

# Brachiopod bio- and ecostratigraphy in the lower part of the Arnestad Formation (Upper Ordovician), Oslo Region, Norway

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The aim of the present study is to improve knowledge of the brachiopod fauna in the lower part of the Arnestad Formation (Caradoc) in the Oslo-Asker district and to document faunal changes prior to the Scoto-Appalachian brachiopod migration into the Oslo Region. This migration appears to have taken place during deposition of the upper Haljala and Keila stages (Lower Caradoc). Like the faunas in other parts of Baltica, the brachiopod fauna in the lower part of the Arnestad Formation, occupied an environment influenced by moderate current or wave regimes. It has a lower diversity than the more cosmopolitan brachiopod fauna in the upper part of the formation. The fauna in the lower part of the Arnestad Formation is, however, more diverse than the equivalent Swedish faunas in the Scania Confacies Belt ("Outer facies belt"). The closest affinity, at the generic level, is with the faunas from the Livonian Tongue of the Central Baltoscandian Confacies Belt ("Middle facies belt"). The *Onniella-Chonetoides* association, known from deep-water facies, appeared for the first time in the Oslo Region during the early Haljala stage. The lower boundary of the Arnestad Formation is diachronous, becoming younger towards the west. When comparing faunas and environmental indicators in the studied sections, it appears that the western most locality (Vollen) was located in a more shallow-water environment with a more marked current or wave-dominated regime than that of the eastern locality.

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## Introduction

The Ordovician brachiopods of the Oslo Region are locally abundant, diverse and well preserved, providing a near-continuous record of faunal change on and around one of the key Early Palaeozoic cratonic areas. Particularly significant were changes in the brachiopod fauna, during the Mid and Late Ordovician (Caradoc-Ashgill), when Baltica rapidly moved into lower latitudes (Torsvik 1998). To date, the most extensive studies on the Caradoc brachiopods from the Arnestad Formation in the Oslo Region are those in Holtedahl (1916) and Spjeldnæs (1957), both focused on strophomenides; Vinn & Spjeldnæs (2000) have described clitambonitides and Harper (1986) listed all genera found in the formation. Harper (1986) noted an abrupt faunal change near the base of the Arnestad Formation, concurrent with the immigration of a Scoto-Appalachian brachiopod fauna into the deeper parts of the basin. An unpublished cand. scient. thesis (Webb 1990) exists on faunadynamics in the upper part of the formation, with special focus on the brachiopods.

The upper part of the Arnestad Formation, lies above a thick K-bentonite bed correlated with the Kinnekulle K-bentonite in Sweden (see Bergström et al. 1995). It is exposed in many places in the Oslo Region where it is fairly well documented, in contrast to the lower part of the formation between the underlying Vollen Formation and

the K-bentonite bed which is poorly known due to insufficient exposure. The best, previously-described exposure is the railway section at Sinsen, Oslo, which according to Hagemann and Spjeldnæs (1955) exposed the entire formation. This has not been further studied because of the dangers of collecting close to a busy railway line.

This paper describes and discusses the distribution of the brachiopods and the other groups of macrofossils recorded from the lower part of the Arnestad Formation exposed on the island of Persteilene (Grid reference 32VNM904321 in WGS84) and at the lower boundary stratotype at Vollen Boat Club (Grid reference 32VNM838308 in WGS84) (Fig. 1). Grid references can be found on the 1:50 000 topographic map sheet M711 Asker 1814 I (2006). A list of the recorded brachiopods and other macrofossils is presented in Table 1. The fossils in the two sections studied provide information on the faunal composition prior to the immigration of the Scoto-Appalachian fauna into the Oslo Region during early Caradoc. This immigration has been discussed by Harper (1986) and others.

## Geological setting and stratigraphy

The Ordovician rocks of the Oslo Region are, today, essentially confined within the Carboniferous-Perm-

ian graben (see Dons & Larsen 1978; Sundvoll & Larsen 1994), but were originally deposited in a cratonic basin or depression situated near the western border of Baltica (Bruton & Harper 1988). The depression was more or less N-S orientated with shallower sedimentary facies occurring west of the central Oslo area and likewise in Sweden (e.g. Størmer 1967; Jaanusson 1982; Bruton, Lindström & Owen 1985; Harper 1986; Sundvoll & Larsen 1994). The deposits in the Oslo Region are subdivided into several confacies belts, characterized both by lithology and faunal composition, across which it is often difficult to correlate (e.g. Harper 1986). During deposition of the Arnestad Formation, however, extensive volcanic activity west of the basin resulted in abundant ash-falls covering large areas of Baltica (e.g. Bruton et al. 1985). Today these

are exposed as K-bentonite layers, which can be correlated over much of Baltoscandia (Bergström et al. 1995). The name Arnestad Formation was first used, informally, by Harper (1986), to include the Lower Chasmops Shale, Stage 4b $\alpha$ , first described by Brøgger (1890) (A "stage" was based on a combination of lithology and fossil content). The lithology of the formation was described by Størmer (1953), who also commented on the occurrence of some of the more characteristic species. The formation was formally defined by Owen et al. (1990).

The siliciclastic, mudstone-dominated Arnestad Formation succeeds the limestone-dominated Vollen Formation and is succeeded by the limestone-dominated Frognerkilen Formation (Fig. 2). To the southwest it correlates with the limestone-dominated Fossum Formation and to the northwest with the shaly part of the Furuberget Formation (Owen et al. 1990). Brøgger (1890) estimated the maximum thickness of the Arnestad Formation to be 40–45 metres in the Asker District, whilst Hagemann and Spjeldnæs (1955) measured the complete Arnestad Formation at Sinsen in Oslo to be 35 metres thick. The lower part of the formation is, when compared to the upper part, characterized by fewer and thinner nodular limestone and limestone beds and by the frequent K-bentonite layers named the Grefsen K-bentonite complex. The lowermost part of the Arnestad Formation up to the top of the Grefsen K-bentonite complex is equivalent to the Idavere Substage of the Haljala Stage while the rest of the formation correlates with the Jöhvi Substage and Keila Stage (cf. Bergström et al. 1995; Nielsen 2004) (Fig. 2).

The lower boundary of the Arnestad Formation was fixed at the level where the limestone horizons become subordinate to the dark siliciclastic mudstones (Owen et al. 1990). The stratotype at the Vollen Boat Club represents about 8 metres of the Arnestad Formation (Figs 3 and 4). The other section, on a beach on Persteilene at the opposite side of the fjord, about 6.5 km east of Vollen, exposes more than 33 metres of the formation (Figs 5 and 6). Both sections include equivalents of the lower part of the Haljala Stage, the Idavere Substage. The measured thickness makes the formation at least 60 metres thick, as the upper part of the formation, including part of the Jöhvi Substage, is about 28 metres thick at Vollen.

**Table 1.** Fossil taxa found in the uppermost part of the Vollen Formation and the lower part of the Arnestad Formation exposed in the two sections located in the Oslo-Asker district. Numbers are total numbers of collected specimens.

