inward curvature anteriorly. Posterior branches diverge markedly from posterior ends of palpebral lobes.

Librigena, rostral plate, hypostome, thorax and pygidium unknown.

Discussion. The As Hoved material includes cranidia that represent a species different from *Epichanipsus anartanus*, here termed *Epichalnipsus* sp. A. Only three more or less completely preserved and fairly well preserved cranidia have been discovered. The large specimen (Fig. 10A, E, G) has a length of 13.5 mm and testifies an adult individual. The other cranidium (Fig. 10B, F, H) is only 7.5 mm long and is regarded as a late immature stage. Both unequivocally represent the same species although they differ in a few aspects, which all can be attributed to ontogenetic development. These characters include a longer (sag.), more strongly extending occipital ring, a more clearly tapering glabella, and slightly longer palpebral lobes in the large specimen.

Epichalnipsus sp. A is well differentiated from *E. anartanus* in having a strongly curved rather than subacute anterior cephalic margin, a less inflated frontal area, broader fixigenae, and the absence of a subterminal occipital spine. Nevertheless, the form shares the typical cephalic morphology of *Epichalnipsus* with a clearly convex, fairly homogenous frontal area separated from the glabella by only a shallow transverse furrow and without a dramatic ventral drop in front of the eye ridges, and exsagittally as well as transversely moderately convex fixigenae, which slope ventrally from the axial furrows. *Epichalnipsus* sp. A is distinguished from *Epichalnipsus* sp. B (described below) by its longer frontal area, broader fixigenae, and a longer (sag.) occipital ring.

Epichalnipsus sp. B
Fig. 10J–L, M?

Material. A single well-preserved cranidium, PMU 28699, and a slightly distorted partial cranidium tentatively assigned to the same form, PMU 28700; both from As Hoved, Palsgård area, Denmark.

Description and discussion. A third species of *Epichalnipsus* from the As Hoved locality is represented by a single well-preserved cranidium and a slightly distorted partial cranidium tentatively assigned to the same taxon. The well preserved cranidium is characterized by a broad (width across L1 slightly less than half cranidial width across palpebral lobes), slightly tapering glabella with a faintly subacute front; a relatively short (sag.) occipital ring of *c.* 15 % cephalic length; relatively narrow and thus clearly rectangular fixigenae; a relatively short (sag.; 24 % cephalic length in the well-preserved specimen) and only moderately convex frontal area; and a subequally curved anterior margin of the cephalon. These characters clearly distinguish it from *E. anartanus* and the form is described as *E.* sp. B. The partial cranidium (Fig. 10M) only shows the anterior two-thirds of the cranidium with the same proportions but apparently a less clearly tapering glabella and a broader front which, however, may be a result of the slight deformation.

Genus *Berabichia* Geyer 1990

Type species. Berabichia vertumnia Geyer 1990; by original designation.

Discussion. The genus *Berabichia* is characterized by a cephalon with the glabella moderately raised over a wavy platform formed by the genae. The fixigenae have their most elevated areas close to the palpebral furrows, but a basal line drawn from the axial furrow to the palpebral furrow dips gently abaxially so that a transverse section is subhorizontal.

The genus has been introduced to encompass three species from the Moroccan Anti-Atlas and High Atlas ranges. Another six forms were attributed by Geyer (1990) to the genus *Berabichia* in open nomenclature. Nevertheless, all come from the upper lower Cambrian

Antatlasia guttapluviae and *Sectigena* zones, upper Banian Stage, suggesting that the Moroccan Atlas ranges depict a major area for the diversification of the *Berabichia* clade.

In addition to the Moroccan species, Geyer (1990) pointed out that *Chorbusulina wilkesi* Palmer & Gatehouse 1972 and *Chorbusulina subdita* Palmer & Gatehouse 1972, both from the uppermost lower Cambrian of the Argentina Range, Antarctica, are also species of *Berabichia*. *Chorbusulina* cf. *subdita*, described by Palmer & Rowell (1995) from the Shackleton Limestone of Antarctica, probably represents another species of the genus. An additional species of *Berabichia* has been described from Sweden under the name *Strenuella primaeva* var. *rotundata* by Kiær (1917) and later dealt with as *Proampyx rotundatus* (e.g., Ahlberg & Bergström 1978). This species, first described from the Gislöv Formation at Forsemölla, Scania, agrees well with the Moroccan species but is known only from imperfectly preserved material (see discussion below under *B. erratica*).

Additional species subsequently assigned to *Berabichia* include *B. milleri* Westrop in Westrop & Landing 2000, *B. eslaensis* Álvaro 2007, *B.? kiaeri* (Czarnocki 1927) (by Geyer 1990) and *B. oratrix* (Orłowski 1985) (by Żylińska *et al.* 2013).

Berabichia milleri has been reported from the so-called *Kingaspidoides* cf. *obliquoculatus* Zone of the Long Island Member of the Hanford Brook Formation, New Brunswick, which directly overlies Matthew's classical *Protolenus* (*P.*) *elegans* fauna and Zone (Westrop & Landing 2000). Despite the overall similarity of *B. milleri* in the relative sizes of the different areas of the cranidium, fundamental differences exist between it and the unequivocal species of *Berabichia*. These differences include: (i) the overall convexity, which shows independently inflated genae in *B. milleri* that do not slope ventrally from the axial furrows; (ii) a relatively strongly convex and slender glabella; (iii) subequally developed, simple and slightly backward directed S1 to S3; (iv) transverse, well developed eye ridges that describe a distinct angle to the palpebral lobes; (v) long palpebral lobes that reach backward and almost reach to the posterior border furrow; and (vi) a distinct ventral slope just anterior to the eye ridges. These characters clearly indicate that *B. milleri* is a species of the *Protolenus* clade rather than the *Berabichia* clade. It does not readily fit into an existing genus, but shows affinities to *Latoucheia* (*Latoucheia*) Hupé 1953 and particularly *Cambrunicornia* Geyer 1990. Both *Latoucheia* (*Latoucheia*) and the variably developed species of *Cambrunicornia*, the latter known from the Anti-Atlas of Morocco (Geyer 1990), the Tröbitz Formation of Saxony, Germany (Geyer *et al.* 2014), and species tentatively assigned to the genus from the *Redlichops* faunule of the Dead Sea area, Jordan (Elicki & Geyer 2013) and from the Láncara Formation of the Cantabrian Mountains, northern Spain (Álvaro 2007), differ in several aspects, particularly in the absence of a distinctly inflated anterior area, but appear to be closely related. Both genera, however, occur in strata equivalent to the *Protolenus* Zone of New Brunswick or even slightly younger strata so that their stratigraphic occurrence would match with the occurrence of *B. milleri* in the Hanford Brook fauna.

Berabichia eslaensis Álvaro 2007 has been described from a fauna that includes a species assigned to *Kingaspis* from the Láncara Formation of the Cantabrian Mountains, northern Spain. Although the species strongly resembles some of the species of *Berabichia* from Morocco, the overall convexity of the frontal area and the manner in which the palpebral lobes are connected with the fixigenae suggest a close relationship with the *Kingaspis* clade rather than *Berabichia*.

Strenuaeva? *kiaeri* Samsonowicz 1959 from the *Protolenus–Issafeniella* Zone of the Holy Cross Mountains of Poland has been transferred to *Ellipsocephalus* by Orłowski (1985) and then tentatively assigned to *Berabichia* by Geyer (1990). Żylińska *et al.* (2013) emphasized that the only known specimen of this species is strongly effaced, shows shallow lateral and axial furrows, and it may in fact represent a distorted specimen of *Issafeniella orlowinensis* (Samsonowicz 1959) that occurs in the same stratigraphic interval of the Holy Cross Mountains (Żylińska & Masiak 2007).

