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Biostratigraphical and palaeoecological significance of graptolites, trilobites and conodonts in the Middle–Upper Ordovician Andersö Shale: an unusual 'mixed facies' deposit in Jämtland, central Sweden

Christian Pålsson, Kristina Månsson and Stig M. Bergström

ABSTRACT: Although only about 20 m thick, the Andersö Shale contains one of the most diverse, if not the most diverse, late Middle–early Late Ordovician faunas known in Baltoscandia. It includes more than 20 trilobite species, more than 20 species of other shelly fossils, about 10 graptolite species, and about 20 conodont species. Based on its lithology, its geographical position near the foreland basin margin, and the presence of trilobites of the raphiophorid association and conodonts of the *Periodon–Pygodus* biofacies, this formation is interpreted to represent an outer shelf–upper slope (ramp) deposit laid down in moderately deep water. The co-occurrence of some widespread and biostratigraphically diagnostic conodonts, graptolites and trilobites makes it possible directly to compare distribution patterns of these fossils, establish ties between graptolite and conodont zones, and correlate the formation with units elsewhere in Europe, North America and China. Stratigraphically and faunally, the Andersö Shale is of particular interest in straddling the Middle–Upper Ordovician Series boundary as this boundary is recognised in the new global classification of the Ordovician System.

KEY WORDS: biostratigraphy, palaeoecology, Sweden

From the standpoint of detailed Lower Palaeozoic biostratigraphy, sections with good representation of several major index fossil groups, such as trilobites, graptolites and conodonts, are of particular importance. Well-exposed such successions of 'mixed facies' are rare in the Middle and Upper Ordovician of Baltoscandia, and indeed elsewhere in the world. That is, zonally significant graptolites tend to occur primarily in dark shales with few conodonts and shelly fossils, whereas the carbonate units commonly contain diverse shelly fossils and conodonts but few, if any, graptolites. This major biofacies difference has led to difficulties in establishing the precise relation between shaly and shelly stratigraphical units, and separate zone schemes have been used in some regions for each of the two major facies. In order to clarify the precise chronostratigraphical relations across lithofacies and biofacies boundaries, 'mixed facies' sections warrant particularly careful study. An excellent and well-exposed succession of this type is represented by the upper Middle–lower Upper Ordovician Andersö Shale in the Lower Allochthon of the Lake Storsjön region in the Province of Jämtland in central Sweden (Fig. 1). Because the potential of this sequence for establishing correlations across facies boundaries was recognised already by Hadding in 1913, it is rather surprising that until recent investigations, the fauna of this formation has received very limited study since Hadding's time and is clearly in need of modern re-appraisal. The purpose of the present study is to summarise some new data at hand bearing on the Andersö Shale trilobites, graptolites and conodonts, and their biostratigraphical and palaeoecological significance.

Such a summary is particularly timely because in the current international effort to establish a new global series and stage classification of the Ordovician System (Webby 1998), the Swedish sequence plays a prominent role. In this global classification, the base of the Upper Ordovician has been proposed to be at the base of the *Nemagraptus gracilis* Zone in the graptolite shale succession at Fågelsång, Scania, southernmost Sweden (Bergström *et al.* 2000). The Andersö Shale is of latest Middle and earliest Late Ordovician age in terms of this global classification (Fig. 2), and because it includes rocks of the *Hustedograptus teretiusculus* and *Nemagraptus gracilis* Zones (Hadding 1913) in 'mixed facies', it has the potential to yield significant information about the biostratigraphical relations between several key index fossil groups, especially in the uppermost Middle Ordovician just below the base of the Upper Ordovician. In view of this, the data presented in this contribution are of not only local but also international interest.

Pioneering studies of the fauna and stratigraphy of the Andersö Shale were carried out by Linarsson (1872, 1875) and Wiman (1893, 1896), but the first comprehensive faunal and stratigraphical investigation was by Hadding (1912, 1913). The latter work focused on the excellent outcrops on Andersön, from which Hadding (1913) described a substantial fauna of 49 taxa, including nine graptolites, three gastropods, one bivalve, seven brachiopods, one hyolith, seven cephalopods and 21 trilobites (including varieties). Subsequent early studies on the Andersö sequence and its faunas include Ulrich (1930), Thorslund & Asklund (1935), Asklund (1936) and Thorslund (1937, 1940). For more recent publications, see Thorslund (1960), Bergström (1971b, 1973a, 1986), Karis (1982, 1998), Ahlberg (1995), Rasmussen & Bruton (1994), Månsson (1998, 2000a, b) and Rasmussen (2001).

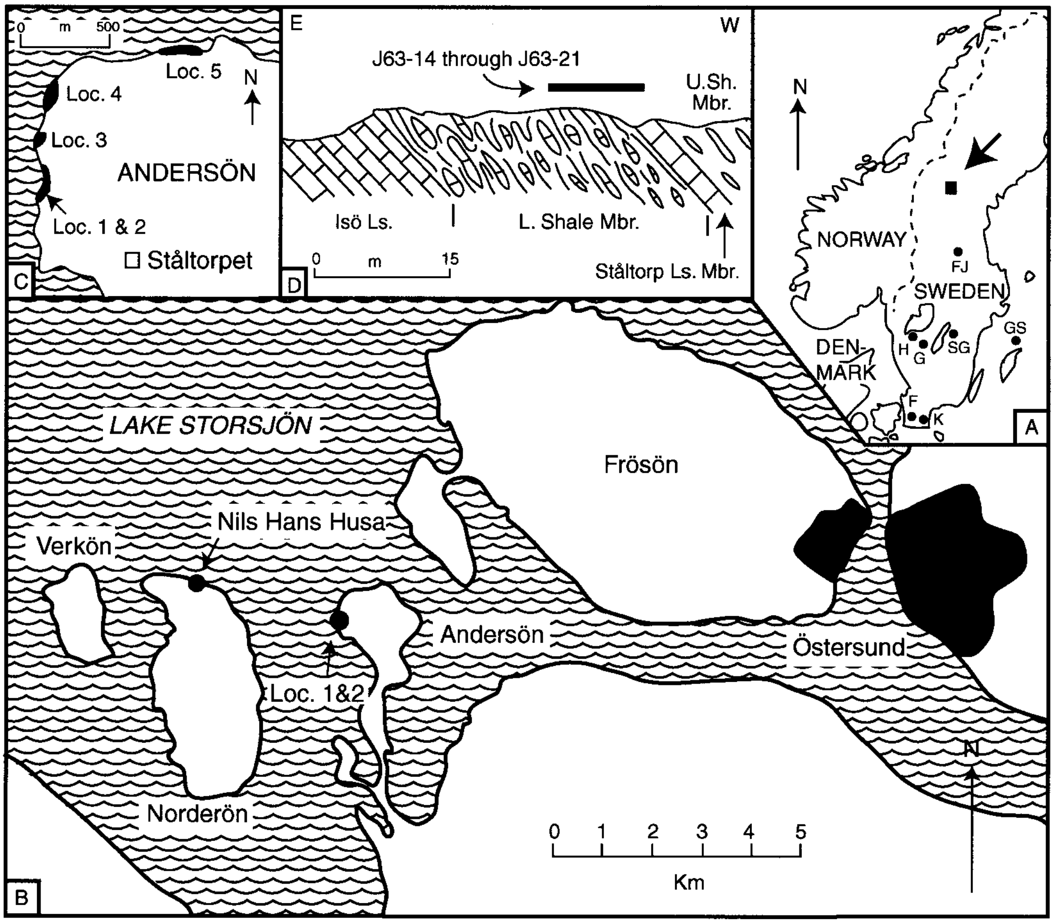

Figure 1 Sketch-maps showing location of the sections investigated : (A) Map of Scandinavia with the study area in the Province of Jämtland marked by black square and arrow. Lettered localities on the map are as follows: F, Fjäcka; GS, Gotska Sandön; G, Gullhögen; H, Hällekis; SG, Smedsby Gård; K, Killeröd; F, Fågelsång. (B) Sketch-map of study area showing geographical situation of the study localities on Norderön and Andersön. (C) Locations of Hadding's (1912, 1913) Localities 1–5 along the NW and N shore of Andersön. (D) Schematic cross-section of the sampled succession of the Andersö Shale along the northern shore of Norderön (modified after Thorslund (1960). J63-14, etc. refer to samples from the Ståltorp Limestone Member, and underlying beds.

Karis (1998) presented a comprehensive and very useful summary of the geology and distribution of the Andersö Shale that also included some palaeontological data. However, in this monograph there is a significant change in lithostratigraphical nomenclature that needs to be addressed. Specifically, it concerns the construction of formation names based on geographical features. With very few exceptions, the common practice in Sweden since at least the 19th century has been to use the stem of geographical names without the definite article (which in Swedish is placed behind the stem), for instance, Andersö Shale instead of Andersön Shale (named for the Island of Andersön). However, Karis (1998) changed many well-established formation names to the longer version (e.g. Dalby Limestone to Dalbyn Limestone) in the English parts of his text but used the short version in his Swedish text (e.g. Dalbykalksten). Having a dual nomenclature like this is unwarranted and confusing, and we see no need to change long-established formation names to the longer form. Accordingly, we use the terms Andersö Shale, Isö Limestone and Örå Shale as they were written when proposed by Karis himself (1982).

The present restudy of the Andersö Shale has been organised as a team project in which Pålsson has been responsible for the graptolites, Månsson for the trilobites and Bergström for the conodonts. Although we have shared fully the results of our investigations between us, we feel it appropriate to show our specific project responsibilities by having individual authorship of the respective faunal chapters. Bergström coordinated the final assembling of the manuscript and takes full blame for any inaccuracies that may have been created during that process.

1. Lithostratigraphy and localites

The Andersö Shale, which was formerly known as the *Ogygiocaris* Shale (Hadding 1913), is a lithologically distinctive, and widely distributed, unit in the Storsjön region. It occupies a low position in a nappe complex (Lower Allochthon; see Karis 1998) and rests on the Lower–Middle Ordovician Isö Limestone. It is locally overlain, probably conformably, by a grey limestone, referred to by Karis (1998) as the Dalby Limestone, or by dark shales of the Örå Shale. Because of locally complex tectonic structure, soil cover and a lithologically poorly defined upper boundary, its precise thickness is not known, but at least locally, it has been estimated to be of the order of 20 m. Recent authors (Karis 1998; Månsson 2000a) have interpreted the Andersö Shale as an outer shelf–upper slope deposit, most of which was laid down in moderately deep to deep water near the margin of a carbonate ramp in

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GLOBAL		BRITISH SERIES	BALTIC SERIES	FM.	MEMBER	CONODONT		GRAPTOLITE ZONE
SERIES	STAGE					ZONE	SUBZONE	
Upper Ordovician	Not yet named	Caradoc	Kukrusean	Andersö Shale	Upper Member	*Pygodus anserinus*	*Amorph. inaequalis*	*Nemagraptus gracilis*
Middle Ordovician	Darriwilian	Llanvirn	Uhakuan		Ståltorp Limestone Member		*Amorph. kielcensis*	*Hustedograptus teretiusculus*
					Lower Member	*Pygodus serra*	*Eopl. lindstroemi* – *Eopl. reclinatus* ?	
				Isö Ls.	Not distinguished	*Eopl. suecicus*		

Figure 2 Classification of the Andersö Shale in terms of some standard chronostratigraphical units; the conodont zone dating of the topmost part of the Isö Limestone is based on Rasmussen (1994, 2001).

the eastern portion of a foreland basin (Fig. 3). To the W, it grades into non-calcareous siliciclastic turbidite sequences and to the E, its stratigraphic equivalents are present in the carbonate rocks of the autochthonous successions.

Our studies have been centred on the Andersö Shale in the classical outcrops on Andersön and Norderön (Fig. 1), where the formation can be subdivided into three lithological units, a lower and an upper shale member, which are separated by a distinctive limestone member (Figs 4, 5). The Lower Shale Member, which is about 6 m thick at Locality 1 of Hadding (1912, 1913) along the NW shore of Andersön, consists of dark shale and mudstone with interbeds and lenses of grey, fine-grained, impure, fossiliferous limestone. At this outcrop, the rocks dip about 50° toward the NW and exhibit minor faulting and folding and some tectonic squeezing of, especially, the shale beds. Although it appears that the contact between the Isö Limestone and the Andersö Shale is faulted, the tectonic structure of the succession is simple at this outcrop compared with that at most other exposures, such as on Norderön, where the shale beds are locally isoclinally folded (Karis 1998). Hadding (1913) recorded graptolites of the *Hustedograptus teretiusculus* Zone (the *Climacograptus putillus* Zone of Hadding) along with quite a diverse shelly fauna from this member on Andersön.

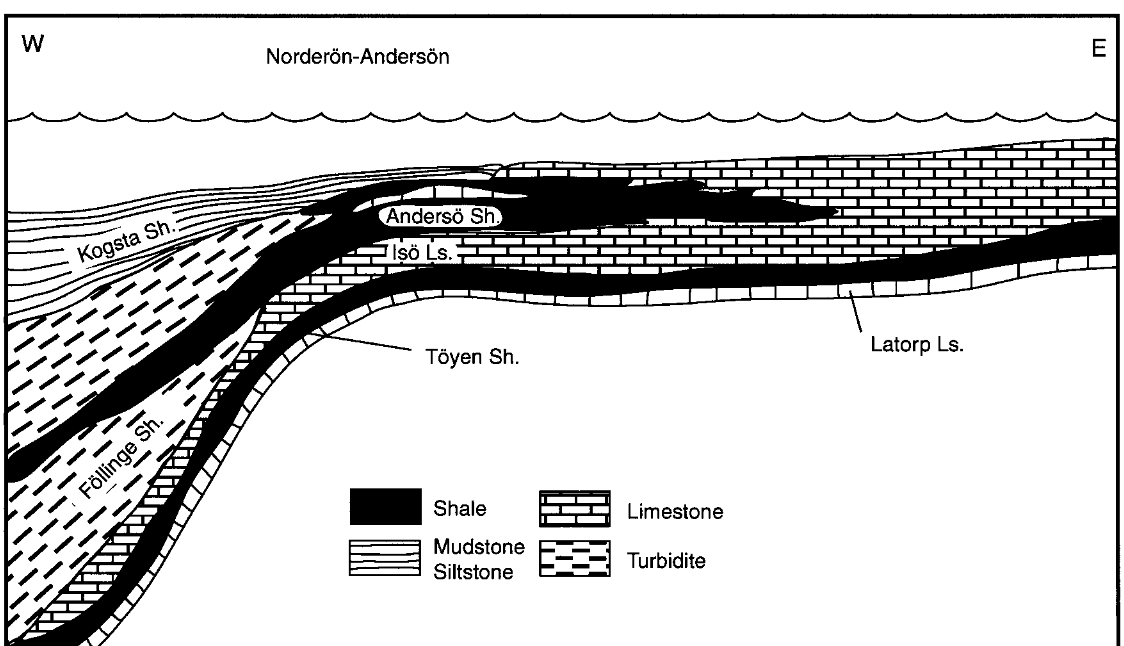

Figure 3 Diagrammatic E–W cross-section showing the inferred position of the Andersö Shale in relation to the E calcareous platform succession and the W foreland basin turbiditic sequence (modified after Jaanusson 1982); illustrated successions are of Early to Late Ordovician age and rocks of the Lower Allochthon are shown in their autochthonous position; note that the Andersö Shale is interpreted to have been deposited in an outer ramp to upper slope deeper-water environment.

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Figure 4 Outcrop of the Lower Shale Member (L) and the Ståltorp Limestone Member (S) of the Andersö Shale at Locality 1 of Hadding (1912, 1913) along the NW shore of Andersön; looking N; the contact between the rocks in the foreground, which are the topmost part of the Isö Limestone, and the Andersö Shale appears to be a small bedding-plane fault; the Lower Shale Member in this section contains graptolites of the *Hustedograptus teretiusculus* Zone and conodonts of the *Pyogodus serra* Zone; most of the Ståltorp Limestone Member belongs to the *Pygodus anserinus* Zone; the base of the Upper Ordovician (base of *Nemagraptus gracilis* Zone) is tentatively taken to be at the top of the Ståltorp Limestone Member, which is at the pine tree at the left margin of this outcrop.

The Lower Shale Member is overlain, with gradational contact, by a distinctive (in the Andersön and Norderön sections about 1·5 m thick), rather pure, dark-coloured, bedded limestone. This unit was informally referred to as the '*Telephina biseriata* beds' by Thorslund (1960) but in more recent studies, the designation '*biseriata* limestone' has been used (Karis 1982, 1998; Rasmussen & Bruton 1994; Månsson 1998, 2000a; Rasmussen 2001). This lithological unit, which is known from several localities in central Jämtland (Karis 1998), is of considerable faunal and biostratigraphical interest and deserves to be recognised with a proper lithostratigraphical name, and we propose that it be called the Ståltorp Limestone Member. It is named for the farm of Ståltorpet, which is located 0·5 km SE of its type section at Hadding's Locality 1 along the NW shore of Andersön (Fig. 1). Rasmussen & Bruton (1994) suggested that this limestone member may be an extension of the still poorly known Elvdal Formation of the S Norwegian Caledonides about 200 km SW of Andersön. However, as pointed out by these authors, the lithology of the Elvdal Formation differs in some significant respects from that of the Ståltorp Limestone Member. Also, the Elvdal conodont fauna (Rasmussen & Bruton 1994) appears to represent the *Amorphognathus inaequalis* Subzone of the *Pygodus anserinus* Zone and hence to be younger than that present in the Ståltorp Limestone Member. In view of this, it appears inappropriate to use the Norwegian formation name for this member. In the study area, the Ståltorp Limestone Member is well exposed at Hadding's (1912) Localities 1, 4 and 5 on Andersön and at the Nils Hans Husa section of Norderön (Fig. 1).