	Vollen Boat Club	Persteilene
<b>Brachiopoda</b>		
" <i>Lingulella</i> " spp.	63	46
<i>Paterula</i> sp.	0	12
Discinoidea? indet.	0	1
<i>Conotreta?</i> sp.	3	1
<i>Acanthambonia</i> sp.	0	1
Lingulata indet.	114	75
<i>Pseudopholidops</i> sp.	2	0
<i>Gorudia glabrata</i> Spjeldnæs	100	96
<i>Leangella (Leptestiina)</i> sp.	108	1
<i>Chonetoides alpha</i> Spjeldnæs	526	35
<i>Septorthis</i> sp.	549	647
<i>Onniella bancrofti</i> Lindström	65	252
<b>Conulata indet.</b>	<b>0</b>	<b>4</b>
<b>Echinodermata indet.</b>	<b>14</b>	<b>204</b>
<b>Graptolithina indet.</b>	<b>126</b>	<b>15</b>
<b>Machaerida indet.</b>	<b>1</b>	<b>0</b>
<b>Mollusca</b>		
Bivalvia indet.	5	25
Cephalopoda indet.	3	0
Gastropoda indet.	17	22
<b>Ostracoda indet.</b>	<b>205</b>	<b>31</b>
<b>Trace fossils</b>		
<i>Chondrites</i> isp.	+	+
<i>Planolites</i> isp.	1302	591
Indet.	3	1
<b>Trilobita indet.</b>	<b>1821</b>	<b>676</b>

## The sediments

The Arnestad Formation consists of dark grey, siliciclastic fissile mudstones with intercalated, thin beds or nodular beds of calcareous mudstone and wackestone and some K-bentonite beds including the Kinnekulle K-bentonite in the upper half. Some of the thin beds of calcareous mudstone changes laterally into nodular beds. Internal depositional features are generally lacking and even though visible trace fossils are difficult to discern in exposures, the beds appear extensively bioturbated in thin sections. A

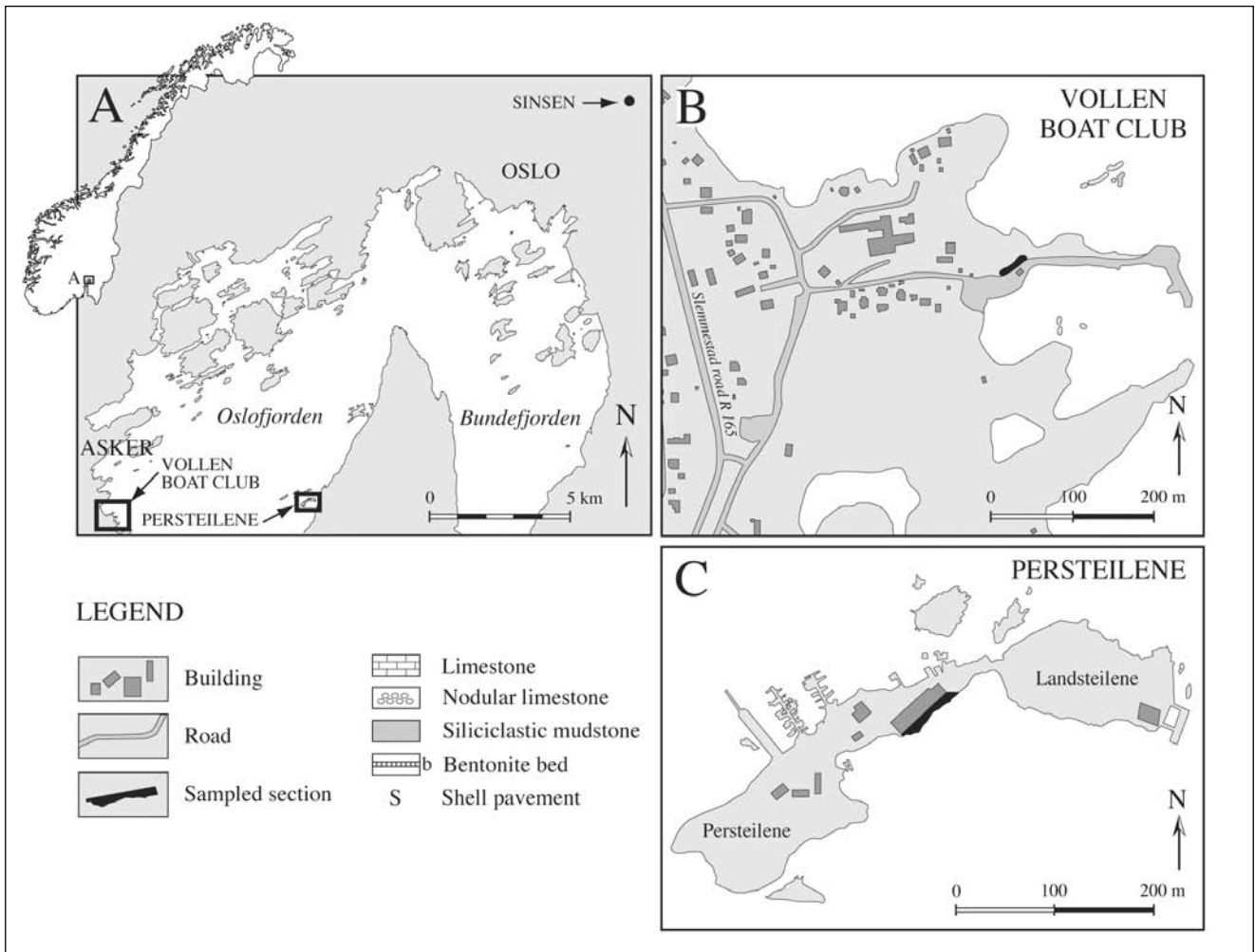


Fig. 1. A. The Oslo fjord with studied localities at Vollen Boat Club and Persteilene; B. Location of the section at Vollen Boat Club (32VNM838308); C. Location of section on Persteilene (32VNM904321). Strata are in both cases dipping to the south with the oldest part to the north. Legend includes symbols for figures 3 to 9.

