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Trilobites and intercontinental tie points in the Upper Cambrian of Scandinavia

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ABSTRACT

The Upper Cambrian faunas of Scandinavia are generally dominated by olenid trilobites, which provide a firm basis for the biostratigraphic classification. The olenids tend, however, to be provincial and facies controlled. By contrast, many agnostoid genera and species have a nearly worldwide distribution and are excellent biostratigraphic indices in Middle and Upper Cambrian strata. Three distinctive and geographically widely distributed agnostoid species are known from the lower part of the Upper Cambrian in Scandinavia: *Linguagnostus reconditus* POLETAEVA and ROMANENKO, 1970, *Aspidagnostus lunulosus* (KRYSKOV in Borovikov and Kryskov, 1963), and *Glyptagnostus reticulatus* (ANGELIN, 1851). They are the most valuable species available for correlations with Upper Cambrian deposits outside Baltica. *L. reconditus* is seemingly confined to the *Agnostus pisiformis* Zone and provides strong evidence for correlation of that zone with the recently defined *L. reconditus* Zone of Peng and Robison. *G. reticulatus* appears in the *Olenus gibbosus* Subzone and ranges up into the *O. wahlenbergi* Subzone, suggesting that the lower part of the *Olenus*/*Agnostus* (*Homagnostus*) *obesus* Zone correlates with the *G. reticulatus* Zone in, e.g., Australia, China, and Kazakhstan. The presence of *A. lunulosus* in the *O. gibbosus* Subzone provides additional evidence for this correlation. Higher in the sequence agnostoids become rare, and the species recorded from the medial and upper Upper Cambrian of Baltica permit only broad correlations with other continents.

KEYWORDS | **Trilobita. Olenidae. Agnostida. Biostratigraphy. Correlation. Upper Cambrian. Scandinavia.**

INTRODUCTION

The Upper Cambrian of Scandinavia is highly condensed and largely represented by dark grey or black, finely laminated mudstones and shales with lenses and beds of dark grey limestones (stinkstones or ”orsten”). The mudstones and shales are referred to as alum shales, and they are notably enriched in organic matter (up to 28%), pyrite, phosphate, and trace elements. The sediments were formed under poorly oxidised (dysoxic to anoxic) and extremely stable tectonic conditions (e.g. Thickpenny, 1984; Andersson et al; 1985; Bergström and Gee, 1985; Buchardt et al., 1997; Schovsbo, 2001). The parallel lamination and the lack of sedimentary structures typical of tidal and shallow marine environments suggest that deposition generally took place below storm wave base, but locally the deposition was affected by currents (e.g. Eklöf et al., 1999). The lithological homogeneity and the large areal extent of the alum shale facies indicate a fairly uniform depositional environment in a broad epicontinental sea, prone to stagnation (e.g. Thickpenny, 1987). To the east, the alum shale facies grades into coarser clastic deposits. The stratigraphically most complete successions are in Scania (Skåne), southern Sweden, and in the Oslo Region of Norway (Fig. 1). In these areas the Upper Cambrian attains a thickness of 55–57 m. In most other areas of Scandinavia the Upper Cambrian is considerably thinner and there are several local gaps in the sequence. The alum shale successions have been extensively quarried in the past, providing many good exposures, and are noted