Comluella oratrix Orłowski 1985 and *Comluella igrzycznae* Orłowski 1985, both described from the *Holmia–Schmidtiellus* Assemblage Zone of the Holy Cross Mountains, have been subject to a recent morphometric analysis by Żylińska *et al.* (2013), who showed that the two species constitute a monospecific assemblage representing a single species dealt with as *Berabichia oratrix* (Orłowski 1985). This species indeed fits very well into the concept of the genus although the relatively strong deformation of the material makes a reliable reconstruction of the species' original morphology difficult.

Berabichia erratica Geyer, Popp, Weidner & Förster 2004

Fig. 10C?, 10D?, 10I?; Fig. 11A–M

v 2004 *Berabichia erratica* n. sp., Geyer *et al.*, pp. 134–135, figs. 5.1, 5.2, 5.4.

Material. Eight cranidia (reposited: PMU 28682/2, PMU 28703 (part and counterpart), PMU 28704–PMU 28707). All specimens from As Hoved, Palsgård area, Denmark. Tentatively assigned to *B. erratica*: three librigenae (reposited: PMU 28701, PMU 28702).

Emended diagnosis. Species of *Berabichia* with frontal area moderately inflated, anterior margin tends to be

subarcuate; glabella gradually tapering forward; fixigenae with highest elevation abaxially; palpebral furrow obsolete, merely a shallow and wide depression; palpebral lobes of about one-fourth cephalic length.

Description. Cephalon with faintly subarcuate anterior margin. Dorsal furrows moderately wide, poorly defined from fixigenae, grading into weakly to moderately convex fixigenal area.

Glabella including occipital ring of 72 to 76 % cephalic length, tapers gradually forward, frontal lobe 66 to 72 % maximum width across L1; front in dorsal view with low triangular tip or shallow curvature. Three pairs of lateral glabellar furrows very faint to obsolescent on the shell exterior; S1 moderately long, distinctly curved backward, relatively broad; S2 and S3 shorter, S2 backward directed. Occipital furrow broad (sag.) medially, shallower laterally. Occipital ring sag. variably of 15 to 22 % cephalic length, fades to narrow lateral portions, posterior margin thus
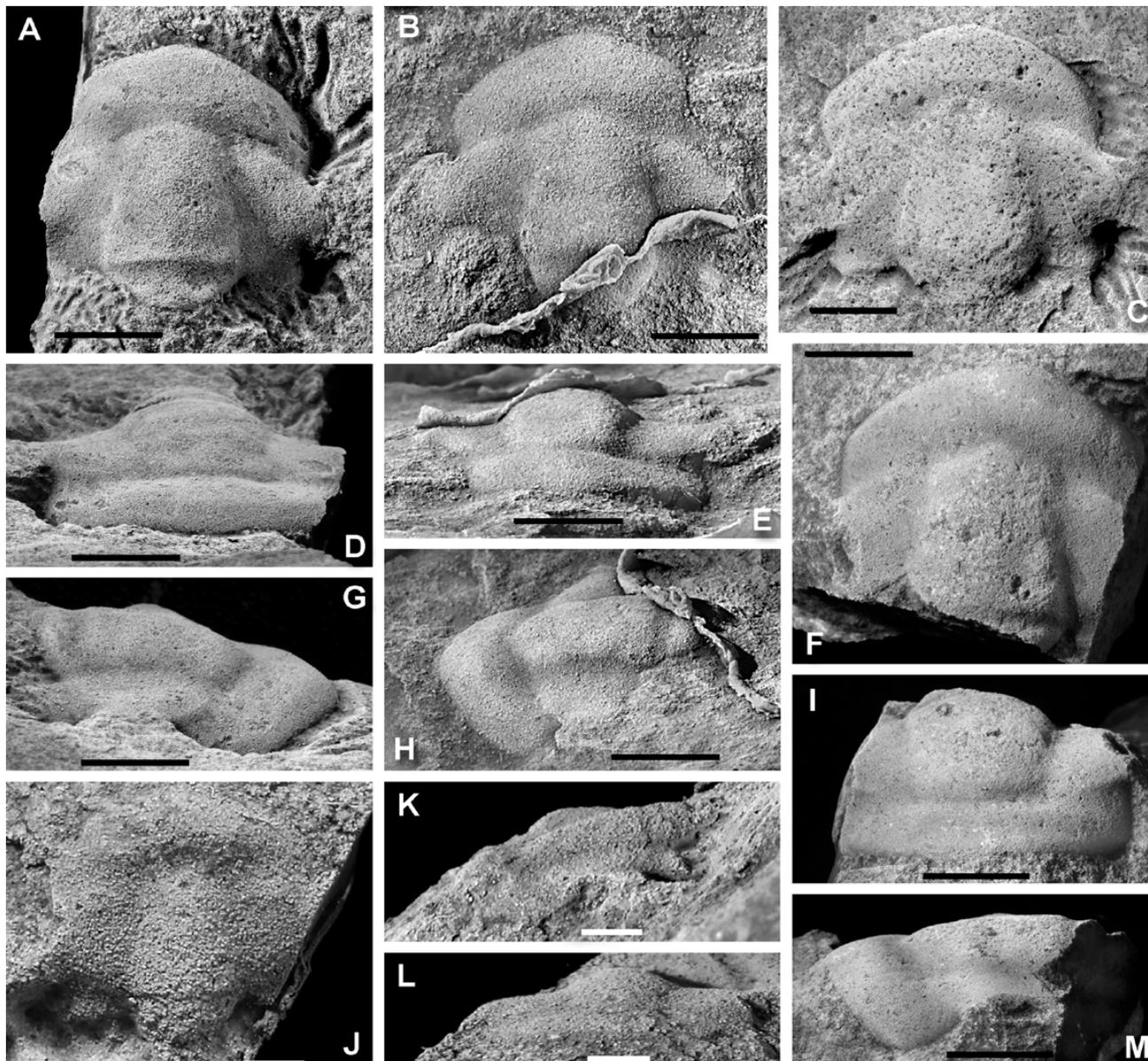
Fig. 11. *Berabichia erratica* Geyer, Popp, Weidner & Förster 2004. **A**, **D**, **G**, PMU 28703a, incomplete cranidium, internal mould, dorsal, anterior and lateral views; **B**, **E**, **H**, PMU 28682/2, incomplete cranidium, latex casts of external mould, dorsal, anterior and lateral views; **C**, PMU 28704, cranidium, internal mould, weathered and partly abraded surface, dorsal view; **F**, **I**, **M**, PMU 28705, partial cranidium, internal mould, dorsal, anterior and lateral views; **J**–**L**, PMU 28706, immature cranidium, dorsal, lateral and anterior views; scale bar 1 mm. All specimens from the As Hoved locality, Jutland, Denmark. Scale bars equal 5 mm except where otherwise noted.

strongly curved in dorsal view, probably with small node (not clearly preserved in any of the studied specimens).

Fixigenae close to dorsal furrows of less than *c.* 40 % cephalic length, width across palpebral lobes 40 to 45 % maximum glabellar width across L1, with slightly extended posterior limb; most elevated point close to palpebral furrows. Eye ridge weakly defined on the shell exterior, faintly connected with indistinct anterolateral corners of glabella. Palpebral lobes moderately long, posterior tips opposite L1, anterior tips opposite S2 or slightly anterior, exsagittally 26 to 31 % of cephalic length, slightly oblique to axis. Palpebral furrows shallow to obsolescent, developed as indistinct depressions or merely a change of convexity.

Preglabellar field moderately long, more or less fused with anterior border to form a slightly inflated frontal area of slightly more than 22 to 28 % cephalic length. Anterior border relatively narrow, defined by shallow and indistinct border furrow laterally. Posterior border weakly sigmoidally curved and with a clear forward bent posterior to palpebral lobes. Posterior border furrow a narrow depression adaxially, widens abaxially, with forward curvature distally to reach posterior tips of palpebral lobes.

Rostral plate, hypostome, thorax and pygidium unknown.