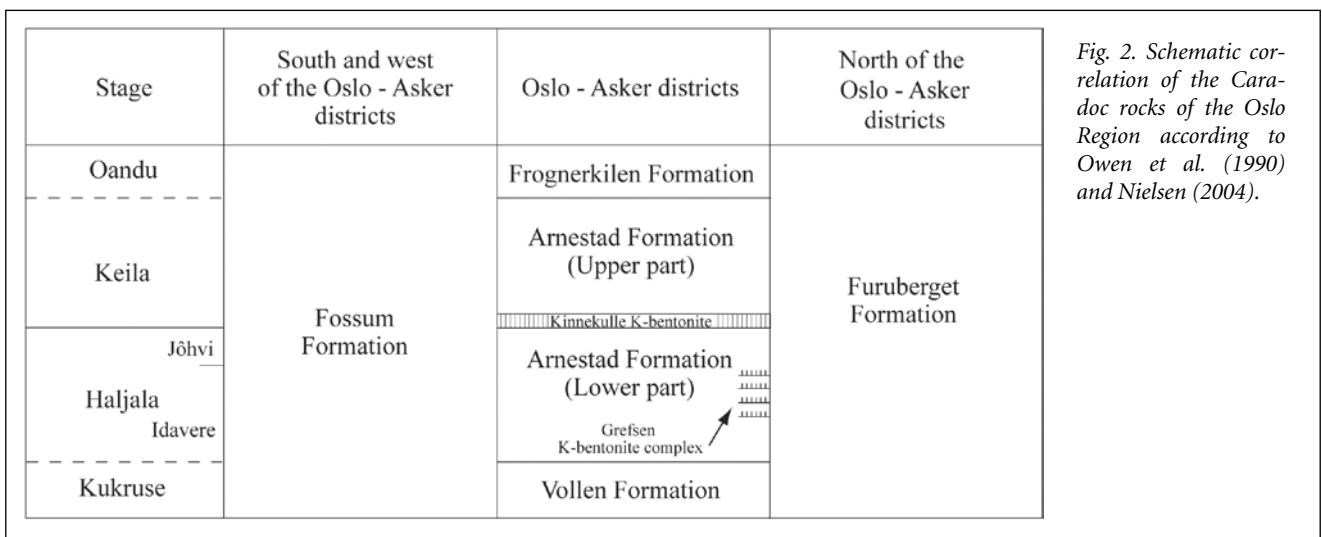


Fig. 2. Schematic correlation of the Caradoc rocks of the Oslo Region according to Owen et al. (1990) and Nielsen (2004).

sedimentological study on the upper part of the Arnestad Formation, closely comparable to the lower part, has been published by Möller & Kvingan (1988).

Fossil remains generally show no preferred orientation along the bedding planes. Exceptions are four horizons

with shell pavements, occurring from 18 to 22.5 metres above the base in the Persteilene section, in which most fossils are orientated with the convex side up. Scattered phosphate pebbles and phosphatized fossils (mostly echinoderm fragments and gastropods) are found in the siliciclastic mudstone on Persteilene in strata between

11.3 m to 19.7 m above the base of the section and at Vollen in strata between 5.9 m to 6.6 m above the base of the measured section.

Thin section studies of the carbonate concretions have shown the presence of poorly preserved flexus, tubular filaments of uniform diameter (~10 µm) composed of relatively thick, calcareous walls. The filaments may be isolated, but usually they occur in groups, twisted together to form loose aggregates up to 25 times as wide as the width of a single filament. The filaments have tentatively been classified as cyanobacteria belonging to the genus *Girvanella*. Their preservation is, however, too poor to give a real idea of their abundance in the sediment.

### Methods

This study is based on examination of skeletal remains in bulk samples of siliciclastic mudstone from beds throughout the exposed sections. Depending on the exposure, bulk samples normally contained at least 1000 g of sediment. The siliciclastic mudstones normally split up in to thin plates whereas the calcareous mudstone tends to split in to blocks, which had to be cut down in size to get a fair idea of their content of fossils. All macrofossil remains on the sample surfaces were counted. The counts were made under a binocular microscope. Following the discussion on methods in Jaanusson (1979, 1984) no recalculations of the faunal composition using arbitrary figures for different skeletal elements have been attempted. Instead the numbers of counted fossils and fossil fragments are illustrated in Figures 3 to 6 as valves and fragments per 1000 g of sediment. To get a general picture of the variations in fossil densities up through the sections, the siliciclastic deposits were chosen for sampling in all but one case (at the 8 metres level in the

stratotype where the surrounding siliciclastic beds were too difficult to sample), as they generally yield more brachiopods per unit weight than the limestone beds. Even though there are differences in density of brachiopods between the two rock types, examination of small samples of nodular limestone beds and observations in the field did not suggest any significant differences in faunal composition. The faunal diversity does not seem to have been affected by the differing sample sizes. This was verified firstly by counting the fossils in control-samples from some of the beds and comparing the resulting numbers with those of the original samples. Secondly, by observing the vertical change in abundances through the sections.

The numbers of trace fossils counted in each bed should not be taken as the numbers of specimens as each part of a trace fossil is counted as one. These counts do, however, give a picture of the vertical changes in the relative numbers of pyritized trace fossils.

### Faunal distribution

The occurrence of the brachiopod taxa and the other macrofossil groups in the two studied sections are shown in Figures 3 to 6.

#### The brachiopod fauna

The brachiopod fauna in the lower part of the Arnestad Formation consists of five rhynchonelliformean, one craniiformean and at least five linguliformean species. All lingulid fragments that are too poorly preserved for identification are referred to as *Lingulata indet.* "*Lingulella*" spp. is a new genus closely related to *Lingulella* Salter, and is thus placed in quotation marks. Generally, the lingulides appear to have been of minor, numerical