The Ståltorp Limestone Member is overlain by the Upper Shale Member of the Andersö Shale (Fig. 5) that consists of dark-grey to black shales and mudstones with occasional interbeds of sandy greywacke, siltstone and impure limestone. There are also relatively common fossiliferous limestone concretions (Hadding 1913). Because of soil cover, folding and faulting, the thickness of this member is difficult to determine precisely but Karis (1998) estimated it to exceed 10 m. Exposures of this member occur along the NW and N shore of Andersön and along the N shore of Norderön. This member has yielded some graptolites and conodonts but few shelly fossils. Hadding (1913) recorded *Nemagraptus gracilis* from the lower 6 m of the unit, and referred its upper part to the *Dicranograptus clingani* Zone. The presence of the latter zone has not been confirmed and the zone identification is unlikely to be correct (Karis 1998). Hadding's (1913) zone record is probably due to a misidentification of the zone index (see below).

2. Graptolites (by Christian Pålsson)

2.1. Occurrence and previous work

The present account of the Andersö Shale graptolites is based on collections from exposures along the NW shore of Andersön (Localities 1–2 of Hadding 1912, 1913). Graptolites are generally relatively rare and poorly preserved in the Andersö Shale in these outcrops, particularly in the lower fine-grained portion of the Lower Shale Member and in the Ståltorp Limestone Member. Their preservation is somewhat better in the calcar-

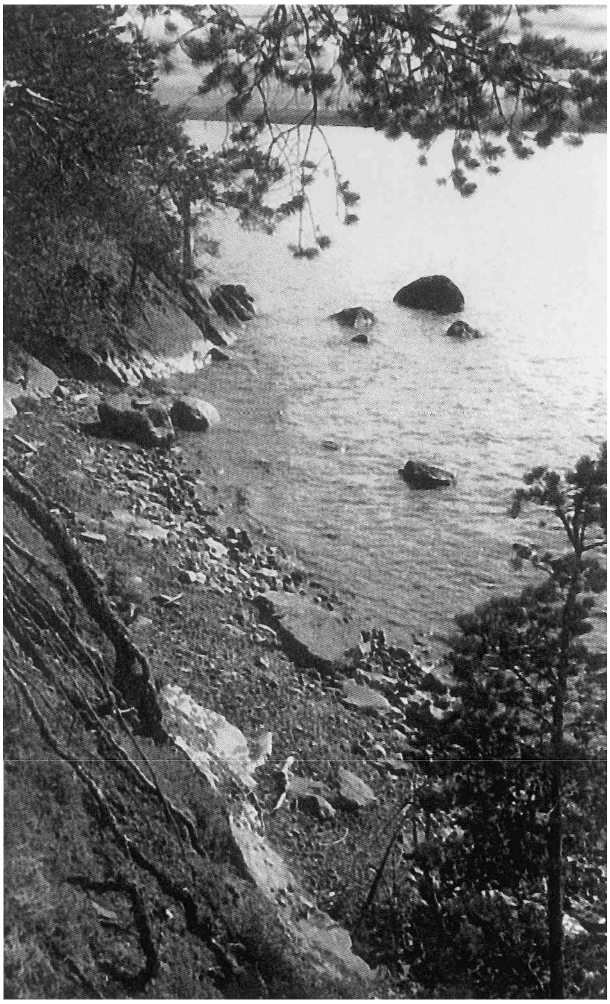

Figure 5 Outcrop of the relatively steeply dipping beds of the Upper Shale Member of the Andersö Shale on the shore and the bluff at Locality 2 of Hadding (1912, 1913); looking S; the topmost portion of the Ståltorp Limestone Member is visible at the distal end of the outcrop; the dark shale and limestone concretions on the shore have yielded *Nemagraptus gracilis* and other graptolites of that zone; this and other localities on Andersön are now in a nature reserve and a collecting permit must be applied for from the Provincial Authority (Länsstyrelsen) in Östersund.

eous mudstones in the higher part of the Lower Shale Member, where graptolites are also more common than in lower parts of the unit. Most specimens are fragmentary, many are strong pyritised, and all have been subjected to considerable heating (see below). A few complete rhabdosomes have been collected from the calcareous mudstones in the upper part of the Lower Shale Member. The graptolite collections at hand are classified into ten taxa, amongst which eight are identified to species. Because of their less-than-perfect state of preservation, it is very difficult, if not impossible, to produce adequate photographs of the Andersö Shale graptolites but some important species are illustrated by camera lucida outline drawings (Fig. 6).

The biostratigraphical investigations by Hadding (1912, 1913) on Andersön resulted in the recognition of three graptolite zones in the Andersö Shale, namely the zones of *Climacograptus putillus*, *Nemagraptus gracilis* and *Dicranograptus clingani*. In current taxonomy, the index species of the former zone is referred to as *Normalograptus haddingi* (Glimberg) and the interval of the former *C. putillus* Zone is now considered to correspond to the upper portion of the *Hustedograptus teretiusculus* Zone. Hadding (1913) recorded, but did not illustrate, seven species of graptolites from the Lower Shale Member. From the Upper Shale Member, he listed three species: *Dicellograptus sextans exilis* Elles & Wood, *Dicranograptus clingani* (Carruthers) and *Nemagraptus gracilis remotus* Elles & Wood. In this unit, he recognised two zones (Hadding 1913, fig. 15), a lower *Nemagraptus gracilis* Zone overlain by a *Dicranograptus clingani* Zone, and illustrated the interpreted contact between these zones at his Locality 3 on the shore 0·3–0·4 km N of Locality 1 (Fig. 1). Hadding (1913) noted the unexpected occurrence of *D. clingani* in association with *N. gracilis* and recognised that this is an anomaly, because in Scania, as well as in the United Kingdom, these species occur in different stratigraphic intervals and are indices of separate graptolite zones. Unfortunately, it has not been possible to locate the specimens assigned to *D. clingani* in Hadding's Andersö collections, which are kept at the Department of Geology, Historical Geology and Palaeontology at Lund University. However, the Upper Shale Member has yielded *Dicroanograptus cf. brevicaulis* Elles & Wood (unpublished data from R. Nilsson). *Dicranograptus brevicaulis* occurs in the *Nemagraptus gracilis* Zone in the United Kingdom and it seems likely that Hadding's (1913) record of *D. clingani* occurring together with *N. gracilis* refers to this species. Clearly, the sparse graptolite fauna in the Upper Shale Member is in need of revision but such a re-examination has not yet been undertaken. As far as I am aware, after Hadding's time and prior to the present research, no additional study has been carried out on the Andersö Shale graptolite faunas.

2.2. Biostratigraphy

The Lower Shale Member, between the Isö Limestone and the Ståltorp Limestone Member, has yielded a moderately diverse graptolite fauna (Fig. 7). Specimens of *Diplograptus notabilis* Hadding, *Nemagraptus subtilis* Hadding and *Normalograptus haddingi* (Fig. 6k) appear just above the Isö Limestone and these species range through the investigated interval. *Dicellograptus* sp., *Didymograptus superstes* Lapworth (Fig. 6e, f). *Hustedograptus teretiusculus* (Hisinger) (Fig. 6h, i), and *Pseudoclimacograptus scharenbergi* (Lapworth) (Fig. 6j, l, m) make their appearance in the middle part of the Lower Shale Member. Among these, *P. scharenbergi* and *H. teretiusculus* range at least as high as the lowermost portion of the Upper Shale Member. Specimens of *Dicranograptus irregularis* Hadding (Fig. 6a–d) and *Amplexograptus perexcavatus* (Lapworth) (Fig. 6p-q) appear near the top of the Lower Shale Member and are also present in the lowermost part of the Upper Shale Member.

Whereas Hadding (1913, fig. 15A) referred the Ståltorp Limestone Member to the *Hustedograptus teretiusculus* Zone (*Climacograptus putillus* Zone in Hadding), Karis (1998, p. 170) brought the unit to the *Nemagraptus gracilis* Zone based on his record of *Nemagraptus gracilis* from shale interbeds in the limestone. I have examined some of Karis' specimens identified as *N. gracilis* and conclude that they represent fragmentary specimens of *Dicellograptus* sp. that are not useful for zonal assignment. During the course of this study, no graptolites were found in the middle and upper part of the Ståltorp Limestone Member (above the 6·7 m level in the section at Locality 1), and direct graptolite evidence of its position in the graptolite zone succession is not yet available. However, as noted below, conodont evidence suggests that Hadding (1913) was correct in referring the limestone interval to the *Hustedograptus teretiusculus* Zone (Hadding's *Climacograptus putillus* Zone).

The black shale just above the limestone has yielded *Amplexograptus perexcavatus*, *Diplograptus notabilis*, *Glyptograptus* sp. and *Paraclimacograptus scharenbergi.* Being relative long-

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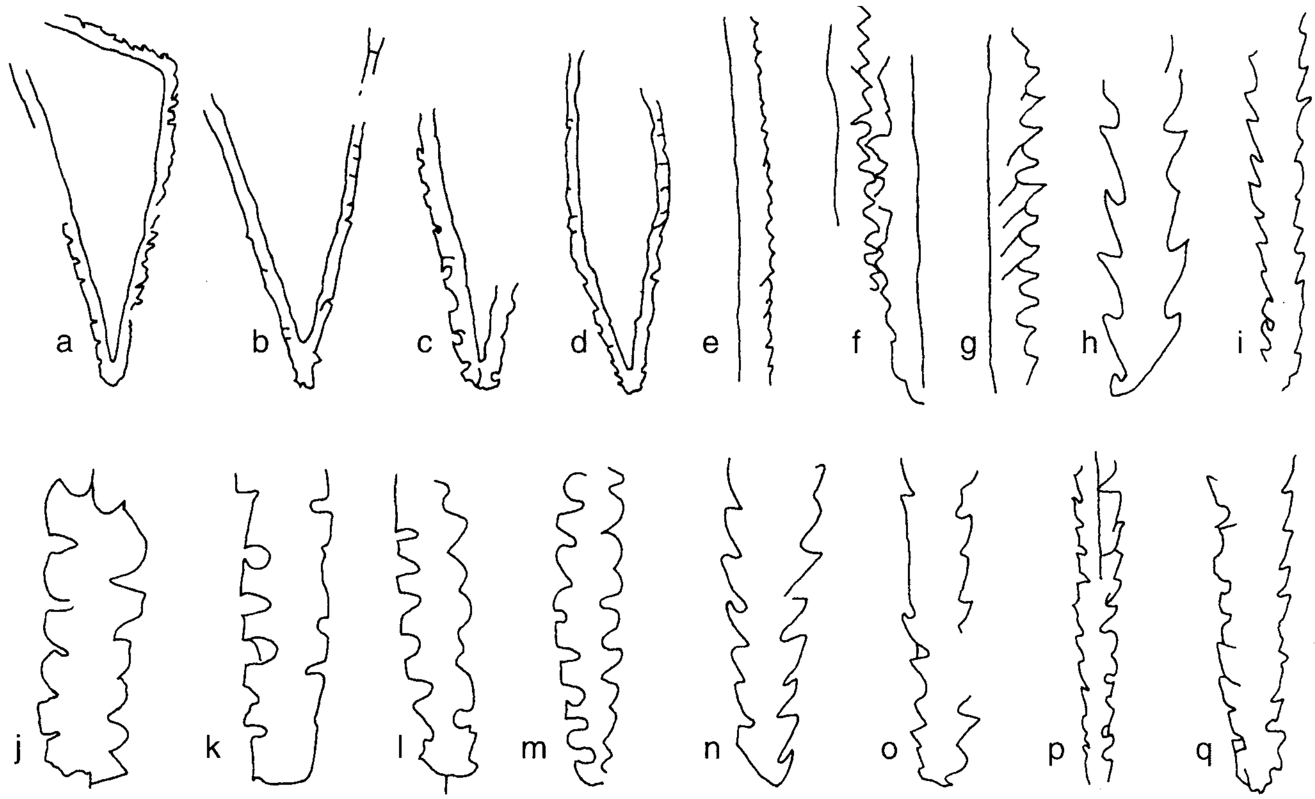

Figure 6 Outline drawings of graptolites from the Andersö Shale at Locality 1 on Andersön. (a–d) *Dicranograptus irregularis* Hadding: (a) LO8445t,×3; (b) LO 8446t, ×3; (c) LO 8447t, ×5·7; (d) LO 8448t, ×3·5. (e, f) *Didymograptus superstes* Lapworth: (e) LO 8449t, ×1·3; (f) LO 8450t, ×1·7; (g) LO 8451t, ×4·8. (h, i) *Hustedograptus teretiusculus* (Hisinger): (h) LO 8452t, ×8·6; (i) LO 8453t, ×3·9. (j) *Pseudoclimacograptus scharenbergi* (Lapworth), LO 8454t, ×10·8. (k) *Normalograptus haddingi* (Glimberg), LO 8455t, ×8·6. (l, m) *Pseudoclimacograptus scharenbergi* (Lapworth): (l) LO 8456t, ×8·9. (m) LO 8457t, ×7·4. (n, o) *Hustedograptus teretiusculus* (Hisinger): (n) LO 8458t, ×8. (o) LO 8459t, ×6·3. (p, q) *Amplexograptus perexcavatus* (Lapworth): (p) LO 8460t, ×3·3; (q) LO 8461t, ×4. All illustrated specimens are deposited in the type collection of the Department of Geology, Historical Geology and Palaeontology at Lund University.

ranging, none of these species is useful for determining the level of the base of the *Nemagraptus gracilis* Zone. More significant biostratigraphically is the occurrence of *Nemagraptus subtilis, Normalograptus haddingi* and *Dicranograptus irregularis* at this stratigraphic level, because in the Fågelsång succession (Fig. 7), this species association ranges no higher than the very basalmost portion of the *Nemagraptus gracilis* Zone (Bergström *et al.* 2000). Hadding (1913) and others have reported *N. gracilis* from the lower few metres of the Upper Shale Member, but the precise level of appearance of this species, which is taken as the base of the *Nemagraptus gracilis* Zone, is not yet established on graptolite evidence. However, conodont evidence suggests that it is likely to be in the lowermost part of the Upper Shale Member, and tentatively, and pending further studies, the zone boundary is herein placed at the base of the Upper Shale Member.

2.3. Comparison with the Fågelsång succession

The standard graptolite zone succession in Baltoscandia around the Middle–Upper Ordovician boundary is based on the sequence in Scania (Skåne), particularly as it is developed in the Fågelsång area, where outcrops and drill-cores have been investigated in considerable detail (Hadding 1913; Hede 1951; Bergström *et al.* 2000). As noted above, the Fågelsång succession has recently been proposed to be the global stratotype section and point (GSSP) for the base of the *Nemagraptus gracilis* Zone that marks the base of the global Upper Ordovician Series (Bergström *et al.* 2000). In view of the fact that the Andersö Shale straddles this important boundary, it is clearly appropriate to compare its graptolite succession with that at Fågelsång, and some reference to that sequence has already been made above. Such a comparison was in fact made by Hadding (1913) and, interestingly, his graptolite-based interpretation of the general biostratigraphical relations between these two sequences, which are separated geographically by a distance of almost 850 km, is supported by the present study. This provides evidence of Hadding's (1913) keen perception of biostratigraphical relationships because far more is now known about the occurrence, taxonomy and stratigraphical range of graptolite species than in Hadding's time almost a century ago.

