Ordovician siliciclastics and carbonates of Öland, Sweden

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INTRODUCTION

The Baltic Basin (also known as the Baltic syneclise) is a large intracratonic basin at the western margin of the East European Craton (Fig. 1). The Baltic Shield slope, the Latvian Saddle and Byelorussian anticlise are respectively the northern, eastern and southeastern limits of the Baltic Basin. The exact boundaries of the Baltic Basin are not well defined, but generally lie where the crystalline basement is buried at depths greater than 0.5–0.8 km. However, the southwest margin of the Baltic Basin is clearly defined by the Trans-European Suture Zone (TESZ; Fig. 1). The Baltic Basin contains a maximum preserved sediment thickness of about 8.000 m of predominantly late Proterozoic (Vendian) to Phanerozoic strata. The sediments are almost entirely shallow marine or terrestrial deposits. The basin is a proven petroleum province and contains several producing hydrocarbon fields with Lower Cambrian sandstones and Upper Ordovician carbonate reefs as reservoirs.
Precambrian crystalline rocks underlie the basin and were peneplained before the beginning of the Cambrian. Erosional remains are preserved in a few areas indicating that a once coherent sedimentary blanket extending from Russia to the front of the Scandinavian Caledonides existed (Fig. 2).

Figure 1: The Baltic Basin.

Sedimentation commenced with the deposition of clastic sediments i.e. quartzitic sandstones, with a thickness that exceeds 100 m only at the margin of the East European Craton. This sandstone appears to be mainly Lower to lower Middle Cambrian and varies in thickness from approximately 10 to 600 m. The 100–140 m thick sandstone at the top of the Lower – Middle Cambrian is the main hydrocarbon-bearing reservoir of the Baltic region. It contains trace fossils as well as some rare inarticulate brachiopods, but at the top of the Lower Cambrian thin silty and glauconitic or calcareous beds accumulated and olenellid trilobites are the most important fossil remains.
The Middle Cambrian may reach a thickness of a few tens of metres. Several hiatuses occur and in some areas it is totally missing. The dominant sediments are silt and fine sand (which may be glauconitic clay), several limestone beds and thin rubbly condensation layers with phosphoritic and glauconitic crusts. Towards the top, s black shale facies invades from the west. Compared with the Lower Cambrian and with the Upper Cambrian the fauna is rich and varied. It mainly comprises trilobites, among them a number of large paradoxidids and many species of the blind agnostids. There are also several species of inarticulate brachiopods.
The entire Upper Cambrian consists of black shale. The succession is almost complete in several areas, although there is evidence of prolonged phases with no sedimentation. There are 6 main trilobite zones, each divided into subzones. Each zone is recognisable by its trilobite fauna, which may be as rich in individuals as it is poor in number of species. Lenses exist of strongly bituminous limestone that may consist almost entirely of the remains of a single olenid or agnostid. The beds were formed in quiet waters. Cross bedding and bioturbation are not seen. The thickness reaches a a maximum of a few tens of metres. Very slow sedimentation was combined with the enrichment of bitumen and trace elements, such as vanadium and uranium.
At the transition to the lower-most Ordovician, the sedimentation of the organic-rich mud underwent a definite change. The bituminous limestone gradually vanishes, and laminae of greensand or quartz sand appear in some places. In the Ordovician up to 10 m of deeper marine siltstone and shale (the Alum Shale and Djupvik formations) were deposited during several transgressive-regressive cycles in a wide epeiric sea.
A final early Early Ordovician regression led to the deposition of siltstone, and then carbonate sedimentation began. The fauna changes rather abruptly. The olenids