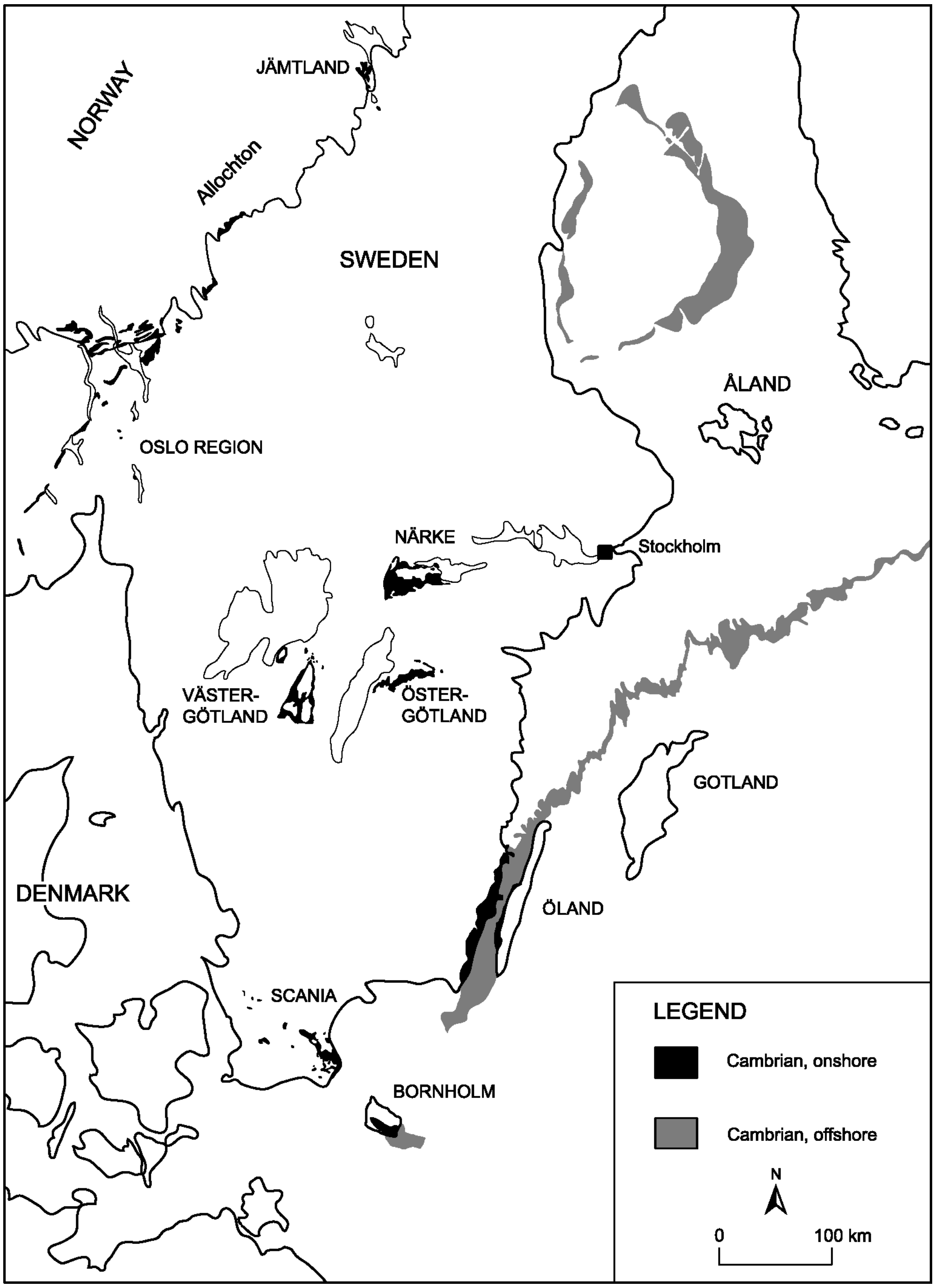

FIGURE 1| **Distribution of Cambrian outcrop areas in southern Scandinavia.**

for the abundance of trilobites, which are often well preserved and form the basis for the zonal subdivision.

BIOSTRATIGRAPHY AND TRILOBITE FAUNAS

The Upper Cambrian alum shale successions are generally richly fossiliferous and furnish a detailed biostratigraphical framework, which is employed also in Poland, England, Wales, and East Maritime Canada. The Scandinavian faunas are taxonomically restricted and dominated by arthropods, especially olenid trilobites, which, along with agnostoids, generally constitute the bulk of the faunas. Brachiopods and conodonts may also be common in certain intervals with stinkstones. The restricted trilobite faunas are rich in individuals, but very low in diversity.