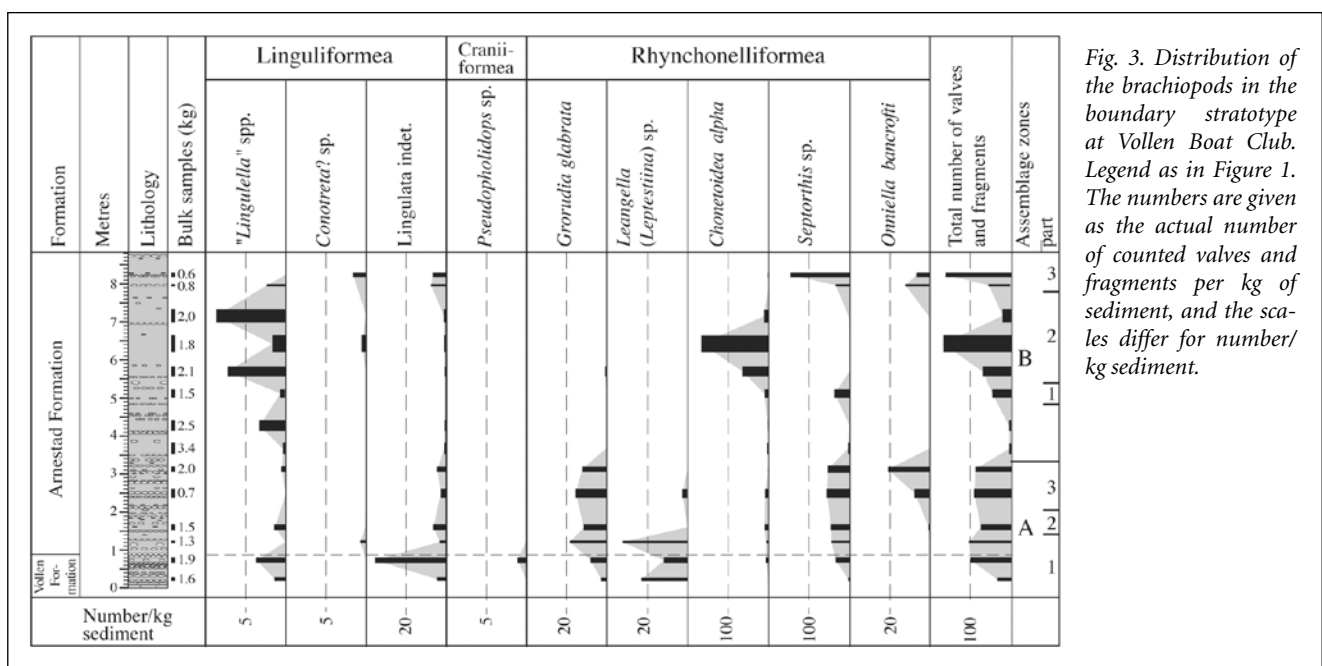


Fig. 3. Distribution of the brachiopods in the boundary stratotype at Vollen Boat Club. Legend as in Figure 1. The numbers are given as the actual number of counted valves and fragments per kg of sediment, and the scales differ for number/kg sediment.



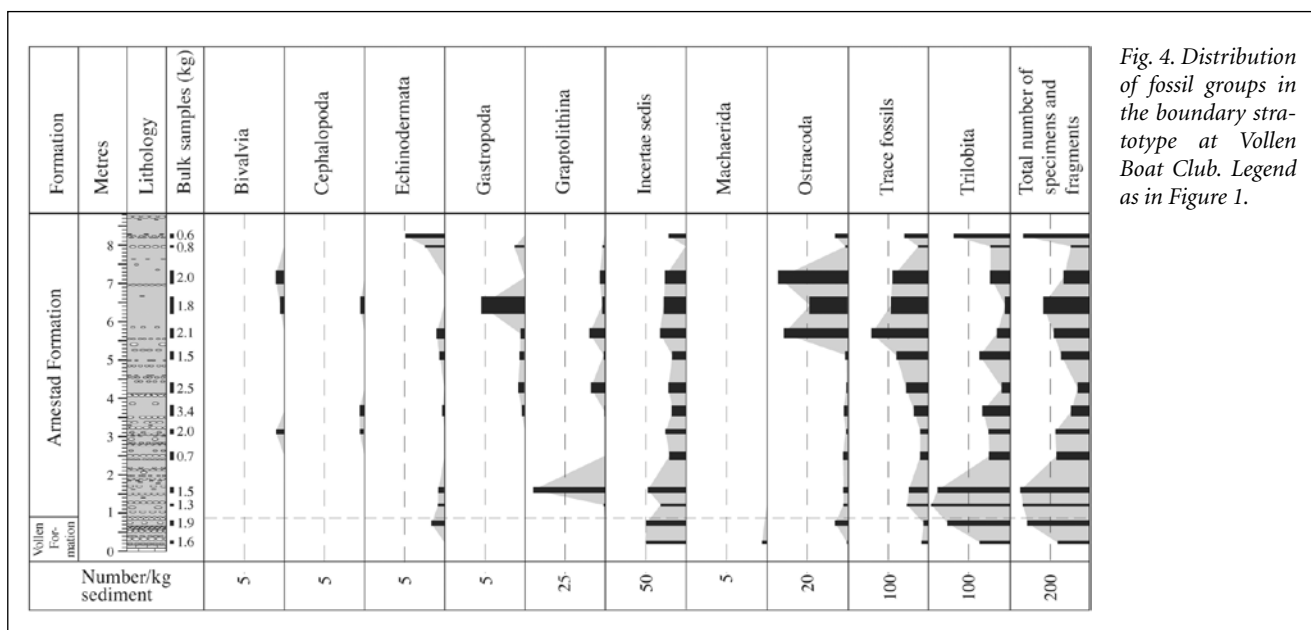


Fig. 4. Distribution of fossil groups in the boundary stratotype at Vollen Boat Club. Legend as in Figure 1.

importance. The rhynchonelliformean fauna consists of the plectambonitoids *Gorudia*, *Chonetoidea* and *Leangella* (*Leptestiina*) and the two orthides *Onniella* and *Septorthis* (a first record of this genus in Norway). The specimens of *Chonetoidea alpha* Spjeldnæs differ somewhat from that of the holo- and paratypes.

The brachiopod fauna in the lower part of the Arnestad Formation is rather sparse compared to the fauna in the upper part of the formation. The composition of the latter together with some genera from the lower part have been listed by Harper (1986), largely based on the palaeontological collections in the Natural History Museum, University of Oslo, Department of Geology.

#### Assemblages

The Vollen Boat Club section exposes the same overall succession of the brachiopod faunas as the lower half of the Persteilene section, though the abundances of the different taxa often differ.

The fauna of the lower Arnestad Formation has been divided into three assemblages (assemblage A to C) each distinguished by the abundance of two or more taxa. The assemblages in the section at Vollen have much higher frequencies of brachiopod valves than corresponding ones in the Persteilene section. This is especially related to a markedly higher abundance of all three plectambonitoids *Chonetoidea*, *Gorudia* and *Leangella* (*Leptestiina*).

Assemblage A is characterized by an abundance of the brachiopods *Gorudia*, *Septorthis* and *Lingulata* together with a high abundance of trilobite fragments. The assemblage is present in the lower part of both sections (Figs 3 to 6). In the Persteilene section the assemblage is found together with the trace fossil *Chondrites* sp., which occurs in abundance in the limestone and nodular limestone in

that assemblage zone. At Vollen *Chondrites* sp. has only been observed in a nodular limestone bed at 0.5 m, but this may be due to incomplete exposure.

The lower part of the assemblage zone in the Vollen Boat Club section is distinguished by the abundance of *Leangella* (*Leptestiina*) sp. (Fig. 3). This species disappears abruptly 0.5 metres above the base of the Arnestad Formation. The middle part of the zone exhibits a significantly high number of graptolites in both sections (Figs 4 and 6). The upper part of the assemblage zone is characterised by the presence of *Onniella bancrofti* Lindström and relative low abundance of trilobite fragments.

Assemblage B is distinguished by an abundance of the brachiopod *Chonetoidea alpha* Spjeldnæs, the presence of gastropods, and common to abundant trace fossils. The assemblage zone is characterized by both fewer fossil remains and by a lower diversity than in the previous assemblage. Three parts of this zone are distinguished on faunal characters. A low peak of *Septorthis* sp. defines the lower middle part, B1, where *Chonetoidea alpha* starts to become abundant in the Vollen Boat Club section (Fig. 3). This part of the section may be present on Persteilene, but is obscured by bigger gaps between samples. Part B2, occurring at both localities, is defined by a brachiopod fauna consisting exclusively of lingulids and *Chonetoidea alpha*. At the Vollen Boat Club, the species *Chonetoidea alpha* is very dominant in the assemblage while it is more sporadic at Persteilene. Among the other fossil groups the abundances of ostracodes and trace fossils are strongly dissimilar between the two sections, being extremely abundant in the Vollen Boat Club section and either common or absent in the Persteilene section. The fauna in the uppermost part (B3) of the assemblage B zone is defined by the abundance of lingulids, *Septorthis* and *Onniella*.