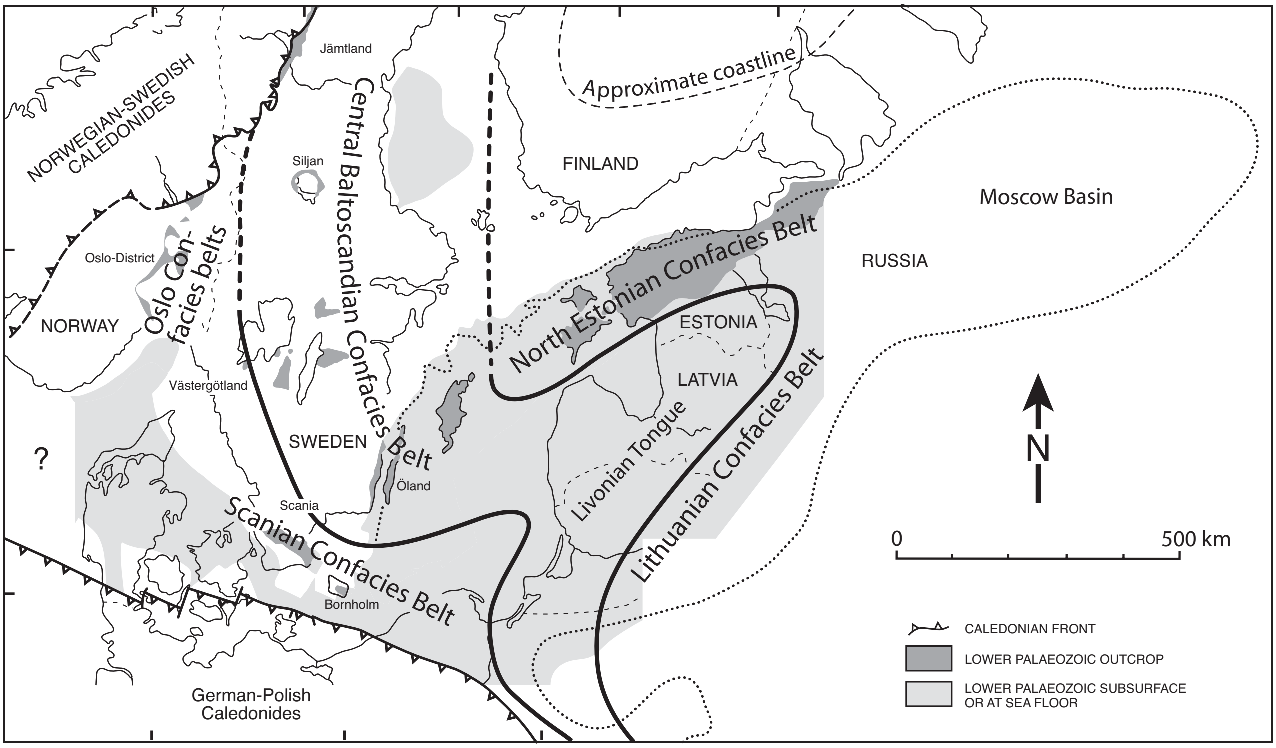

Figure 2: The Baltic Basin and confacies of Jaanusson (1976; modified from Nielsen 1995).

all but disappear. In their place dendroid graptolites, principally species of *Rhabdinopora,* inarticulate brachiopods and conodonts become common in the basin. The upper part of the Tremadoc contains a trilobite fauna that is characterised by *Ceratopyge forficula*. This upper part becomes calcareous and thus is the first representative of the succession of bedded limestones so characteristic of the Ordovician of the Baltic Shield.

The Ordovician may be about 100 m thick. Its lower and middle sections consist of a cool to temperate water limestone that is known as the '*Orthoceras* Limestone'. It is made up of beds a few tens of millimetres thick, which are separated by thin, irregular marly partings or by discontinuity surfaces with some kind of stain e.g. yellow from goethite, green from glauconite, or dark red from haematite. The limestone is mostly very fine-grained bioclastic limestone with no other internal structures apart from a great deal of bioturbation. Particularly in the lower part, the fauna is poor in species and consists mainly of arthropods. Higher up, disarticulated echinoderm fragments contributed to the sediment, and cephalopods appear in the macrofauna. Sessile benthos are rare or absent in the lowermost Ordovician. Conodonts are abundant throughout the Lower Ordovician and frequencies of 1.000 spms/1.000 g of rock are normal.

In the Middle and Upper Ordovician the deposits are largely composed of three separate facies: the deep water black bituminous shale in the west, the limestone, marl and clay in the central part and the shallow shelf carbonate rocks in the east. Later in the Ordovician the Baltic Basin underwent subsidence (Taconic movements) during which the facies became more varied and the fossil diversity more extensive. Ordovician deep-water fine-clastic sediments accumulated in a fore-reef setting with reef-like build-ups and back-reef sediments accumulating in the shallow water environment. This pattern continued until the end of the Silurian, but was interrupted by the short lived Hirnantian glaciation. The reef-like structures re-entered the basin after the glaciation ended.

The Silurian deposits consist of limestone and shale. The composition of the formations change with increased distance from the platform margin. Shaley deposits with graptolites predominate in the south and the south-west and grade into marl and limestone towards the east. The succession is only relatively complete in the south-central and south-eastern part of the East European Craton. The classical Silurian succession is exposed on the Isle of Gotland, where it is 400–500 m thick. The sediments comprise marl and biogenic limestone, the latter is partially developed as reef. The fauna is as rich and varied. There is evidence particularly in the upper part of phases of shallow-water sandy sedimentation.

The later part of the Silurian witnessed a gradual withdrawal of the sea from the East European Craton. This late Silurian to Devonian uplift occurred along the Caledonian margin of the basin (Scandian phase of the Caledonian Orogeny). Marine to non-marine clastic sediments accumulated in a fore-deep basin that developed on the south-west flank of the Baltic Basin. Most of the deformation of the margin of the Baltic Basin in the form of thrust faulting and folding occurred during this orogeny.

ORDOVICIAN OF THE BALTIC BASIN

Ordovician strata – predominantly carbonates - are preserved and widely exposed in the north-east to south-

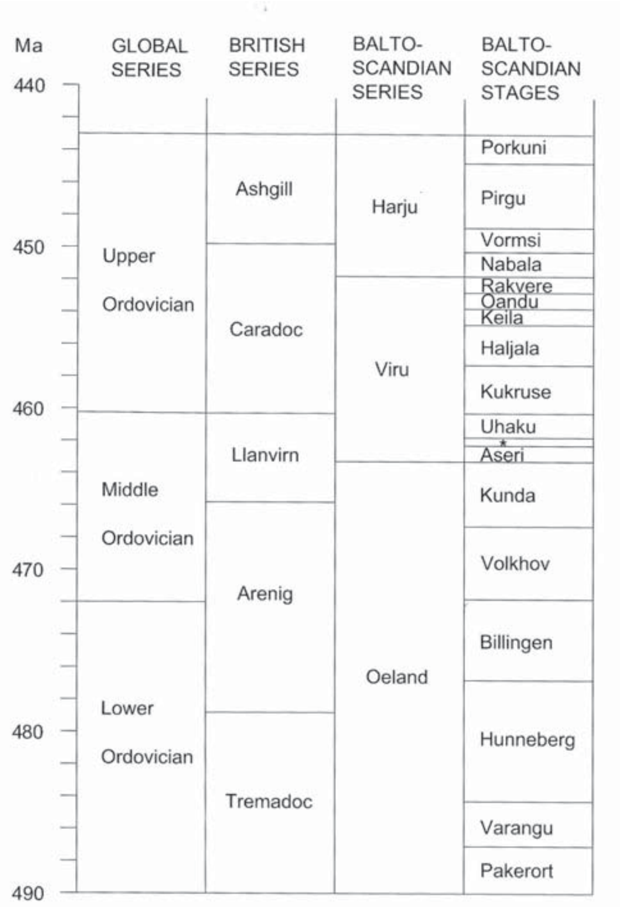

Figure 3: Chronostratigraphy of the Baltiscandian region (modified from Männil & Meidla 1994 and Webby *et al*. 2004).