Three librigenae from the As Hoved material are tentatively assigned to the species. Librigena moderately broad (tr.), with a moderately long genal spine of slightly less than half length of the anterior part. Genal spine with a broad base, tapers rapidly backward. Lateral margin with low curvature, progressing with a faint flaw into the genal spine, which has a nearly straight abaxial margin. Posterior margin very shallow, with a shallow but notable indentation towards the genal spine. Librigenal lateral and posterior border and border furrow obsolescent. Librigenal field ('ocular platform') moderately broad (tr.), weakly convex, grades into distinctly upturned ocular socle.

Discussion. The description of *Berabichia erratica* was based on only two well preserved cranidia from a gravel pit at Wilsche near Gifhorn, northern Germany. Additional material discovered at the As Hoved locality slightly complements the information on the species as described above. Particularly noteworthy is that the figured specimens from Wilsche are slightly smaller than the average specimens from As Hoved and have a slightly more slender glabella which is attributable to allometric growth.

As discussed by Geyer *et al.* (2004), *Berabichia erratica* falls within the morphological range of *Berabichia*, although the species appears to differ from all other species of the genus in showing a tendency to develop a subarcuate anterior margin of the cephalon due to a slightly narrower curvature medially. This feature is known, however, from a few specimens of *Berabichia vertumnia* Geyer 1990 as well, the type species of the genus. The palpebral lobes of *B. erratica* are defined from the fixigenae by only a shallow and wide depression, which is known also from *B. vertumnia*. Further differences between *B. erratica* and *B. vertumnia* are discussed in Geyer *et al.* (2004). Particularly noteworthy is that the abaxial part of the fixigenae is developed in *B. erratica* as a rather flat area so that it indicates some similarity to the striking depression that crosses the fixigenae in *Sectigena* and can be used for generic distinction.

The most similar species formally described to date are *Berabichia oratrix* (Orłowski 1985) (see discussion under genus and Żylińska *et al.* 2013) and *B. subdita* (Palmer & Gatehouse 1972). *Berabichia oratrix* differs in having broader fixigenae and slightly longer palpebral lobes. However, specimens of *B. oratrix* may develop a faint subarcuate anterior cephalic margin as well (see Żylińska *et al.* 2013, fig. 6B, 6D, 6E).

Berabichia rotundata (Kiær 1917) is also fairly similar to *B. erratica*. It differs, among other characters, by a sagittally shorter frontal area and a longer occipital ring (see Ahlberg & Bergström 1978, pl. 3, figs. 1, 2).

Stratigraphy

The biostratigraphy of the Scandinavian lower Cambrian (Cambrian Series 2) (Fig. 2) is surprisingly poorly constrained. The major reason is the fairly humble fossil record from scattered localities due to the prevalence of shallow marine, siliciclastic deposits; a dominance of endemic trilobite species and a high amount of endemic genera; and a preliminary stage of generic concepts for the ellipsocephalid trilobites and a preliminary stage of the taxonomic treatment of brachiopods.

A more or less well agreed biostratigraphic framework has been established for the entire Baltica continent since the monographic correlation chart (Mens *et al.* 1990). However, almost none of the recognized trilobite zones could be correlated into any other Cambrian continent with satisfactory precision. The recognition of distinct acritarch zones apparently helped to correlate the trilobite zones into distant regions, but correlations entirely based on acritarch assemblages led to surprising results, which partly contradicted correlations based on trilobites as indicated in Landing *et al.* (2013) and Sundberg *et al.* (submitted).

A profound reappraisal of the biostratigraphy of Baltica backed by sequence stratigraphic criteria led

to a partial revision of the established biostratigraphic scheme (Nielsen & Schovsbo 2011). Particularly noteworthy is the abandoning of the Holmia inusitata Zone and the partial amalgamation of the *Holmia kjerulfi* group Zone with the *'Ornamentaspis' linnarssoni* Zone. This in fact leads to the assumption that a tremendously shorter time interval is represented by the *Holmia* and *'O.' linnarssoni* ranges than previously assumed. Nielsen & Schovbo's (2011) analyses prove that the profoundly incomplete depositional record in many parts of Scandinavia hampers the construction of a sufficiently detailed biostratigraphic framework. They also show that the acritarch zones may be controlled in part by facies. Correlations based on acritarch assemblages are a helpful tool, but they must be used with caution. Nevertheless, the revised zonal scheme with a *Holmia kjerulfi–'Ornamentaspis' linnarssoni* and a *Comluella?–Ellipsocephalus lunatus* Zone sensu Nielsen & Schovsbo (2011) does not allow a direct recognition of the biostratigraphic position for most of the relevant recorded Scandinavian faunas and awaits further revisions of the faunal assemblages and a revision of the ellipsocephaloid trilobites.

The *Epichalnipsus* Fauna from the glacial erratic boulders described herein illustrates the problem of the suggested zones. As shown above, there is little doubt that the boulders from As Hoved, Jutland, are derived from the Lingulid Sandstone Member of the Västergötland region so that the *Epichalnipsus* Fauna portrays a fauna typical for Nielsen & Schovsbo's (2011) LC2-4 sequence, which the authors place in the suggested *Comluella?–Ellipsocephalus lunatus* Zone. However, the eponymous index fossils are scarce and almost nowhere distinctive for the fauna in which they are found. In addition, indirect correlation suggests the trilobites of the *Epichalnipsus* Fauna to be slightly older than the assemblages with *'Ellipsocephalus' lunatus* due to reasons detailed in the following paragraphs. However, the occurrence of *'E.' lunatus* in the assemblages does not appear to precisely determine both the lower boundary of the zone, nor can it be proved that the base of Nielsen & Schovsbo's (2011) LC2-4 sequence coincides with the base of their *Comluella?–Ellipsocephalus lunatus* Zone. Therefore it is suggested that the *Epichalnipsus* Fauna is a representative of the boundary interval of the *Holmia kjerulfi–'Ornamentaspis' linnarssoni* to *Comluella?–Ellipsocephalus lunatus* zones although the fauna is not known with certainty from outcrops in Scandinavia.

Key areas for correlation from Scandinavia and Baltica into other Cambrian continents and for biostratigraphic resolution are the Holy Cross Mountains, southern Poland, and subsurface occurrences in central and northern Poland although the stratigraphic sequences from these regions are as well incompletely known. Recent investigations and taxonomic revisions of the lower and middle Cambrian Holy Cross Mountains faunas (e.g., Żylińska 2013a, 2013b; Żylińska & Masiak 2007; Żylińska & Szczepanik 2009; Żylińska *et al.* 2013) indicate different faunal assemblages and a possibility to subdivide the ellipsocephaloid-bearing pre-*Paradoxides* strata. Nevertheless, the significance of the crucial *Holmia–Schmidtiellus* and *Protolenus–Issafeniella* faunas from the Holy Cross Mountains also suffer from poor outcrops and unresolved taxonomic problems of the generic concepts.

Nielsen & Schovbo's (2011) sequence stratigraphical analyses help to identify the sea-level fluctuations that indicate an extremely varying termination of the lower Cambrian sequences which is partly a result of the late early Cambrian regressive–transgressive events (commonly termed the 'Hawke Bay regression'; Palmer & James 1979) and partly a result of Neogene and Pleistocene erosion that removed parts of the Cambrian strata. Thus, the young to youngest early Cambrian faunas from various areas of Scandinavia are not necessarily of similar age, and the most diverse of these faunas offer a glimpse into characteristic biota. A few of these faunas merit a brief characterisation.

