

# An integrated biostratigraphical analysis of the Volkhov–Kunda (Lower Ordovician) succession at Fågelsång, Scania, Sweden

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The Komstad Limestone is composed of dark grey to black micritic limestone deposited in an outer shelf environment on the margin of the East European Platform. It represents an interval of low sea level during the late Volkhov to early Kunda that led to the spread of limestones into the shale-dominated western lithofacies belt.

The *Baltoniodus norrlandicus*, *Lenodus antivariabilis*, *Lenodus variabilis*, *Yangtzeplacognathus crassus* and *Lenodus pseudoplanus* conodont zones were identified in the upper Volkhov to lower Kunda interval. Based on the most recent taxonomic and biostratigraphical framework, the *Megistaspis limbata* (with two subzones), *Asaphus expansus* and *Asaphus raniceps* trilobite zones were identified.

A shale intercalation in the lower part of the Komstad Limestone contains the graptolites *Phyllograptus cor* in association with *Glyptograptus* sp. and is referred to Darriwilian 1 (Upper Arenig). In the Baltoscandian zonation this matches the upper part of the *Didymograptus hirundo* graptolite Zone. The upper level of the Komstad Limestone and the basal part of the overlying Almelund Shale do not contain graptolites, whereas the succeeding black shales of the Almelund Shale belong to the *Holmograptus lentus* Zone (Llanvirn). The Arenig–Llanvirn boundary is situated at or very near the top of the Komstad Limestone.

The conodont assemblage in the lower part of the Komstad Limestone at Fågelsång is associated with forms of Gondwanan affinity, which probably reflects the cool water environment of the outer shelf setting. The higher part of the limestone contains the Whiterockian conodont species *Dzikodus* sp. and *Histiodella tableheadensis*. These important Laurentian forms occur together with abundant *Gothodus* sp. 1 and *Cyclopyge umbonata* in the base of the *Asaphus expansus* Zone. The arrival of the Laurentian taxa – as well as *Cyclopyge* with an ‘Gondwana’ affinity – is related to a transient sea level rise at the base of the *A. expansus* trilobite Zone.

**Key words:** Komstad Limestone, Almelund Shale, Fågelsång, Scania, Sweden, biostratigraphy, conodonts, trilobites, graptolites, Volkhov and Kunda stages, Arenig–Llanvirn boundary, Lower Ordovician.

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In Scania, southern Sweden (Fig. 1), the Ordovician succession is dominated by graptolitic shales and mudstones that accumulated on the deep shelf near the margin of the East European Platform. The Scanian–Bornholm lithofacies comprise mostly black shales (Bergström *et al.* 1982; Bergström *et al.* 2002) and are included in the Scanian Confacies Belt (Jaanusson 1976, 1982). The Ordovician shaly succession is interrupted by the Lower Ordovician Komstad Limestone (Jaanusson 1960), which corresponds to the upper Volkhov and lower Kunda stages of the Bal-

toscandian chronostratigraphical scheme (Männil & Meidla 1994). It is regarded as a lateral facies of the cool-water platformal ‘Orthoceras’ Limestone, which covered much of the East European Platform in the Early and Middle Ordovician (Männil 1966; Lindström 1971a). The appearance of limestone facies in the Scania–Bornholm region has been related to a series of sea level falls (Nielsen 1995).

The Komstad Limestone is or has been exposed at many localities in Scania and Bornholm (Moberg 1896, 1911; Bergström 1982; Bergström *et al.* 1982; Nielsen



Fig. 1. Location map with detailed map from Fågelsång (Fig 1A). CDF = Caledonian Deformation Front; TESZ = Trans European Suture Zone.

1995). Most of the known exposures are abandoned small quarries, which are either covered by rubbish or filled with water. This is also the case in the Fågelsång area (Fig. 1), where strip mining of the limestone has taken place since early medieval time and quarrying ended in the middle part of the 19<sup>th</sup> century (Ekström 1937). At Fågelsång the former mining area is today a nature reserve (Ahlberg 1992).

The purpose of this paper is to present an integrated biostratigraphical analysis of the upper Volkhov – lower Kunda interval at Fågelsång, based on conodonts, trilobites and graptolites.

## Geological setting

The studied section lies on the East European Platform (or the East European Craton; Pharaoh *et al.* 1997) of the Baltica palaeocontinent (Torsvik *et al.* 1996). The southwestern margin of Baltica extends to the Elbe Line, some 200 km south of Rügen and south of the Caledonian Deformation Front (Fig. 1). The Caledonian Deformation Front represents the northern limit of the preserved remnants of a thick accretionary wedge that was thrust onto the southwestern margin of Baltica. The thrust belt was formed by the oblique collision of Avalonia and Baltica from Late Ordovician into the Late Silurian ((Franke 1990;

Chronostratigraphy						Lithostratigraphy					
System	International		British	Baltoscandian		South Sweden		Denmark	North Germany	North Poland	
	Series	Stages		Series	Stages	Scania	Bornholm				G 14
Ordovician	Upper	Not yet distinguished	Ashgill	Upper Ordovician (Harju)	Hirnant	Kallholn Formation	Rastrites Shale	(No name)	Prabuty Shale and Marl		
					Jerrestad	Lindegård Formation	Tommarp Mudstone				
					Vasagaard	Fjäckå Shale	Jerrestad Mudstone				
			Caradoc	Middle Ordovician (Viru)	Rakvere	Mossen Formation	Dicellograptus Shale	Dicellograptus Shale	Sasino Shale		
					Oandu	Skagen Formation	Dicellograptus Shale				
					Keila	Sularp Formation					
					Haljala						
					Kukruse						
					Uhaku	Killeröd Fm.					
	Middle	Darrivillian	Llanvirn	Lower Ordovician (Oeland)	Lasnamägi	Almelund Shale					
					Aseri						
					Kunda	Komstad Limestone		Komstad Limestone	Komstad Limestone	Kopalino Limestone	
			Volkhov								
			Billingen		Tøyen Shale		Tøyen Shale	Sluchowo Fm.			
			Hunneberg		Ceratopyge Lmst.		Björkåsholmen Fm.				
			Varangu		Ceratopyge Shale						
			Pakerort		Alum Shale	Alum Shale	Alum Shale	Piasnica Shale			

Fig. 2. Stratigraphy of Scania, Bornholm, northern Germany (G 14) and northern Poland with indications of main lithologies. Compiled from Bednarczyk (1998), Beier, Maletz & Böhnke (2000), Bergström *et al.* (2002), Stouge (2001) and Poulsen (1966).

Berthelsen 1992; Thomas *et al.* 1993; MONA LISA Working Group 1997a, b).

North of the Caledonian Deformation Front the Lower Palaeozoic succession consists of undeformed sediments. These are preserved in downfaulted and southwest dipping blocks (e.g. Thomas *et al.* 1993; Vejbaek *et al.* 1994).

The Lower and Middle Ordovician successions in SE Scania, on Bornholm, in the north German offshore G-14 well and north Poland are incomplete (Maletz *et al.* 1997; Stouge 2001; Fig. 2). The observed gaps were probably created by local uplift and erosion (Katzung *et al.* 1995; Nielsen 1995; Beier *et al.* 2001).