west trending edge or crest on the north-west side of the Baltic Basin or the southern slopes of the Baltic Shield. The exposures extend from southern Öland towards the north-east and are virtually continuous from the North Estonian coastline and into western Russia. These exposures present the best Cambrian to Ordovician succession of sedimentary rocks in Baltoscandia.

A number of K-bentonite beds occur in the Baltic Basin and these are of remarkable correlative importance (Bergström *et al*. 1995). Within the Baltic Basin various lithofacies are arranged in belts, which are characterised by comparatively stable complexes of litho- and biofacies. Männil (1966) applied the term 'facies zone' to delineate the complex litho- and biofacies and Jaanusson (1976) called these 'Confacies belts' (Fig. 2). In general they reflect differences in depth, but their actual nature are much more complicated than just a simple depth zonation (Jaanusson 1973).

CHRONOSTRATIGRAPHY

Trilobites are the obvious marker fossils of the Ordovician of the Baltic Basin. They were widely distributed and occur in a fairly precise succession, but outside the basin very few of the Baltic genera and species are present. Cephalopods and brachiopods are other groups of useful index fossils for part of the succession.

The classical Ordovician stratigraphy is based mainly on graptolites, and as graptolites are mostly scarse or absent in the Baltic Basin facies, a set of major divisions (Series, Stages) have come into use. This division is independent of other schemes and cannot be precisely correlated with the global scheme. Schmidt (1881) initially distinguished six series in the Ordovician. Öpik (1930) used a four-fold subdivision of the Ordovician System and referred those to *Obolus*,-, conodont-, *Asaphus*, *Chasmops*- and *Isotelus*-Series. Later, these series named after the type areas, and Iru, Tallinn, Viru and Harju Series came into use. Kaljo *et al*. (1958) combined the Iru and Tallinn Series into the new Oeland Series. Hence, the Ordovician of Baltoscandia is referred to the Oeland, Viru and Harju Series with seven sub-series and 18 stages (Männil & Meidla 1994).

The regional chronostratigraphical time scale (Männil & Meidla 1994) (Fig. 3) is used in this guide but reference to the international timescale (Webby *et al*. 2004) is made, wherever necessary.

Oeland Series

The Oeland Series (Kaljo *et al*. 1958) refers to the Lower Ordovician of the region (*sensu* Raymond 1916). The Oeland Series corresponds to the Lower and *pars* Middle Ordovician of the international time scale (of Webby *et al*. 2004; Fig. 3).

The series includes the succession from the base of the Ordovician System to the top of the Kunda Stage, which corresponds to the *Didymograptus artus* Zone. The name of the series originates from Öland, which is chosen as the type area for the Lower Ordovician Series (Kaljo *et al*. 1958; Männil & Meidla 1994; Stouge *et al*. 1995).

ORDOVICIAN SUCCESSION OF ÖLAND

Öland is approximately 150 kilometers long and 15 kilometers wide (Fig. 4). Inland, it consists of a plain with thin vegetation, and is called Alvar.

Öland is situated at the western margin of the Baltic Basin. Cambrian and Lower – Middle Ordovician sediments overlie the Precambrian basement with a slightly eastward dip. The slight eastward dip on the western flank of the Baltic Basin led to a structure where the oldest formations are exposed in the west-facing sea-cliffs and inland scarps along the Sound of Kalmar. The oldest beds on the island belong to the uppermost Lower Cambrian sandstones in the west and the youngest beds are the Middle Ordovician lower Dalby Limestone in the east. However, the '*Orthoceras*' limestone covers most of the island and the inland plain or Alvaret consists essentially of a single bed of limestone. The Ordovician succession continues from the land and disappears eastwards with a very gentle dip under the sea. Some of succession can be reconstructed from erratic boulders, which were transported westwards and deposited on the island by differential movement of the Pleistocene land ice.