Tømten Member fauna

The traditional fauna of the 'Holmia shale' (now Tømten Member of the Ringstrand Formation; Nielsen & Schovsbo 2006) of the Mjøsa region, Norway (Kiær 1917) includes the trilobites *Holmia kjerulfi*, *Kjerulfia lata*, cf. *Runcinodiscus index*, *Strenuaeva primaeva*, and *Ellipsostrenua* cf. *gripi* (Kiær 1917; Skjeseth 1963; Ahlberg & Bergström 1978; Bergström 1981; Høyberget *et al.* 2015). The overlying Evjevik Member includes two major limestone beds in the lower and upper part, respectively. Both appear to bear a fairly rich fauna of the *'Ornamentaspis' linnarssoni* assemblage (earlier termed the *Strenuella* limestone) with trilobites such as *Calodiscus lobatus* (Münster 1900; Nikolaisen 1986; Cederström *et al.* 2012; Høyberget *et al.* 2015). Most determinable material has been collected from weathered loose blocks so that apparently no biostratigraphical distinction between them had been achieved, but Høyberget *et al.* (2011a, 2011b, 2015) showed that a similar fauna with *'O.' linnarssoni*, *E. gripi* and helcionelloid molluscs occurs in both limestone levels. In addition, the upper limestone bed yielded *'Ornamentaspis' sularpensis*, *Strenuaeva spinosa* and *Calodiscus lobatus*, but it remains doubtful whether these indicate a biostratigraphical change in the trilobite spectrum. More significant seems to be the fact that *Holmia kjerulfi* and *Kjerulfia lata* occur in the lower limestone bed and *H. kjerulfi* is found in the shales between the limestone beds but is not found any higher in the succession of

the Ringstrand Formation (Nikolaisen 1986; Høyberget *et al.* 2011a, 2011b, 2015). However, it should be emphasized that Høyberget *et al.* (2011b, 2015) report the helcionelloid *Helcionella antiqua* (Kiær 1917) from the lower limestone bed, which is also known from strata with *'O.' sularpensis* of the middle part of the Gislöv Formation of Scania (see below). The only trilobite identified from the overlying Skyberg Member in Norway is *'Ellipsocephalus'* cf. *lunatus* indicative of the *Comluella?–Ellipsocephalus lunatus* Zone (Høyberget *et al.* 2011b, 2015).

Gislöv Formation faunas

A detailed study of the Gislöv Formation of eastern Scania (Bergström & Ahlberg 1981) appears to indicate (despite the strong condensation) a relatively continuous sequence to be present, and the ranges of trilobites portray a slight change in faunal composition from the middle to the uppermost part of the formation. A lower trilobite-bearing assemblage is recognizable in a shaly interval of the middle part of the formation. It bears, according to Bergström & Ahlberg (1981), *Holmia*? sp., *'Ornamentaspis' grandis*, *'O.' sularpensis*, *Berabichia*? *rotundata*, *Kingaspidoides*? cf. *nordenskioeldi* and an obolellid brachiopod assigned to *Magnicanalis* sp. (generic assignment partly revised herein). Nathorst's (1877) report of fossils from the formation at Forsemölla lists *Holmia sulcata*, *Kingaspidoides*? *nordenskioeldi* and *Lingulella*? *nathorsti* as additional species from probably this interval of the Gislöv Formation. Additional faunal elements from this interval were reported by Troedsson (1917) from the Hardeberga quarry. These include *Calodicus* cf. *lobatus*, which was firmly assigned to *Calodiscus lobatus* in Cederström *et al.* (2009). The latter authors confirmed a range of *C. lobatus* from the upper part of the *H. kjerulfia* assemblage into the lowest part of the *'O.' linnarssoni* range zone.

The presence of holmiids and the synchronous absence of *'Ornamentaspis' linnarssoni* prompted the interpretation of these strata and the interval to the *Holmia kjerulfi* group Zone. As discussed by Nielsen & Schovsbo (2011), the occurrence of *Holmia* and holmiid trilobites in general is, however, not restricted to the eponymous *Holmia* 'zones'. The presence of typical late to latest early Cambrian ellipsocephalid trilobites, in contrast, indicates a distinct faunal turnover so that the fauna represented in the middle part of the Gislöv Formation indeed signifies a new, recognizable zone.

A higher, but not the highest, part of the Gislöv Formation (generally developed as light coloured limestone) is characterized by a low diverse fauna with *'Ornamentaspis'* cf. *linnarssoni*, an obolellid assigned to *Magnicanalis* sp. and additional brachiopods. This part has been regarded as the lower part of the

'Ornamentaspis' linnarssoni Zone, but its faunas are insufficient to distinguish it biostratigraphically from the underlying strata.

The uppermost part of the formation, generally developed as a light or dark limestone with phosphoritic nodules, bears a fauna with *'Comluella' scanica*, *'Ellipsocephalus' lunatus*, *'Strenuaeva'* sp., *Amphigeisina danica*, *Magnicanalis* sp., and *Hyolithellus* cf. *micans* (Bergström & Ahlberg 1981; Cederström *et al.* 2009, 2012).

Remarkably, the well-known *'Ornamentaspis' linnarssoni* fauna from the dark grey shales at Forsemölla includes additional trilobites such as a new species of *Strenuaeva* and a species of *Protolenus s.l.* that will be described elsewhere. They appear to indicate a distinctly younger age of the fauna than previously assumed, probably related to the earliest *Protolenus s.l.* bearing strata in Avalonia and West Gondwana (Geyer, unpublished data). A similar development with *Holmia* spp., *'Strenuella'* and *Berabichia* occurs in the *Holmia–Schmidtiellus* Zone of the lower parts of the Ociesęki and Kamieniec Formations and is replaced by species of *Kingaspidoides* and *Issafeniella* in the shallower marine facies of the Ociesęki Formation and *Protolenus* and *Issafeniella* in the deeper marine facies of the Kamieniec Formation. These are followed by a typical middle Cambrian fauna with species of *Paradoxides s.l.* and ellipsocephalines (Żylińska 2013b).

Torneträsk Formation faunas

A fauna from the Torneträsk Formation in the Luobákti section near Lake Torneträsk, northern Sweden, assigned to the *Ornamentaspis*? *linnarssoni* Assemblage Zone includes *Geyerorodes*? *lapponicus*, *Strenuaeva inflata*, *Neocobboldia* aff. *dentata* and *Chelediscus acifer* (Axheimer *et al.* 2007). An earlier report of an assemblage from the Torneträsk Formation by Ahlberg (1980) reported *Strenuaeva inflata* together with *S. triangularis*, *Ellipsostrenua* cf. *gripi*, and *Geyerorodes*? *lapponicus*. *Geyerorodes*, first introduced as *Orodes* Geyer 1990 and replaced because of homonymy (Özdikmen 2009), is a genus indicative of late sub-*Paradoxides* strata in Avalonia (Fletcher 2006) or latest sub-*Paradoxides* to earliest *Paradoxides*-bearing strata in Moroccan West Gondwana (Geyer 1990; Geyer *et al.* 1995). The specimen illustrated by Axheimer *et al.* (2007, fig. 4r) has been re-examined by P. Cederström and appears to be a deformed cranidium of *G.*? *lapponicus* (P. Ahlberg, personal communication 2015). Although a confident generic assignment is difficult, it is tentatively assigned to *Cambrunicornia*, a genus known from the lower–middle Cambrian boundary interval in West Gondwana, where it ranges from the *Hupeolenus* Zone to the *Morocconus notabilis* Zone of the Moroccan biostratigraphical zonation in the lowermost Agdzian Stage (see discussions in Geyer *et al.* 2014).

Grammajukku Formation faunas

The traditional *Ellipsostrenua gripi* fauna of the upper part of the Grammajukku Formation from a ravine at Mount Aistjakk (now commonly spelled Assjatj) in the Laisvall region (Kautsky 1945) includes the trilobites *Holmia*? *ljungneri* and *Ellipsostrenua gripi*, and a bradoriid, the helcionelloid mollusc *Helcionella antiqua*, and three species of linguliform brachiopods. Two additional faunas slightly below Kautsky's original horizon have been reported by Ahlberg (1984a), Cederström in Nielsen & Schovsbo (2011, p. 222) and Cederström *et al.* (2012) from the Mt. Assjatj and the nearby Delliknäs sections. According to Cederberg *et al.* (2012) these include also *Holmia*? *ljungneri* and *Ellipsostrenua gripi* as in the upper faunal horizon, and a fairly diverse assemblage comprising *'Ornamentaspis' linnarssoni*, *Ellipsostrenua gripi*, *Holmia* cf. *inusitata*, *Kjerulfia palpebra*, *Strenuaeva spinosa*, and *S.? kullingi*.