	ZONES	SUBZONES	IMPORTANT SPECIES
	Acerocare	*Acerocare ecorne*	
		Westergaardia	
		Peltura costata	
		Peltura transiens	
Peltura Zones	*Peltura scarabaeoides*	*Peltura paradoxa*	
		Parabolina lobata	
		Ctenopyge linnarssoni	*Lotagnostus trisectus* s.l. (*Ctenopyge linnarssoni*–*Ctenopyge spectabilis*)
		Ctenopyge bisulcata	
	Peltura minor	*Ctenopyge affinis*	
		Ctenopyge tumida	
		Ctenopyge spectabilis	
		Ctenopyge similis	
	Protopeltura praecursor	*Ctenopyge flagellifera*	
		Ctenopyge postcurrens	
		Leptoplastus neglectus	
	Leptoplastus	*Leptoplastus stenotus*	
		Leptoplastus angustatus	
		Leptoplastus ovatus	
		Leptoplastus raphidophorus	
		Leptoplastus paucisegmentatus	
	Parabolina spinulosa	*Parabolina spinulosa*	
		Parabolina brevispina	← *Pseudagnostus cyclopyge*; ? *Irvingella suecica* (*Parabolina brevispina*–*Olenus dentatus*)
Olenus Zones	*Agnostus* (*Homagnostus*) *obesus*	*Olenus scanicus*	
		Olenus dentatus	
		Olenus attenuatus	
		Olenus wahlenbergi	*Glyptagnostus reticulatus* (*Olenus wahlenbergi*–*Olenus gibbosus*)
		Olenus truncatus	
		Olenus gibbosus	← *Aspidagnostus lunulosus*
	Agnostus pisiformis		← *Linguagnostus reconditus*

FIGURE 2 | **Biostratigraphic subdivision of the Upper Cambrian of Scandinavia and occurrences of important species. Biostratigraphy based on Henningsmoen (1957), Martinsson (1974), and Nielsen and Schovsbo (1999).**

Thus, the olenids may occur in immense numbers, but there are never more than three co-occurring genera. It is therefore generally accepted that the olenid biofacies in Scandinavia reflects a stressed environment, characterised by low oxygen levels and cold-water conditions (for general reviews, see Clarkson and Taylor, 1995a, 1995b).

The alum shales have a long history of palaeontological research, extending well back into the eighteenth century. The succession of trilobites in the Upper Cambrian of Scandinavia has been studied since the second half of the nineteenth century, and a detailed subdivision of the Upper Cambrian has gradually been established, from the time of Linnarsson (1868), Nathorst (1869, 1877), and Tullberg (1880, 1882) onwards. The most comprehensive study is that by Westergård (1922), who subdivided the Upper Cambrian into six biozones. As species turnover rate is high, the zonation was refined in a subsequent paper by Westergård (1947). In that paper the six biozones are further subdivided into 24 subzones. An even more refined zonation was introduced by Henningsmoen (1957), who monographed the olenid trilobites and subdivided the Upper Cambrian of Scandinavia into eight zones and 32 subzones. Three of Henningsmoen´s subzones have recently been rejected by Nielsen and Schovsbo (1999). The reasons for doing this seem well founded and currently 29 subzones can be recognised (Fig. 2). The stratigraphical resolution may be so high that each subzone could represent a time span of less than quarter of a million years (Cope, 1993).