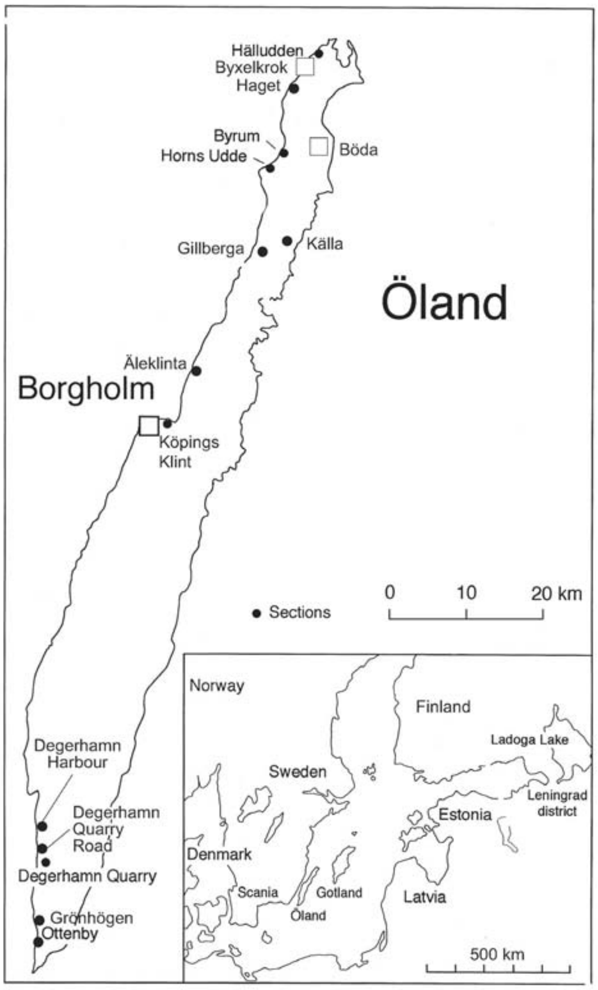

Figure 4: Öland and the localities (= black dots) mentioned in the text.

On Öland, the Ordovician is approximately 41 m thick (Böda Hamn well); the Lower Ordovician is around 17 m thick and the Middle Ordovician is about 24 m thick.

The base of the Ordovician

The Cambrian–Ordovician transition on Öland is developed as a hiatus. The hiatus is situated within the Alum Shale Formation and the base of the Ordovician is recognised by the appearance of *Rhabdinopora flabelliforme*. The hiatus comprises the uppermost Upper Cambrian trilobite subzones and two graptolite subzones of the Pakerort Stage (Westergård 1922, 1944). On the northern part of the island the black shale facies of the Alum shale Formation is very thin or it is completely absent (Westergård 1922). The hiatus comprises the Middle and most of the Upper Cambrian and parts of the Lower Ordovician.
In the north, the oldest Lower Ordovician strata are developed as a conglomerate, known as the '*Obolus*' conglomerate (Westergård 1947). It is named after the brachiopod *Obolus apollinis*, which is present in the conglomerate and corresponds to the *Rhabdinopora flabelliforme typica* Subzone.

ORDOVICIAN FORMATIONS OF ÖLAND

The stratigraphic terminology of Öland evolved from the first field impressions i.e. using distinctive colours (red-green-grey) and applying fossil names, mainly from trilobites and cephalopods, to the units. Later, a topostratigraphic approach was applied. Topostratigraphic units are combinations of litho- and faunal characteristics. The application of lithostratigraphic units *sensu stricto* (i.e. defined on the basis of a stratotype and given a geographic name) has begun (van Wamel 1974; Stouge & Bagnoli 1990), but it is not yet completed on Öland (Stouge in prep.).

ALUM SHALE FORMATION

Previous names. – Olenid shale, *Dictyonema* Shale and *Ceratopyge* Shale (*pars*).
The Alum Shale Formation consists of bituminous black shale with bituminous limestone nodules (called antraconites - or 'orsten' in Swedish), which locally can become extremely large (2 x 1 mtrs). Sedimentation of the unit began in the Middle Cambrian and the facies persisted with interruptions into the Lower Ordovician. The uppermost black shales of the Alum Shale Formation described here were previously called the *Ceratopyge* Shale, but this black shale cannot lithologically be distinguished from the underlying black shales of the Alum Shale and thus it is now allocated to the Alum Shale Formation.
The Ordovician part of the Alum Shale Formation is referred to the Pakerort and Varangu stages of the Oeland Series. It is well exposed on south Öland, where it becomes up to 8 m thick at Ottenby, but decreases in thickness northwards (Westergård 1947). On northern Öland and north of Horns Udde it is absent and an extensive hiatus ranging down to the Middle Cambrian is developed.
The fossils include graptolites and the *Rhabdinopora flabelliforme* and *Bryograptus kjerulfi* graptolite zones are recorded. *Clonograptus heres* and a few phosphate shelled brachiopods i.e. *Broeggeria salteri* and *Nanorthis*? *cristianiae* are found in the uppermost part of the unit. Conodonts occur at certain levels, and also in the antraconites from which *Cordylodus proavus* and *Cordylodus angulatus* are recorded (Lindström 1971; van Wamel 1974).

DJUPVIK FORMATION

Previous name. - *Ceratopyge* Shale (*pars*), member Dk1.
The unit consists of glauconite-bearing silt- and sandstone with small limestone lenses. The unit can be interbedded with grey bituminous and laminated shale of the Alum Shale facies. In the south it is barely 35 cm thick, but it becomes up to 1.5 m thick on the northern part of the Island. The fauna includes the brachiopod *Broeggeria salteri* and the trilobite *Shumardia*.
The Djupvik Formation, as it is applied here, does not follow the original definition given by van Wamel (1974), who included Middle and Upper Cambrian and Lower Ordovician black shales of the Alum Shale Formation in

the Djupvik Formation. Here the formation is only used for the Lower Ordovician strata as indicated above.

KÖPINGSKLINT FORMATION

Previous names. - *Ceratopyge* Limestone, Lower *Planilimbata* Limestone; Latorp Limestone (*pars*). It is equivalent to the Bjørkåsholmen Formation in the Oslo Region, Norway.