The fossil assemblages portrayed above accumulate to a consistent succession of trilobites without detectable biostratigraphic gaps. On the other hand, the similarities with faunas of the Holy Cross Mountains, Poland, and the Atlas ranges, Morocco, appear to indicate that the *Epichalnipsus* fauna cannot be younger than the younger part of the traditional *'Ornamentaspis' linnarssoni* Zone, or Nielsen & Schovsbo's *Comluella*?–*'Ellipsocephalus' lunatus* Zone. Nielsen & Schovbo's (2011) assignment of the member to the LC2-4 sequence appears to be accurate. Accordingly, the endemic character of the *Epichalnipsus* fauna must be regarded as result of biofacies differentiation due to depositional settings of the well washed and reworked, shallow sand accumulations.

Intercontinental and global correlation

A precise, direct correlation of the *Epichalnipsus* fauna with the uppermost part of the *Holmia kjerulfi*–*'Ornamentaspis' linnarssoni* Zone (lower part of the former *'Ornamentaspis' linnarssoni* Zone) or lowermost *Comluella*?–*Ellipsocephalus lunatus* Zone (upper part of the former *'Ornamentaspis' linnarssoni* Zone) into regions outside Scandinavia is almost impossible. As demonstrated by Sundberg *et al.* (submitted), who provide a detailed correlation chart for the Cambrian Series 2–Series 3 boundary interval, a correlation of the late early Cambrian trilobites known from Scandinavia is slightly facilitated by a comparison with faunas from the Holy Cross Mountains, Poland, which provide links to faunas from West Gondwana (particularly Morocco) and western Avalonia (southeast-

ern Newfoundland). The *Epichalnipsus* fauna correlates with part of the *Protolenus–Issafeniella* faunal assemblage (Żylińska & Szczepanik 2009) and probably with the lowermost Agdzian Stage of the Moroccan Atlas ranges (*Hupeolenus* Zone; see Geyer & Landing 2004).

An equivalent of the *Epichalnipsus* level in Avalonian Newfoundland is probably Fletcher's (2006) *Orodes howleyi* Zone in the upper Branchian Stage. All other correlation must be derived from indirect correlations of these stratigraphic intervals, e.g. with the *Acimetopus bilobatus* Zone of the upper Dyeran in the Taconic Allochthon of eastern Laurentia and coeval strata in the upper, but not uppermost *Olenellus* 'Zone' of western Laurentia; the mid-Toyonian of the Siberian Platform; and the mid-Duyunian *Arthricocephalus chauveaui–Changaspis elongata* Zone of the South China/Yangtze Platform.

References

Ahlberg, P. 1979: Early Cambrian trilobites from Mount Luopakte, northern Sweden. Sveriges Geologiska Undersökning C 765, 1–12.

Ahlberg, P. 1980: Early Cambrian trilobites from northern Scandinavia. Norsk Geologisk Tidsskrift 60, 153–159.

Ahlberg, P. 1984a: Lower Cambrian trilobites from the Laisvall area, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 105 (for 1983), 251–259.

Ahlberg, P. 1984b: A Lower Cambrian trilobite fauna from Jämtland, central Scandinavian Caledonides. Geologiska Föreningens i Stockholm Förhandlingar 105 (for 1983), 349–361.

Ahlberg, P. 1984c: Lower Cambrian trilobites and biostratigraphy of Scandinavia. Lund Publications in Geology 22, 1–37.

Ahlberg, P. 1985: Lower Cambrian trilobite faunas from the Scandinavian Caledonides – a review. In: Gee, D.G. & Sturt, B.A. (eds): The Caledonide Orogen – Scandinavia and Related Areas, 339–346. London: John Wiley & Sons.

Ahlberg, P. & Bergström, J. 1978: Lower Cambrian ptychopariid trilobites from Scandinavia. Sveriges Geologiska Undersökning, Avhandlingar och Uppsatser, Ca 49, 1–41.

Ahlberg, P. & Bergström, J. 1983: Lower Cambrian trilobites from southern Swedish Lapland. Geologiska Föreningens i Stockholm Förhandlingar 104 (for 1982), 241–246.

Ahlberg, P. & Bergström, J. 1991: The trilobite *Calodiscus lobatus* from the Lower Cambrian of Scania, Sweden. Geologiska Föreningens i Stockholm Förhandlingar 115, 331–334.

Ahlberg, P., Bergström, J. & Johansson, J. 1986: Lower Cambrian olenellid trilobites from the Baltic Faunal Province. Geologiska Föreningens i Stockholm Förhandlingar 108, 39–56.

Álvaro, J.J. 2007: New ellipsocephalid trilobites from the lower Cambrian member of the Láncara Formation, Cantabrian Mountains, northern Spain. Memoirs of the Association of Australasian Palaeontologists 34, 343–355.

Andersson, A., Dahlmann, B., Gee, D.G. & Snäll, S. 1985: The Scandinavian Alum Shales. Sveriges Geologiska Undersökning Ca 56, 1–50.

Axheimer, N., Ahlberg, P. & Cederström, P. 2007: A new lower Cambrian eodiscoid trilobite fauna from Swedish Lapland and its implications for intercontinental correlation. Geological Magazine 144, 953–961, doi:10.1017/S0016756807003597.

Barrande, J. 1852: Système Silurien du Centre de la Bohême. 1ère Partie. Recherche paléontologiques. Crustacés, Trilobites, 1. xxx + 935 pp. Prague, Paris.

Bergström, J. 1973: Classification of olenellid trilobites and some Balto-Scandian species. Norsk Geologisk Tidsskrift 53, 283–314.

Bergström, J. 1981: Lower Cambrian shelly faunas and biostratigraphy in Scandinavia. In: Taylor, M.E. (ed.): Short papers for the Second International Symposium on the Cambrian System 1981. U.S. Geological Survey Open File Report 81-743, 22–25.

Bergström, J. & Ahlberg, P. 1981: Uppermost Lower Cambrian biostratigraphy in Scania, Sweden. Geologiska Föreningens i Stockholm Förhandlingar 103, 193–214.

Bergström, J. & Gee, D.G. 1985: The Cambrian in Scandinavia. In: Gee, D.G. & Sturt, B.A. (eds): The Caledonide Orogen – Scandinavia and Related Areas, 247–271. Chichester: John Wiley & Sons.

Brøgger, W.C. 1879: Om Paradoxidesskifrene ved Krekling. Nyt Magazin for Naturvidenskaberne 24, 18–88.

Cederström, P., Ahlberg, P., Clarkson, E.N.K., Nilsson, C.H. & Axheimer, N. 2009: The lower Cambrian eodiscoid trilobite *Calodiscus lobatus* from Sweden: Morphology, ontogeny and distribution. Palaeontology 52, 491–539.

Cederström, P., Ahlberg, P., Nilsson, C.H., Ahlgren, J. & Eriksson, M.E. 2011: Moulting, ontogeny and sexual dimorphism in the Cambrian ptychopariid trilobite *Strenuaeva inflata* from the northern Swedish Caledonides. Palaeontology 54, 685–703.

Cederström, P., Ahlberg, P., Babcock, L.E., Ahlgren, J., Høyberget, M. & Nilsson, C.H. 2012: Morphology, ontogeny and distribution of the Cambrian Series 2 ellipsocephalid trilobite *Strenuaeva spinosa* from Scandinavia. GFF 134, 157–171.

Czarnocki, J. 1927: Kambr i jego fauna w środkowej części Gór Świętokrzyskich. Sprawozdania Polskiego Instytutu Geologicznego 4, 189–207.

Ebbestad, J.O.R., Ahlberg, P. & Høyberget, M. 2003: Redescription of *Holmia inusitata* (Trilobita) from the Lower Cambrian of Scandinavia. Palaeontology 46, 1039–1054.