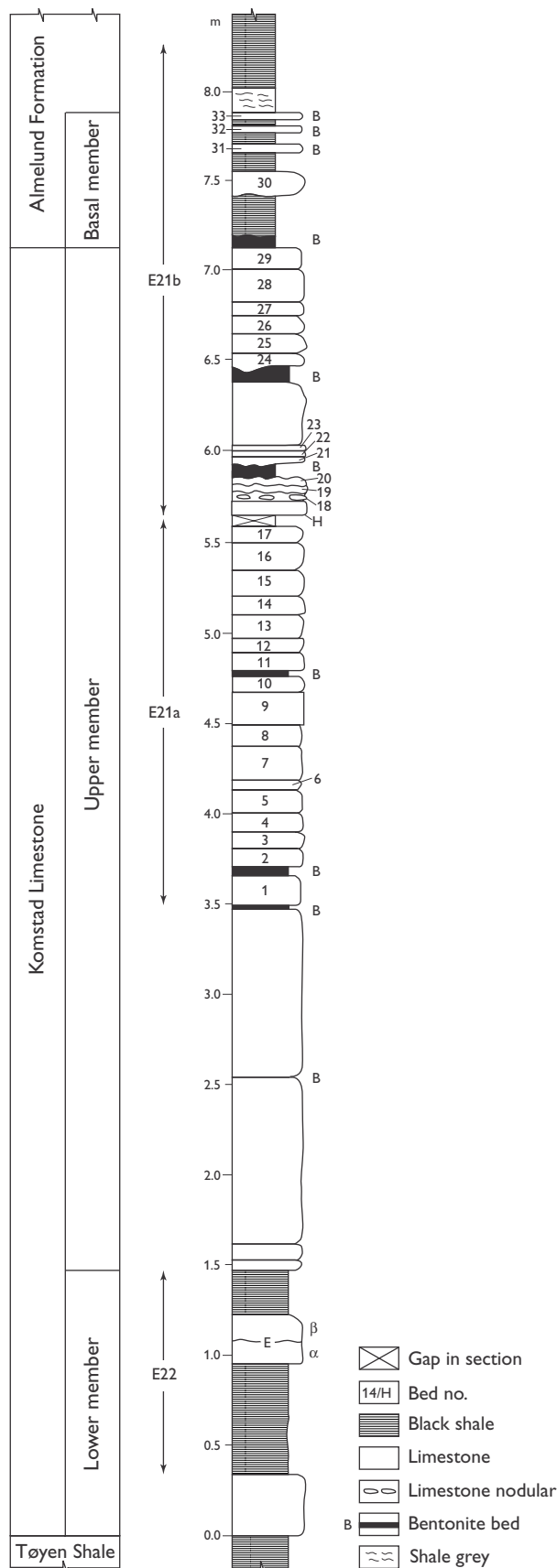
During the Early and Middle Ordovician the East European Platform was covered by a carbonate ramp, where cool-water carbonates slowly accumulated (Jaanusson 1973; Lindström 1963, 1984; Nestor 1990). Net depositional rates were 1–2 mm/1000 yrs (Lindström 1963, 1971a, 1974), which reflect slow carbonate production and accumulation and low clastic supply to the basin. The latter condition resulted from the extensive submergence of the craton and peneplaned land-source areas were small and distant (e.g. Jaanusson 1982; Lindström 1963, 1971a, 1974). Depth of deposition has been a contentious issue (i.e. Lindström 1963, 1991 *vs* Jaanusson 1973, 1982), but the outer shelf environment may have been as deep as 200–250 m. The sediments of the Fågelsång section

were deposited in an outer shelf environment situated close to the shelf break.

## Ordovician stratigraphy of Scania

The Ordovician succession in the Scania-Bornholm region, southern Scandinavia, is composed predominantly of black shales (Bergström 1982; Bergström *et al.* 1982; Fig. 2). The Ordovician strata are up to 200 m thick in the offshore well Terne-1 in Kattegat (Michelsen & Nielsen 1991) and in northwestern Scania (Bergström *et al.* 1982; Nielsen 1995; Fig. 1). The succession becomes thinner towards the southeast and on Bornholm the Ordovician succession is only about 40 m thick and stratigraphically less complete (Poulsen 1966; Michelsen & Nielsen 1991; Nielsen 1995; Vejbaek *et al.* 1994). In the German offshore well G-14 between Bornholm and Rügen (Fig. 1), the Ordovician is 65 m thick (Maletz 1997a; Fig. 2).

Bentonite beds are known from the Lower and Middle Ordovician (Lindström 1974; Nilsson 1984), but are particularly common in the Caradoc Sularp Formation (Lindström 1953; Bergström & Nilsson 1974; Huff *et al.* 1992; Bergström *et al.* 1995; Bergström *et al.* 2002).



## Komstad Limestone at Fågelsång

The Fågelsång area is located 8 km east of Lund, Scania, the southern province of Sweden (Fig. 1). In his guide to the Fågelsång area Moberg (1896, 1911) labelled all exposures, including temporary points of observation, with a code number. Moberg's 1911 version of the guide was used by Ekström (1937), Ahlberg (1992) and Nielsen (1995) for reference and is also followed here (Fig. 1A). The Komstad Limestone exposures are referred to as E20 and E21, the latter subdivided into E21a (southern quarry) and E21b (middle quarry) (Fig. 1A).

Ahlberg (1992) presented a history of research for the Fågelsång district. The area has now been elected as the Global Stratotype and Point (GSSP) marking the base for the international Upper Ordovician series (i.e. at the first appearance of *Nemagraptus gracilis*; Bergström *et al.* 2000; Bergström *et al.* 2002; Finney 2002). Nielsen (1995) provided new data and new descriptions of the Komstad Limestone exposures in the area.

The rich fauna of trilobites from the Komstad Limestone was initially described by Angelin (1851–78), who reported more than 20 species. Moberg (1907) recorded a prolific cyclopygid trilobite fauna from the bottom layers of the southern quarry. Strandmark (1902) and Ekström (1937) listed additional species and Nielsen (1995) redescribed a substantial part of the trilobite fauna.

Conodonts are also known from the Fågelsång area. Hadding (1913) described well-preserved specimens preserved on bedding-planes of the Llanvirn graptolitic Almélund Shale (see also Lindström 1955; Bergström 1971). Ekström (1937, p. 15) noted that 'annelidan-jaws' (single jaws of *Drepanodus*-type) were present, which are probably simple cone conodonts. Conodonts of Kunda age from the upper part of the Komstad Limestone were recorded by Stouge (1975) and some were illustrated by Stouge & Bagnoli (1999).

The record of graptolites dates back to at least 1744 (see Regnéll 1949, 1991). The graptolite fauna below, within and immediately above the Komstad Limestone has been described by Strandmark (1902), Hadding (1913), Ekström (1937), Hede (1951), Lindholm (1981, 1991a, b) and Cooper & Lindholm (1985) [see also Mitchell (1992) and Mitchell & Maletz (1995)].

Fig. 3. Fågelsång composite section. The information is from exposures at Fågelsång and from the Fågelsång-2 borehole (Fig. 1A). Vertical arrows show the stratigraphic extend of the outcrops in the quarries. Bed H mentioned in the text is situated just below Bed 18. The Komstad Limestone is > 7.1 m and may be as much as 7.5 m thick. Meter scale at column.

Today, the Fågelsång quarries are filled with water covering exposures in the 21b quarry, whereas the upper portion of the Komstad Limestone and the lower part of the overlying Almelund Shale are exposed in the E21a quarry. Some limestone is also visible in the old quarry labelled E20. The lower part of the Komstad Limestone is exposed at E22 (Fig. 1). The contact between the underlying Tøyen Shale and the lower unit of the Komstad Limestone is covered.

The Komstad Limestone is penetrated by a shallow well (Fågelsång-2) positioned on the field approx. 100 m west of localities E21a and E21b (Fig. 1). Unpublished information from this well regarding the lower 5 m of the Komstad Limestone is incorporated in Fig. 3.

At Fågelsång the Komstad Limestone is a dark grey to black fossiliferous micrite to biomicrite. It lies between the graptolitic Tøyen Shale and Almelund Shale formations. The Komstad Limestone is here subdivided into two informal members. The lower member conformably overlies the Tøyen Shale and is 1.50 m thick. It consists of two limestone beds with shaly interbeds. The top of the lower limestone bed forms the streambed immediately north of locality E22 (Fig. 1A). The upper limestone bed and the adjacent shales are exposed at locality E22.

The upper member of the Komstad Limestone is approximately 5.6 m thick. Part of the section however was faulted out in the Fågelsång-2 drill-core, so a definite figure cannot be given and the unit may be somewhat thicker than given here. The upper member of the Komstad Limestone consists of bedded limestone and a thin horizon is composed of nodular bedded limestone with shaly partings (Nielsen 1995; Fig. 3). The upper member is partly exposed in the quarries at the E20, E21a and E21b localities (Ekström 1937; Nielsen 1995). In total, the Komstad Limestone is more than 7.1 m thick at Fågelsång and may be about 7.5 m (Fig. 3).

A 0.8 m thick unit of interbedded limestone and shale conformably follows above the Komstad Limestone. Previously Ekström (1937, p. 49) referred to the beds as the 'Transition layer'. This unit is the basal member of the Almelund Shale. It is composed of both limestones and shale and is accessible at localities E21a and b, although in the latter quarry the exposures are mostly covered.