The Köpingsklint Formation includes red-brown, violet or green lime mudstone and wackestone with abundant glauconite and pyrite and with interbeds of glauconite silt- and sandstone. Recrystallised limestone is common within the formation at certain levels. Glauconite grains are the most frequently occuring allochems. The Köpingsklint Formation (van Wamel 1974) is 0.85 m thick at the type location but becomes thicker on southern Öland. Several beds, if traced laterally, display great variation with respect to thickness and lack of persistence within the formation.

The Köpingsklint Formation differs from the underlying Djupvik Formation by the predominance of limestone in the former and the predominance of terrigeneous clastics in the latter. It differs from the overlying Bruddesta Formation by having a high glauconite content.

Van Wamel subdivided the formation into three informal members; these are difficult to trace laterally and hence are not used here.

The Köpingsklint Limestone is referred to the Hunnebergian and early Billingenian substages of the Latorp Stage (Tjernvik 1956; van Wamel 1974). The lower part of the unit belongs to the *Apatocephalus serratus* trilobite Zone (Tjernvik 1956) and the conodonts (van Wamel 1974; Bagnoli *et al*. 1988) are referred to the *Paltodus deltifer* Zone of Lindström (1971). The upper part of the formation comprises the *Megastaspis armata* and the *M. planilimbata* trilobite zones (Tjernvik 1956). The conodonts represent the *Paroistodus proteus* Zone and the *Prioniodus elegans* conodont Zone is recorded from the uppermost part of the formation (van Wamel 1974; Bagnoli *et al*. 1988). The uppermost of the formation also include the basal (transgressive) part of the *Oepikodus evae* conodont Zone.

The Tremadoc–Arenig Series boundary is placed within the *Paroistodus proteus* Zone (Maletz *et al*. 1996) and on Öland the boundary is recorded within the upper third of the Köpingsklint Formation. A hiatus is often developed at the boundary.

BRUDDESTA FORMATION

Previous names. - *Planilimbata* Limestone (*pars*), *Limbata* Limestone (*pars*) and Lanna Limestone (*pars*).

The unit consists of red to brown to light-grey, slightly marly, fossiliferous limestone with many disconformitites. Marl beds are common, except in the upper section. Remains of fossils are the most frequently occurring allochems.

On northern Öland and at about half way up the Bruddesta Formation a rock-interval occurs with intensively red-brown coloured limestone. In this interval disconformities with frequent amphora-shaped borings are present. Below these disconformities and around the trace fossils brownish yellow (goethitisation) zones are found. This interval occurs throughout the area and is called 'Blommiga Bladet' (= the 'Flowery Sheet').

The Bruddesta Formation is referred to the Billingenian Substage of the Latorp Stage and to the lower Volkhov Stage (Tjernvik 1956; van Wamel 1974; Bagnoli & Stouge 1997). The lower part of the formation belongs to the *M. dalecarlicus* trilobite Zone (Tjernvik 1956) and the conodonts (van Wamel 1974; Bagnoli *et al*. 1988; Bagnoli & Stouge 1997) are referred to the *Oepikodus evae* Zone of Lindström (1971). The upper part of the formation comprises the *Megistaspis polyphemus* trilobite zone (Tjernvik 1956) and the '*Baltoniodus*' *triangularis* and *Baltoniodus navis* conodont zones (van Wamel 1974; Bagnoli *et al*. 1988; Bagnoli & Stouge 1997; Löfgren 2000).

HORNS UDDE FORMATION

Previous name. – *Limbata* Limestone; Lanna Limestone.

The formation consists of greenish red, or green and red variegated highly fossiliferous and haematitic limestone (wackestone and grainstone). It is interspersed by innumerable (stylotitic) disconformities and remains of fossils are the most frequently occurring allochems. Orthoceratids are relatively abundant, glauconite grains may occur. Most fossil fragments are impregnated with glauconite, goethite or haematite. Haematite is present throughout the Horns Udde Formation concentrated sedimentarily and secondarily. On northern Öland an approximately 10 cm. thick intensively red-brown coloured interval exists; it is called 'Blodlaget' (= the Bloody layer') and is found in the basal portion of the formation. On southern Öland a similar horizon is present but is situated in the upper part of the formation.

The Horns Udde Formation is uniformly developed on Öland, both in the vertical and lateral sense; its total thickness varies between 1.55 and 1.65 m.

The macrofauna from the Horns Udde Formation is not well known. It is tentatively referred to the *Megistaspis polyphemus* Zone of the Volkhov Stage. The conodont fauna however is very distinct and Lindström (1971) named it the *Paroistodus originalis* (acme) Zone.

FORMATION A+B

Previous names. - *Limbata* Limestone, Lanna Limestone, *Lepidurus* Limestone,
Volkhov Stage, *Asaphus* Limestone, Hjorthamn Limestone, Holen Limestone.

Remarks. – Stouge & Bagnoli (1990) introduced Formations A and B and considered the units as potential formations. Subsequent fieldwork reveals that it is better to combine the two units into one. Bohlin (1949) introduced the Hjorthamn Limestone for a narrow part of the succession on northern Öland.

Formation A+B (= to be named the Gillberga formation) includes grey to green lime mudstone and wackestone with abundant glauconite and some pyrite. Interbeds of glauconite silt- and sand are common. Fe-ooids may occur within the formation and two distinct levels (a lower ooid and an upper ooid) can be distinguished in the unit on northern Öland. A dark grey to black, organic-rich, thin shale occurs in the formation. Glauconite grains are the most frequently occuring allochems. Phosphatisation is a common feature in the formation.