Above the *Agnostus pisiformis* Zone trilobites of the family Olenidae dominate the Upper Cambrian faunas. They are widely used for intraregional correlations and provide a firm basis for the biostratigraphic classification. The olenids tend, however, to be provincial and facies controlled, being most common in offshore or outer shelf successions deposited under oxygen-deficient conditions. Hence, they are of limited value for intercontinental correlations. More valuable for correlation are other sporadically occurring trilobites, such as *Irvingella*, *Drepanura*, *Proceratopyge* and *Pedinocephalus* (see, e.g. Rushton, 1983: p. 112). These trilobites indicate faunal connections with realms where olenids are rare or absent. Members of *Irvingella*, *Drepanura* and *Pedinocephalus* are, however, very rare in Scandinavia, and, as noted by Rushton (1983), little is known of their stratigraphical ranges and morphological variation.

Agnostoids are the most precise tools available for intercontinental correlation of Cambrian strata. Some twenty species of agnostoids are known from the Upper Cambrian of Scandinavia. Most of these occur in the lower part of the Upper Cambrian. Higher in the sequence agnostoids become very rare, and only six species have been recorded from the upper part (Westergård, 1947; Ahlberg and Ahlgren 1996).

LOWER PART OF UPPER CAMBRIAN

The lower part of the Upper Cambrian comprises three biozones. In ascending order these are the zones of *Agnostus pisiformis*, *Olenus*/*Agnostus* (*Homagnostus*) *obesus* and *Parabolina spinulosa*. The *Agnostus pisiformis* Zone is dominated almost entirely by the zonal index. *A. pisiformis* generally occurs in phenomenal numbers, but it appears to be restricted to Scandinavia, England, Novaya Zemlya and the Avalon terrane (Rushton, 1978; Peng and Robison, 2000). Other agnostoids are very rare in the *A. pisiformis* Zone of Scandinavia. These rare species include *Linguagnostus reconditus* POLETAEVA and ROMANENKO, 1970, *Peratagnostus obsoletus* (KOBAYASHI, 1935) (Fig. 3A–D), and *Lotagnostus*? *mystacinus* TJERNVIK, 1953. The