Several thin bentonite horizons are present in the upper member of the Komstad Limestone at Fågelsång, which is unusual as the preservation potential for bentonites in limestones is considered to be low. Bentonite beds are also recorded in the overlying Almelund Shale and have proved very useful for correlation (Nielsen 1995; Bagnoli & Stouge 1999).

## Methods and material

Samples from the exposed limestone beds in the E21a and E20 quarries were collected in 1972 and used for recovery of conodonts (Stouge 1975). The E21a and E21b quarries were drained and cleaned in 1983 (Nielsen 1995) and trilobites were collected bed by bed. The accessible exposures represent only part of the Komstad Limestone succession (Fig. 3). Nielsen also investigated and sampled the limestone at locality E22. The labelling of the sections and the numbering of individual beds used here (Figs 3, 6, 7) follow Nielsen (1995, figs 24 & 35).

Approximately 400 trilobite specimens were collected during fieldwork in 1983. The trilobites were collected from levels with an accuracy of  $\pm 0.5$  cm. This material was supplemented by museum specimens housed at the Geological Institute, University of Lund, the Swedish Museum of Natural History, Stockholm and the Geological Museum, University of Copenhagen. Waste rock from the trilobite preparation sampling was used for conodont extraction. Most of the conodont samples represent one bed (typically 10–15 cm). The samples collected in 1972 (Stouge 1975) are included in this study as their position could be easily established in the section. Ekström's collection of trilobites from quarry E21a (Ekström 1937) has given additional and useful information for this study.

## Biostratigraphy

The Baltoscandian chronostratigraphical scheme (Männil & Meidla 1990) is used as reference for the shelly faunas in this paper (Fig. 2). Reference to the British chronosystem and the international chronosystem follows Fortey *et al.* (1995) and Webby (1998), respectively.

## Conodonts

*Conodont zonation.* The modern conodont biozonation of the Volkhov and Kunda stages was introduced by Lindström (1971b; Fig. 4). Subsequent work (van Wamel 1974; Löfgren 1978, 1985, 1993, 1994, 1995, 2000; Stouge 1989; Stouge & Bagnoli 1990; Bagnoli & Stouge 1997; Zhang 1998a, b; Rasmussen 1991, 2001) has provided further information, improvements and additions to Lindström's zonation (Fig. 4).



Conodont zones and subzones							
Baltoscandian Platform							Baltoscandian Platform Margin
Series	Stages	Lindström 1971 Löfgren 1978, 1994, 1995			Bagnoli & Stouge 1997 Zhang 1998b		Rasmussen 2001
Oeland	Kunda	Amorpho- gnathus variabilis	Eoplaco- gnathus? variabilis	E.? var. - M. oz.	Lenodus pseudoplanus	M. ozarkodella	Microzarkodina ozarkodella
				E.? variabilis- M. flab. parva	M. hagetiana		Baltoniodus medius- Histiodella holodentata
					Yangtzeplacognathus crassus		
					Lenodus variabilis		
	Volkhov	Microzarkodina parva			Lenodus antivariabilis		Baltoniodus norrlandicus- Drepanoistodus stougei
					Baltoniodus norrlandicus		
		Paroistodus originalis		Phases 3-5	Microzarkodina parva		P. rectus - M. parva
				Phases 1-2			Periodon zgierzensis
		Baltoniodus navis		Upper	Baltoniodus navis		Microzarkodina flabellum- Drepanoistodus forceps
				Middle			
				Lower			
		Baltoniodus? triangularis		Upper	Microzarkodina flabellum		
Lower	Baltoniodus? triangularis						

Fig. 4. Lower Ordovician conodont zonation of Baltoscandia.

*Conodont fauna.* Conodonts were obtained from all the investigated beds. The preservation of the conodont elements varies from moderate in the lower part to good towards the top of the Komstad Limestone. Conodont elements from the limestone Bed E at locality E20 and Beds 1–14 from the E21 quarry (Figs 1, 3) are partly covered by silty material and identification at the species level is difficult. In total 12,499 conodont elements are identified (Table 1). The specimens are dark brown with conodont alteration index 3.5–4 (Epstein *et al.* 1977) suggesting that the host sediments have been heated to a maximum of 200°C.

Many of the conodont species recorded in this study are documented by Löfgren (1978, 1998, 1999), Dzik (1983, 1994), Stouge & Bagnoli (1990), Rasmussen (1991, 2001), Bagnoli & Stouge (1997) and Zhang (1997, 1998a). Some species are characteristic for the Scania-Bornholm region representing the areas marginal to the East European Platform (Dzik 1994; Rasmussen 2001) or are of foreign affinity. Other taxa are new or cannot at this stage be referred to one or another species with certainty because their characters are transitional to the known species. This is particularly true for *Baltoniodus* and *Lenodus* and they are referred to under open nomenclature.

Stratigraphically important taxa for correlation with the succession of the East European Platform include *Baltoniodus norrlandicus*, *Baltoniodus clavatus*,

*Lenodus antivariabilis*, *Lenodus variabilis* and *Lenodus pseudoplanus*. Other taxa such as *Dzikodus*, *Gothodus* sp. 1 (see Stouge & Bagnoli 1999, fig. 1: 22–28), *Histiodella tableheadensis*, *Periodon* and *Yangtzeplacognathus crassus* are important for long distance correlations (Stouge 1984; Rasmussen & Stouge 1988; Bagnoli & Stouge 1997; Zhang 1998b; Bergström & Zhi-Hao 1998).

*Conodont succession.* Three samples from the oldest limestone Bed E exposed at locality E22 of the Fågelsång section contain a rich conodont fauna (Figs 1, 5; Table 1). The E $\alpha$  bed includes *Baltoniodus norrlandicus*, *Microzarkodina flabellum*, *Paroistodus originalis* and *Triangulodus brevibasis* while the E $\beta$  bed includes the addition of *Lenodus antivariabilis*. *L. antivariabilis* occurs together with *Microzarkodina flabellum*, *Microzarkodina parva*, *Paroistodus originalis*, *Scalpellodus latus*, *Scalpellodus gracilis* and an undescribed species of *Drepanodus*, which is tentatively referred to as *Drepanodus* sp. 1. Restricted to the lime-

Fig. 5. Ranges of selected conodont species at Fågelsång. The complete information of the conodont distribution is given in Table 1.