Eklund, C. 1990: Lower Cambrian acritarch stratigraphy of the Bårstad 2 core, Östergötland, Sweden. Geologiska Föreningens i Stockholm Förhandlingar 112, 19–44.

Elicki, O. & Geyer, G. 2013: Cambrian trilobites of Jordan: taxonomy, stratigraphic affinity, and functional morphology revised. Acta Geologica Polonica 63, 1–56.

Fletcher, T.P. 2003: *Ovatoryctocara granulata*, the key to a global Cambrian stage boundary and the correlation of the Olenellid, Redlichiid and Paradoxidid realms. Special Papers in Palaeontology 70, 73–102.

Fletcher, T.P. 2006: Bedrock geology of the Cape St. Mary's Peninsula, southwest Avalon Peninsula, Newfoundland (includes parts of NTS map sheets 1M/1, 1N/4, 1L/16 and 1K/13), Newfoundland. Government of Newfoundland and Labrador, Geological Survey, Department of Natural Resources, Report 06-02, 117 pp.

Frech, F. 1897–1902: Lethaea geognostica oder Beschreibung und Abbildung der für die Gebirgs-Formationen bezeichnendsten Versteinerungen. 1. Theil: Lethaea palaeozoica. 2. Band, 788 pp. Stuttgart: Schweizerbart.

Fritz, W.H. 1972: Lower Cambrian trilobites from the Sekwi Formation type section, northwestern Canada. Geological Survey of Canada Bulletin 212, 1–90.

Geyer, G. 1990: Die marokkanischen Ellipsocephalidae. Beringeria 2, 1–363.

Geyer, G. 2005: The base of a revised Middle Cambrian: are suitable concepts for a series boundary in reach? Geosciences Journal, Seoul, 9, 81–99.

Geyer, G. & Landing, E. 2004: A unified Lower-Middle Cambrian chronostratigraphy for West Gondwana. Acta Geologica Polonica 54, 179–218.

Geyer, G. & Palmer, A.R. 1995: Neltneriidae and Holmiidae (Trilobita) from Morocco and the problem of Early Cambrian intercontinental correlation. Journal of Paleontology 69, 459–474.

Geyer, G., Landing, E. & Heldmaier, W. 1995: Faunas and depositional environments of the Cambrian of the Moroccan Atlas region. In: Geyer, G. & Landing, E. (eds), MOROCCO '95 – the Lower-Middle Cambrian standard of western Gondwana. Beringeria Special Issue 2, 47–119.

Geyer, G., Popp, A., Weidner, T. & Förster, L. 2004: New Lower Cambrian trilobites from Pleistocene erratic boulders of northern Germany and Denmark and their bearing on the intercontinental correlation. Paläontologische Zeitschrift 78, 127–136.

Geyer, G., Buschmann, B. & Elicki, O. 2014: A new lowermost middle Cambrian (Series 3, Stage 5) faunule from Saxony (Germany) and its bearing on the tectonostratigraphic history of the Saxothuringian domain. Paläontologische Zeitschrift 88, 239–262. doi:10.1007/s12542-013-0195-z.

Gil Cid, M.D. 1972: Strenuaeva melendezi nov. sp. del Cámbrico

inferior de Alanís (Sevilla). Estudios geológicos XXVIII, 463–467.

Hadding, A. 1927: The pre-Quaternary sedimentary rocks of Sweden II. The Paleozoic and Mesozoic conglomerates of Sweden. Meddelanden från Lund Geologisk-Mineralogiska Institutionen 32, 42–171.

Hagenfeldt, S.E. 1989a: Lower Cambrian acritarchs from the Baltic Depression and south-central Sweden, taxonomy and biostratigraphy. Stockholm Contributions in Geology 41, 1–176.

Hagenfeldt, S.E. 1989b: Middle Cambrian acritarchs from the Baltic Depression and south-central Sweden, taxonomy and biostratigraphy. Stockholm Contributions in Geology 41, 177–250.

Hagenfeldt, S.E. 1994: The Cambrian File Haidar and Borgholm Formations in the central Baltic and south central Sweden. Stockholm Contributions in Geology 43, 69–110.

Hagenfeldt, S. & Bjerkéus, M. 1991: Cambrian acritarch stratigraphy in the central Baltic Sea, Sweden. Geologiska Föreningens i Stockholm Förhandlingar 113, 83–84.

Hansen, K. 1933: Den kambriske Sandsten paa Hunneberg i Vestergötland. Meddelelser fra Dansk Geologisk Forening 8, 224–230.

Holm, G. & Munthe, H. 1901: Kinnekulle, dess geologi och den tekniska användningen af dess bergarter. Sveriges Geologiska Undersökning C 172, 1–76.

Houmark-Nielsen, M. 1987: Pleistocene stratigraphy and glacial history of the central part of Denmark. Bulletin of the Geological Society of Denmark 36, 1–189.

Houmark-Nielsen, M. 1994: Geologisk set: Det mellemste Jylland, 272 pp. Geografforlaget, Copenhagen.

Høyberget, M., Ebbestad, J.O.R., Funke, B. & Nakrem, H.A. 2011a: Biostratigraphy of the Early Cambrian Evjevik Member, Ringstrand Formation, Mjösa Area, Norway. In: Kear, B.P. & Streng, M. (eds), The 2nd Wiman meeting, Uppsala 17–18 November 2011, Abstracts, 10–11.

Høyberget, M., Ebbestad, J.O.R., Funke, B. & Nakrem, H.A. 2011b: Biostratigraphy of the Early Cambrian Evjevik Member, Ringstrand Formation, Mjösa Area, Norway. In: The 2nd Wiman meeting, Uppsala 17–18 November 2011, Poster downloadable from https://www.researchgate.net/profile/Magne_Hoyberget/publication/263090054_Biostratigraphy_of_the_Early_Cambrian_Evjevik_Member_Ringstrand_Formation_Mjsa_area_Norway/links/02e7e539dee2782384000000.pdf?origin=publication_detail.

Høyberget, M., Ebbestad, J.O.R., Funke, B. & Nakrem, H.A. 2015: The shelly fauna and biostratigraphy of the lower Cambrian (provisional series 2, Stage 4) Evjevik Member, Ringstrand Formation in the Mjøsa area, Norway. Norwegian Journal of Geology 95, 23–56.

Hupé, P. 1953: Contribution à l'étude du Cambrien inférieur et du Précambrien III de l'Anti-Atlas marocain. Notes et Memoirs de la Service géologique du Maroc 103, 1–402. ("1952").

Jensen, S. 1997: Trace fossils from the Lower Cambrian Mick-

witzia sandstone, south-central Sweden. Fossils and Strata 42, 110 pp.

Karlsson, C. 2001: Diagenetic and petrophysical properties of deeply versus moderately buried Cambrian sandstones of the Caledonian foreland, southern Sweden. Examensarbete i Geologi vid Lunds Universitet, Historisk geologi och paleontologi, 138, 1–23.

Kautsky, F. 1945: Die unterkambrische Fauna vom Aistjakk in Lappland. Geologiska Föreningens i Stockholm Förhandlingar 67, 129–211.

Kiær, J. 1917: The Lower Cambrian Holmia Fauna at Tømten in Norway. Norske Videnskapsselskapets Skrifter, I. Matematisk-Naturvidenskaplig Klasse 1916, 1–140. Christiania: Dybwad.

Landing, E., Geyer, G., Brasier, M.D. & Bowring, S.A. 2013: Cambrian Evolutionary Radiation: context, correlation, and chronostratigraphy – overcoming deficiencies of the first appearance datum (FAD) concept. Earth-Science Reviews 123, 133–172.

Lazarenko, N.P. 1962: Novye nizhnekembriyskie trilobity Sovetskoy Arktiki [New Lower Cambrian trilobites from the Soviet Arctic]. In: Shvedov, N.A. (ed.), Sbornik statey paleont. biostrat. Trudy nauchno-issledovatel'skogo instituta geologii Arktiki (NIIGA) 29, 29–78.