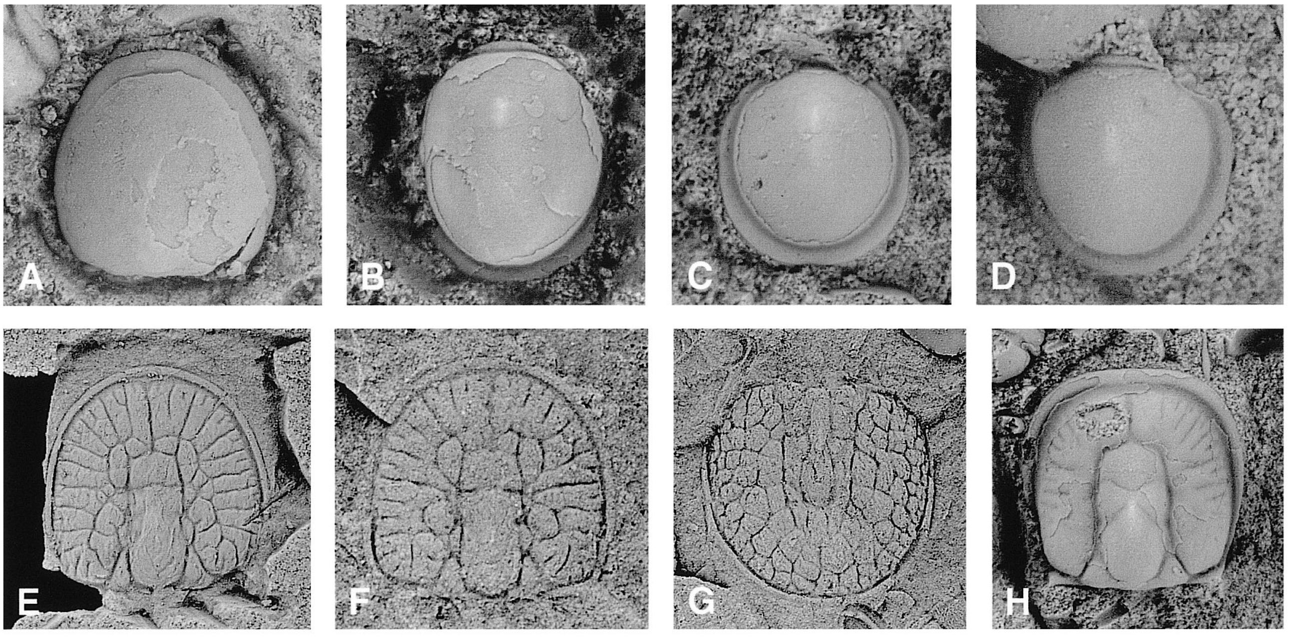

FIGURE 3| **A–C) *Peratagnostus obsoletus* (KOBAYASHI, 1935) from the *Agnostus pisiformis* Zone at Hjelmsäter, Kinnekulle, Västergötland, Sweden; coll. J. Ahlgren 1997. A) Cephalon; LO 8300; x7. B) Pygidium; LO 8301; x7. C) Pygidium; LO 8302; x9. D) *Peratagnostus obsoletus* (KOBAYASHI, 1935). Pygidium from the *Agnostus* (*Homagnostus*) *obesus* Zone; Kinnekulle, Västergötland, Sweden; coll. J. Ahlgren; LO 8303; x15. E–G) *Glyptagnostus reticulatus* (ANGELIN, 1851) from the *Olenus wahlenbergi* Subzone in the Great Quarry, Andrarum, Scania (Skåne), southern Sweden; coll. E.N.K. Clarkson and P. Ahlberg 1993. E) Cephalon; original of Clarkson et al. (1998, fig. 3D); LO 7515; x5. F) Cephalon; LO 8304; x12. G) Pygidium; latex cast from external mould; LO 8305; x7. H) *Lotagnostus* cf. *trisectus* (SALTER, 1864). Cephalon from the upper part of the *Peltura minor* Zone at Hällekis, Kinnekulle, Västergötland, Sweden; coll. J. Ahlgren 1999; LO 8306; x8. All illustrated specimens are deposited in the type collections of the Department of Geology, Lund University (LO).**

last-mentioned species has not been recorded outside Scandinavia (Ahlberg and Ahlgren, 2000). *L. reconditus* and *P. obsoletus* were described as *Cristagnostus papilio* and *Peratagnostus falanensis* from Scandinavia by Ahlberg and Ahlgren (1996). However, Peng and Robison (2000) showed that the latter species names can be regarded as junior subjective synonyms of the former. *L. reconditus* is a distinctive and widespread species, that is known from Altay in Siberia, China, England and Sweden (Peng and Robison, 2000). It has a relatively short stratigraphic range, and a new zone, the *L. reconditus* Zone, was recently defined by the lowest appearance of this species (Peng and Robison, 2000). The presence of *L. reconditus* in Scandinavia and England provides strong evidence for correlation of at least the lower–middle part of the *A. pisiformis* Zone with the lower part of the Youshuian Stage (*L. reconditus* Zone) in South China. *P. obsoletus* (Fig. 3A–D) is effaced and shows a wide range of morphological variation. It is geographically widespread, but appears to be long-ranging. In Scandinavia and England it has an observed temporal range from the upper *Lejopyge laevigata* Zone into the *Parabolina spinulosa* Zone (Rushton, 1983; Ahlberg and Ahlgren, 1996). Therefore, it has significantly less biostratigraphic utility than *L. reconditus*.