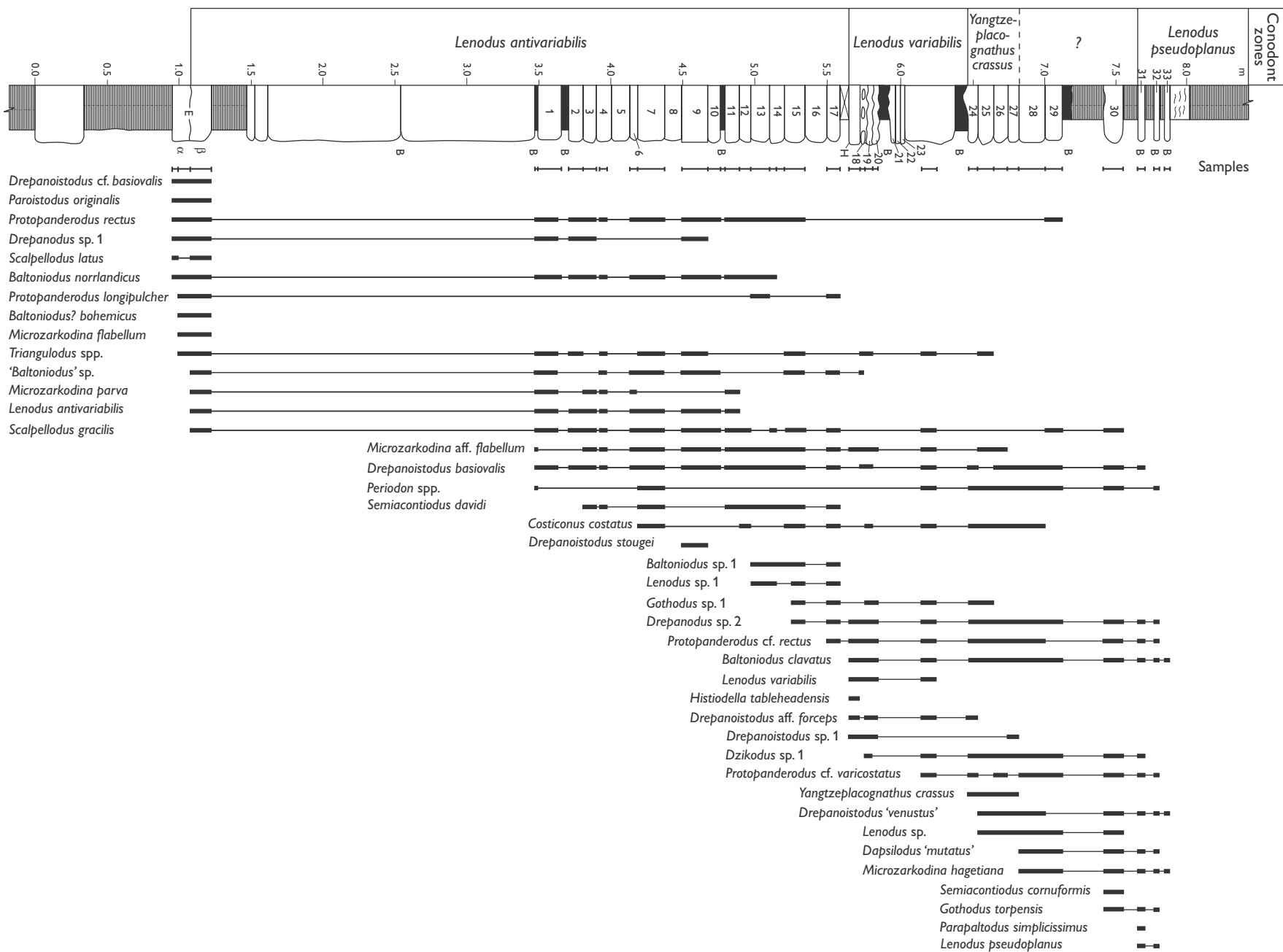


Table 1. Number of conodont elements

Taxa	Fågelsång samples																
	Bed EaL	Bed EaU	Bed Eb	Bed 1L	Bed 1U	Bed 2	Bed 3	Bed 4	Bed 6	Bed 7	Bed 9	Bed 10	D11L	Bed 11U	Bed 12	Bed 13	Bed 14L
<i>Baltionodus norlandicus</i>	10	25	173	126	139	42	115	238	117	98	228	5	8	23	19	36	
<i>Drepanodus arcuatus</i>	8	12	113	76	43	7	42	35	14	15	74	14	3	14	10	35	30
<i>Drepanodus</i> n. sp. 1	1	13	33	7	2	1	4				3						
<i>Drepanostodus</i> cf. <i>basiovalis</i>	10	61	86														
<i>Microzankodina parva</i>	1	3	33	18	3			48	27				8	15			
<i>Parastodus originalis</i>	2	3	17														
<i>Protopanderodus rectus</i>	14	4	108	141	177	40	65	50	13	39	46	10	13	67	53	46	54
<i>Protopanderodus longipulcher</i>	16	227	81														
<i>Scalpellodus latus</i>	3		2														
<i>Baltionodus</i> cf. <i>bohemicus</i>		2	61														
<i>Baltionodus</i> sp.		5	9	5	2			2	6	10		2					
<i>Decarionus</i> ? spp.		2		1							1		1	1	10		4
<i>Drepanostodus</i> cf. <i>stoupei</i>		1	21														
<i>Triangulodus</i> spp.			1	4	5	1		1		5	7						
<i>Comodus longibasis</i>			4	11	3	3	9	16	4	4	11	4	3	18	22	19	16
<i>Scalpellodus gracilis</i>			11	12	8	4	2	9	5	3	4	1	1	16	10		5
<i>Lenodus antivariables</i>			22	15	11	2	19	30	11	16	22	1	1			1	
<i>Microzankodina</i> aff. <i>finboellum</i>			12	5	4	5	25	15	4	18	34	6		6	37	15	20
<i>Pariodon</i> spp.				1						1							
<i>Drepanostodus basiovalis</i>				145	92	15	109	114	65	78	168	14	11	27	92	75	87
<i>Semiacanthodus davidi</i>							25	4					1		15	21	17
<i>Coelacanthodus costatus</i>										1					1		
<i>Drepanostodus stoupei</i>											28						
<i>Baltionodus</i> sp. 1																4	33
<i>Lenodus</i> sp. 1																	2
<i>Drepanodus</i> sp. 2																	
<i>Gothodus</i> sp. 1																	
<i>Baltionodus clavatus</i>																	
<i>Lenodus variabilis</i>																	
<i>Protopanderodus</i> cf. <i>rectus</i>																	
<i>Drepanostodus</i> sp. 1																	
<i>Histiodelphis tobolskensis</i>																	
<i>Ozarkodus</i> sp.																	
<i>Drepanostodus</i> aff. <i>forceps</i>																	
<i>Protopanderodus</i> cf. <i>varicosatus</i>																	
<i>Milaculum</i> sp.																	
<i>Yangtzeplacognathus crassus</i>																	
<i>Protopanderodus</i> sp.																	
<i>Lenodus</i> sp.																	
<i>Microzankodina</i> sp.																	
<i>Drepanostodus 'variosus'</i>																	
<i>Microzankodina hugeliana</i>																	
<i>Drepanostodus</i> sp. 2																	
<i>Lenodus pseudoplanus</i>																	
<i>Plectrodina</i> ? sp.																	
<i>Dapsilodus 'mutatus'</i>																	
<i>Semiacanthodus corniformis</i>																	
<i>Gothodus fowensis</i>																	
<i>Parapanderodus simplicissimus</i>																	
Total per sample	65	358	787	567	489	120	415	560	266	286	624	57	50	187	269	252	268
L = lower																	
U = upper																	

Table 1. Conodont abundances in the Fågelsång Section.



Bed 14a	Bed 15	Bed 17	Bed H	Bed 18	Bed 19	Bed 20	Bed 23A	Bed 24	Bed 25	Bed 26	Bed 27	Bed 28	Bed 29	Bed 30	Bed 31	Bed 32	Bed 33	Total per species
																		1398
18	40	21	23	16	13	6	27	38	99	134	86	42	34	33	15	8		1197
																		64
																		157
																		156
																		22
70	231	105																1346
																		324
																		5
	3																	86
	9	8		2														60
	5	7			1									2				35
																		22
	1		1	1	1		1	5	2	3								39
19	29	14	3		3		26			3	2	2	12	9	2			271
	82	36					3						5	9				226
																		151
14	48	20	53	24	30	30	25											448
							4	8	6	5	1	4	2	1				35
46	89	52	27	7	17	12	26	24		47	30	39	56	22	19	2		1604
14	64	69																230
	1	1			2		1	9	12	12	3	2						45
																		28
43	149	62																291
4	16	13																35
	10	11			3	6	3	7	36	23	9	6	7	11	2	1		160
	15	47			1	1	265	310	13									652
			40	25	140	70	78	72	166	182	168	279	210	73	70	26	1	1600
			50	16	8	7	11	6										98
			118	44	72	49	162	141	125	88	111	85	82	108	39	35		1259
			1	1	3	2			24									31
																		1
					2		5	4	6	6	9	2	2	3	4			43
					4	3	2	4										13
							1	1		2	3	2	2	26	6	2		45
							2						1					3
								26	75	34	4							139
								2										2
									7	4	9							20
									3									3
									2	1	5	4		1	3	2	1	19
										3	1	2	1	3	1		1	12
											13							13
													8	4	5	8	3	28
													3					3
													16	13	8	8	9	54
															7			7
															8	23	7	38
																1		1
228	792	486	340	138	300	186	642	657	676	547	453	486	430	329	201	95	3	12499

stone Bed E is the record of *Baltoniodus? bohemicus*, *Microzarkodina flabellum*, *Paroistodus originalis* and *Scalpellodus latus*.

Except for the presence of *Baltoniodus? bohemicus* and *Drepanodus* sp. 1 and perhaps *Triangulodus brevis*, the faunal assemblage from bed E $\alpha$  is known from the *Baltoniodus norrlandicus* Zone (Stouge 1989; Bagnoli & Stouge 1997; Löfgren 2000) on the East European Platform. *Triangulodus brevis*, however, is considered to be a marker for the older *Paroistodus originalis* Zone (Lindström 1971b), but this taxon has a longer range in Scania (Table 1) and Poland (Dzik 1994) than otherwise recorded from the platform. The same fauna is contained in the *Baltoniodus norrlandicus*-*Drepanoistodus stougei* Zone from the Scandinavian Caledonian margin (Rasmussen 2001).