Linnarsson, J.G.O. 1869: Om några försteningar från Vestergötlands sandstenslager. Öfversigt af Kongliga Svenska Vetenskaps-Akademiens Förhandlingar, 1869, XXVI, 337–357.

Linnarsson, J.G.O. 1871: Geognostiska och paleontologiska iakttagelser öfver Eophytonsandstenen i Vestergötland. Kongliga Svenska Vetenskaps-Akademiens Handlingar 9, 1–19.

Martinsson, A. 1974: The Cambrian of Norden. In: Holland, C.H. (ed.), Cambrian of the British Isles, Norden, and Spitsbergen, pp. 185–283. London, New York, Sydney, Toronto: John Wiley & Sons.

Matthew, G.F. 1887: Illustrations of the fauna of the St. John Group. No. IV. – On the smaller-eyed trilobites of Division 1, with a few remarks on the species of the higher divisions of the group. Canadian Record of Science 2, 357–363.

Mens, K., Bergström, J. & Lendzion, K. 1990: The Cambrian system on the East European platform. International Union of Geological Sciences Publication No. 25, 1–73.

Moczydłowska, M., Jensen, S., Ebbestad, J.O.R., Budd, G.E. & Martí-Mus, M. 2001: Biochronology of the autochthonous Lower Cambrian in the Laisvall–Storuman area, Swedish Caledonides. Geological Magazine 138, 435–453.

Münster, T. 1900. Kartbladet Lillehammer. Tekst. Norges geologiske undersøkelse 30, 49 pp.

Nathorst, A.G. 1877: Om de kambriska och siluriska lagren vid Kiviks Esperöd i Skåne, jemte anmärkningar om primordialfaunans lager vid Andrarum. Geologiska Föreningens i Stockholm Förhandlingar 37, 263–272.

Nielsen, A.T. & Schovsbo, N.H. 2006: Cambrian to basal Ordovician lithostratigraphy in southern Scandinavia. Bulletin of the Geological Society of Denmark 53, 47–92.

Nielsen, A.T. & Schovsbo, N.H. 2011: The Lower Cambrian of

Scandinavia: Depositional environment, sequence stratigraphy and palaeogeography. Earth-Science Reviews 107, 207–310.

Nikolaisen, F. 1986: Olenellid trilobites from the uppermost Lower Cambrian Evjevik Limestone at Tømten in Ringsaker, Norway. Norsk Geologisk Tidsskrift 66, 305–309.

Orłowski, S. 1985: Lower Cambrian and its trilobites in the Holy Cross Mts. Acta Geologica Polonica 35, 231–250.

Özdikmen, H. 2009: Nomenclatural changes for twenty trilobites genera. Munis Entomology & Zoology 4, 155–171.

Palmer, A.R. & Gatehouse, C.G. 1972: Early and Middle Cambrian trilobites from Antarctica. Geological Survey of America Professional Paper 456-D, 1–37.

Palmer, A.R. & James, N.P. 1979: The Hawke Bay event: a circum-Iapetus regression near the lower Middle Cambrian boundary. In: Wones, D.R. (ed.), The Caledonides in the U.S.A., Proceedings. I.G.C.P. Project 27 Caledonide orogen 1979 meeting, Blacksburg, Virginia. Virginia Polytechnic Institute and State University, Department of Geological Sciences, Memoir 2, 15–18.

Palmer, A.R. & Rowell, A.J. 1995: Early Cambrian trilobites from the Shackleton Limestone of the central Transantarctic Mountains. Paleontological Society Memoir 45, 1–28.

Popp, A. 1999: Der unterkambrische *Proampyx*?-"Sandstein" mit *Proampyx*? cf. *rotundatus* (Trilobita). Der Geschiebesammler 32, 3–8.

Richter, R. & Richter, E. 1940: Die *Saukianda*-Stufe von Andalusien, eine fremde Fauna im europäischen Ober-Kambrium. Abhandlungen der senckenbergischen naturforschenden Gesellschaft 450, 1–88.

Samsonowicz, J. 1959: On *Strenuaeva* from Lower Cambrian in Klimontów Anticlinorium. Bulletin de l'Académie Polonaise des Sciences, Série des sciences chimiques, géologiques et géographiques 7, 521–524.

Schlotheim, E.F. von 1823: Nachträge zur Petrefactenkunde. Zweyte Abtheilung. 114 pp. Gotha: Beckersche Buchhandlung.

Skjeseth, S. 1963: Contributions to the geology of the Mjøsa District and the classical Sparagmite area in southern Norway. Norges geologiske undersøkelse 220, 1–126.

Sundberg, F.A., Fletcher, T., Geyer, G., Kruse, P., McCollum, L., Pegel, T.V., Żylińska, A. & Zhuravlev, A. in press: International correlation of the traditional lower-middle Cambrian (Series 2–3, Stage 4–5). Memoirs of the Association of Australasian Palaeontologists.

Thorslund, P. 1960: The Cambro-Silurian of Sweden. In: Magnusson, N.H., Thorslund, P., Brotzen, F., Asklund, B. & Kulling, O.: Description to accompany the map of the pre-Quaternary rocks of Sweden. Sveriges Geologiska Undersökning Ba 16, 96–110.

Thorslund, P. & Westergård, A.H. 1938: Deep boring through the Cambro–Silurian at File Haidar, Gotland. Sveriges Geologiska Undersökning C 415, 1–48.

Torell, O. 1870: Petrificata Suecana Formationis Cambricae. Lunds Universitets Årsskrift 6, Afd. 2, 8, 1–14.

Troedsson, G.T. 1917: En skärning i Fågelsångstraktens undre kambrium. Geologiska Föreningens i Stockholm Förhandlingar 39, 603–633.

Walcott, C.D. 1890: Descriptive notes on new genera and species from the Lower Cambrian or Olenellus zone of North America. Proceedings of the U.S. National Museum 13 (for 1889), 33–46.

Wallin, J.A. 1868: Bidrag till kännedomen om Västgötabergens byggnad. 1, 17 pp. Lund: Lundbergs.

Weidner, T.R., Ahlberg, P., Axheimer, N. & Clarkson, E.N.K. 2004: The middle Cambrian *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones in Västergötland, Sweden. Bulletin of the Geological Society of Denmark 51, 39–45.

Westergård, A.H. 1931: Den kambro-silurska lagerserien. In: Lundquist, G., Högbom, A. & Westergård, A.H.: Beskrivning till kartbladet Lugnås. Sveriges Geologiska Undersökning Aa 172, 29–67.

Westergård, A.H. 1953: Non-agnostidean trilobites of the Middle Cambrian of Sweden. III. Sveriges Geologiska Undersökning C 526, 1–58.

Westrop, S.R. & Landing, E. 2000: Lower Cambrian (Branchian) trilobites and biostratigraphy of the Hanford Brook Formation, southern New Brunswick. Journal of Paleontology 74, 858–878.

Wiman, C. 1905: Studien über das nordbaltische Silurgebiet. I. Olenellussandstein, Obolussandstein und Ceratopygeschiefer. Bulletin of the Geological Institution of the University of Upsala, No. 11, VI (I), for 1902, 12–76.

Wurm, A. 1925: Über ein Vorkommen von Mittelcambrium (Paradoxidesschichten) im bayrischen Frankenwald bei Wildenstein südlich Presseck. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. Beilagen-Band 52, 71–93.

Zenker, J. 1833: Beiträge zur Naturgeschichte der Urwelt. Organische Reste (Petrefacten) aus der Altenburger Braunkohlen-Formation, dem Blankenburger Quadersandstein, jenaischen bunten Sandstein und böhmischen Uebergangsgebirge, mit 6 illuminirten Kupfertafeln. 67 pp. Jena: Friedrich Mauke.

Żylińska, A. 2013a: The oldest Cambrian trilobites from the Holy Cross Mountains, Poland: taxonomic, stratigraphic and biogeographic reappraisal. Acta Geologica Polonica 63, 57–87.