Figure 7 illustrates the known ranges of graptolites in the Andersön and Fågelsång successions. As shown in this figure, the association of *Nemagraptus subtilis, Climacograptus haddingi, Didymograptus superstes* and *Dicranograptus irregularis* is at Fågelsång characteristic of the upper *Hustedograptus teretiusculus* Zone, although *Climatograptus haddingi, Dicranograptus irregularis* and *Didymograptus superstes* are also recorded from the very lowermost *Nemagraptus gracilis* Zone. Hughes (1989) reported a similar range for *Nemagraptus subtilis* and *Dicranograptus irregularis* in Wales and the Welsh Borderland. The presence of *N. subtilis*, the probable ancestor of *N. gracilis*, in the lowermost part of the Lower Shale Member is of special significance because recent re-examination of the nemagraptids in the Fågelsång succession indicates that there, this species first appears well above the base of the

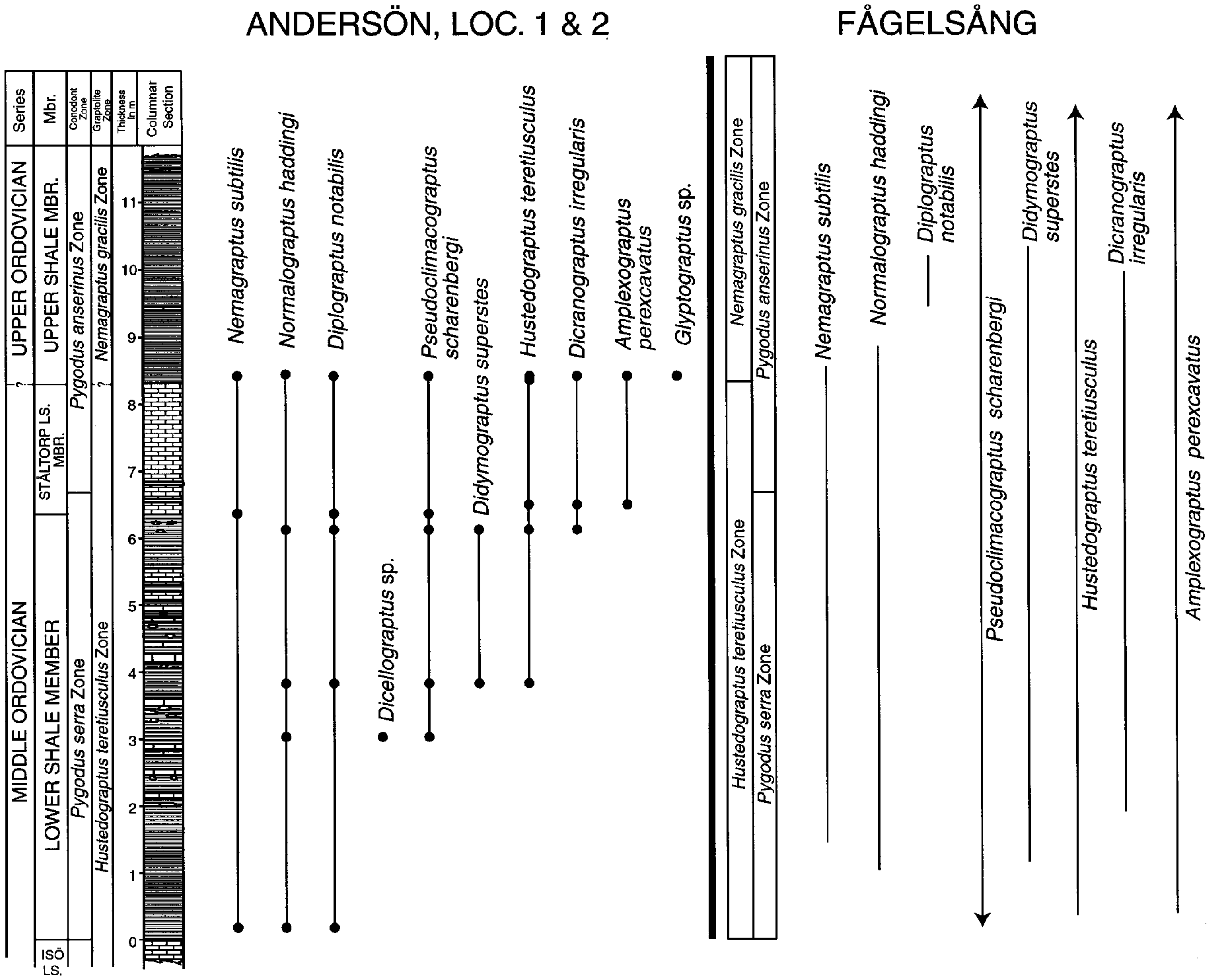

Figure 7 Vertical distribution of graptolites in the Andersö Shale at Localities 1 and 2 on Andersön and a comparison with the distribution in the Fågelsång succession (Fågelsång ranges after Bergström *et al.* 2000); the vertical distribution of graptolite species in the Fågelsång sequence suggests that the base of the Upper Shale Member is not younger than the lowermost part of the *Nemagraptus gracilis* zone; also the conodonts in the Ståltorp Limestone Member are not older than those present in the upper *Hustedograptus teretiusculus* Zone elsewhere; this indicates that the base of the *Nemagraptus gracilis* Zone is at, or close to, the base of the Upper Shale Member.

Hustedograptus teretiusculus Zone (Bergström *et al.* 2000). Hence, it provides evidence that the Andersö Shale at Locality 1 does not extend below the base of this graptolite zone, and that its base is of Uhakuan age in terms of the Baltic stage classification. This conclusion is of interest in view of the fact that Karis (1998) recorded a *Didymograptus murchisoni* Zone fauna in strata mapped as the Andersö Shale in the Hammerdal region about 65 km NE of Andersön. This may indicate that the base of the Andersö Shale is diachronous regionally, or that the lowermost portion of the Lower Shale Member is missing at Locality 1 due to faulting.

Pseudoclimacograptus scharenbergi, Amplexograptus perexcavatus and *Hustedograptus teretiusculus* are more long-ranging and are recorded as high as the *Diplograptus foliaceus* (formerly *D. multidens*) Zone at Fågalsång. As shown in Figure 7, the Andersö Shale graptolite ranges are in broad agreement with those recorded from the Fågelsång succession. The more diverse graptolite fauna in the latter (Bergström *et al.* 2000) is attributed to the fact that this portion of the Fågelsång succession represents a deeper-water environment with thriving graptolite species assemblages that are now preserved in a typical graptolite shale with a very sparse shelly fauna.

3. Trilobites (by Kristina Månsson)

3.1. Composition of trilobite fauna and previous research

As noted by Hadding (1913), the Andersö Shale contains a very substantial shelly fauna. Among the shelly fossils, only the trilobites have been re-assessed since Hadding's time, and as now known, the trilobite fauna may be the most diverse described from the Uhakuan interval in Scandinavia. For instance, according to Jaanusson (1960), the well-known Uhakuan (late Darriwilian) trilobite fauna from Öland contains about 15 species which compares with at least 22 in the Andersö Shale. Compared with other macrofossil groups in the formation, the Andersö trilobites have been the subject of a considerable amount of past and recent research, and the major part of this fauna has been described in detail: the remopleuridids have been dealt with by Nikolaisen (1965, 1983, 1991); the trinucleids by Owen (1987); the telephinids by Ahlberg (1995); and the olenids, raphiophorids and dionidids by Månsson (1998, 2000b).

As noted in these papers, some of the described species are present not only on Andersön but also at several other outcrops of the Andersö Shale. For a summary account, see Månsson (2000a). Important trilobite species are illustrated in Figures 8 and 9.

The Lower Shale Member and the Ståltorp Limestone Member contain at least 12 genera of trilobites, namely *Ampyx* Dalman, 1827, *Botrioides* Stetson, 1927, *Cnemidopyge* Whittard, 1955, *Lonchodomas* Angelin, 1854, *Nileus* Dalman, 1827, *Ogygiocaris* Angelin, 1854, *Porterfieldia* Cooper, 1953, *Paraceraurus* Männil, 1958, *Pseudomegalaspis* Jaanusson, 1953, *Robergia* Wiman, 1905, *Sculptaspis* Nikolaisen, 1983 and *Telephina* Marek, 1952 (Hadding 1913; Månsson 2000a). Nine genera have been recorded from the Upper Shale Member, namely *Ampyx*, *Ampyxoides* Whittington, 1965, *Botrioides*, *Lonchodomas*, *Nileus*, *Ogygiocaris*, *Paraceraurus*, *Robergia* and *Telephina* (Hadding 1913; Månsson 2000a). In addition, based on a single cranidium, Hadding (1913) described *Fialoides antiquatus* Hadding, 1913 from the lower part of the Andersö Shale but his specimen has not been available for re-examination.

3.2. Preservation and occurrence

The trilobites in the Andersö Shale are generally disarticulated. They occur throughout the section but they are most abundant and diverse in the Lower Shale Member (except its basal part) and in the Ståltorp Limestone Member. They are rare in the lowermost part of the Lower Shale Member which has yielded only *Lonchodomas striolatus* Månsson 2000b, *Robergia sparsa* Nikolaisen, 1983 and *Telephina mobergi* (Hadding 1913). This may be partly due to their poor preservation in this part of the section where the rocks are strongly weathered, as is also the case in the outcrops of the Upper Shale Member.

The known vertical distribution of trilobite species through the study sequence on Andersön is shown in Figure 10.

The most common trilobites are species of the asaphid genus *Ogygiocaris* which is represented by two species, *O. lata* Hadding, 1913 and *O. regina* Henningsmoen, 1960. These species are particularly frequent in the lowermost Ståltorp Limestone Member where they comprise about 50% of the trilobite specimens. In the strata below and above this interval, *Ogygiocaris* specimens are less common although they are present in some abundance in a few beds. Whereas the cranidia and hypostomes are characteristic of each species, their pygidia are very similar and in many cases difficult to identify to species. Both species appear in the lower, but not lowermost, portion of the Andersö Shale and range concurrently through this unit. *Ogygiocaris lata* seems to be restricted to Jämtland but *O. regina* also occurs in the Oslo region of Norway. The Jämtland specimens of *O. regina* are in most cases considerably larger than the Norwegian ones. Several large cranidia and pygidia of this species have been collected on Andersön, including the huge pygidium figured by Hadding (1913; text-fig. 23) as *O. dilatata* var. *sarsi*. Its size suggests that the entire trilobite was at least 20 cm long. In all other respects, the Swedish and Norwegian specimens of *O. regina* are closely similar morphologically.

Specimens of *Ogygiocaris* are common in the Oslo region and Henningsmoen (1960) showed that the various species and subspecies are useful biostratigraphically. The stratigraphically earliest species, *O. dilatata*, appeared during the early Darriwilian (early Llanvirn) in the Oslo region whereas in the Andersö Shale, species of *Ogygiocarius* first make their entrance considerably higher in the succession, namely well up in the late Darriwilian Lower Shale Member of the Andersö Shale (Fig. 10). Also, whereas in the Oslo region the genus has not been recorded with certainty from beds younger than the middle–late Darriwilian Elnes Formation (formerly *Ogygiocaris* Shale), it ranges higher in Jämtland with *O. lata* being present in the uppermost part of the Andersö Shale.

Apart from the outcrops on Andersön, specimens of *Ogygiocaris* have been collected in carbonate-rich facies at several other Andersö Shale outcrops in central Jämtland. The species is rarer in siliclastic facies and appears to be absent in the dark-grey mudstones and shales with *Triarthrus* that represents the formation on Frösön (Månsson 1998). In Sweden, *Ogygiocaris* also occurs in Västergötland and on Öland (Jaanusson 1953).

Nileids are fairly common in calcareous beds in the middle and upper part of the Lower Shale Member but occasional specimens are present throughout the study interval (Fig. 10). Only a single species seems to be represented that Hadding (1913) identified as *Nileus armadillo*. This early Darriwilian (early Kundan) species, which is well known in Scandinavia, was thoroughly re-described by Nielsen (1995). The Andersö specimens closely resemble *N. armadillo* but differ in some minor details, which, however, may be due to different states of preservation. They are herein referred to as *N.* cf. *armadillo*.

A raphiophorid trilobite species association is present in the shales and mudstones on Andersön (Månsson 2000a, b). Five species are represented, namely *Ampyx clavifrons* Hadding, 1913, *Ampyxoides minor* Månsson, 2000b, *Cnemidopyge costata* (Angelin 1854), *Lonchodomas striolatus* Månsson, 2000b and *Lonchodomas* sp. *Ampyx clavifrons* and *C. costata* range through a substantial part of the Andersö Shale, whereas *L. striolatus* appears to be restricted to the lowermost portion of the Lower Shale Member and *A. minor* to the Upper Shale Member.

Telephinid trilobites occur throughout the section, but are particularly common in the Ståltorp Limestone Member, and just below and above this member. At least five species are recognised (Ahlberg, 1995): *Telephina bicuspis* (Angelin, 1854), *T. biseriata* (Asklund, 1936), *T.* aff. *biseriata* (Asklund, 1936), *T. granulata* (Angelin, 1854) and *T. mobergi* (Hadding, 1913). Specimens of *T. mobergi* have been found only in the lower half of the Lower Shale Member and *T. granulata* is recorded only from the Upper Shale Member. Three of the Andersö Shale species, namely *T. bicuspis, T. mobergi* and T. granulata, are present also in the Oslo region in Norway.

Specimens of *Robergia* are common in some beds in the Andersö Shale. Among the two species present, *R. sparsa* Nikolaisen, 1983 is known only from the lowermost part of the Lower Shale Member. The other species, *R. microphthalma* (Linnarsson, 1875), ranges from the middle portion of the Lower Shale Member into the Upper Shale Member.

Two species of *Sculptaspis* Nikolaisen, 1983, a fairly common genus in the Middle Ordovician of Sweden, are present in the Andersö Shale, namely *S. circularis* (Hadding, 1913) and *S. subquadratus* (Hadding, 1913). Both occur in the Lower Shale Member but the latter species is quite rare, being known only from a few specimens. Neither of these species has been found outside Jämtland. Although being considerably younger stratigraphically, *S. impolita* Nikolaisen, 1983 from the Oslo region has similar cranial proportions as *S. circularis*, but it has sculptural lines on the median area which are missing in the latter species. However, it is possible that the lack of these lines may be due to poor preservation of the Jämtland specimens.

Olenid trilobites are rare, or absent, in much of the Andersö Shale on Andersön, the only species present being *Porterfieldia humilis* (Hadding, 1913), which has been collected from the Lower Shale Member. No specimen of *Triarthrus* has been found in the Andersön sections, but several *Triarthrus* species

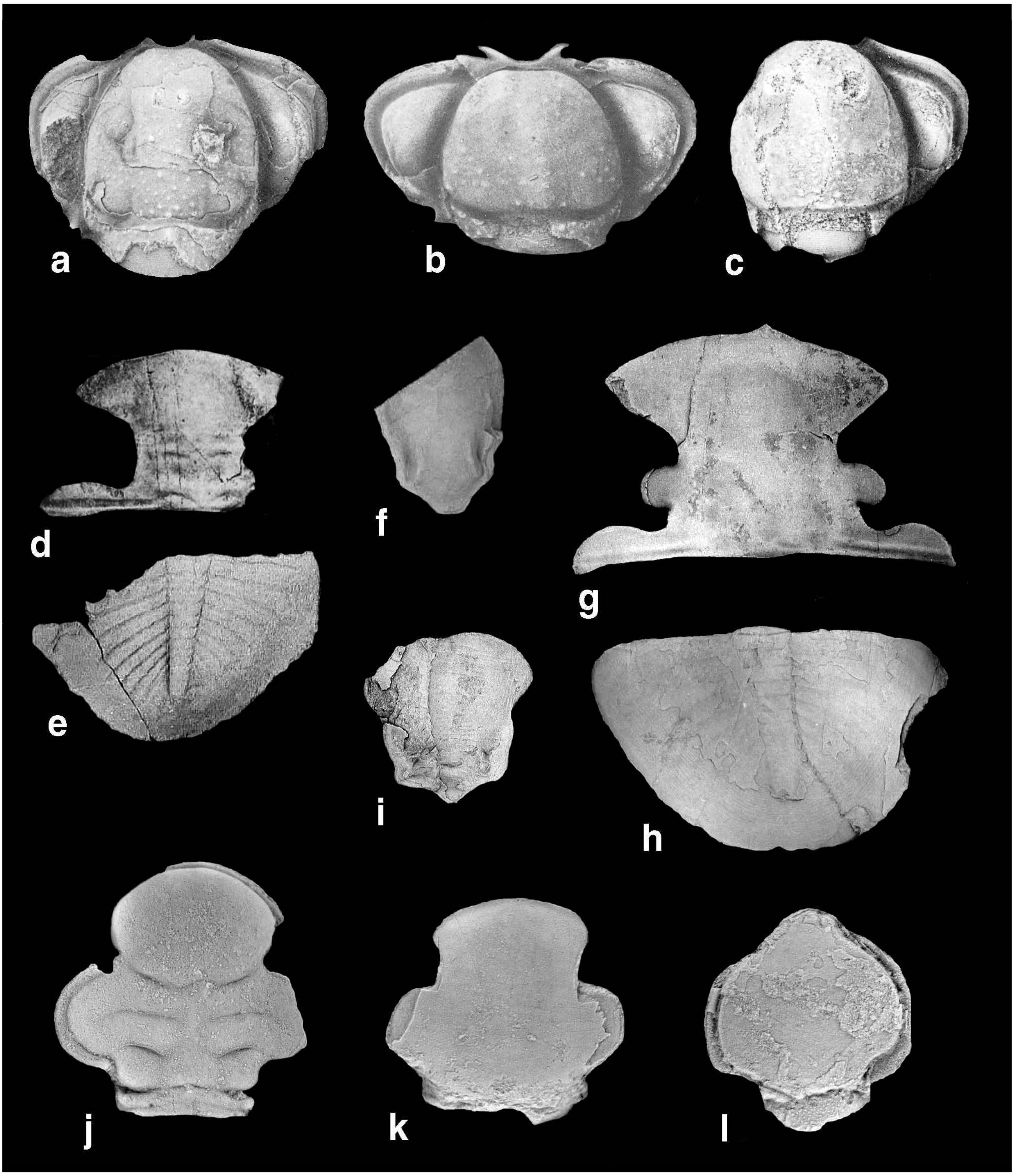

Figure 8 Important trilobites from the Andersö Shale: (a) *Telephina biseriata* (Asklund, 1936), cranidium, SGU 8653, ×7·5, also figured by Ahlberg (1995, pl. 6, figs 11, 12) and Månsson (2000a, fig, 7i–j); (b) *Telephina bicuspis* (Angelin, 1854), cranidium, LO 2565, ×7·5, also figured by Hadding (1913, pl. 1, fig. 3a, b), Ahlberg (1995, pl. 1, fig. 7) and Månsson (2000a, fig. 7g); (c) *Telephina granulata* (Angelin, 1854), cranidium, SGU 8651, ×7·5, also figured by Ahlberg (1995, pl. 5, fig. 8) and Månsson (2000a, fig. 7h); (d–f) *Ogygiocaris lata* Henningsmoen, 1960: (d) distorted cranidium, LO 8297, ×2·5, also figured by Månsson (2000a, fig, 8i); (e) pyrgidium, LO 8298, ×2·8, also figured by Månsson (2000a, fig. 8j); (f) hypostome, LO 2528, ×2, also figured by Hadding (1913, pl. 7, fig. 7) and Månsson (2000a, fig. 8f); (g–i) *Ogygiocaris regina* Henningsmoen, 1960: (g) cranidium, LO 2522, ×1·2, also figured by Hadding (1913, pl. 7, fig. 1) and Månsson (2000a, fig. 8g); (h) pygidium, LO 2527, ×1·2, also figured by Hadding (1913, pl. 7, fig. 6) and Månsson (2000a, fig. 8k); (i) hypostome, LO 8294, ×1, also figured by Månsson (2000a, fig. 8d); (j) *Robergia microphthalma* (Linnarsson, 1875), cranidium, LO 2556, ×5, also figured by Hadding (1913, pl. 8, fig. 15), Nikolaisen (1991, fig. 13A) and Månsson (2000a, fig. 7k); (k) *Nileus* cf. *armadillo* (Dalman, 1827), cranidium, LO 2533, ×4·5, also figured by Hadding (1913, pl. 7, fig. 11) and Månsson (2000a, fig. 8b); (1) *Sculptaspis subquadratus* (Hadding, 1913), cranidium, LO 2552, ×4·5, also figured by Hadding (1913, pl. 8, fig. 11) and Månsson (2000a, fig. 9k).