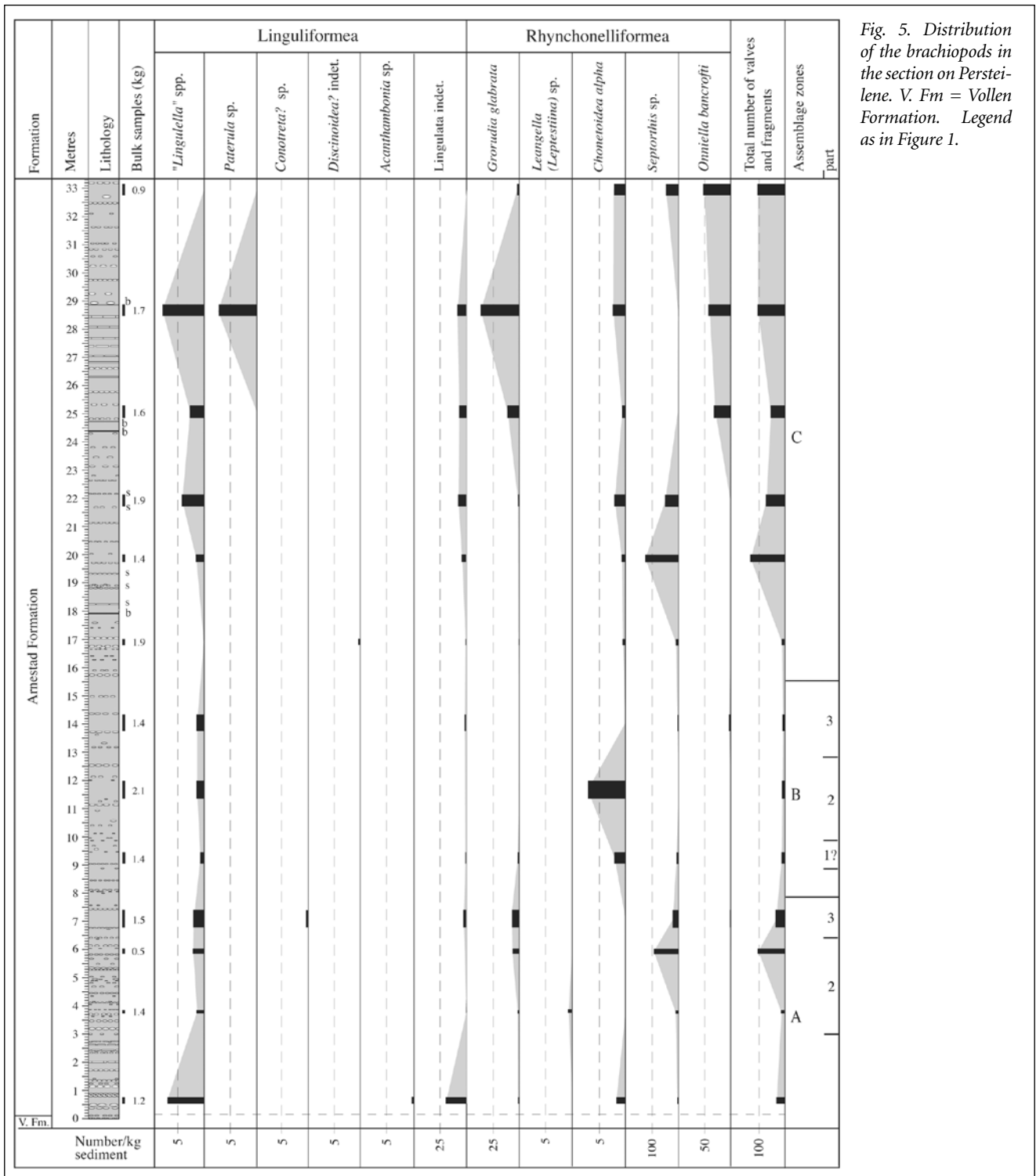


Fig. 5. Distribution of the brachiopods in the section on Persteilene. V. Fm = Vollen Formation. Legend as in Figure 1.

Assemblage C, which succeeds assemblage B in the section on Persteilene (Fig. 5), is characterized by a significantly more diverse and abundant fauna. Several taxa which are associated in this assemblage, are not found together in assemblages A and B. Two of these taxa are *Chonetoides alpha* and *Onniella bancrofti*.

*Local and regional correlation*

The two sections are correlated by comparing the patterns in abundances of both brachiopods and other mac-

rofosil taxa (Fig. 7). The correlation indicates that the lower boundary of the Arnestad Formation is diachronous, being situated about 4.5-5 m lower at Persteilene than at the Vollen Boat Club. It also appears that the correlative part of the section on Persteilene is thicker than in the Vollen Boat Club section.

Most of the brachiopod taxa occurring in the studied sections have a wide stratigraphical range or belong to specific biofacies and are thus of little use for correlative purpose. The collected graptolites too, are of little stratigraphical