Because of their nearly cosmopolitan distribution, *Glyptagnostus stolidotus* ÖPIK, 1961 and *G. reticulatus* (ANGELIN, 1851) are extremely valuable for intercontinental correlations of lower Upper Cambrian deposits (e.g. Palmer, 1962; Rushton, 1983; Choi and Lee, 1995; Peng and Robison, 2000; Geyer and Shergold, 2000). In Scandinavia, *G. reticulatus* occurs in the lower three subzones of the *Olenus*/*Agnostus* (*Homagnostus*) *obesus* Zone, indicating that this part of the Scandinavian succession can be correlated with the *G. reticulatus* Zone and equivalent beds elsewhere in the world. The record of *Aspidagnostus lunulosus* (KRYSKOV in Borovikov and Kryskov, 1963) (= *A.* cf. *stictus* ÖPIK, 1967 of Ahlberg and Ahlgren, 1996; see Peng and Robison, 2000) in the *Olenus gibbosus* Subzone provides additional evidence for a precise correlation of the *G. reticulatus* Zone (lower Idamean Stage) of Australia with the lowermost part of the *Olenus*/*A.* (*H.*) *obesus* Zone of Scandinavia. Peng and Robison (2000) showed that *A. lunulosus* is a geographically widespread species, that is known from the *G. stolidotus* and/or *G. reticulatus* Zone in Australia, Kazakhstan, South Korea, Sweden, and China. The species is also known from a loose boulder in the glacial drift at Wismar in northern Germany (Weidner, 1997).