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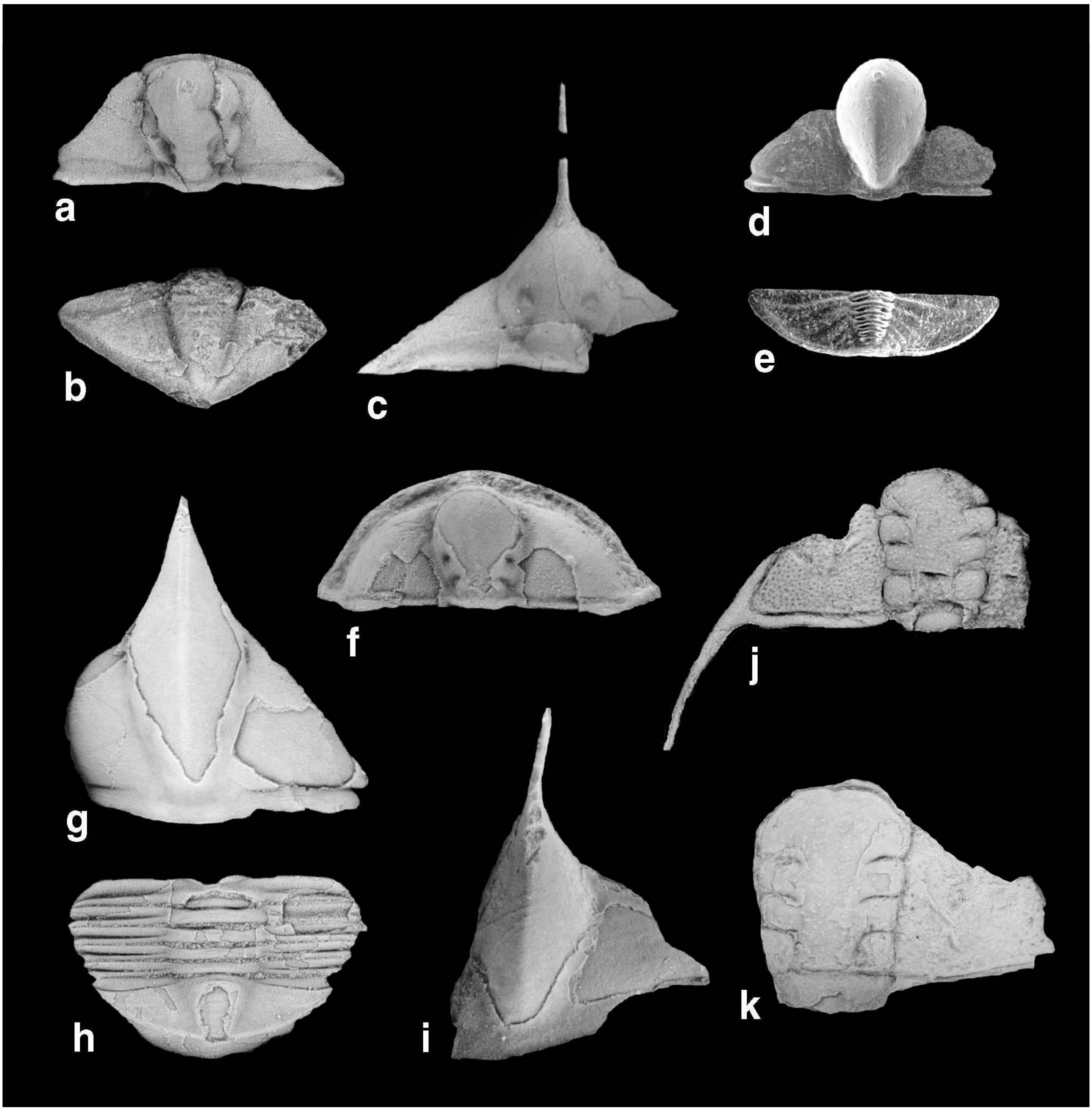

Figure 9 Important trilobites from the Andersö Shale. (a, b) *Ampyx clavifrons* Hadding, 1913: (a) cranidium, LO 8098, ×4, also figured by Månsson (2000b, fig. 6d); (b) pygidium, LO 8099, ×4, also figured by Månsson (2000a, fig. 9g and 2000b, fig. 6j); (c) *Cnemidopyge costata* (Angelin, 1854), cranidium, LO 2539, ×3, also figured by Hadding (1913, pl. 7, fig. 17) and Månsson (2000a, fig. 9c and 2000b, fig. 8a); (d, e) *Ampyxoides minor* Månsson, 2000b: (d) cranidium, holotype, SGU 9146, ×12, also figured by Månsson (2000a, fig. 9h and 2000b, fig. 7d); (e) pygidium, SGU 9149, ×10, also figured by Månsson (2000b, fig. 7g); (f) *Botroides efflorescens* (Hadding, 1913), cranidium, holotype, LO 2540, ×7, also figured by Hadding (1913, pl. 7, fig. 18), Owen (1987, pl. 13, fig. 8) and Månsson (2000a, fig. 9i); (g, h) *Lonchodomas striolatus* Månsson, 2000b: (g) cranidium, holotype, SGU 9157, ×6, also figured by Månsson (2000a, fig. 9i and 2000b, fig. 9a–b); (h) thorax and pygidium, SGU 9158, ×9·5, also figured by Månsson (2000a, fig, 9j and 2000b, fig. 9c); (i) *Lonchodomas* sp., cranidium, SGU 9155, ×5, also figured by Månsson (2000b, fig. 9m); (k) *Paraceraurus* sp., cranidium, LO 2535, ×2·5, also figured by Hadding (1913, pl. 7, fig. 13) and Månsson (2000a, fig. 9n).

are present, in many cases in abundance, in fine-grained parts of the Upper Andersö Shale at other localities in the Lake Storsjön region (Månsson 1998). Indeed, parts of the Andersö Shale were formerly known as the *Triarthrus* Shales (Thorslund 1960).

3.3. Palaeoecological significance

Asaphids have been interpreted as being typical of relatively shallow-water facies (Nielsen 1995), but whether this applies to *Ogygiocaris* is questionable, in view of its presence in rocks representing a variety of environments from the platform limestones on Öland to the outer shelf-slope rocks in Jämtland. The raphiophorids may be more sensitive environmental indicators. The presence of several blind forms suggests environments with low light levels in either deep or turbid waters. The shales and mudstones in the Andersö Shale represent a notable influx of fine-grained siliciclastics, some of which have been interpreted to be turbidites (Karis 1998). Fortey & Owens (1978, 1987)

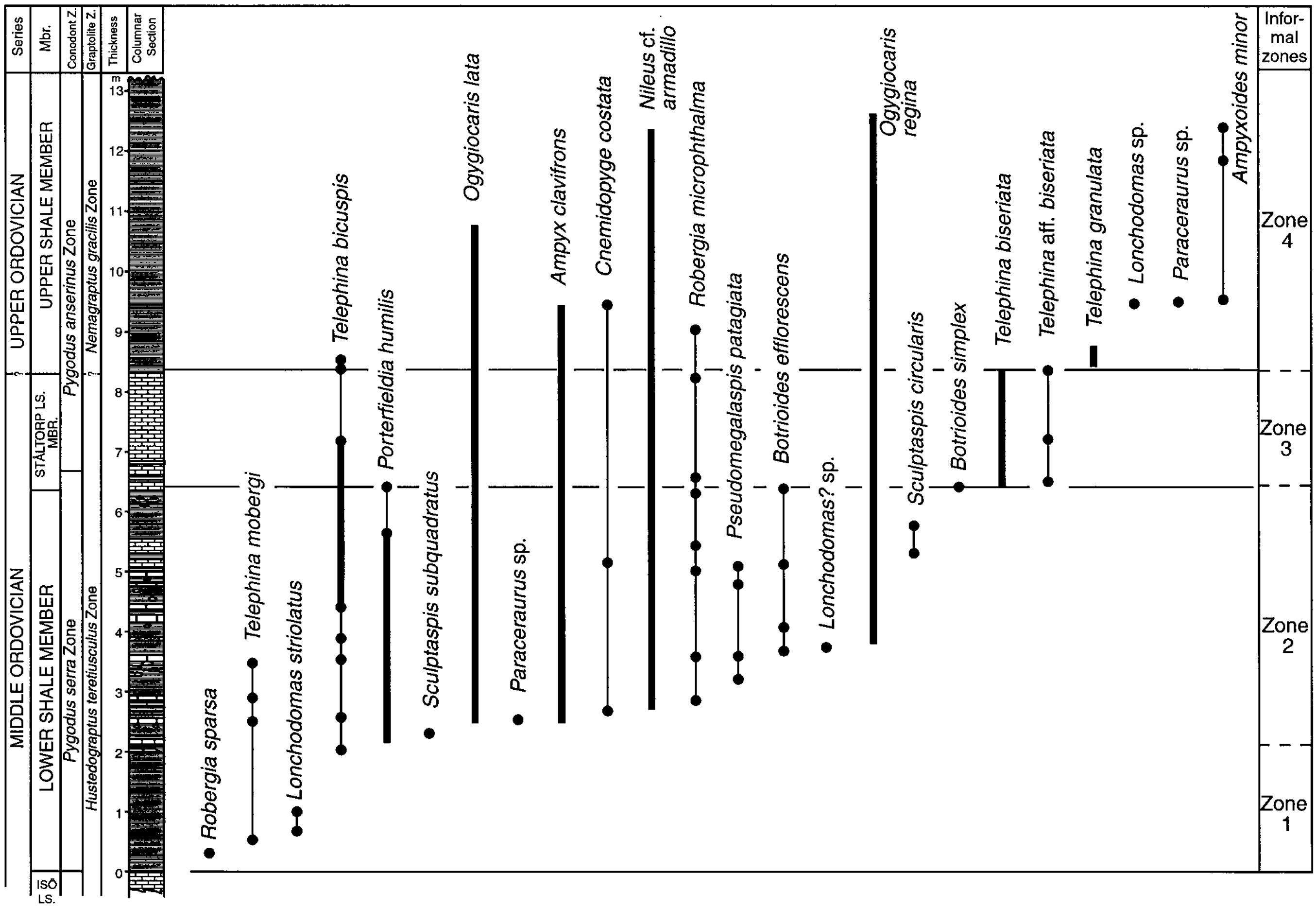

Figure 10 Vertical ranges of trilobites in the Andersö Shale succession at Locality 1 on Andersön; note the greatest diversity is in the upper part of the Lower Shale Member, in the Ståltorp Limestone Member and the lowermost Upper Shale Member, whereas other parts of the formation contain less diverse trilobites although the vertical distribution pattern suggests that the Andersö Shale may be subdivided into four trilobite zones (corresponding to the lowermost part of the Lower Shale Member; middle and upper part of the Lower Shale Member; the Ståltorp Limestone Member; and the Upper Shale Member), confirmation of this range pattern in other successions of the Andersö Shale is needed before formally named trilobite zones are proposed; pending this, the intervals are informally marked Zone 1, etc.; note that the contact between the Andersö Shale and the Isö Limestone is faulted (F) in this section.

applied the term 'raphiophorid community' for a trilobite species association in the Lower Ordovician of S Wales which is dominated by species adapted to life on soft substrates. It appears that the raphiophorid–trinucleid assemblages in the Andersö Shale on Andersön may be an equivalent to the Welsh community that was interpreted by Fortey & Owens (1978) to have occupied an outer-shelf position. Månsson (2000a) noted that the Andersö Shale on Andersön contains a more diverse fauna than the typical deeper-water, low-oxygen olenid community, and interpreted the depositional environment of the former as well-oxygenated, fairly deep water in an outer-shelf setting (Fig. 11).

4. Conodonts (by Stig M. Bergström)

4.1. Samples and biostratigraphy

Conodont samples were collected from six limestone interbeds in the Lower Shale Member, from about a dozen levels in the Ståltorp Limestone Member and from two limestone beds in the Upper Shale Member (Fig. 12), at Localities 1 and 2 on Andersön. A similar set of nine samples was obtained from the eastern part of the Nils Hans Husa section on Norderön (Thorslund 1960; Fig. 1D). The samples from the Lower and Upper Shale Members at both sections contained only small numbers of conodont specimens, but several from the Ståltorp Limestone Member were quite productive, yielding hundreds of elements. The state of conodont element preservation ranges from poor to excellent. All specimens have been heated, showing a Color Alteration Index (CAI) of 5 (Bergström 1980, fig, 4), which indicates heating of about 300°C. If this heating was caused by overburden alone, it would require a stratal thickness of as much as 8,000–10,000 m (Epstein *et al.* 1977). This thickness of the overburden is considerably larger than Karis' (1998) estimate of 3,000 m for the Lockne area about 25 km SE of Andersön, where the CAI values are also around 5.

The Andersö Shale conodont collection totals approximately 2000 elements which are grouped into 16 multielement species. In addition, there are several taxa that require further study and access to additional specimens for safe identification. Hence, the total number of multielement species is likely to exceed 20. Virtually all of the identified species are well-known taxa that have been adequately described in the recent literature (see, for instance, Dzik 1994) and there is no need or redescribe these forms herein. Some of the important species are illustrated in Figures 13 and 14. The vertical distribution of individual species is shown in Figure 12. An interesting and

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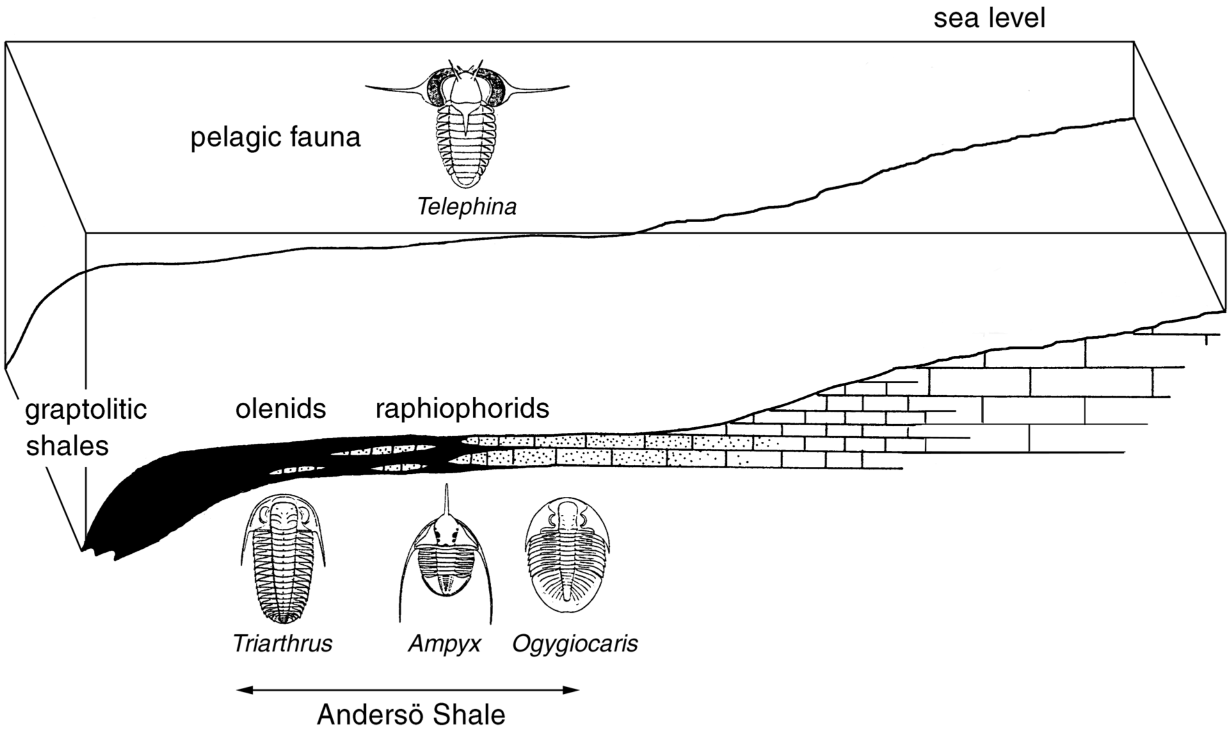

Figure 11 Trilobite biofacies model, showing inferred position of the Andersö Shale on the outer shelf and the presumed preferred environments of olenids, raphiophorids and ogygiocarids; modified after Månsson (2000a).

unexpected occurrence in the Ståltorp Limestone Member is several specimens of '*Roundya*' *bispicata* Sweet & Bergström (Fig. 14e, f), a rare species of a new genus that was previously known only from the uppermost Middle Ordovician of the Southern Appalachians (Sweet & Bergström 1962).