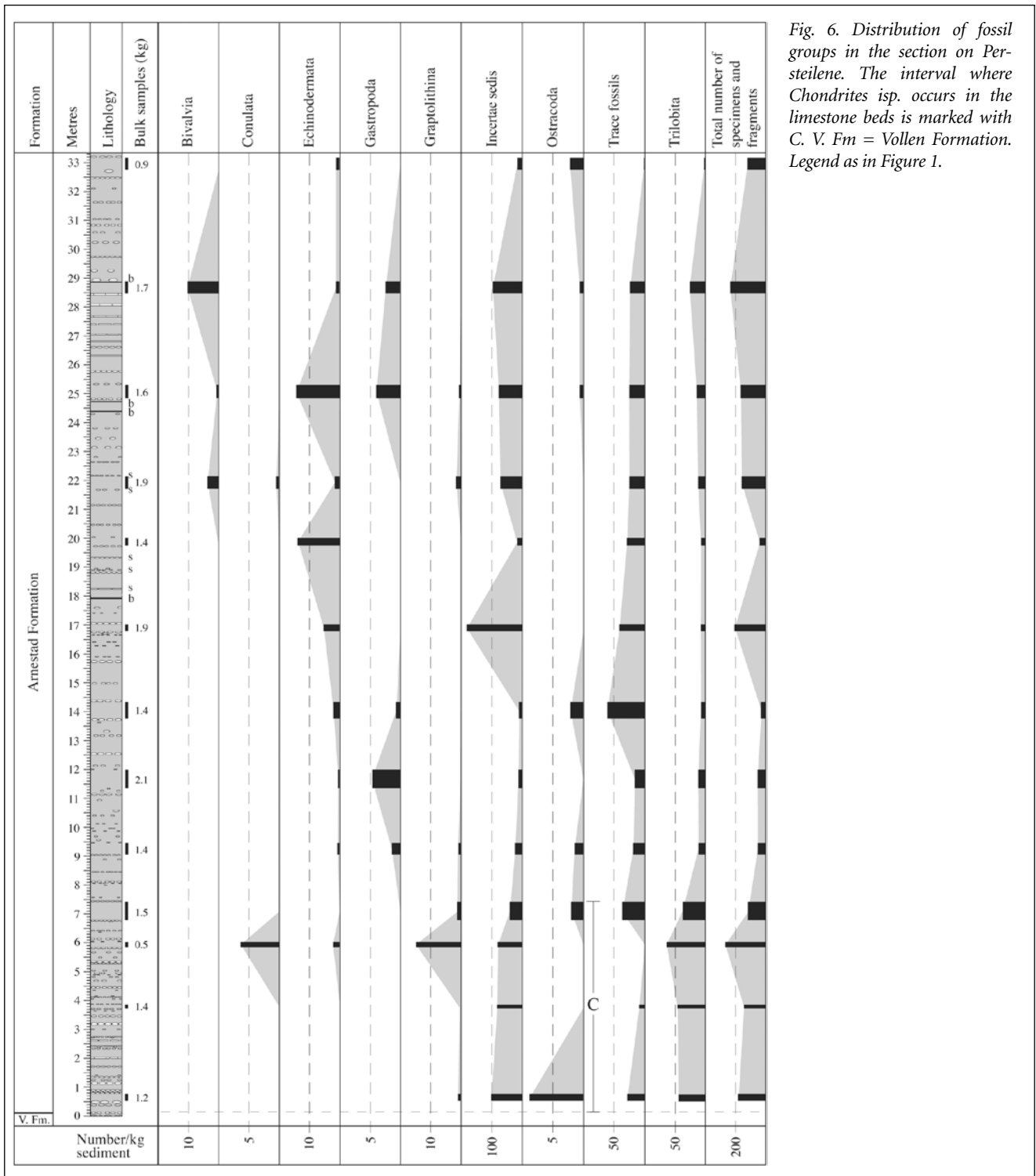


Fig. 6. Distribution of fossil groups in the section on Persteilene. The interval where *Chondrites isp.* occurs in the limestone beds is marked with C. V. Fm = Vollen Formation. Legend as in Figure 1.

significance (Dr. Jörg Maletz 2004: pers. comm.). The K-bentonite beds, however, provide an upper boundary, as both sections are below the top of the Grefsen K-bentonite complex, making it possible to compare the brachiopod fauna with that found in Västergötland in the Fågelsång district of Sweden (Lindström 1953; Jaanusson 1964; Nilsson 1977) and in the East Baltic Region. The lithofacies of Västergötland are dominated by limestone whereas they are more shale-dominant in the Fågelsång district. However, the faunas from both Swedish areas are sparse compared to those of the Oslo Region with three to four rhy-

chonelliformean and a few linguliformean brachiopod genera. Among the Swedish rhychonelliformean brachiopods only *Onniella bancrofti* occurs in the lower part of the Arnestad Formation. This species seems to appear at about the same time or slightly earlier in Västergötland compared to the Oslo Region, as it occurs in the limestone-dominated Lower Dalby Formation below the Grefsen K-bentonite complex (a correlative of the Vollen Formation [e.g. Jaanusson 1982; Owen et al. 1990]).

Even though the species are different, the brachiopod

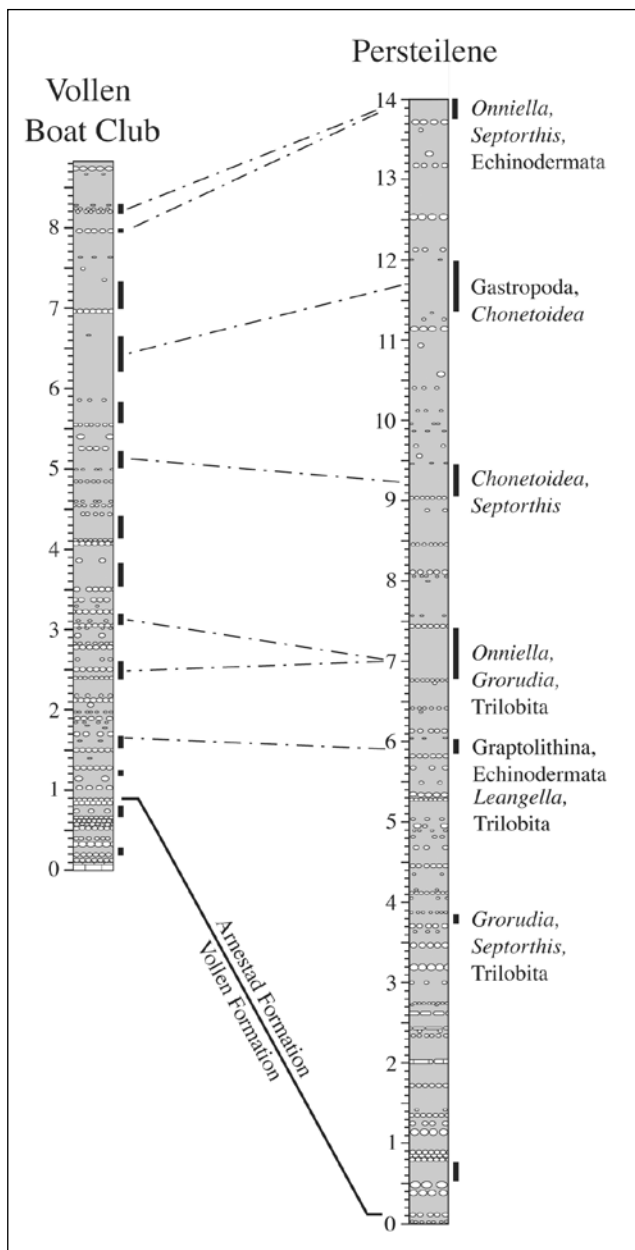


Fig. 7. Ecostratigraphical correlation of the section at Vollen Boat Club and the lower part of the section at Persteilene. Tie lines are based on the best fit of significant changes in abundance of the different fossil taxa. Names to the right indicate which taxa the lines are based on. Vertical bars mark the sampled beds. Legend as in Figure 1.

fauna of the present study corresponds more on the generic level to the East Baltic fauna related to the Livonian Tongue of the Central Baltoscandian Confacies Belt than to the Swedish fauna belonging to the deeper Scanian Confacies Belt, as they are both more diverse and include *Onniella*, *Septorthis* and *Chonetoida* (cf. Hints & Harper 2003).