The first appearance of *Lenodus antivariabilis* in the E $\beta$  limestone bed represents the base of the *Lenodus antivariabilis* Zone (*sensu* Bagnoli & Stouge 1997).

The next investigated interval spans Beds 1 to 17 exposed at the E21b locality (Fig. 1) (= part section D of Nielsen 1995, fig. 24). The conodont fauna from Beds 1–13 includes – in addition to species from below, i.e. *Lenodus antivariabilis* and *Baltoniodus norrlandicus* – *Costiconus costatus*, *Drepanoistodus basiovalis*, *Microzarkodina* aff. *flabellum*, *Semiacontiodus davidi* (from Bed 3), a single appearance of *Drepanoistodus stougei* (Bed 9), and sporadic occurrences of *Periodon* sp. and *Triangulodus* sp. Löfgren (1999) reported *Semiacontiodus davidi* from the Kunda Stage, but the precise biostratigraphical significance of *Semiacontiodus davidi* is not known. This interval is included in the *Lenodus antivariabilis* Zone of Bagnoli & Stouge (1997). It corresponds to the highest part of the *Microzarkodina parva* Zone *sensu* Lindström (1971b) and to Rasmussen's (2001) *Baltoniodus norrlandicus*-*Drepanoistodus stougei* Zone.

From Beds 14–15 and up to Bed 17 the yield of conodonts increases gradually (Table 1) and the preservation becomes better upwards. New taxa appear and a new faunal succession begins. The most characteristic newcomers are *Baltoniodus* sp. 1, *Drepanodus* sp. 2, *Lenodus* sp. 1 and *Gothodus* sp. 1.

The next samples were collected from the section exposed at quarry E21b (Nielsen 1995, fig. 24). New species additional to those recorded in Bed 17 appear in Bed H indicating that the faunal succession from Bed 17 continues into these higher beds of the Komstad Limestone. There is marked shift from Bed 17 to Bed H with *Baltoniodus clavatus*, *Drepanoistodus* aff. *forceps*, *Dzikodus* sp. 1, *Lenodus variabilis*, *Protopanderodus* cf. *rectus* and *Histiodela tableheadensis* as characteristic species. This indicates that Bed 17 cannot be identical to Bed H in section A' as suggested by Nielsen (1995, fig. 24), and an interval of unknown

thickness at this level is unaccounted for. (This level is faulted out in the Fågelsång-2 core). This new faunal succession, starting with Bed 14 and certainly the assemblage from Bed H, shows that the base of the *Amorphognathus variabilis* Zone of Lindström (1971b) or the base of the Kunda Stage is situated at or slightly below Bed H.

The following samples were collected from section C (Nielsen 1995, fig. 24). An interval of 0.85 m between section A' and C was not accessible for sampling. The fauna includes *Protopanderodus* cf. *varicosatus*, succeeded by *Yangtzeplacognathus crassus*, *Drepanoistodus 'venustus'* and *Lenodus* sp. *Milaculum*, a taxon of unknown zoological affinity, is also present in the interval. *Gothodus* sp. 1 dominates the fauna in Bed H and up to Bed 24, where *Lenodus variabilis* has disappeared and the interval from Bed H and up to Bed 24 corresponds to the *Lenodus variabilis* Zone.

*Yangtzeplacognathus crassus* appears in Bed 24. It is common in Beds 25 and 26 and the *Yangtzeplacognathus crassus* Zone *sensu* Zhang (1998b) is recorded from Beds 24 to 27 (Fig. 5). An interval from the upper range of *Y. crassus* to the first appearance of *Lenodus pseudoplanus* (Bed 31) cannot be assigned to a biozone with certainty in the Fågelsång succession due to the lack of index species.

*Dapsilodus 'mutatus'* and *Microzarkodina hagetiana* are recorded from Bed 28 and most species that are present in Bed 29, i.e. the top bed of the Komstad Limestone, range into Bed 30 of the basal member of the Almelund Shale (Figs 3, 5). *Gothodus torpensis* and *Semiacontiodus cornuformis* (in Bed 30 only) appear in the basal member of the Almelund Shale.

The *Lenodus pseudoplanus* Zone of Zhang (1998b) is recognised from Bed 31, where the nominate species appears; it ranges up to the top of the basal member of the Almelund Shale. *Parapaltodus simplicissimus* (in Bed 31) is a characteristic associate. The interval from bed H and to the top of the Komstad Limestone is incorporated in the *Baltoniodus medius*-*Histiodela holo-dentata* Zone of Rasmussen (2001). A decrease upwards in the number of specimens and species is characteristic of the basal limestone and shale member of the Almelund Shale and towards the top of the section (Table 1).

## Trilobites

*Trilobite zonation.* The Volkhov Stage of Sweden was divided into the *Megistaspis lata*, *Megistaspis simon* and *Megistaspis limbata* zones by Tjernvik & Johansson (1980) (Fig. 6), who also listed the trilobite faunas characteristic of these zones within the mainland of Sweden. The *Megistaspis lata* Zone was subsequently re-

named the *Megistaspis polyphemus* Zone by Nielsen (1995), who also divided the *Megistaspis limbata* Zone into two informal subzones (Fig. 6). The upper of these subzones is largely equivalent to the *Asaphus lepidurus* Zone ( $B_{III}\gamma$ ) on the inner parts of the East European Platform (Lamansky 1905; Hansen & Nielsen 2003, this volume). The trilobite distribution within the Volkhov Stage is rather poorly documented and detailed data are available only from the Finngrundet drill-core (Golf of Bothnia in Sweden), Slemmestad (Oslo region in Norway) and various localities in the Komstad Limestone area (Tjernvik & Johansson 1980; Nielsen 1995).

The Kunda Stage is also divided into three zones, viz. *Asaphus expansus*, *A. raniceps* and *Megistaspis obtusicauda* & *M. gigas* (Bohlin 1949; Jaanusson & Mutvei 1951, 1953; Jaanusson 1952, 1956, 1960, 1982; Nielsen 1995). As far as can be established these zones correspond to  $B_{III}\alpha$ ,  $B_{III}\beta$  and  $B_{III}\gamma$  in the east Baltic area (Lamansky 1905; Schmidt 1907). For a while the *A. raniceps* Zone has been referred to as *A. 'raniceps'* Zone (see Nielsen 1995 for details), but new systematic work indicates that this is in error (Bergström *et al.* 2003, this volume). Detailed data on trilobite distribution are likewise sparse for the Kunda Stage and limited mainly to the same localities as listed above. Additional information may be found in Bohlin (1949), Jaanusson & Mutvei (1951) and Jaanusson (1957, 1982). A recent study has been made of the *A. expansus* and lower *A. raniceps* zones in Västergötland (Villumsen 2001).

In the present context comparisons are made with southeastern Scania (type area of the Komstad Limestone), Bornholm, and Slemmestad, southern Norway (Fig. 1). Compared to mainland Sweden and southern Norway the *Megistaspis polyphemus*, *Megistaspis simon*, *Asaphus expansus* and *Asaphus raniceps* zones of the Komstad Limestone can be correlated with a high degree of confidence, whereas very few trilobite elements from the *Megistaspis limbata* Zone of the Scanian Confacies Belt are shared with the Swedish mainland successions. It is stressed that the Swedish trilobite zonation is not based on the range zone principle (*sensu* Salvador 1994), and neither *Megistaspis simon* nor *Megistaspis limbata* are restricted to the zone carrying their name (Nielsen 1995). In practice the concept of the Oppel biozone *sensu* Hedberg (1976) and Salvador (1994) is applied.

*Trilobite succession.* The stratigraphical ranges of selected trilobite species are shown in Figure 7. Only some of the material has been examined in detail (Nielsen 1995), and several groups will not be referred to, as they are in need of taxonomic revision.

The limestone Bed E exposed at the E22 locality

yielded only a few trilobite fragments, of which one almost certainly represents a *Nileus*. Strandmark (1902) reported *Nileus armadillo* from this level, but this identification is unlikely, because the occurrence is too low compared with the known range of the species in the region (Nielsen 1995, p. 204). It is assumed to represent the long-ranging *N. depressus schranki*.