In most respects, the conodont species association in the Andersö Shale is closely similar to that present in coeval stratigraphical intervals in other Baltoscandian successions such as the Furudal Limestone and the Gullhögen Formation of S Sweden (Lindström 1960; Fåhraeus 1966; Bergström unpublished), the 'Dicellograptus Shale' (Bergström *et al.* 2000) and Killeröd Formation (Bergström 1973a) in Scania, and the Vollen Formation (formerly Ampyx Limestone) of SE Norway (Hamar 1964, 1966). The presence of the biostratigraphically highly significant species *Baltoniodus prevariabilis* (Fåhraeus) (Fig. 13a), *B. variabilis* (Bergström) (Fig. 13c), *Cahabagnahus sweeti* (Bergström), *Eoplacognathus lindstroemi* Bergström (Fig. 14a–d), *Pygodus anserinus* Lamont & Lindström (Fig. 13g–j) and *P. serra* (Hadding) (Fig. 13k) is of particular significance for the classification of the succession in terms of the Atlantic conodont zonal scheme (Bergström, 1971a, 1983).

Rasmussen (1994, 2001) and Rasmussen & Bruton (1994) recorded the zonal index *Eoplacognathus suecicus* Bergström 1971a from the uppermost part of the Isö Limestone, indicating the *E. suecicus* Zone and a pre-Lasnamägian age. I have collected apparently conspecific specimens from the top 0·5 m of the Isö Limestone at both Locality 1 and at Nils Hans Husa. As noted above, graptolite evidence indicates that the base of the overlying Andersö Shale is no older than the lower *Hustedograptus teretiusculus* Zone, which is earliest Uhakan or latest Lasnamägian in age (Bergström 1973a). Hence, much of the Lasnamägian seems to be missing, but whether this is due to faulting, to the presence of an unconformity, or some other reason, requires further study. Karis (1998) correlated the topmost part of the Isö Limestone with the late Lasnamägian Folkeslunda Limestone, but this is in conflict with the conodont evidence at hand.

Although the Lower Shale Member is poor in conodonts, the presence of *P. serra*, and the absence of specimens of *P. anserinus*, indicate that it represents the *Pygodus serra* Zone. This is consistent with Rasmussen's (1994, 2001) record of *Eoplacognathus reclinatus* (Fåhraeus 1966), which is the index of the next lowest subzone of the *Pygodus serra* Zone (Bergström 1971a), from a level about 5 m above the base of the Andersö Shale at Locality 1. This record is of particular interest for the correlation between graptolite and conodont subzones, because it provides the first firm evidence that the upper part of this subzone corresponds to part of the *Hustedograptus teretiusculus* Zone as suggested by Bergström (1986, fig. 3). Previous studies (Bergström 1973a, fig. 4) have shown that the lower part of this subzone is equivalent to the uppermost part of the *Didymograptus murchisoni* Zone, but the graptolite zone equivalent of the upper part of this subzone has previously been uncertain (Bergström 1973a).

The appearance of *P. anserinus* in the lowermost part of the Ståltorp Limestone Member marks the base of the *Pygodus anserinus* Zone (cf. Rasmussen & Bruton 1994). The presence of *B. prevariabilis, C. sweeti* and well-preserved specimens of *E. lindstroemi* (of a type present in the lower part of the *P. anserinus* Zone elsewhere) supports assignment of the Ståltorp Limestone Member to the *A. kielcensis* Subzone (Bergström 1983) of the *Pygodus anserinus* Zone. The occurrence of *Baltoniodus variabilis* in the Upper Shale Member of the Andersö Shale suggests that this unit is not older that the upper part of the *Pygodus anserinus* Zone, the *Amorphognathus inaequalis* Subzone (Bergström 1983). This is consistent with the graptolite evidence that indicates that this unit is referable to the *Nemagraptus gracilis* Zone (Hadding 1913; Thorslund 1960; Karis 1998). Based both on graptolites and conodonts, the base of the Upper Ordovician is at, or near, the base of the Upper Shale Member in the sections studied.

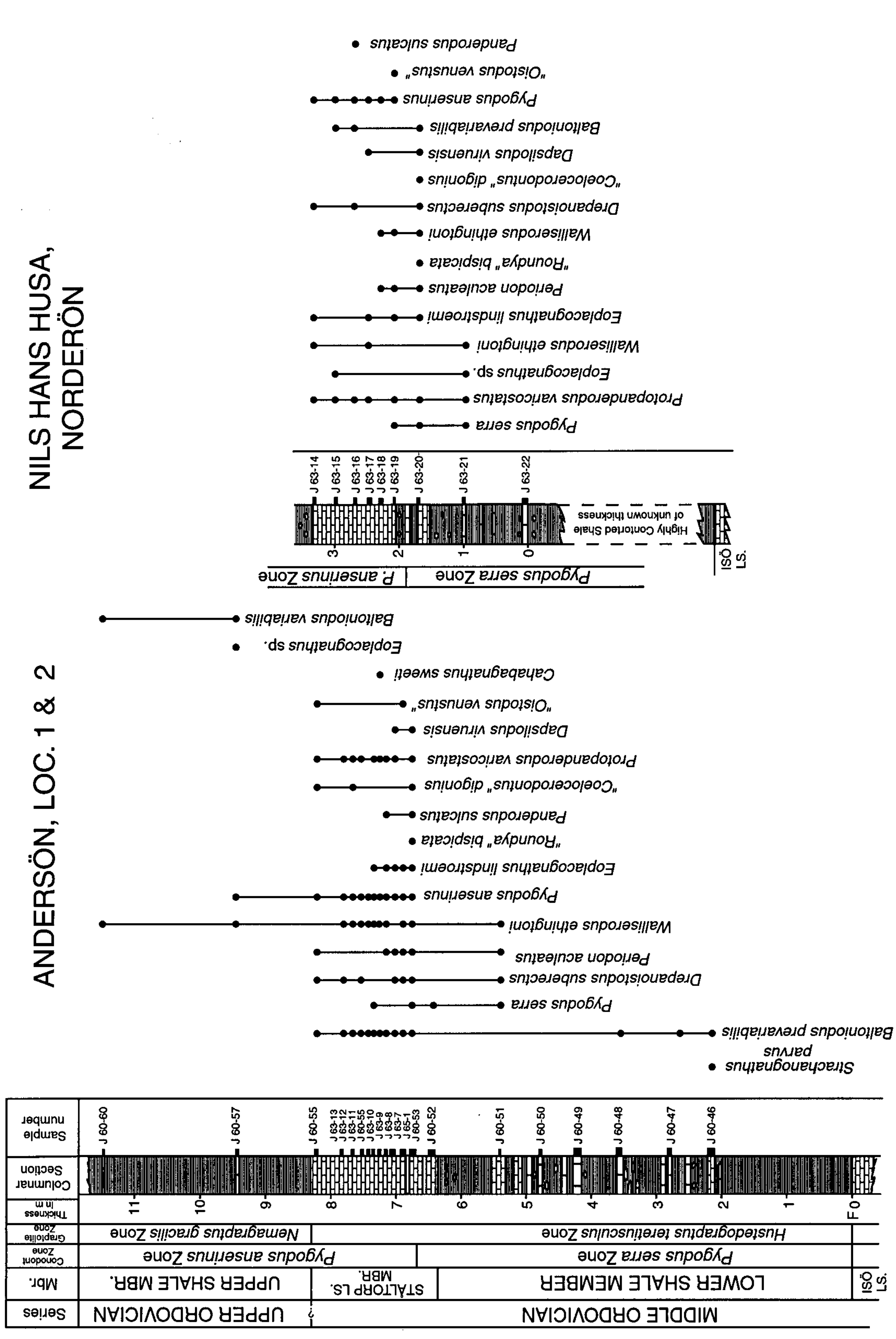

Figure 12 Vertical ranges of conodonts in the studied Andersön and Norderön sections; note the position of the *Pygodus serra*/*Pygodus anserinus* Zone boundary in the lowermost part of the Stålorp Limestone Member.

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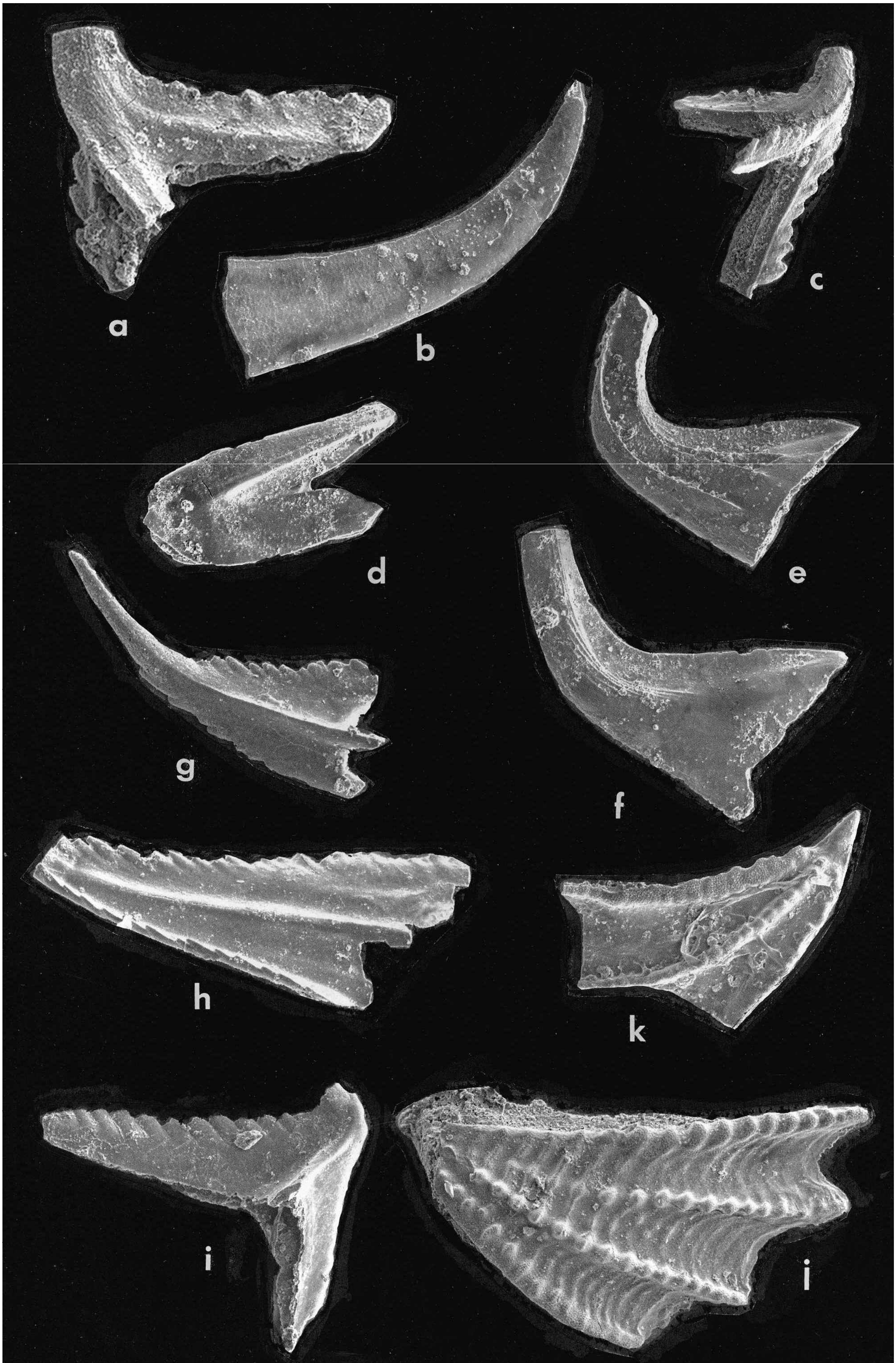

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Several species in the Andersö Shale conodont fauna, especially representatives of *Cahabagnathus, Eoplacognathus* and *Pygodus*, have short vertical ranges combined with a virtually global distribution and are very useful for extraordinarily precise local and long-distance correlations. A particularly important level biostratigraphically is the base of the *Pygodus anserinus* Zone, which is based on a speciation event in the *Pygodus* lineage, namely the evolution of *Pygodus anserinus* from *P. serra* (Bergström 1971a, 1983; Zhang 1998). This takes place within a very narrow stratigraphical interval, in many cases less than 0·5 m thick, and because of the distinctive morphology of the taxa involved, it can be readily recognised in both shelly and shaly facies. It is present near the base of the Ståltorp Limestone Member (also cf. Rasmussen & Bruton 1994; Rasmussen 2001).

Within Sweden this level in the lowermost Ståltorp Limestone Member can be correlated with, for instance (Fig. 15), a horizon 4·95–5·20 m below the top of the Furudal Limestone in the Fjäcka section, Dalarna (Bergström, unpublished); a level 4·49–5·23 m below the top of the same unit in the Gotska Sandön drill-core, Gotland (Bergström, unpublished); a level 2·15–2·60 m below the top of the Gullhögen Formation at the Hällekis Quarry, Västergötland (Bergström, unpublished; Zhang 1998); a level 2·6–2·7 m below the top of the same formation at the Gullhögen Quarry, Västergötland (Bergström, unpublished); a level of 0·1–0·15 m above the base of the Killeröd Formation at its type locality, Scania (Bergström 1973a); and a level about 3·5 below the base of the *Nemagraptus gracilis* Zone in the 'Dicellograptus Shale' at Fågelsång, Scania (Bergström *et al*. 2000).

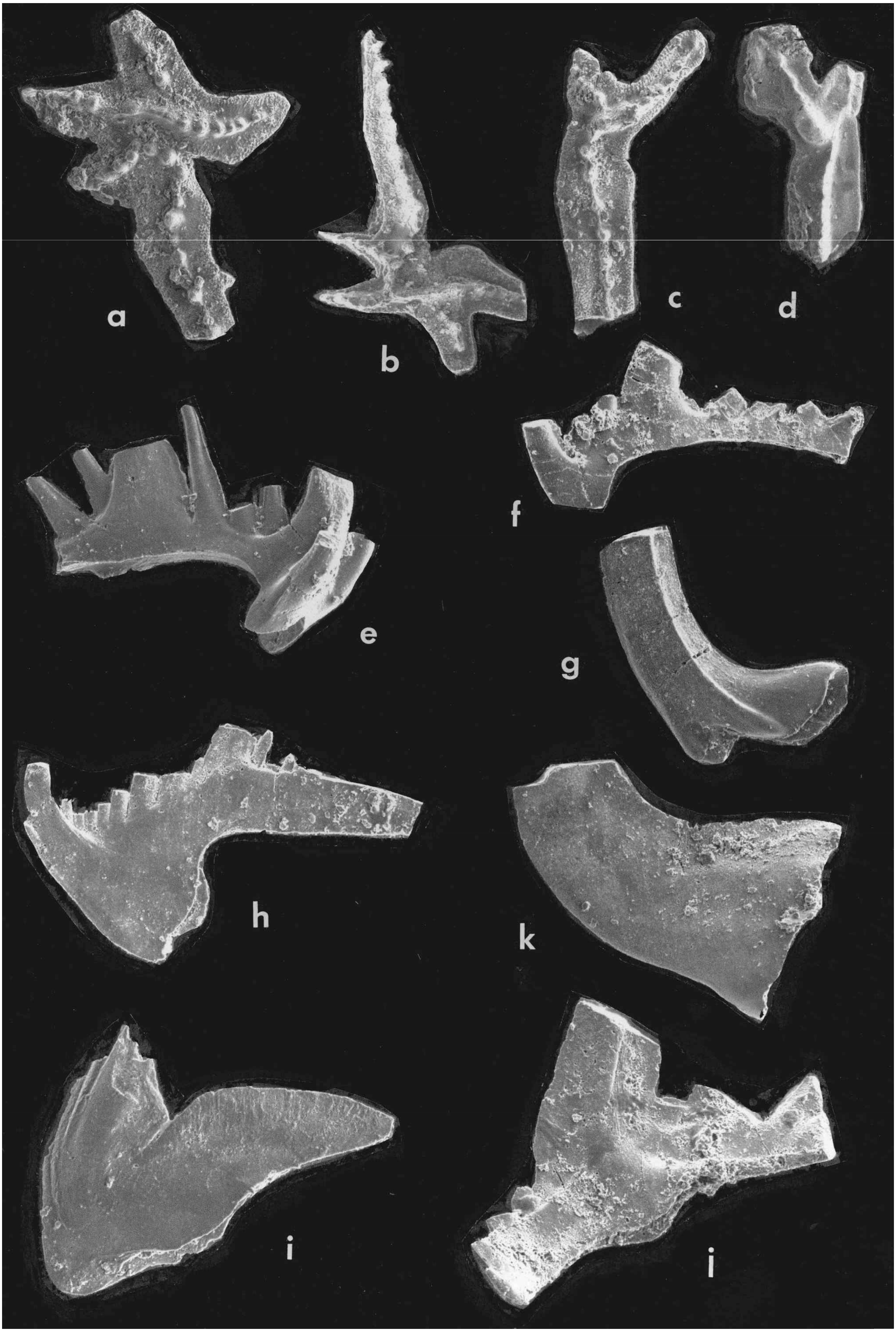
Outside Sweden, the base of the *Pygodus anserinus* Zone can be recognised in many regions around the world (Fig. 15), for instance, about 1 m below the K-bentonite in the Mo'jcza Limestone at its type locality, Holy Cross Mountains, Poland (Dzik 1994); 1·2–1·8 m above the base of the Pratt Ferry beds in Alabama (Hall *et al*. 1986); about 33 m above the base of the Cobbs Arm Limestone on Cottle's Island, Newfoundland (Bergström *et al*. 1974; Fåhraeus & Hunter 1981); and about 9 m above the base of the Saergan Formation at Dawangou, Tarim, China (Bergström *et al*. 1999).