Żylińska, A. 2013b: Ewolucja zespołów trylobitowych z drugiego i trzeciego oddziału kambru Gór Świętokrzyskich i ich znaczenie biogeograficzne. Przegląd Geologiczny 61, 30–39.

Żylińska, A. & Masiak, M. 2007: Cambrian trilobites from Brzechów, Holy Cross Mountains (Poland) and their significance in stratigraphic correlation and biogeographic reconstructions. Geological Magazine 144, 661–686.

Żylińska, A. & Szczepanik, Z. 2009: Trilobite and acritarch assemblages from the Lower–Middle Cambrian boundary interval in the Holy Cross Mountains (Poland). Acta Geologica Polonica 59, 413–458.

Żylińska, A., Szczepanik, Z. & Salwa, S. 2006: Cambrian of

the Holy Cross Mountains, Poland; biostratigraphy of the Wiśniówka Hill succession. Acta Geologica Polonica 56, 4, 443–461.

Żylińska A., Kin A. & Nowicki, J. 2013: Application of morphometric techniques for taxonomic revision of *Berabichia oratrix* (Orłowski, 1985) (Trilobita, Cambrian) from the Holy Cross Mountains, Poland. Geodiversitas 35, 505–528.

Appendix 1. Petrological characters of the three samples from the studied erratic boulders from the As Hoved cliff, Jutland, and the Lingulid Sandstone Member of Kvillen, Halleberg and Djupadalen, Falbygden

	AS HOVED	KVILLEN	DJUPADALEN
Grain size	Fine	Fine	Coarser than the As Hoved and Kvillen samples
Compaction	High	High	Low
Grain contact	Poorly visible due to general absence of Fe-oxide coats.	Poorly visible due to general absence of Fe-oxide coats.	Irregularly stepped, straight/linear ≥ concave-convex, << point contacts.
Grain bond	Predominantly direct grain contacts and mostly syntaxial quartz overgrowth.	Predominantly direct grain contacts and usually syntaxial quartz overgrowth.	Predominantly direct grain contacts and syntaxial quartz overgrowth.
Pores	1–5 vol.%, syntaxial quartz overgrowths, grain contacts << interporous spaces.	1–5 vol.%, syntaxial quartz overgrowths, grain contacts << interporous spaces.	10–15 vol.%, pore cement, prevailing interporous spaces 0.05–0.1 mm, scattered large, branched interporous spaces (L 0.6 mm, B 0.1–0.15 mm).
Contact cement	Argillaceous-chloritic, rarely ferritic (goethite) on grain margins	Argillaceous-chloritic, small amounts of goethite pigment	Locally argillaceous-ferritic (illite + goethite) at grain contacts, scattered glauconite
Pore cement	Argillaceous-chloritic, argillaceous-illitic, minute interporous spaces (0.07×0.04 mm to 0.25×0.05 mm), small amounts of goethite pigment. Goethite granulose (0.02–0.09 mm), brownish-grey semitransparent.	Argillaceous-chloritic, argillaceous-illitic, minute interporous spaces (0.1×0.03–0.06 mm), small amounts of goethite pigment. Goethite granulose (0.02–0.09 mm), brownish-grey semitransparent.	Locally argillaceous-ferritic (illite + goethite) in minute and scattered large interporous spaces. Syntaxial quartz overgrowths. ferritic (goethite) in large branched interstitial pore (0.35×0.2 mm).
Quartz	c. 94 vol.%, 0.03–0.3 mm, maximum 0.3 mm. Monocrystalline, minor subgrain phenomena. Rare Fe oxide coats. Small grains (0.03–0.1 mm) predominantly isometric, subrounded, irregular shapes, moderate to high sphericity. Large grains platy, poorly rounded (L 0.2–0.3 mm, W 0.05–0.1 mm), angular or splintered grains (L 0.13 mm, B 0.01–0.03 mm), subtriangular in section.	c. 90 vol.%, mostly 0.04–0.1 mm, maximum 0.15 mm. Monocrystalline, minor subgrain phenomena. Rare Fe oxide coats. Small grains (0.04–0.07 mm) predominantly isometric, subrounded, irregular shapes, moderate to high sphericity, some angular or splintered grains. Large grains (>0.15 mm) platy, poorly rounded (L 0.15–0.25 mm, W 0.04 –0.05 mm), no angular or splintered grains observed.	c. 97 vol.%, 0.05–0.3 mm. Monocrystalline, minor subgrain phenomena. Frequent Fe oxide coats. Small grains (0.05–0.15 mm) predominantly subrounded/with rounded corners, irregular shapes, partly very angular, low sphericity. Large grains (>0.15 mm) either with low sphericity and poorly rounded corners or platy. Some grains with Boehm lamellas possible relics of the parent rocks, scarce inclusions of rutile (sagenite).
Alkali feldspar	0.05–0.1 mm. Fresh cleavage fragments with rounded edges or subrounded, microcline (twinning), rare perthitic unmixing.	0.06 mm. Fresh cleavage fragments with rounded edges or subrounded, microcline (twinning), rare perthitic unmixing.	0.12–0.17 mm. Fresh cleavage fragments with rounded edges or subrounded, microcline (twinning), fringe altered to illite or white mica.
Plagioclase	0.07–0.09 mm, max L 0.18 mm, B 0.03 mm. Fresh cleavage fragments with rounded edges, platy (L 0.18 mm, W 0.03 mm).	0.05–0.07 mm. Fresh cleavage fragments with rounded edges, platy (L 0.08–0.18 mm, W 0.05 mm); altered cleavage fragments (L 0.12 mm, W 0.05 mm; sericite, illite, goethite pigment).	0.15 mm. Fresh cleavage fragments with rounded edges.
Glauconite	0.04–0.12 mm. Subangular, deformed during compaction, partly with pale brown crust.	0.05–0.15 mm, maximum 0.25 mm (angular). Subangular, with rounded edges and angular, deformed during compaction, partly with pale brown crust.	0.05–0.15 mm. Subangular, deformed during compaction, no pale brown crust observed.
Tourmaline	0.04–0.07 mm. Cleavage fragments, generally with rounded edges, rarely polygonal.	0.07–0.08 mm. Cleavage fragments, generally with rounded edges.	0.04–0.1 mm. With rounded edges.
Zircon	0.03–0.04 mm, with rounded edges, partly with clearly recognizable oscillatory zonal composition.	0.04 mm, with rounded edges.	0.07 mm, with rounded edges, partly with clearly recognizable oscillatory zonal composition.
Apatite	L 0.1–0.12 mm W 0.03 mm. Long prisms, transparent.	L 0.05–0.12 mm, W 0.02–0.04 mm. Prismatic, transparent.	Not observed.

	AS HOVED	KVILLEN	DJUPADALEN
Goethite, detritic	0.05–0.09 mm. Rounded.	0.04 mm. Rounded.	0.06–0.08 mm. Subrounded.
Dark mica (biotite)	L 0.07–0.15 mm. Scarcely present, pleochroism yellow brown to pale brown, altered.	L 0.22 mm. Pleochroism dark yellow brown to pale brown, altered to chlorite and goethite.	L 0.07 mm. Pleochroism yellow brown to pale brown, partly altered to chlorite.
White mica (muscovite)	L 0.06–0.17 mm, maximum 0.3 mm.	L 0.15–0.25 mm, maximum 0.6 mm (bent by compaction).	L 0.04–0.12 mm, maximum 0.3 mm.
Chlorite	L 0.15–0.22 mm, W 0.01–0.04 mm. Pleochroism yellowish green, pale green to colourless, lamellar intergrowth with white mica, goethite (altered dark mica).	L 0.22 mm, W 0.08 mm. Pleochroism yellowish green, pale green to colourless, lamellar intergrowth with white mica (altered dark mica).	Pleochroism yellowish green to pale green.
Chert grains	0.07 mm. Elongated, subrounded.	0.04 mm. Rounded.	0.09 mm. Subrounded.