*Megistaspis* (*M.*) *limbata* type 9 (see Nielsen 1995) is present in Bed 1 at the E21b locality. By comparison with SE Scania and Bornholm the presence of this morph defines a level not higher than the lower subzone of the *Megistaspis limbata* Zone. It ranges from the lower part of the *Megistaspis simon* Zone in the Komstad Limestone of SE Scania and Bornholm. Bed 1 also contains *Nileus depressus schranki*, which ranges throughout the Volkhov Stage on Bornholm and the *Megistaspis simon* and *Megistaspis limbata* zones in SE Scania. It is, however, relatively uncommon in the upper subzone of the *M. limbata* Zone. Well-preserved ptychopygids seem to represent *Metaptychopyge*, and may be close to *M. broeggeri*, occurring in the *A. lepidurus* Zone of Russia (Schmidt 1904). *Gog cf. explanatus* has also been found in Bed 1; this rare trilobite occurs sporadically in the middle part of the *M. limbata* Zone of the Komstad Limestone and probably also in the *M. simon* Zone (Nielsen 1995). The presence of *Niobe* (*Niobe*) *schmidtii* is highly unusual; this species is elsewhere characteristic of the *A. expansus* Zone (Nielsen 1995).

Bed 2 yielded mainly small brachiopods and only a single specimen of *Symphysurus* was found. This group is in need of a revision and currently has no stratigraphical value.

Bed 3 includes the appearance of *Megistaspis* (*M.*) *geminus*, which is characteristic of the upper subzone of the *M. limbata* Zone at Bornholm and in SE Scania, but also ranges into the very basal part of the *Asaphus expansus* Zone at the former locality. The same pattern is seen at Fågelsång, where its last occurrence is in Bed 20. It occurs together with *Nileus armadillo* and *Megistaspis* (*M.*) sp. A (aff. *M. (M.) simon*) in Bed 3. This is an early occurrence of *N. armadillo*, but the species has also been recorded at the base of the upper *Megistaspis limbata* subzone at Killeröd in SE Scania (Nielsen unpubl. data). *Megistaspis* (*M.*) sp. A (aff. *M. (M.) simon*) also appears in the upper part of the *Megistaspis limbata* Zone in SE Scania and on Bornholm; here it ranges into the basal part of the *Asaphus expansus* Zone.

Three specimens of *Nileus implexus* in the collection of the University of Lund were collected by Ekström. According to the label they are from bed I:k *sensu* Ekström (1937) (= Bed 7 of this paper). The species has otherwise been found in the *A. expansus* and

*A. raniceps* zones at Fågelsång and Killeröd. *Niobe* (*Niobe*) *tjernviki* turns up in Bed 9. Just like the presence of *Niobe* (*N.*) *schmidt*i in Bed 1 this is an unusually early occurrence. Elsewhere in the Komstad Limestone domain the species is characteristic of the *A. expansus* and *A. raniceps* zones (Nielsen 1995). Fågelsång is the only locality in Baltoscandia known so far where species of *Niobe* (*Niobe*) occur in the Volkhov.

Sparse material of *Lonchodomas volborthi* from Bed 9 has been reinvestigated by Hansen (2002). According to him it represents *L. v. schmidt*i rather than *L. v. volborthi*, as indicated previously by Nielsen (1995). Hansen also revised the Norwegian material, sampled by Nielsen (1995) and suggested that only the specimens from the upper part of the *M. limbata* Zone and higher should be identified as *L. v. schmidt*i. In the Russian Lynna section (Hansen & Nielsen 2002, 2003) this subspecies occurs from the uppermost part of the *A. lepidurus* Zone and higher. The occurrence at Fågelsång thus indicates a level not below the uppermost part of the *M. limbata* Zone.

Ptychopygids are common in Bed 9 and seem to represent a species different from the *Metaptychopyge* in Bed 1. However, '*Ptychopyge*' (*sensu lato*) is in need of a thorough revision. In Bed 9 also occur representatives of *Cyrtometopus*, *Pterygometopus*, *Bornholmsaspis*, *Cybele* and *Pliomera*.

Only a limited quantity of limestone was available from Beds 10–17, and no search was made for trilobites. An interval of unknown thickness is missing between Beds 17 and H.

Trilobite zones and subzones			
Series	Stages	Tjernvik & Johansson 1980 Nielsen 1995, Bergström et al. this volume	
Oeland	Kunda	<i>Asaphus raniceps</i>	
		<i>Asaphus expansus</i>	
	Volkhov	<i>Megistaspis limbata</i>	Upper
			Lower
		<i>Megistaspis simon</i>	
		<i>Megistaspis polyphemus</i>	

Fig. 6. Middle Ordovician trilobite zonation of Baltoscandia.

A plexus of new trilobites appears in Bed 18 marking the base of the *Asaphus expansus* Zone. The main part of the rich fauna described by Angelin (1851–1878) is from this richly fossiliferous level. The *Asaphus expansus* Zone is characterised by *Asaphus* (*A.*) *acuminatus* at Fågelsång, on Bornholm and in south-eastern Scania (Nielsen 1995). At Slemmestad, southern Norway, this species ranges into the basal part of the *Asaphus raniceps* Zone. *Ampyx nasutus* and *Megistaspis* (*Megistaspidella*) *extenuata* are characteristic species not known from levels below the *A. expansus* Zone. They are widely distributed in Baltoscandia (Nielsen 1995); *A. nasutus* has subsequently also been found to mark the base of the *A. expansus* Zone at Kinnekulle, Västergötland (Villumsen 2001), and the same seems to be the case in the east Baltic area. *A. nasutus* has a long range upwards, whereas *M. (M.) extenuata* typically is restricted to the *A. expansus* Zone. It appears, however, to range into the basal part of the *A. raniceps* Zone at Kinnekulle, Västergötland (Villumsen 2001).

*Nileus armadillo* and *N. latifrons* are common in the basal part of the *A. expansus* Zone at Fågelsång, which is another characteristic pattern shared with SE Scania and Bornholm. The latter species is present just below the *Megistaspis limbata*/*Asaphus expansus* zonal boundary on Bornholm and just above the zonal boundary in SE Scania; it ranges into the basal part of the *A. raniceps* Zone at Kinnekulle, Västergötland (Villumsen 2001). *Cnemidopyge costatus* subsp. A occurs in the basal part of the *Asaphus expansus* Zone at Fågelsång as well as on Bornholm. Månsson (2000) suggested that this form represents a new species. Representatives of *Phacops* have been found in Beds 19–22.

The basal beds (Beds 18–20) of the *Asaphus expansus* Zone in the Fågelsång section are known for the prolific presence of *Cyclopyge umbonata* (Moberg 1907; Poulsen 1936). The same species is recorded from the base of the *Asaphus expansus* Zone on Bornholm (Nielsen 1995).

Upwards, the faunal content becomes very sparse in the Fågelsång section and the upper part of the *Asaphus expansus* Zone is characterised mainly by *Asaphus* sp. A. This form is most likely identical to *Asaphus* n. sp. Johansson, 1980 (in Tjernvik & Johansson 1980), which characterises the upper *Asaphus expansus* Zone in Sweden. *A. sp. A* and *A. n. sp. sensu* Johansson may be identical to *A. incertus* from the upper part of the *A. expansus* Zone of the Oslo area (cf. Nielsen 1995).