4.2. Palaeoecology and biofacies

The conodont species association in the Andersö Shale, and particularly in the Ståltorp Limestone Member, is dominated by representative of *Eoplacognathus, Periodon, Protopanderodus, Pygodus* and *Walliserodus*. Specimens of *Baltoniodus*, which are abundant in most Baltoscandic Middle Ordovician sections, are relatively rare in the lower half of the Ståltorp Limestone Member but occur more commonly in the upper 0·5 m of this unit. Other genera are represented by comparatively few elements in most samples. A diagrammatic comparison of the relative frequency of the six most common genera in samples through the Ståltorp Limestone Member at the two study localities (Fig. 16) shows several interesting features. As might be expected in view of the relatively close geographical proximity of these sections, and the virtually identical thickness of the Ståltorp Limestone Member, the frequency curves are, by and large, similar. It may be significant that at both sections, the lower half of the Ståltorp Limestone Member is characterised by a relatively abundant occurrence of *Eoplacognathus, Periodon* and *Pygodus*, whereas *Baltoniodus* is absent or present in only very small numbers. In most of the upper half of the same unit, *Pygodus* is less common, and *Eoplacognathus* and *Periodon* are missing, but *Baltoniodus* is present is markedly higher frequency. That *Baltoniodus* and *Periodon* show contrasting frequency changes, which has previously been observed in several Swedish sections, suggests that these genera had somewhat different palaeoecological preferences, which were possibly related to water depth. Although not restricted to such deposits, *Periodon* is known from deep-water deposits, such as dark shales and cherts (Hadding 1913; Lindström 1957; Lamont & Lindström 1957; Sweet & Bergström 1966; Bergström *et al*. 2000), whereas *Baltoniodus* is most common in shallower-water strata such as the Darriwilian limestone deposits in Baltoscandia (Löfgren 1978; Rasmussen & Stouge 1995; Zhang & Sturkell 1998). Based on the apparent depth preferences of these genera, their Ståltorp distribution curve could be interpreted as indicating that the lower half of the unit was deposited in deeper water that the upper half. This is consistent with the fact that *Periodon* and *Eoplacognathus* reappear, and the frequency of *Baltoniodus* decreases, in the very uppermost portion of the Ståltorp Limestone Member. This is also shown by a sample from the very uppermost, *Lituites*-bearing, portion of the Ståltorp Limestone Member at Hadding's Locality 5 (Fig. 1) just W of Käringnäset on the N shore of Andersön. This sample contains many specimens of *Pygodus anserinus* and *P. serra*, but no *Baltoniodus* elements. This presumably reflects a deepening of the depositional environment just prior to the deposition of the overlying dark graptolite shales of the Upper Shale Member that are likely to have been laid down on relatively deep water. Apparently, these shales represent the *Nemagraptus gracilis* Zone (basal Caradoc) transgressive eustatic event that has been recognised in many parts of the world (Fortey 1984).

The species association in the lower half of the Ståltorp Limestone Member is particularly similar to one described from the Southern Appalachians and referred to as the *Periodon–Pygodus* Recurrent Species Association (RSA) by Bergström & Carnes (1976). In updated terminology, the RSAs may be taken to denote biofacies. This North American biofacies (Fig. 17) differs from the Andersö one in containing specimens of *Ansella, Belodina* and *Phragmodus*. The two latter genera have not been recorded in coeval faunas in

Figure 13 SEM micrographs of selected conodonts from the Andersö Shale on Andersön; all specimens are kept in the type collections of the Orton Geological Museum at the Ohio State University, Columbus, Ohio, USA. (a) *Baltoniodus prevariabilis* (Fåhraeus, 1966), OSU 51001, Pa element, lateral view, ×115, Ståltorp Limestone Member, sample J63-12; (b) *'Coelocerodontus' digonius* Sweet & Bergström, 1962, OSU 51002, lateral view, ×115, same sample as (a); (c) *Baltoniodus variabilis* (Bergström, 1961), OSU 51003, Pa element, lateral view, ×55, Upper Shale Member, sample J60-57; (d) *'Oistodus venustus* Stauffer, 1935', OSU 51004, lateral view, ×130, Ståltorp Limestone Member, sample J65-1; (e) *Walliserodus ethingtoni* (Fåhraeus, 1966), OSU 51005, lateral view, ×115, same sample as (d); (f) *Dapsilodus viruensis* (Fåhraeus, 1966), OSU 51006, lateral view, ×120, Ståltorp Limestone Member, sample J60-53; (g–j) *Pygodus anserinus* Lamont & Lindström, 1957: (g) OSU 51007, lateral view of alate S element, ×170, same sample as (d); (h) OSU 51008, lateral view of quadriramate S element, ×170, same sample as (d); (i) OSU 51009, lateral view of Pa element, ×90, same sample as (d); (j) OSU 51010, upper view of Pb element, ×90, same sample as (d); (k) *Pygodus serra* (Hadding, 1913), OSU 51011, upper view of Pb element, ×95, Lower Shale Member, sample J60-51.



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Jämtland or elsewhere in Baltoscandia, but they are present in the Upper Ordovician of Sweden, Norway and Estonia (Viira 1974; Bergström *et al*. 1998). *Ansella* occurs in the Lower and Middle Ordovician elsewhere in Scandinavia (Löfgren 1978; Zhang & Sturkell 1998) and the reason for its absence in the present fauna is unclear.

The *Periodon–Pygodus* biofacies is typical of relatively deep, cold-water, slope-basin environments in many parts of the world. Its position in the deepest-water part of a transect from shallow to deep-water depositional environments in the S Appalachians in Tennessee is illustrated in Figure 17. The occurrence in the Andersö Shale, which represents an outer shelf-upper slope (ramp) environment (Månsson 2000a; Fig. 3), is consistent with this model. Broadly coeval strata in the autochthonous limestone succession farther to the E in Jämtland, which were laid down in shallower water, have similar conodont species associations but the relatively more abundant specimens of *Baltoniodus* and *Eoplacognathus* may justify their reference to the *Baltoniodus–Eoplacognathus* biofacies of Bergström & Carnes (1976) (Fig. 17).

It is of interest to note that the upper Middle and lower Upper Ordovician conodont biofacies differentiation is less pronounced in Baltoscandia than in eastern North America. Only two, apparently integrading, biofacies are currently recognised in the study interval, namely the *Periodon–Pygodus* biofacies and the *Baltoniodus–Eoplacognathus* biofacies. The former is characteristic of deeper-water strata, whereas the latter occurs in shallower-water continental platform deposits. The horizontal distribution of some of the important conodont genera in terms of major depositional environments in Sweden is schematically shown in Figure 18. There are at least two principal reasons for this apparent uniformity of conodont biofacies in the study interval.

Firstly, very shallow-water (intertidal or high subtidal) deposits comparable to the Mosheim Limestone in eastern Tennessee are not known in Sweden. Somewhat older (Aserian–Lasnamägian Stages, middle Darriwilian Stage) limestones in the autochthonous eastern platform succession in Jämtland have locally stromatolites, structures interpreted as desiccation surfaces, and other features best known from shallow-water environments, as described in detail by Larsson (1973). However, Lindström (1984a, b) noted that such structures may also be formed under subtidal conditions, and their palaeoenvironmental significance is currently somewhat controversial. Interestingly, the condont fauna of the stromatolitic intervals (the Lunne facies of Larsson (1973)) does not show any unique features compared with that in the non-stromatolitic intervals (Löfgren 1978, fig. 20; Zhang & Sturkell 1998, figs 5–6). Both lithological and biological indications in the somewhat younger outer shelf and upper slope Andersö Shale suggest deposition at a water depth well below wave base, possibly as much as several tens of metres to more than 100 m. Hence, the conodont species that were ecologically restricted to very shallow cold-water marine conditions did not find their preferred ecological conditions in Sweden during the time interval studied herein.

Secondly, because Baltoscandia seems to have occupied a position in the temperate zone (Jaanusson 1973), perhaps at a latitude of 30–40° S during early Late Ordovician time (Torsvik *et al*. 1996; Torsvik 1998), the range of water temperatures was more restricted than in the tropics. Relatively cold water also prevailed in the platform environments as suggested by, among other things, the non-bahamitic carbonate lithology (Jaanusson 1973). In view of the fact that recent faunal distribution patterns clearly demonstrate that water temperature is one of the most important factors controlling the distribution of marine organisms, the regional uniformity of the Baltic conodont faunas of this age is not surprising.

That depth and temperature of the sea water had a profound influence on the composition of Ordovician conodont faunas in Scandinavia is illustrated by the species associations in the Oanduan Stage (middle Caradoc). As recently described (Bergström 1997; Bergström *et al*. 1998), the diverse conodont faunas of the shallow-water, bahamitic Mjösa Limestone in SE Norway and the Svartsætra limestone in central Norway, as well as that of coeval strata in Estonia, are strikingly similar to equivalent tropical shallow-water faunas in the North American Midcontinent (Sweet 1979) but quite different from equivalent deeper-water faunas in Sweden.

4.3. Comparison with other Middle–Upper Ordovician conodont biofacies in Baltoscandia

In a pioneering study of middle Upper Ordovician conodont biofacies in Baltoscandia, Sweet & Bergström (1984) recognised a *Hamarodus europaeus–Dapsilodus mutatus–Scabbardella altipes* and a *Phragmodus undatus–Icriodella–Plectodina* biofacies, neither of which is similar to those in the study interval. Based on multivariate analysis, Rasmussen & Stouge (1995) distinguished five biofacies in the early Darriwilian of Scandinavia, and correlated biofacies replacements with relative sea-level changes. Among these, their shelf-slope *Protopanderodus–Periodon* biofacies is likely to be equivalent to our *Periodon–Pygodus* biofacies, and their outer-shelf *Baltoniodus* biofacies, although containing some genera not present in the Andersö Shale, is probably comparable to our *Baltoniodus–Eoplacognathus* biofacies. Using cluster analysis of middle Caradoc collections from central Sweden, Leslie (1995) recognised a *Baltoniodus alobatus–Protopanderodus liripipus* biofacies, which is probably equivalent to our *Baltoniodus–Eoplacognathus* biofacies, and a slightly younger *Besselodus semisymmetricus–'Oistodus'* sp. A biofacies.

4.4. *Periodon–Pygodus* biofacies outside Baltoscandia

In the United Kingdom, the *Periodon–Pygodus* biofacies is known from southern Scotland (Bergström *et al*. 1974; Bergström 1990; Armstrong 1997). The diverse and well-described

Figure 14 SEM micrographs of selected conodonts from the Andersö Shale. (a–d) *Eoplacognathus lindstroemi* (Hamar, 1964): (a) OSU 51012, upper view of sinistral stelliplanate element, ×80, Ståltorp Limestone Member, sample J63-20, Norderön; (b) OSU 51013, upper view of dextral stelliplanate element, ×100, Ståltorp Limestone Member, sample J60-53, Andersön; (c) OSU 51014, upper view of sinistral pastiniplanate element, ×80, same sample as (a); (d) OSU 51015, upper view of dextral pastiniplanate element, ×80, same sample as (b); (e, f) '*Roundya' bispicata* Sweet & Bergström, 1962: (e) OSU 51016, lateral view of Sa element, ×120, same sample as (b); (f) OSU 51017, lateral view of Sc element, ×95, same sample as (b); (g) *Protopanderodus varicostatus* (Sweet & Bergström, 1962), OSU 51018, lateral view, ×90, same sample as (b); (h–j) *Periodon aculeatus* Hadding, 1913: (h) OSU 51019, lateral view of Sc element, × 150, Ståltorp Limestone Member, sample J65-1, Andersön; (i) OSU 51020, lateral view of M element, ×120, same sample as (h); (j) OSU 51021, lateral view of P element, ×115, same sample as (b); (k) *Walliserodus ethingtoni* (Fåhraeus, 1966), OSU 51022, lateral view of unornamented element, ×115, same sample as (b).

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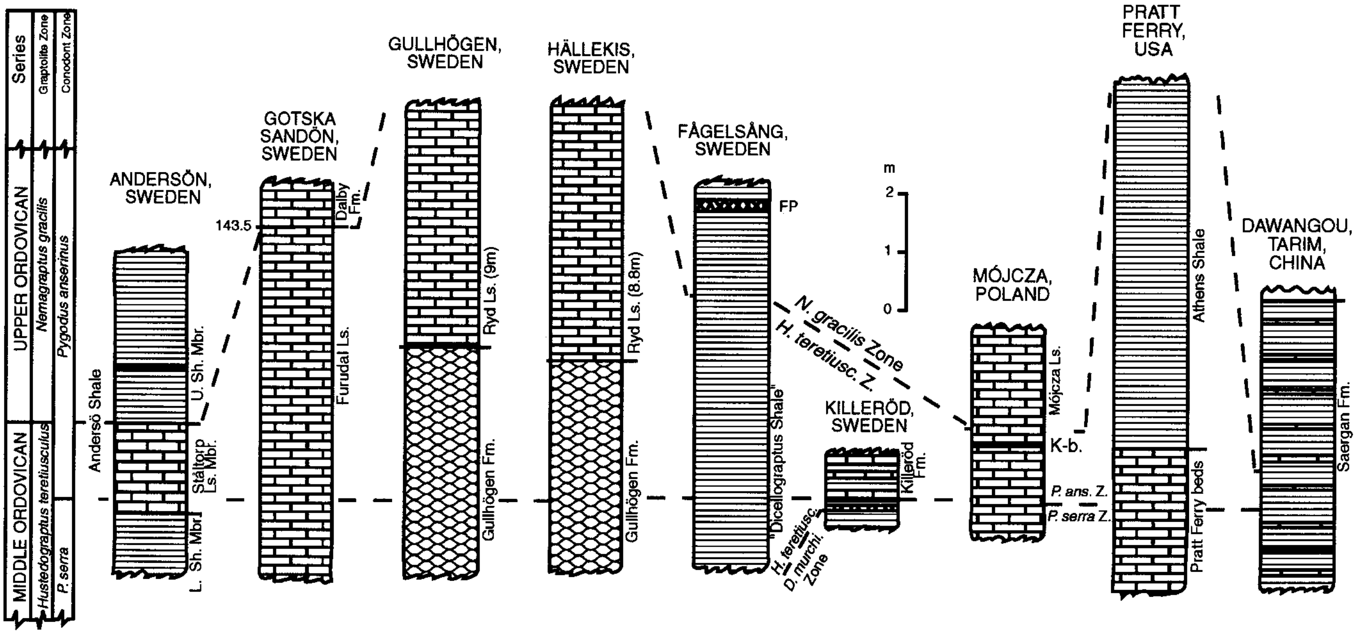

Figure 15 Correlation of the Andersö Shale with some successions in Sweden, Poland, North America, and China; the base of the *Pygodus anserius* Zone is used as a reference line; all columns are at the same scale; note that the base of the *Nemagraptus gracilis* Zone in the Gullhögen and Hällekis sections is correlated with the top of the Ryd Limestone and hence is well above the illustrated columns; FP denotes the Fågelsång Phosphorite, K-b, K-bentonite; the biostratigraphy of the Fågelsång section is after Bergström *et al.* (2000), that of the Mo'jcza section after Dzik (1994), that of the Pratt Ferry section after Finney (1977) and Hall *et al.* (1986) and that of the Dawangou section after Bergström *et al.* (1999).