On southern Öland red haematite impregnated horizons characterise the upper part of the formation. A key horizon or 'Sphaeronites Bed' forms the upper part of the formation on southern Öland.

Formation A+B is very fossiliferous. Within the formation many fossils display disrupted orientation, which suggests that the fauna has been transported by storms (Bohlin 1949).

Trilobites are the characteristic faunal elements and *Megistaspis limbata*, *Asaphus expansus* and *Asaphus* '*raniceps*' (Late Volkhov to early Kunda i.e. Valastean Substage) are recognised in the unit. Brachiopods may also be well-represented in this unit. The conodonts are referred to the *Baltoniodus norrlandicus*, *Lenodus antivariabilis*, *Lenodus variabilis* and *Yangtzeplacognathus crassus* zones (Stouge & Bagnoli 1990; Löfgren 2000).

The green limestone in the formation is very rich in organic shelled fossils and graptolites. Acritarchs and chitinozoans have also been recorded from several levels within the formation.

FORMATION C

Previous names. - *Asaphus* Limestone, Holen Limestone.

The formation consists of light grey, yellow to pink wackestone with scattered glauconite and grains of phosphorite. It is interspersed with innumerable disconformities and stylolites. Fossil remains are the most frequently occurring allochems. Trilobites and orthoceratids occur frequently and glauconite grains may occur.

Fossils from Formation C have have not been investigated systematically. The trilobite fauna includes *Asaphus* '*raniceps*' (Bohlin 1949 p. 566) indicating that the formation may belong to the Valastean Substage of the Kundan Stage.

Conodonts are abundant (Löfgren 2000) and are referred to *Lenodus kielcensis* Zone (Stouge unpublished).

FORMATION D

Previous names. – *Asaphus* Limestone (*pars*), '*Vaginatum*' Limestone, '*Obtusicauda*' Limestone, '*Gigas*' Limestone, Holen Limestone.

The unit consists of grey, yellow to red fossiliferous limestones. Marly intercalations are commonly present. Trilobite remains are the most frequently occurring allochems. In Formation D, red haematite impregnation of the limestone and haematite surrounding the fossils is common.

Formation D is referred to the highest trilobite zones of the Kunda Series (Bohlin 1949). *Megistaspis centaurus*, *Megistaspis gigas* and *Megistaspis bombifrons* are present in the unit. The conodonts *Lenodus pseudoplanus* and *Microzarkodina ozarkodella* are characteristic species in the formation (Löfgren 2000; Stouge unpublished).

MIDDLE ORDOVICIAN (VIRU SERIES) OF ÖLAND

Middle Ordovician (Viru) limestones are poorly exposed on Öland and only one locality will be visited in this excursion (Källa Limestone, Locality 7). This is due to the scarcity of Middle Ordovician exposures and the best of those are not easily accessible. Most of the exposures on the shore are found on the east coast, where the sections are poorly developed because of the eastward dip of the rocks. Inland exposures are confined to small quarries, now water-filled, or to ditches which today are mostly overgrown.

The Middle Ordovician units are named the Segerstad, Skärlöv, Seby, Folkeslunda, Furudal, Källa, Persnäs and Dalby Limestones (Jaanusson 1960).

The Segerstad Limestone (former term = *Platyurus* Limestone) overlies the Kunda succession without any distinct boundary. It comprises a bright red wackestone with mudcracks and stromatolitic algal mats. The limestone is up to 5 m thick. The fauna changes from below and pygidia of *Asaphus* (*Neoasaphus*) *platyurus* have been recorded from the formation.

The Skärlöv Limestone is red-brown, nodular and argillaceous with a thickness from 1.4 m (north) to 2.0 m (south).

The Seby Limestone is a variegated red and grey limestone. It is only some tens of centimetres thick. Fossils include cephalopods and hyolithids.

The Folkeslunda Limestone is a grey unit with many macrofossils with a thickness of about 2.8 m.

Using older terminology the Chiron (or '*Scroeteri*') Limestone corresponds to the Skärlöv, Seby and Folkeslunda Limestones. The Furudal, Källa and Persnäs Limestones (all three were part of the '*Crassicauda*' Limestone using older terminology) are of Uhakuan age and they represent different facies that developed on Öland during Uhakuan time. The Furudal Limestone is the offshore, finely nodular, grey lime mudstone recorded in southern Öland, whereas the Källa Limestone on northern Öland represents a nearshore equivalent. The Persnäs Limestone is a grainstone and becomes 5.5 m thick.

The Dalby Limestone (or '*Ludibundus*' Limestone) is developed as a grainstone and cannot easily be distinguished lithologically from the Persnäs Limestone as it is a topostratigraphic unit. Earlier the Dalby Limestone was exposed near Böda harbour, but it is completely covered today. The macrofauna of the Dalby Limestone includes cystoids and bryozoans.

ITINERARY

5th SEPTEMBER

The first stop on the first day is a visit to the Fågelsång locality near Lund, Sweden. The rest of the day will largely be used to the travel from the Fågelsång locality to Öland, Sweden and the trip ends at Ekerum campsite on Öland (see Bergström & Ahlberg 2004, this volume).