*Asaphus* sp. A is replaced within Bed 25 by *Asaphus* (*A.*) '*maximus*'. The associated taxa *Nileus implexus* and *Iliaenus schuberti* occur in southeastern Scania together with *Asaphus* (*A.*) *striatus*, *Asaphus* (*A.*) *raniceps*, *Megi-*



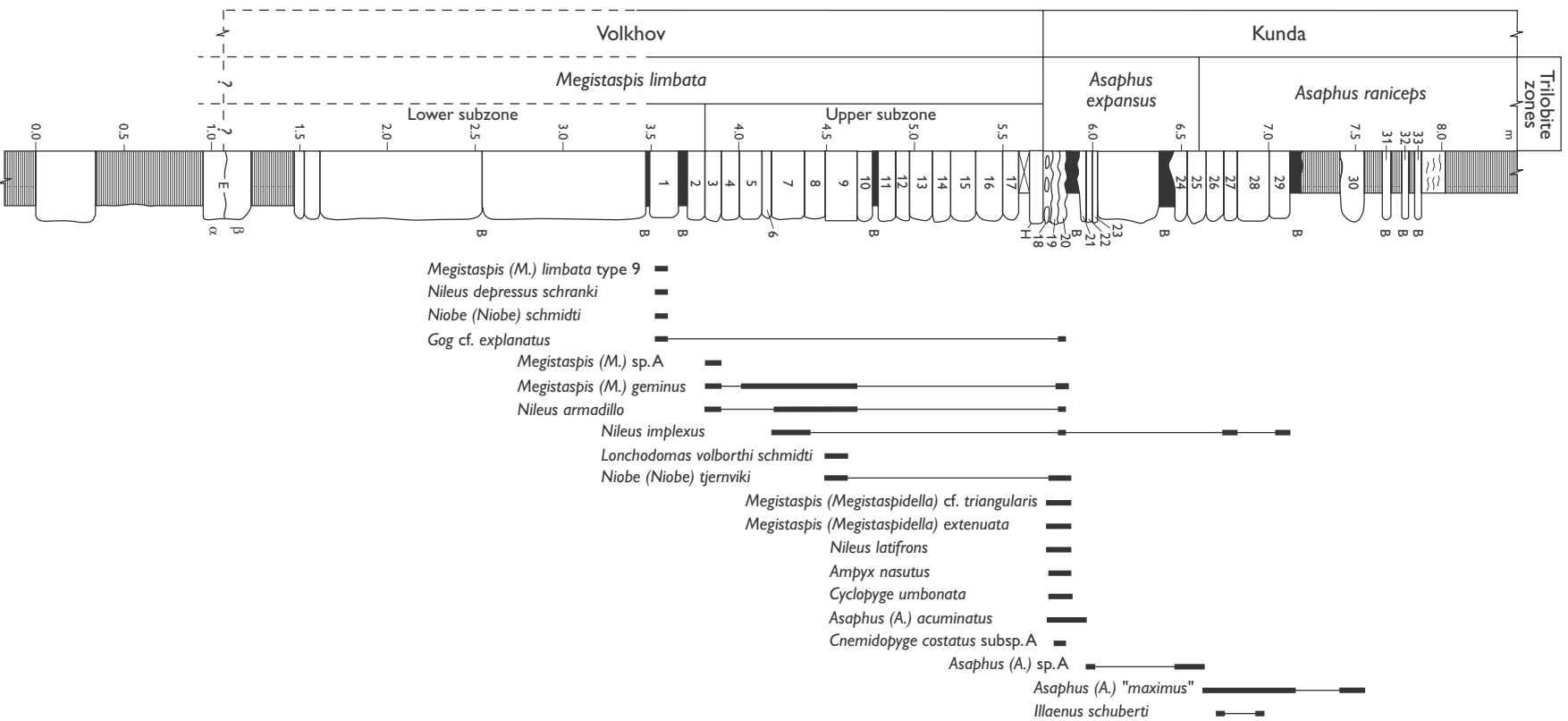


Fig. 7. Ranges of selected trilobite species at Fågelsång (modified from Nielsen 1995).



*staspis* (H.) cf. *heroica* and *Iliaenus aduncus*, which are all characteristic constituents of the *Asaphus raniceps* Zone of Sweden and southern Norway. A few specimens of *Cyrtometopus* have been found in Beds 28–29. Hence, the top part of the Komstad Limestone at Fågelsång represents the *Asaphus raniceps* Zone.

A juvenile pygidium from Bed 30 most likely represents *Asaphus* (A.) '*maximus*' suggesting that the lower member of the Almelund Shale with interbedded thin limestones is also within the *Asaphus raniceps* Zone. A specimen of *Bergamia johanssoni* was found in Bed 30. The material described by Owen (1987) indicates that this species ranges from the lower part of the *A. expansus* Zone at Fågelsång, but it has not been recorded below Bed 30 during the present study.

## Graptolites

**Graptolite zonation.** The graptolite faunas of the Tøyen Shale have been described by many authors. Monsen (1937) established a zonation that was subsequently modified and emended by Tjernvik (1956), Erdtmann (1965), Lindholm (1991a) and Maletz *et al.* (1997). For a correlation with successions elsewhere, see Cooper & Lindholm (1990).

Ekström (1937) introduced a graptolite zonation for the Llanvirn Series in the Scanian region, which is currently used in Scandinavia in a slightly modified form (Maletz 1995, 1997b).

**Graptolite succession.** The Tøyen Shale in the Fågelsång area is poorly known. A fault in the Fågelsång-1 core cuts out most of the Komstad Limestone and the Tøyen Shale (see Hede 1951). Only the lower part of the Tøyen Shale was preserved in the core, comprising 0.3 m without graptolites (by Hede 1951 referred to as Ceratopyge shale) and 4.1 m that was correlated with the *Didymograptus balticus* and *Phyllograptus densus* zones. Lindholm (1981) assigned the highest level of the Tøyen Shale preserved in the Fågelsång-1 core to the upper part of the *Phyllograptus angustifolius elongatus* Zone; subsequently the interval was assigned to the *Didymograptus hirundo* Zone (Lindholm 1991a). In the new drill-core, Fågelsång-2, the Tøyen Shale is cut by a number of faults, and the true stratigraphical thickness cannot be established. The drilled thickness is 7.1 m between the base of the Komstad Limestone and the top of the Ceratopyge Limestone. This must be regarded as a minimum thickness. Most of the unit seems to be of *D. hirundo* Zone age, judging from Lindholm (1991a).

The graptolite fauna, which Strandmark (1902) described, occurs within the lower member of the Komstad Limestone at the E22 locality (Fig. 8). Cooper

& Lindholm (1985) revised Strandmark's graptolite material and according to these authors *Tetragraptus* (T.) cf. *serra*, *Tetragraptus* (T.) *bigbyi* and *Pseudoclimacograptus* sp. occur below the limestone here referred to as Bed E (= Bed B of Strandmark 1902) (Fig. 8). *Phyllograptus cor* and extensiform didymograptids are present in the shales above the limestone bed (Strandmark 1902; Cooper & Lindholm 1985, p. 284; Fig. 8). *Glyptograptus* sp. is also reported from this locality, but the precise position of the fossiliferous horizon is unknown (Cooper & Lindholm 1985).

A correlation between Fågelsång and the Tøyen Shale in the Lovisefred core (Fig. 1) described by Nilsson (1984) is possible. In the Lovisefred core *Tetragraptus bigbyi* is common in the interval 466–475 m and *Phyllograptus cor* ranges from 462 m to 463 m (Nilsson 1984; Cooper & Lindholm 1985). The level with *Phyllograptus cor* is referred to the Darriwilian 1 (Mitchell & Maletz 1995), which is within the upper part of the *Didymograptus hirundo* Zone.

Graptolites are not present in the upper member of the Komstad Limestone. The graptolite fauna found immediately above the basal limestone and shale member of the Almelund Shale in the Fågelsång succession (Ekström 1937; Hede 1951) is referred to the *Holmograptus lentus* graptolite Zone (Lower Llanvirn; Maletz 1995, 1997a).

The boundary between the Arenig and Llanvirn (Fortey *et al.* 1995) lies either at the top of or within the Komstad Limestone (see Jaanusson 1960, p. 345; Skevington 1963, 1965; Kohut 1972 and Owen *et al.* 1990, p. 12 for a discussion). The correlation of the bentonite levels in the Lovisefred core with those preserved in the limestone at Fågelsång suggests that the *Didymograptus hirundo*/*Didymograptus artus* graptolite zonal boundary corresponds to a level close to the top of the Komstad Limestone, and probably at the limestone and shale transition (Nielsen 1995). It thus appears that the Arenig/Llanvirn boundary matches a level slightly above the base of the *A. raniceps* trilobite Zone and approximates the boundary between the *Yangtzeplacognathus crassus* and the *Lenodus pseudoplanus* conodont zones. This correlation of bentonites can be extended farther onto the East European Platform (Bagnoli & Stouge 1999).

## Integration and correlation of the trilobite, conodont and graptolite zonation at Fågelsång

Bed E at locality E22 represents the *Baltoniodus norrlandicus*-*Lenodus antivariabilis* zonal boundary (Fig. 9).