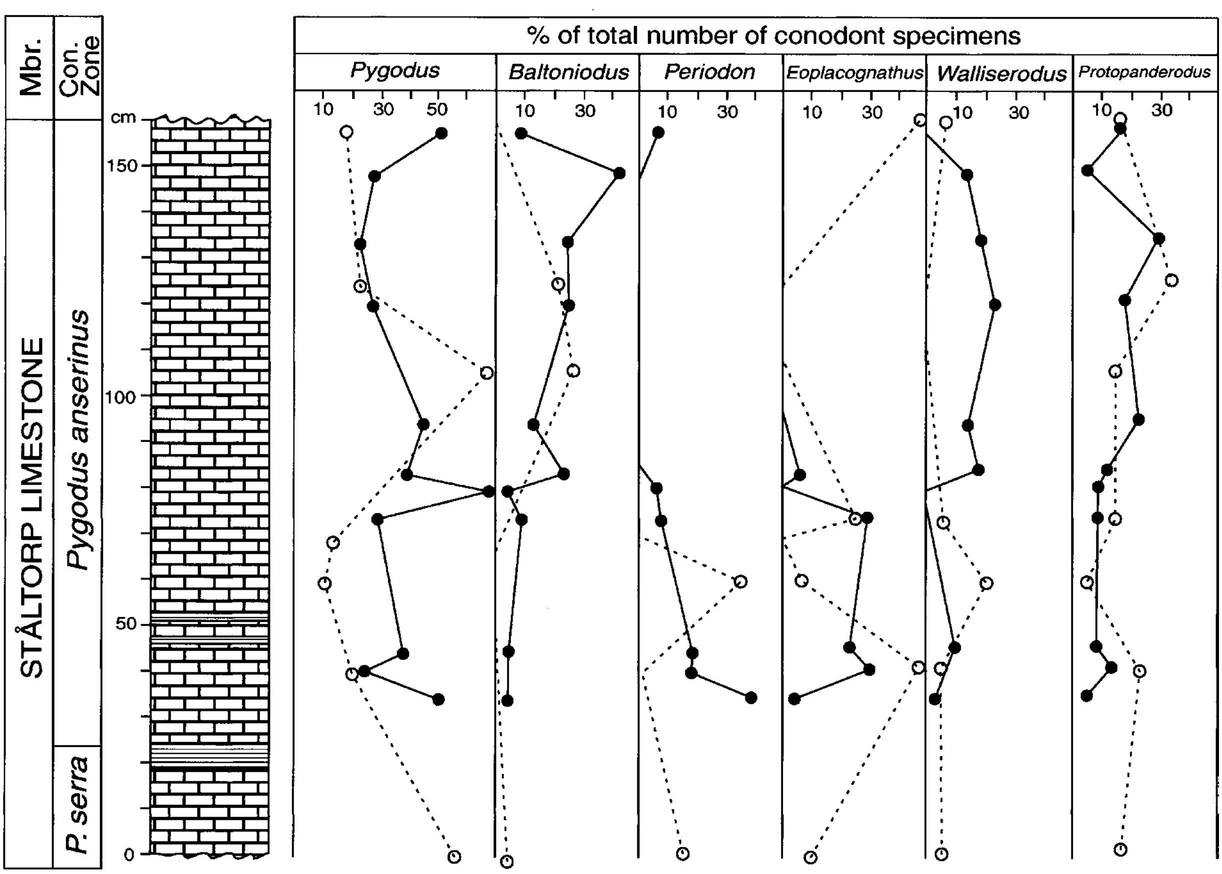

Figure 16 Relative frequency of elements representing common conodont genera in samples from the Ståltorp Limestone Member at Locality 1 of Hadding (1912, 1913) (black dots) and Nils Hans Husa (open circles); samples containing fewer than 25 elements have been omitted; note the relatively high frequency of *Eoplacognathus, Periodon* and *Pygodus* in the lower half of the Ståltorp Limestone Member, and the frequency decrease of these genera, and increase of *Baltoniodus*, in most of the upper half of this unit.

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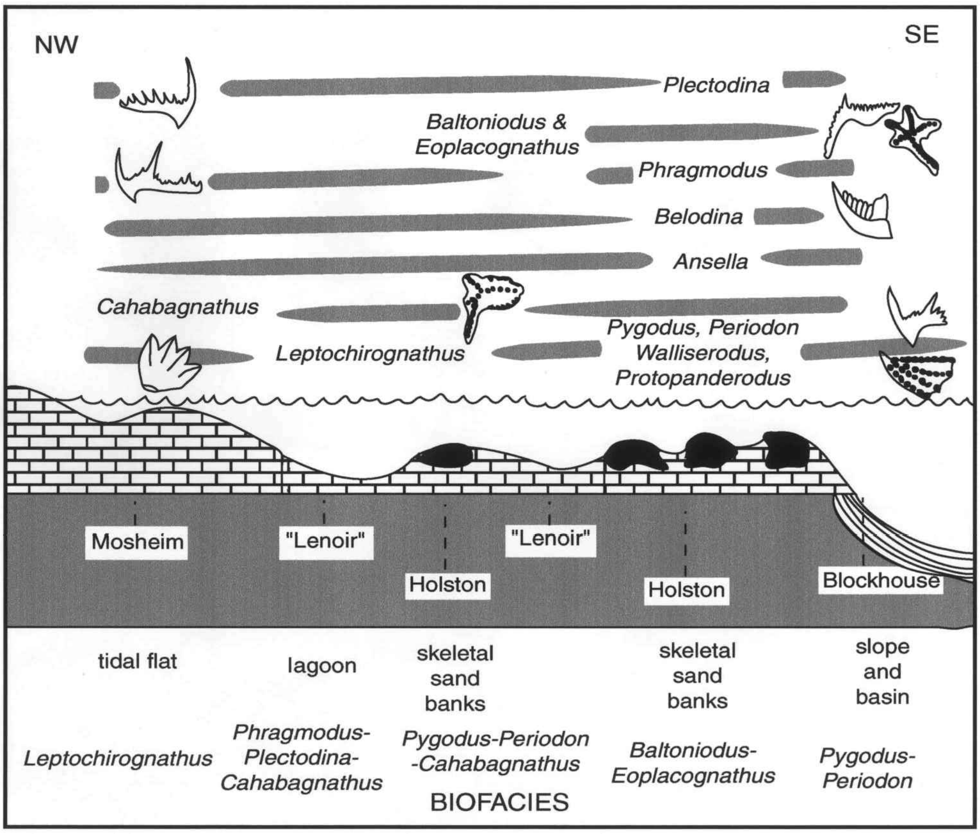

Figure 17 Upper Middle Ordovician (upper Darriwilian) biofacies differentiation in a NW–SE transect across the Appalachian Valley in eastern Tennessee (modified after Bergström & Carnes 1976); the Andersö Shale species association is comparable to that distinguished as the *Periodon–Pygodus* biofacies, which is present in the slope and basin part of the transect; this represents the deepest-water portion of the transect.

coeval faunas from the Holy Cross Mountains of Poland (Dzik 1994) are dominated by *Baltoniodus* and *Eoplacognathus* but *Pygodus* and *Periodon* are relatively rare. Hence, it appears that they represent the *Baltoniodus–Eoplacognathus* biofacies. The *Periodon–Pygodus* biofacies is also represented at many localities in the Appalachians of eastern North America from Newfoundland (Bergström *et al.* 1974; Fåhraeus & Hunter 1981) to Tennessee and Alabama (Sweet & Bergström 1962; Bergström 1973b; Hall *et al.* 1986). Other occurrences include the Womble Shale in Arkansas (Repetski & Ethington 1977) and the upper Fort Pena and Woods Hollow Formations in West Texas (Bradshaw 1969; Bergström 1978), and several regions in China (Wang & Luo 1984; An 1987; An & Zheng 1990; Bergström *et al.* 1999; Finney *et al.* 1999). In all these regions, this biofacies occurs in deeper-water and/or cold-water sediments, and is typically represented in limestone interbeds in black shales.

5. Concluding remarks

'Mixed facies' successions with diverse macrofossil and microfossil faunas, including a good representation of key index fossil groups, are as unusual in the Ordovocian of Baltoscandia as they are elsewhere in the world. Such sequences provide a unique opportunity to clarify the distributional relationships between various significant fossil taxa, and they may provide direct ties between biostratigraphical schemes based on different index fossil groups. The Andersö Shale in the Andersön–Norderön region in Jämtland is an outstanding example of such a unit, having a fauna that includes more than 70 recorded species. Because its presumably rather diverse ostracodes and acid-resistant microfossils (such as acritarchs, chitinozoa and scolecodonts) have not yet been studied, it seems safe to predict that after appropriate investigation of these fossil groups, the total number of recorded species in this unit will exceed 100. This figure is one of the highest, if not *the* highest, for any comparable stratigraphical interval in the Scandinavian Ordovician.

The Andersö Shale is of special biostratigraphical interest in that it straddles the Middle–Upper Ordovician boundary, according to the definition of this boundary in the new global stage and series classification scheme (Webby 1998). Although current graptolite collections from the Andersö Shale do not permit recognition of the level of this boundary more precisely that its being at some level in the lowermost portion of the Upper Shale Member, conodont evidence suggests that it is close to the base of this member. The co-occurrence of trilobites, graptolites and conodonts in the latest Middle Ordovician part of the Andersö Shale clarifies the relations between the distribution patterns of key index fossils. This is important for regional correlations and establishment of age relations across lithofacies and biofacies boundaries. Particularly by use of globally distributed conodonts, the Andersö Shale can be correlated with exceptional precision with successions in Sweden and elsewhere in the world.

Lithological evidence suggests that the Andersö Shale was deposited in an outer shelf-slope environment. This is consistent with the fact that the trilobites represent the deeper-water raphiophorid community and the conodonts belong to the deeper-water *Periodon–Pygodus* biofacies. Although the

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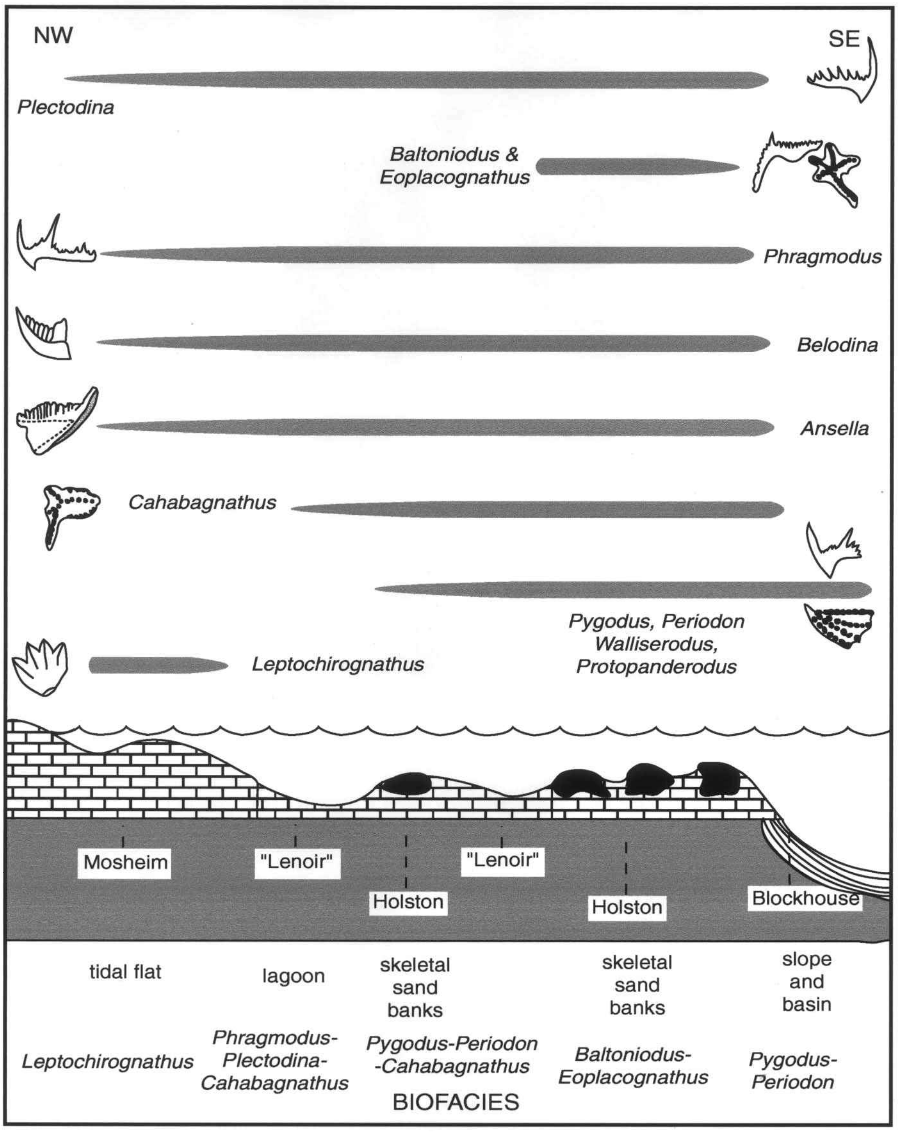

Figure 18 Swedish upper Middle Ordovician (upper Darriwilian) conodont biofacies differentiation based on the horizontal distribution of common genera; the different thickness of horizontal bars reflects the relative frequency of different genera at different sites; the sampled key localities represent a transect from continental platform to foreland basin; note that only two biofacies are recognised, and that the Andersö fauna is referred to the deeper-water *Periodon–Pygodus* biofacies.

water depth in this environment is difficult to estimate with a high degree of confidence, it is likely that the entire Andersö Shale sequence was laid down well below wave base, probably at a water depth of several tens of metres to more than 100 m. The Ståltorp Limestone Member may reflect a minor shallowing and/or greatly reduced influx of siliciclastic material. The overlying dark shale succession of the Upper Shale Member, which contains some beds of turbiditic aspect, appears to indicate a renewed deepening that ultimately led to the deposition of the superadjacent basinal and graptolitiferous Örå Shale which contains a *Triarthrus*-dominated deep-water trilobite assemblage (Månsson 1998).

The fact that the rich faunas, biostratigraphy and depositional environments of the Andersö Shale have received only limited study prior to the present investigations is by no means unique for such an important ‘mixed facies’ sequence in the Ordovician. We hope that the present multicomponent investigation will direct attention to such successions elsewhere and stimulate much-needed modern studies of these fascinating deposits.

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7. References

Ahlberg, P.1995. Telephinid trilobites from the Ordovician of Sweden. *Paleontology* **38,** 259–85.

An Tax-xiang 1987. [*The Lower Paleozoic conodonts of South China.*] Beijing: Beijing University Press [in Chinese with English summary].

An Tai-xiang & Zheng Zao-chang 1990. [*The conodonts of the marginal areas around the Ordos Basin, North China.*] Beijing: Science Press [in Chinese with English summary].

Angelin, N.P. 1854. *Palaeontologica Scandinavica 1: Crustacea formationis transitionis*, Fasc. 2, 21–92, Leipzig, Lund.

Armstrong, H. A. 1997. Conodonts from the Ordovician Shinnel Formation, Southern Uplands, Scotland. *Palaeontology,* **40,** 763–97.

Asklund, B. 1936. Zur Kenntnis der Jämtländischen Ogygiocarisschiefer-Fauna. *Sveriges Geologiska Undersökning* **C395,** 1–12.

Bergström, S. M. 1971a. Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and eastern North America. *Geological Society of America Memoir* **127,** 83–161.

Bergström, S. M. 1971b. Correlation of the North Atlantic Middle and Upper Orodovician conodont zonation with the graptolite succession. *Mémoirs du Bureau de Recherches Géologiques et Minières* **73,** 177–87.

Bergström. S. M. 1973a. Correlation of the late Lasnamägian Stage (Middle Orodovician) with the graptolite succession. *Geologiska Föreningen i Stockholm Förhandlingar* **95,** 9–18.

Bergström, S. M. 1973b. Biostratigraphy and facies relations in the lower Middle Ordovician of easternmost Tennessee. *American Journal of Science* **273-A,** 261–93.

Bergström, S. M. 1978. Middle and Upper Ordovician conodont and graptolite biostratigraphy of the Marathon, Texas graptolite zone reference standard. *Palaeontology* **21,** 723–58.

Bergström, S. M. 1980. Conodonts as paleotemperatue tools in Ordovician rocks of the Caledonides and adjacent areas in Scandinavia and the British Isles. *Geologiska Föringens I Stockholm Förhandlingar* **102,** 377–92.

Bergström, S .M. 1983. Biogeography, evolutionary relationships, and biostratigraphic significance of Ordovician platform conodonts. *Fossils and Strata* **156,** 33-58.

Bergström, S. M. 1986. Biostratigraphic integration of Ordovician graptolite and conodont zones—a regional review. *In* Hughes, C .P. & Rickards, R. B. (eds) *Palaeocology and biostratigraphy of graptolites, Geological Society, London, Special Publication*, **20,** 61–78.

Bergström, S. M. 1990. Biostratigraphic significance of Middle and Upper Ordovician conodonts in the Girvan succession, southwest Scotland. *Courier Forschungsinstitut Senckenberg* **118,** 1–43.

Bergström, S. M. 1997. Conodonts of Laurentian faunal affinities from the Middle Ordovician Svartsætra limestone in the Trondheim region, central Norwegian Caledonides. *Geological Survey of Norway Bulletin* **432,** 59–69.

Bergström, S. M., Riva, J. & Kay, M. 1974. Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland. *Canadian Journal of Earth Sciences* **11,** 1625–60.

Bergström, S. M., Hamar, G. & Spjeldnaes, N. 1998. Late Middle Ordovician conodonts with Laurentian affinities from the Mjøsa and Furuberget Formations in southeastern Norway. *VII International Conodont Symposium held in Europe, Abstracts*, 14–15.

Bergström, S. M., Finney, S. C., Chen Xu & Wang Zhi-hao 1999. The Dawangou section, Tarim Basin (Xinjian Autonomous Region), China: Potential as global stratotype for the base of the *Nemagraptus gracilis* Biozone and the base of the global Upper Ordovician Series. *Acta Universitatis Carolinae-Geologica 1999* **43,** 69–71.

Bergström, S. M., Finney, S. C., Chen, Xu, Pålsson, C., Wang Zhi-hao & Grahn, Y. 2000. A proposed global boundary stratotype for the base of the Upper Series of the Ordovician System: The Fågelsång section, Scania, southern Sweden. *Episodes* **23,** 102–109.

Bergström, S. M. & Carnes, J. B. 1976. Conodont biostratigraphy and palaeoecology of the Holston formation (Middle Ordovician) and associated strata in eastern Tennessee. *Geological Association Canada Special Paper* **15,** 27–57.

Bergström. S. M. & Nilsson, R. 1974. Age and correlation of the Middle Ordovician bentonites on Bornholm. *Bulletin of the Geological Society of Denmark* **23,** 27–48.