In the Småland province, basal layers of Lower Cambrian sandstone are exposed along the coast and mostly cover the

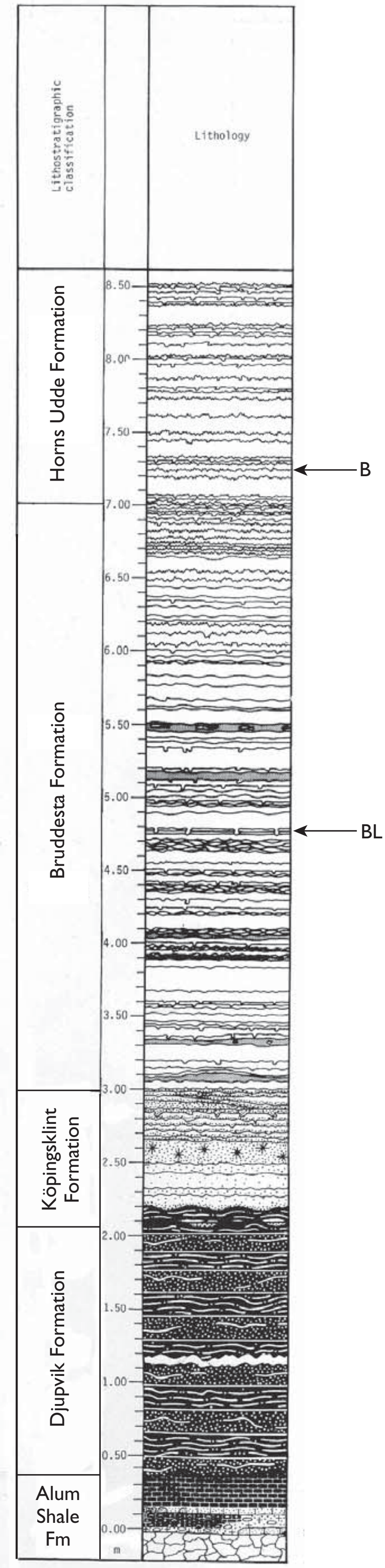

Figure 5: Section at Köpingsklint (from van Wamel 1974). Köpings Klint is the type-section for the Köpingsklint Formation of van Wamel (1974).

Precambrian rocks. This sandstone continues eastwards under the Baltic Sea, becoming covered by an increasingly thick succession of Cambrian, Ordovician, and ultimately Silurian sediments. The sandstone reappears at the surface on the south-east shores of the Baltic Sea. The Baltic Sea is thus a structural basin with the oldest deposits exposed at the western and eastern margins.

The Kalmar Sound, between Kalmar and Öland, is crossed by bridge. The sound is underlain by the continuation of the same Lower Cambrian sandstone that outcrops on the mainland coast. As the succession is built upwards by younger formations it rises above the seas as the Isle, which thus consists exclusively of Lower Palaeozoic sedimentary rocks in an undisturbed succession.

6th SEPTEMBER

The Lower and Middle Ordovician shelf-carbonate facies of the Ordovician epicontinental sea will be examined in outcrops on the northern half of Öland during the second day of the excursion. Collectively, these outcrops represent most of the rock-types of Öland and also of the Baltic Basin.

Locality 1 .... Köpings Klint
Locality 2 .... Äleklinta
Locality 3 .... North of Horns Udde
Locality 4 .... Byrum
Locality 5 .... Haget
Stop in Byxelkrok
Locality 6 .... Hälludden
Locality 7 .... Källa
Locality 8 .... Gillberga

7th SEPTEMBER

The third day of excursion will take us to the southern part of Öland where Lower and Middle Ordovician sediments will be inspected.

Locality 9 .... Degerhamn harbour
Locality 10 .... Degerhamn quarry
Locality 11 .... Degerhamn quarry road
Lunch
Locality 12 .... Grönhögen quarry
Locality 13 .... Ottenby