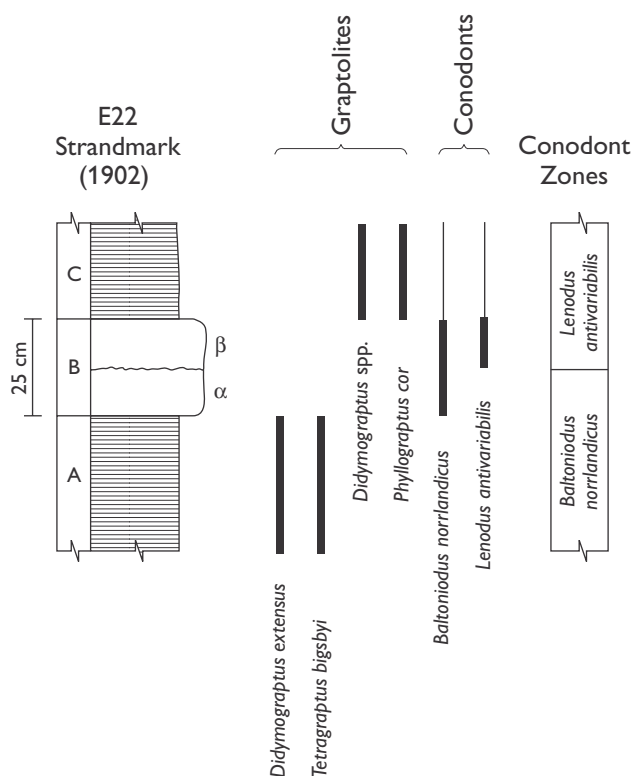


Fig. 8. Detail from locality E22 showing the ranges of selected graptolite and conodont species. Data from Strandmark (1902) and Cooper & Lindholm (1985). The Beds A, B and C are those of Strandmark (1902). Strandmark's (1902) Bed B corresponds to Bed E of Nielsen (1995) and this paper.

As mentioned above, diagnostic trilobites were not recovered from this limestone horizon, but a position in the uppermost part of the *Megistaspis simon* or the lower part of the *M. limbata* Zone is anticipated (Nielsen 1995). The lower graptolite fauna with *Tetragraptus bigsbyi* is recorded from the *Baltoniodus norrlandicus* Zone and the succeeding fauna with *Phyllograptus cor* appears in the lower part of the *Lenodus antivariabilis* Zone, i.e. probably near the base of the *Megistaspis limbata* trilobite Zone (Fig. 9).

The higher Beds 1–2 from the E21a quarry belong to the lower subzone of the *Megistaspis limbata* trilobite Zone, which is contained within the *Lenodus antivariabilis* conodont Zone.

The upper subzone of the *Megistaspis limbata* Zone starts at Bed 3. The conodont species do not change at this boundary, where the conodont faunal succession across the subzonal boundary is composed a.o. by the co-occurrence of *Baltoniodus norrlandicus* and *Lenodus antivariabilis*. '*Semiacontiodus*' *dauidi* however is a rare but notable newcomer at this level.

The interval from Beds 14–17 with the beginning of a new conodont faunal succession is included in the uppermost *Megistaspis limbata* Zone. Based on the

information above correspondence between the *Megistaspis limbata* trilobite Zone and the *Lenodus antivariabilis* conodont Zone is likely.

In the Fågelsång section, *Baltoniodus clavatus* and *Lenodus variabilis* characterise the *Asaphus expansus* trilobite Zone. The conodont fauna of the *A. expansus* Zone is also characterised by the dominance of *Gothodus* sp. 1. *Dzikodus* sp. 1 and *Histiodela tableheadensis* appear in the zone.

The *Asaphus expansus*/*Asaphus raniceps* zonal boundary is positioned in the middle of Bed 25. In terms of conodonts, the trilobite zonal boundary is marked by the first appearance of *Lenodus* sp. and by the disappearance of *Lenodus variabilis*. *Yangtzeplacognathus crassus*, the defining species of the range zone, appears just below the trilobite zonal boundary and it ranges into the basal portion of the *Asaphus raniceps* Zone. *Gothodus torpensis* appears in the *A. raniceps* Zone and is recorded previously from the marginal deposits of the Scandinavian Caledonides (Rasmussen 2001).

The correlation is summarised in Figure 9.

## Concluding remarks

The upper Volkhov – lower Kunda deposits of the Fågelsång section at the margin of the East European Platform are characterised by shales and carbonate facies that indicate accumulation on the outer shelf. The carbonates, known as the Komstad Limestone, represent a shoaling interval that interrupted the dysoxic environment characterised by hemipelagic, graptolitic shales.

By means of an integrated biostratigraphical analysis of the section, two main objectives were targetted: (1) Development of a precise and detailed biostratigraphical framework for the conodont and trilobite zones and (2) a detailed dating of the change from cool water conditions with incoming of Gondwanan faunal elements to the relatively warmer water conditions with the arrival of Whiterockian (Tableheadian) faunal components typical of the Iapetus Ocean.

The conodont assemblage from the *Megistaspis limbata* Zone in the lower part of the Fågelsång section has a marked Gondwanan component. *Baltoniodus? bohemicus* and *Drepanodus* sp. 1 are neither known from the East European Platform nor from the marginal deposits of the Scandinavian Caledonides that faced the Iapetus Ocean (Rasmussen 2001). The former taxon has been described from the Barrandian Klabava Formation in Bohemia (Dzik 1983), whereas the latter is a new species.

The appearance in the *Asaphus expansus* Zone of

Balto-scandian stages	Fågelsång			British graptolite zones	British series
	Trilobites	Conodonts	Graptolites		
Kunda	<i>Asaphus raniceps</i>	<i>Lenodus pseudoplanus</i>	<i>Holmograpthus lentus</i>	<i>Didymograptus artus</i>	Llanvirn
		?			
	<i>Asaphus expansus</i>	<i>Yangtzeplacognathus crassus</i>			
Volkhov		<i>Lenodus variabilis</i>	no data		Arenig
	<i>Megistaspis limbata</i>	<i>Lenodus antivariabilis</i>		<i>Didymograptus hirundo</i>	
	Upper				
	Lower		<i>Phyllograptus cor</i>		
	?		?		
	<i>Megistaspis simon</i>	<i>Baltoniodus norrlandicus</i>			

Fig. 9. Integrated correlation of graptolite, trilobite and conodon biozones and the probable position of the Arenig-Llanvirn Series boundary.

*Dzikodus* and *Histiodela* is associated with the *Gothodus* sp. 1 and *Cyclopyge umbonata* acmes. *Dzikodus* and *Histiodela* are well known genera from the Toquima-Table Head Faunal Realm, which characterised the marginal deposits of Laurentia (Ross & Ingham 1970; Stouge 1984). The record of Table Head conodonts at this level has also been reported from the marginal deposits of the Scandinavian Caledonides (Rasmussen & Stouge 1988, 1995; Rasmussen 2001). The appearance and immigration of the Table Head conodonts characterises the base of the Kunda Stage in the Fågelsång section and marks the beginning of a transgression onto the Baltica palaeocontinent (Rasmussen & Stouge 1988, 1995).

*Yangtzeplacognathus crassus* occurring within the *Asaphus raniceps* Zone is considered to be a migrant species as it disappears as fast as it appears. It is known from South China and similar to the Fågelsång section, it has a short range on the East European Platform (Zhang 1998a, b). This taxon is not recorded from the marginal deposits of the Scandinavian Caledonides (Rasmussen 2001) nor is it known

from Laurentia. Hence, the appearance of the species along with Laurentian species in the Komstad Limestone at Fågelsång and farther on to the East European Platform remains a puzzle. The later record of species, e.g. *Microzarkodina hagetiana* and *Dapsilodus 'mutatus'* from the top of Komstad Limestone is within the *Asaphus raniceps* Zone and this is identical to the faunal succession on the East European Platform.

The trilobite fauna is generally comparable to the Komstad Limestone faunas of SE Scania and Bornholm, and the zonation can be defined with a high degree of confidence. The early occurrence of *Niobe* (*Niobe*) species as well as *Nileus implexus* are puzzling and point to special palaeoecological conditions in the Fågelsång area. The diversity of genera/species in the lower part of the upper subzone of the *Megistaspis limbata* Zone is also comparatively high in the Fågelsång area; this will become more obvious when the total fauna is eventually revised. These trends indicate a comparatively shallow-water environment at this stratigraphical level. The sparse faunas of the higher part of the *A. expansus* Zone and the *A. raniceps* Zone point to a relatively deep depositional environment in the Fågelsång area.

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