Bradshaw, L. E. 1969. Conodonts from the Fort Peña Formation (Middle Ordovician), Marathon Basin, Texas. *Journal of Paleontology* **43,** 1137–68.

Cooper, B. N. 1953. Trilobites from the lower Champlainian formations of the Appalachian Valley. *Memoir of the Geological Society of America* **55,** 1–69.

Dalman, J. M. 1827. Om Palaeaderna eller de så kallade trilobiterna. *Kongliga Svenska Vetenskaps-Academiens Handlingar* 1826, 113–52; 226–94.

Dzik, J. 1994. Conodonts of the Mójcza Limestone, *In* Dzik, J., Olempska, E. & Pisera, A. *Orodovician carbonate platform ecosystem of the Holy Cross Mountains, Palaeontologica Polonica* **53,** 43–128.

Epstein, A. G., Epstein, J. B. & Harris, L. D. 1977. Conodont color alteration—an index to organic metamorphism. *U.S. Geological Survey Professional Paper* **995,** 1–27.

Fåhraeus, L. E. 1966. Lower Viruan (Middle Ordovician) conodonts from the Gullhögen quarry, southern central Sweden. *Sveriges Geologiska Undersökning* **C610,** 1–40.

Fåhraeus, L. E. & Hunter, D. R. 1981. Paleoecology of selected condontophorid species in the Cobb's Arm Formation (Middle Ordovician), New World Island, north-central Newfoundland. *Canadian Journal of Earth Sciences* **18,** 1653–65.

Finney, S. C. 1977. Graptolites of the Middle Ordovician Athens Shale in Alabama (Unpublished Ph.D. dissertation, The Ohio State University, Columbus, Ohio).

Finney, S. C., Bergström. S. M., Chen Xu & Wang Zhi-hao 1999. The Pingliang section, Gansu Province, China: Potential as global stratotype for the base of the *Nemagraptus gracilis* Biozone and the base of the global Upper Ordovician Series. *Acta Universitatis Carolinae-Geologica 1999*, **43,** 73–5.

Fortey, R. A. 1984. Global earlier Ordovician transgressions and regressions and their biological implications. *Palaeontological Contributions from the University of Oslo* **295,** 37–63.

Fortey, R. A., Harper, D. A. T., Ingham, J. K., Owen, A. W., Parkes, M. A., Rushston, A. W. A. & Woodcock, N. H. 2000. A revised correlation of Ordovician rocks in the British Isles. *Geological Society Special Report* **24,** 1–83.

Fortey, R. A. & Owens, R. M. 1978. Early Ordovician (Arenig) stratigraphy and faunas of the Carmarthen district, south-west Wales. *Bulletin of the British Museum (Natural History) Geology* **30**(3), 225–94.

Fortey, R. A. & Owens, R. M. 1987. The Arenig Series in South Wales. *Bulletin of the British Museum (Natural History) Geology* **41,** 69-307.

Hadding, A. 1912. Några iakttagelser från Jämtlands ordovicium. *Geologiska Föreningens I Stockholm Förhandlingar* **21,** 589–603.

Hadding, A. 1913. Undre Dicellograptusskiffern i Skåne jemte några därmed ekvivalenta bildningar. *Lunds Universitets Årsskrift, N.F.* **2,** 9(15), 1–91.

Hall, J. C., Bergström, S. M. & Schmidt, M. A. 1986. Conodont biostratigraphy of the Middle Ordovician Chickamauga Group and related strata of the Alabama Appalachians. *In* Benson, D. J. & Stock, C. W. (eds) *Depositional history of the Middle Ordovician of the Alabama Appalachians, Alabama Geological Society 23rd Annual Field Trip, Guide-book*, 61–80.

Hamar, F. 1964. The Middle Ordovician of the Oslo region, Norway. 17. Conodonts from the lower Middle Ordovician of Ringerike. *Norsk Geologisk Tidsskrift* **44,** 243–92.

Hamar, G. 1966. The Middle Ordovician of the Oslo region, Norway. 22. Preliminary report on conodonts from the Oslo-Asker and Ringerike districts. *Norsk Geologisk Tidsskrift* **46,** 27–83.

Hede, J. E. 1951. Boring through Middle Ordovician–Upper Cambrian strata in the Fågelsång district, Scania (Sweden). 1. Succession encountered in the boring. *Lunds Universitets Årsskrift, N.F.* **46**(7), 1–78.

Henningsmoen, G. 1960. The Middle Ordovician of the Oslo region, Norway. 13. Trilobites of the family Asaphidae. *Norsk Geologisk Tidsskrift* **40,** 203–57.

Hughes, R. A. 1989. Llandeilo and Caradoc graptolites of the Builth and Shelve inliers. *Palaeontological Society Monographs* **577,** 1–89.

Jaanusson, V. 1953. Untersuchungen über baltoskandische Asaphiden. I. Revision der mittel-ordovizischen Asaphiden des Siljan-Gebietes in Dalarna. *Arkiv för Mineralogi och Geologi* **1,** 377–464.

Jaanusson, V. 1960. The Viruan (Middle Ordovician) of Öland. *Bulletin of the Geological Institutions of the University of Uppsala* **38,** 207–88.

Jaanusson, V. 1973. Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. *Lethaia* **6,** 11–34.

Jaanusson, V. 1982. Introduction to the Ordovician of Sweden. *In* Bruton, D. l. & Williams, S. H. (eds) *IV International Symposium on the Ordovician System, Field Excursion Guide*. *Palaeontological Contributions from the University of Oslo* **279,** 1–9.

Karis, L. 1982. The sequence in the Lower Allochthon of Jämtland. *In* Bruton, D. L. & Williams, S. J. (eds) *IV International Symposium on the Ordovician System, Field Excursion Guide*. *Palaeontological Contributions from the University of Oslo* **279,** 55–63.

Karis, L. 1998. Jämtlands östliga fjällberggrund. *In* Karis, L. & Strömberg, L. (eds) Beskrivning till berggrundskartan över Jämtlands Iän. Del 2: Fjälldelen. *Sveriges Geologiska Undersökning* **Ca53:2,** 1–184.

Lamont, A. & Lindström, M. 1957. Arenigian and Llandeilian cherts identified in the Southern Uplands of Scotland by means of conodonts, etc. *Transactions of the Geological Society of Edinburgh* **17,** 60–70.

Larsson, K. 1973. The lower Viruan in the autochthonous Ordovician sequence of Jämtland. *Sveriges Geologiska Undersökning* **C683,** 1–82.

Leslie, S. A. 1995. Upper Middle Ordovician conodont biofacies and lithofacies distribution patterns in eastern North America and northwestern Europe: Evaluations using the Deicke, Millbrig and Kinnekulle K-bentonite beds as time planes (Unpublished Ph.D. dissertation, The Ohio State University, Columbus, Ohio).

Lindström, M. 1955. The conodonts described by A. R. Hadding, 1913. *Journal of Paleontology* **29,** 105–11.

Lindström, M. 1957. Two Ordovician conodont faunas found with zonal graptolites. *Geologiska Föreningens I Stockholm Förhandlingar* **79,** 161–78.

Lindström, M. 1960. A Lower–Middle Ordovician succession of conodont faunas. *Reports of the 21st International Geological Congress* **7,** 88–96.

Lindström, M. 1984a. The Ordovician climate based on a study of carbonate rocks. *In* Bruton, D.L. (ed.) *Aspects of the Ordovician System*. *Palaeontological Contributions from the University of Oslo* **295,** 81–8.

Lindström, M. 1984b. Baltoscandic conodont life environments in the Ordovician: Sedimentologic and palaeogeographic evidence. *Geological Society of America Special Paper* **196,** 33–42.

Linnarsson, G. 1872. Anteckningar om den kambrisk–siluriska lagerserien i Jemtland. *Geologiska Föreningens i Stockholm Förhandlingar* **1,** 34–47.

Linnarsson, G. 1875. En egendomlig trilobitfauna från Jemtland. *Geologiska Föreningens i Stockholm Förhandlingar* **2,** 491–7.

Löfgren, A. 1978. Arenigian and Llanvirnian conodonts from Jämtland, northern Sweden. *Fossils and Strata* **13,** 1–129.

Männil, R. 1958. [*Trilobites of the family Cheiruridae and Encrinuridae from Estonia*]. Geoloogia-Ist. Uurim. 3, 165–212 [in Russian; with Russian, Estonian and English summaries.]

Månsson, K. 1995. Trilobites and stratigraphy of the Middle Ordovician Killeröd Formation, Scania, Sweden. *GFF* **117,** 97–106.

Månsson, K. 1998. Middle Ordovician olenid trilobites (*Triarthrus* Green and *Porterfieldia* Cooper) from Jämtland, Sweden. *Transactions of the Royal Society of Edinburgh: Earth Sciences* **89,** 47–62.

Månsson, K. 2000a. Trilobites from the Middle and Upper Ordovician Andersön Shale Formation in Jämtland and the equivalent Killeröd Formation in Skåne, Sweden. *Lund Publications in Geology* **152,** 1–21.

Månsson, K. 2000b. Dionidid and raphiophorid trilobites from the Middle Ordovician of Jämtland, central Sweden. *Transactions of the Royal Society of Edinburgh: Earth Sciences* **90** (for 1999), 317–29.

Marek, L. 1952. [Prispevek ke stratigrafii a faune nejvýí cásti bridli c kralodvorskych (dzl)]. *Sbornik Ústredního ústavu geologického, paleontologickeho* **19,** 429–55. [in Czech, with English summary pp. 449–455.]

Moberg, J. C. 1907. Ett par bidrag till kännedomen om Skånes dicellograptusskiffer. *Geologiska Föreningens i Stockholm Förhandlingar* **29,** 75–88.

Nielsen, A. T. 1995. Trilobite systematics, biostratigraphy and palaeoecology of the Lower Ordovician Komstad Limestone and Huk Formations, southern Scandinavia. *Fossils and Strata* **38,** 1–374.

Nikolaisen, F. 1965. The Middle Ordovician of the Oslo region, Norway, 18. Rare trilobites of the family Olenidae, Harpidae, Ityophoridae and Cheiruridae. *Norsk Geologisk Tidsskrift* **45,** 231–48.

Nikolaisen, F. 1983. The Middle Ordovician of the Oslo Region, Norway, 32. Trilobites of the family Remopleurididae. *Norsk Geologisk Tidsskrift* **62,** 231–329.

Nikolaisen, F. 1991.The Ordovician trilobite genus *Robergia* Wiman, 1905 and some other species hitherto included. *Norsk Geologisk Tidsskrift* **71,** 37–62.

Nilsson, R. 1977. A boring through Middle and Upper Ordovician strata at Koängen in western Scania, southern Sweden. *Sveriges Geologiska Undersökning* **C733,** 1–58.

Owen, A. W. 1987. The Scandinavian Middle Ordovician trinucleid trilobites. *Palaeontology* **30,** 75–103.

Rasmussen, J. A. 1994. Stratigraphy, conodont faunas and depositional setting of the Lower Allochthonous limestones within the Scandinavian Caledonides (Unpublished Ph.D. dissertation, University of Copenhagen).

Rasmussen, J. A. 1998. A reinterpretation of the conodont Atlantic realm in the late Early Ordovician (early Llanvirn). *Palaeontologica Polonica* **589,** 67–77.

Rasmussen, J. A. 2001. Conodont biostratigraphy and taxonomy of the Ordovician shelf margin deposits in the Scandinavian Caledonides. *Fossils and Strata* **48,** 1–180.

Rasmussen, J. A. & Bruton, D. L. 1994. Stratigraphy of Ordovician limestones, Lower Allochthon, Scandinavian Caledonides. *Norsk Geologisk Tidsskrift* **74,** 199–212.

Rasmussen, J. A. & Stouge, S. 1995. Late Arenig–Early Llanvirn conodont biofacies across the Iapetus Ocean. *In* Cooper, J. D., Droser, M. L. & Finney, S. C. (eds) *Ordovician Odyssey: Short Papers for the Seventh International Symposium on the Ordovician System*, 443–7. *The Pacific Section Society for Sedimentary Geology (SEPM)* **77.**

Repetski, J. & Ethington, R. L. 1977. Conodonts from graptolite facies in the Ouachita Mountains, Arkansas and Oklahoma. *Arkansas Geological Commission Symposium on the geology of the Ouachita Mountains*. *Stratigraphy, sedimentology, petrography, tectonics, and paleontology* **1,** 92–106.

Stauffer, C. R. 1935. Conodonts from the Glenwood beds. *Bulletin of the Geological Society of America* **46,** 125–88.

Stetson, H. C. F. 1927. The distribution and relationship of the Trinuleidae. *Bulletin of the Museum of Comparative Zoology* **68,** 87–104.

Sweet, W. C. 1979. Conodonts and conodont biostratigraphy of post-Tyrone Ordovician rocks of the Cincinnati region. *United States Geological Survey Professional Paper* **1066-G**, G1–G26.

Sweet, W. C. & Bergström, S. M. 1962. Conodonts from the Pratt Ferry Formation (Middle Ordovician) of Alabama. *Journal of Paleontology* **36,** 1214–52.

Sweet, W. C. & Bergström, S. M. 1966. Ordovician conodonts from Penobscot County, Maine. *Journal of Paleontology* **40,** 151–4.

Sweet, W. C. & Bergström, S. M. 1984. Conodont provinces in the Late Ordovician. *Geological Society of America Special Paper* **196,** 69-87.

Thorslund, P. 1937. Kvartsiter, sandstenar and tektonik inom Sunneområdet i Jämtland.*Sveriges Geologiska Undersökning* **C409,** 1–30.

Thorslund, P. 1940. On the Chasmops series of Jemtland and Södermanland (Tvären). *Sveriges Geologiska Undersökning*, **C436,** 1–191.

Thorslund, P. 1960. Notes on the Cambro-Silurian of Jämtland and Road-log. *In* Thorslund, P. & Jaanusson, V. *The Cambrian, Ordovician, and Silurian in Västergötland, Närke, Dalarna, and Jämtland, central Sweden. 21st International Geological Congress, Guide to Excursions Nos A 23 and C 18*, 35–51.

Thorslund, P. & Asklund B. 1935. Stratigrafiska och tektoniska studier inom Föllingeområdet i Jämtland. *Sveriges Geologiska Undersökning* **C388,** 1–61.

Torsvik, T. H. 1998. Palaeozoic palaeogeography. A North Atlantic viewpoint. *GFF* **120,** 109–18.

Torsvik, T. H., Smethurst, M. A., Meert, J. G., Van der Voo, R., McKerrow, W. S., Brasier. M. D., Sturt, B. A. & Waldenhaug, H. J. 1996. Continental break-up and collison in the Neoproterozoic and Palaeozoic–A tale of Baltica and Laurentia. *Earth Science Reviews* **40,** 229–58.

Ulrich, E. O. 1930. Ordovician trilobites of the Family Telephidae and concerned stratigraphic correlations. *Proceedings United States National Museum* **76,** 1–101.

Viira, V. 1974. [*Ordovician conodonts of the East Baltic*] Tallinn 'Valgus' [in Russian], 1–42.

Wang Zhi-hao & Luo Kun-quan 1984. [Late Cambrian and Ordovician conodonts from the marginal areas of the Ordos Platform, China.] *Bulletin of the Nanjing Institute of Geology and Palaeontology, Academia Sinica Oct. 1984*, 237–304. [in Chinese with English summary.]

Webby, B. 1998. Steps towards a global standard for Ordovician stratigraphy. *Newsletters on Stratigraphy* **36,** 1–33.

Whittard, W. F. 1955. The Ordovician trilobites of the Shelve Inlier, West Shropshire. Part 1. *Palaeontographical Society Monographs* **470,** 229–64.

Whittington, H. B. 1965. Trilobites of the Ordovician Table Head Formation, Western Newfoundland. *Bulletin of the Museum of Comparative Zoology* **132**, 277–441.

Wiman., C. 1893. Über die Silurformation in Jemtland. *Bulletin of the Geological Institution of the University of Upsala* **1**, 256–76.

Wiman, C. 1896. Kambrisch–silurische Faciesbildungen in Jemtland. *Bulletin of the Geological Institution of the University of Upsala* **3,** 269–303.

Wiman, C. 1905. Paläontologische Notizen 3–6. 3. Über *Robergia microphthalus* Lns. und *Triarthrus jemtlandicus* Lns. *Bulletin of the Geological Institution of the University of Upsala* **6,** 77–83.

Zhang Jianhua 1998. The Ordovician conodont genus *Pygodus. In* Szaniawski, H. (ed.) *Proceedings of the Sixth European Conodont Symposium (ECOS VI)*. *Palaeontologia Polonica* **58,** 87–105.

Zhang, Jianhua & Sturkell, E. F. F. 1998. Aserian and Lasnamägian (Middle Ordovician) conodont biostratigraphy and lithology at Kullstaberg and Lunne in Jämtland, central Sweden. *GFF* **120,** 75–83.

CHRISTIAN PÅLSSON and KRISTINA MÅNSSON*, Department of Geology, Historical Geology and Palaeontology, Lund University, Sölvegatan 13, SE-223 62 Lund, Sweden
e-mail: christian.palsson@geol.lu.se
STIG M. BERGSTRÖM, Department of Geological Sciences, The Ohio State University, 125 S. Oval Mall, Columbus, Ohio 43210, U.S.A.
e-mail: stig@geology.ohio-state.edu

*Present address: Förlagshuset Hägern AB, Box 414, SE-201 24 Malmö, Sweden
e-mail: kristina@forlagshusethagern.se

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