It is interesting to note that only the genus *Onniella* seems new for the Baltic province. All the other genera are, at that time, restricted to Baltica or, in the case of "*Lingulella*", *Paterula* and *Conotreta*, have more worldwide distributions and had been long established else-

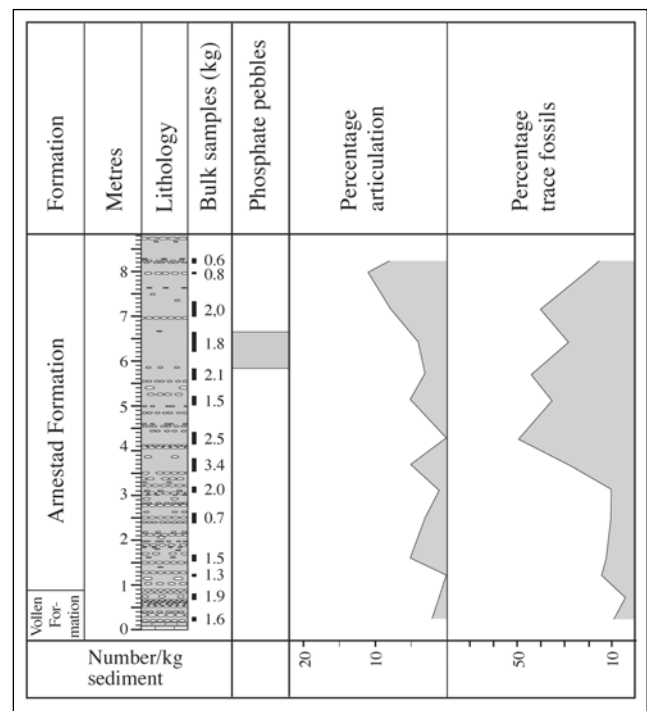


Fig. 8. Ratio of articulated/disarticulated specimens of brachiopods in percent, and percent trace fossils (*Planolites* isp.) out of the total number of fossils in the Vollen Boat Club section.

where (e.g. Parkes 1992). The genus *Onniella* seems to mark the incoming of a more cosmopolitan fauna associated with the immigration of the Scoto-Appalachian province noted by Harper (1986) in the upper part of the Arnestad Formation.

## Environment

The percentage of mechanically fragmented fossils is high throughout the strata. The fossil fragments show no sign of abrasion and appear invariably angular. In order to acquire more information on the depositional environment, plots for the relative number of articulated brachiopod specimens together with plots for the relative number of pyritized trace fossils compared to the total number of fossils are presented (Figs. 8 and 9). At the Vollen Boat Club (Fig. 8) there is a gradual increase in the content of articulated relative to disarticulated specimens, increasing from less than five to about ten percent. The relative number of pyritized trace fossils, however, is fairly constant at about ten percent up until 3.5 metres above the base of the section, after which it increases dramatically to about 50%. From a maximum of 50%, the number of trace fossils slowly decreases until 7.5 metres above datum, after which the decrease becomes dramatic. On Persteilene (Fig. 9) the relative number of articulated specimens also increases through the first 14 metres (from 0% to 25%), but then decreases, nearly continuously, to the top. The relative number of trace fossils, on the other hand, expresses a more uneven trend, abruptly increasing from sparse to



common and abundant in the middle part of the section, but decreasing again through the rest of the section.

The high amount of mechanically fragmented fossils that indicates the sedimentary environment was at least moderately influenced by current/wave activity and thereby probably within maximum storm wave base. It also indicates that the fossils experienced some transport and thus, the assemblages are at least partly death assemblages. However, as there is no obvious dominance of convex, upwards orientated fossils, the environment was sufficiently quiet, so that bioturbation became as important a factor for the orientation of shells as the hydrodynamics of the environment (cf. Brenchley & Harper 1998). The aggregates of the photic cyanobacteria *Girvanella* are thought to be allochthonous and thus suggest moderate water depth. The graphs for the number of articulated, relative to disarticulated valves give an indication of the variation in current/wave influence on the sea floor during sedimentation at the two sites (Figs. 8, 9). The general trend of the graph from Persteilene (Fig. 9) is very like that suggested by Nielsen (2004) for sea-level variations during the Idavere Substage in Baltoscandia. Therefore, it seems reasonable to suggest that the variation is in response to sea-level variations. The maximum relative amount of articulated brachiopod specimens on Persteilene occurs where the beds contain phosphate pebbles though at Vollen the phosphate only occurs when the articulation ratio increases. Phosphate is normally associated with low sedimentation rates, changing sea level and sediments deposited in environments with low-oxygenated waters (cf. Einsele 1992). There is no indication of significantly reduced sedimentation rates in the actual interval except in the upper part where several shell-pavements occur (Fig. 9). A low abundance of brachiopods, consisting of small species, and generally low amounts of other skeletal remains may indicate reduced oxygen levels in the bottom waters. This is supported by the number of pyritized trace fossils, which is high, indicating a reduced oxygenation level in the upper sedimentary layer. Thus the presence of phosphate may in this case be a result of low oxygen levels at the water/sediment interface in response to waning bottom currents.

Comparison of the relative numbers of articulated valves between the two localities described in this study reveals a significantly lower number in the Vollen Boat Club section (Fig. 8) which is characterized by a higher content of nodular limestone. As this section is more fossiliferous and may have experienced a lower net sedimentation rate (if the biozones are time-equivalent), the beds were probably deposited in a more shallow water environment bypassed by some of the siliciclastic mud as suggested for the upper part of the formation by Möller & Kvingan (1988). The actual and relative amounts of pyritized trace fossils appear to be markedly higher in the part of the sections most dominated by siliciclastic mudstones. Also, on Persteilene, there is suggested that the deposits were less oxygenated due to changing energy levels following higher sea levels.