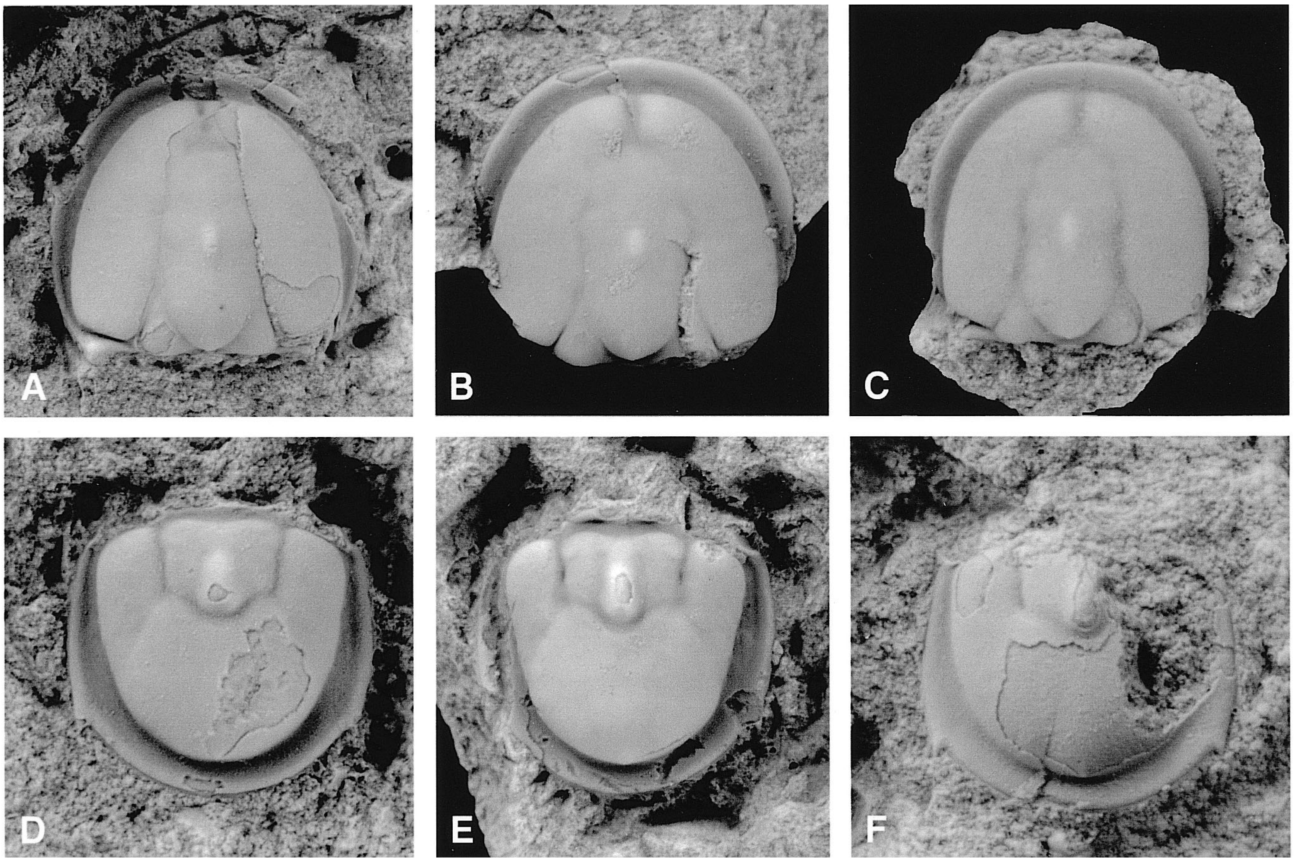

FIGURE 4 **_Pseudagnostus cyclopyge_ (TULLBERG, 1880). Topotype material; _Parabolina brevispina_ Subzone, Andrarum, Scania (Skåne), southern Sweden. A) Cephalon; original of Westergård (1922, pl. 1, fig. 7) and Shergold (1977, pl. 15, fig. 1); coll. A.G. Nathorst; LO 3066; x8. B) Cephalon; LO 8307; x8.5. C) Cephalon; LO 8308; x13. D) Pygidium; LO 8309; x12. E) Pygidium; original of Westergård (1922, pl.1, fig. 8) and Shergold (1977, pl. 15, fig. 2); coll. A.G. Nathorst; LO 3067; x8. F) Incomplete pygidium; LO 8310; x12. All illustrated specimens are deposited in the type collections of the Department of Geology, Lund University (LO).**

G. stolidotus and the zone bearing its name are not known from Scandinavia. However, cephala which are morphologically intermediate between those of *G. stolidotus* and those of *G. reticulatus* have recently been collected from alum shales slightly above *G. reticulatus*-bearing beds at Andrarum in Scania, southern Sweden (Clarkson et al., 1998, fig. 3D; Fig. 3E–G herein). This is puzzling because in other parts of the world *G. stolidotus* precedes *G. reticulatus* and the intermediate forms are found in the transitional beds. The *stolidotus*-like specimens from Andrarum are, however, flattened and provided with faint cross furrows on the rugae, and nevertheless they probably belong to *G. reticulatus*.

Agnostoids are generally rare in beds above the *Olenus*/*A.* (*H.*) *obesus* Zone, and precise correlation of the Scandinavian medial and upper Upper Cambrian with other areas cannot yet be satisfactorily determined. *Pseudagnostus cyclopyge* (TULLBERG, 1880) (Fig. 4A–F) is fairly common in the *Parabolina brevispina* Subzone (lower *Parabolina spinulosa* Zone) at Andrarum in Scania Skåne), southern Sweden. The presence of *Pseudagnostus cyclopyge* (TULLBERG, 1880) *sensu lato* in the upper Steptoean Stage of northwest Canada (Pratt, 1992) may indicate a general correlation with the *Parabolina spinulosa* Zone of Scandinavia. The upper Steptoean Stage corresponds approximately also to the upper part of the *Olenus*/*Agnostus* (*Homagnostus*) *obesus* Zone. This correlation is supported by the occurrence of *Proceratopyge rectispinata* (TROEDSSON, 1937) in the *Olenus cataractes* Subzone of England and the uppermost Steptoean Stage of northwest North America (Rushton, 1983; Pratt, 1992).

During the early–middle Late Cambrian there was a nearly worldwide dispersal of *Irvingella* species. The first appearance of *Irvingella* is a widely recognised biostratigraphic horizon, important for intercontinental correlations (e.g. Geyer and Shergold, 2000). In Scandinavia, *Irvingella* is represented by a single species, *I. suecica* Westergård, 1947. It is very rare and known only from two localities in north-central Sweden. Westergård (1947) believed that the type material of *I. suecica* was from the upper *Leptoplastus* Zone or from the lower *Protopeltura praecursor* Zone. However, he subsequently revised himself and suggested that the stratigraphic position of *I. suecica* lies within or below the *Parabolina brevispina* Subzone (Westergård, 1949). This is more in accordance with the appearance of *Irvingella* species in other parts of the world, such as in, England, Laurentia, Australia, Kazakhstan, South Korea, and China (e.g. Rushton, 1983).

UPPER PART OF UPPER CAMBRIAN

Six species of agnostoids seem to be present in the upper part of the Scandinavian Upper Cambrian: *Trilobagnostus rudis* (SALTER, 1864), *T. holmi* (WESTERGÅRD, 1922), *Pseudagnostus leptoplastorum* WESTERGÅRD, 1944, *Lotagnostus trisectus* (SALTER, 1864), *L. subtrisectus* Westergård, 1944, and "*Agnostus* sp." of WESTERGÅRD (1922). Of these species, *L. trisectus* appears to have a fairly wide geographic distribution. It should be noted, however, that the species concept is in need of revision based on topotype material from Malvern Hills, England. In Sweden, England, and Wales *L. trisectus sensu lato* (Fig. 3H) occurs in the *Peltura minor* and *P. scarabaeoides* zones. Closely related or conspecific forms are known from, e.g., eastern Canada, Argentina, and Tasmania (Shergold et al., 1995; Tortello and Bordonaro, 1997; Bao and Jago, 2000), and their occurrences suggest a broad correlation with the *Peltura* Zones of Scandinavia. *T. rudis*, *T. holmi*, *P. leptoplastorum*, and *L. subtrisectus* are either based on single specimens and/or are fairly poorly known. They furthermore seem to have a restricted distribution based on our present knowledge.

Conodonts show an interesting potential for correlations in the upper half of the Upper Cambrian. Studies during the last two decades have revealed that they are abundant and taxonomically diverse in the Scandinavian Upper Cambrian, and recently Szaniawski and Bengtson (1998) proposed an euconodont-based correlation of the uppermost Cambrian of Baltoscandia with Laurentia. Further investigations, particularly in the *Acerocare* trilobite Zone, are desirable. In Scandinavia, the *Cordylodus proavus* conodont Zone has been described from the Oslo Region only, where it corresponds to the upper part of the *Acerocare* Zone (Bruton et al., 1988; Szaniawski and Bengtson, 1998).

CONCLUDING REMARKS

The Upper Cambrian faunas of Scandinavia are taxonomically restricted and dominated by arthropods, especially olenid trilobites, which, along with agnostoids, generally consitute the bulk of the faunas. Agnostoids are the most precise tools available for intercontinental correlation of Middle and Upper Cambrian strata. Some twenty species of agnostoids are known from the Upper Cambrian of Scandinavia. Most of these occur in the lower part of the Upper Cambrian. *Linguagnostus reconditus*, *Aspidagnostus lunulosus*, and *Glyptagnostus reticulatus* are the most important species for correlations with lower Upper Cambrian deposits outside Baltica. Agnostoids become rare higher in the succession, and only six species are known from the upper part of the Scandinavian Upper Cambrian. These species permit only broad correlations with other continents.

Bradoriid and phosphatocopid arthropods represent significant but generally neglected components in many Cambrian faunas. These bivalved arthropods had a worldwide distribution and most species are apparently short-ranging (e.g. Hinz-Schallreuter, 1993; Siveter and Williams, 1997; Williams and Siveter, 1998). Thus they appear to have considerable potential for use in biostratigraphy (e.g. Williams et al., 1994; Siveter et al., 1996). Bradoriids and phosphatocopids are generally sparsely represented in the Upper Cambrian of Scandinavia, and little is known of their stratigraphical ranges and geographical distribution. Further studies are required to resolve their stratigraphical potential.

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