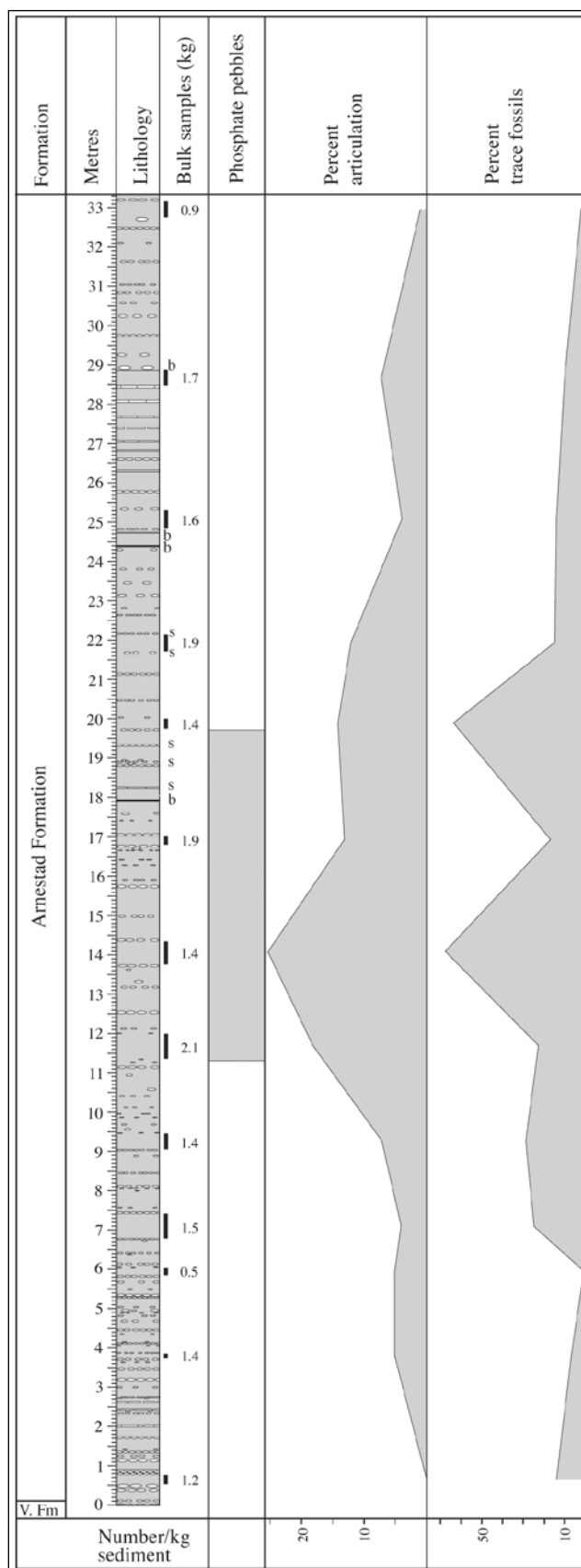


Fig. 9. Interval with phosphate pebbles, ratio of articulated/disarticulated specimens of brachiopods in percent, and percent of trace fossils (*Planolites* isp.) out of the total number of fossils in the Persteilene section. V. Fm = Vollen Formation.

### Faunal responses to environment

The composition of the brachiopod faunas in the two sections shows some similarities with those documented from other parts of the world. Harper & Pickerill (1997) among others found that a *Chonetoidea*-lingulid association, which landwards was replaced by an association dominated by *Chonetoidea/Sericoidea* and *Onniella*, occupied the distal parts of the shelf and the slope. The *Chonetoidea*-lingulid association is part of assemblage B in the present study. At both localities the association occurs prior to the interval with the highest number of articulated valves relative to disarticulated valves indicating that the association did not occur at the highstand in this case, but rather during the final part of the transgression. In the present case the strata deposited during highstand seem to have been occupied by orthides and lingulids. The low abundance of *Chonetoidea* on Persteilene compared with that in the Vollen Boat Club section somewhat deviates from that expected, as Persteilene appears to have been situated in a more distal environment. However, as the assemblage B is very low to diverse, the low abundance may be a result of a more restricted environment at Persteilene. The genera *Chonetoidea* and *Onniella* known to occur together, are virtually never found together below assemblage C, suggesting that they responded to different environmental factors. The occurrence of the nearly-cosmopolitan *Onniella-Chonetoidea/Sericoidea* association documented in Llanvirn to Ashgill strata (e.g. Lockley 1980; Jaanusson 1984; Harper 1986; Harper & Pickerill 1997; Harper & Hints 2001) is established for the first time in the Oslo Region, within the lower part of the Arnestad Formation. The association appears when the relative number of articulated valves becomes rather low indicating more current/wave activity and possibly a lower sea level. The association, represented by *Sericoidea restricta* and *Onniella bancrofti*, developed at about the same time in the Swedish part of the Baltoscandian Sea (Nilsson 1977; Jaanusson 1984). *Leangella (Leptestiina)*, which is abundant in the lower part of the Vollen Boat Club section but nearly absent at Persteilene, is normally found elsewhere in slightly coarser sediments. These are interpreted as having been deposited in a more proximal outer shelf environment compared with the environment of the other two associations (e.g. Lockley 1980; Jaanusson 1984). This suggests a more proximal environment for the Vollen Boat Club section as a whole in agreement with the above observations. The stratigraphical occurrence of the brachiopod *Grorudia glabrata* Spjeldnæs correlates well with that of the relative amount of articulated valves, suggesting it dominated the brachiopod fauna where the influence of the current/waves was moderately high. *Leangella (Leptestiina)* sp., however, seem to have preferred still more current/wave influenced environments than *Grorudia glabrata*.

### Conclusion

The palaeoenvironments at Vollen and Persteilene in the Oslo Region were moderately influenced by bottom currents or waves during the Idavere, though generally not strongly enough to sustain the hydrodynamically stable convex-up position against disruption by bioturbation. The brachiopod fauna in this environment was of low diversity compared to that in the upper part of the Arnestad Formation deposited during and after the Scoto-Appalachian immigration (cf. Harper 1986; Webb 1990). It consists of a mix of endemic taxa and more worldwide distributed genera. The brachiopod fauna, when compared with the laterally equivalent Swedish and East Baltic faunas, shows a closer affinity on the generic level with the fauna in the Livonian Tongue (in Latvia) of the Central Baltoscandian Confacies Belt than with that of the Swedish Scanian Confacies Belt. Parallel associations are at the same time developed in deeper-water facies (BA4-5) around some of the other palaeoplates. For example, Lower Mohawkian, deep-water strata in eastern North America are dominated by nonarticulated brachiopods, plectambonitoids together with the dalmanellidine *Paucicrura* (Patzkowski 1995) and later, on both Avalonia (Lockley 1980) and in Bohemia (Havlíček 1998) during the mid Ordovician. Here assemblages of small dalmanellidines together with plectambonitoids occur in deep-water facies.

The faunas in the two sections have been divided into three death assemblages. The genus *Chonetoidea*, occurred within associations occupying outer shelf and slope environments, and was dominant during the last part of a transgression, but disappeared during the highstand. Instead, the highstand appears to have been dominated by lingulids and small orthids. In the more current or wave-influenced strata (shallower environments) associations with the medium-sized plectambonitoids *Grorudia* and *Leangella (Leptestiina)* dominated. *Leangella (Leptestiina)* is restricted to where the current regime was the strongest.

The co-occurrence of the genera *Onniella* and *Chonetoidea* in the late phase of an apparent regression, an association documented from many Late Ordovician outer shelf environments in other parts of the world (see e.g. Harper 2001), was established for the first time in the Oslo Region. This marked the first step towards a more cosmopolitan brachiopod fauna and occurred at about the same time in the Swedish part of the Baltoscandian Sea. The two genera did not, however, co-occur in the lower parts of the sections, suggesting they were controlled by different environmental factors. This type of association was recurrent within the Oslo Basin, appearing again in the upper Caradoc Nakkholmen Formation, when deep-water dysoxic conditions were established in the basin (Harper et al. 1985).

The base of the Arnestad Formation is diachronous, becoming older to the east with was apparently the seaward direction. The Vollen Boat Club section, situated more landward, contained the richest fauna.

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