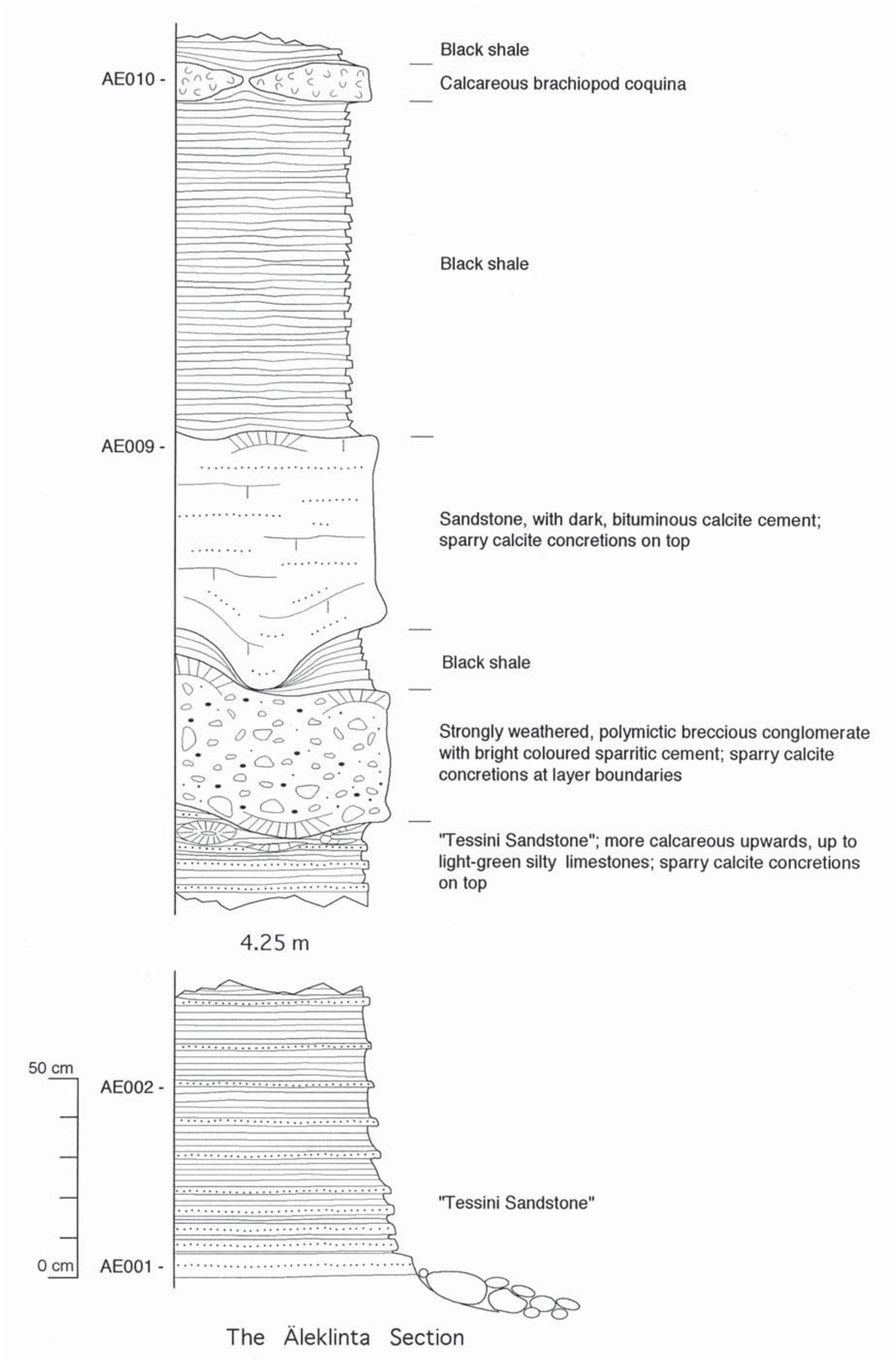

Figure 6: The Cambrian–Ordovician succession at Äleklinta. The top of Cambrian is the thick antraconite bed; the basal Ordovician sediments are composed by the '*Obolus*' conglomerate.

8th SEPTEMBER

On the fourth day we will depart from Öland and continue to Gotland.

DESCRIPTION OF EXCURSION LOCALITIES

NORTHERN ÖLAND: LOCALITIES 1–8

LOCALITY 1: KÖPINGS KLINT SECTION – TYPE LOCALITY FOR THE KÖPINGSKLINT FORMATION

Location. – Raised sea-cliffs between Borgholm and Köpingsvik.
Main topics. - Köpingsklint and Bruddesta formations.
Secondary topics. - Djupvik Formation.
Description. – In this section 7 m of Latorpian and Volkhovian bedded limestone of the '*Orthoceras* Limestone' are well exposed in the cliff. Following formations are displayed in ascending order: The Alum Shale Formation, Djupvik Formation, Köpingsklint and Bruddesta Formations (van Wamel 1974) and the lower part of Formation A+B (Fig. 5).

Stratigraphic succession

>1 m - Formation A+B

Grey-green limestone with glauconite, mostly covered by vegetation and scree.

1.55 m - Horns Udde Formation

Red to grey and violet limestone, stylolitic. The 'Bloody layer' is seen near the base of the formation.

4.0 m - Bruddesta Formation

Red-brown limestone and marls with yellow discontinuity surfaces.

0.85 m - Köpingsklint Formation

Green, violet to red limestone, glauconite silt and sands.

1.70 m - Djupvik Formation

Green to dark grey siltstone and shale.

0.65 m - Alum Shale Formation

Black to dark grey limestone nodules, calcite prisms and dark shales. The outcrop is not well seen and may be covered on the day of our visit.

Few cm's - Borgholm Formation

Light Green sandstone and shale.

Fossils and biostratigraphy

Tjernvik (1956) recorded the *Shumardia*, *Ceratopyge forficula*, *Megistaspis (E.) armata, M. (V.) planilimbata*, *Megalaspides (M.) dalecarlicus* and *Megistaspis (V.) estonica* zones in the section. The *Megistaspis polyphemus* Zone is present in the Volkhov succession.
The black shale of the Alum Shale Formation contains *Rhabdinopora flabelliforme* (Westergård 1947).
Conodonts are present in the whole section and all conodont zones spanning the *Cordylodus angulatus*, *Paltodus deltifer* to the Volkhovian *Baltoniodus navis* Zones are represented (van Wamel 1974; Bagnoli *et al*. 1988).
Acritarchs are abundant in the Borgholm, Alum Shale and Djupvik Formations and are also very well preserved (Bagnoli *et al*. 1988).

LOCALITY 2: ÄLEKLINTA

Location. – Sea-cliff at Äleklinta, about 11 km north north-east of Köpings Klint, and a small quarry above the sea-cliff about 400 m north of the village of Äleklinta.

Main topics. – The Middle Cambrian Borgholm Formation and the Lower Ordovician Alum Shale Formation.

Secondary topics. – The Djupvik, Köpingsklint and Bruddesta Formations.

Description. – The Cambrian–Ordovician transition can be observed at the Äleklinta locality (Fig. 6). The Middle Cambrian Borgholm Formation and the Lower Ordovician Alum Shale Formation will be examined.

Borgholm Formation
The formation consists of sandstone and siltstone with abundant trilobite fragments of trilobites. About 7 m are exposed in the sea-cliff.

Alum Shale Formation
The unit consists of polymict conglomerate, black shale and large coarse-grained antraconites with calcite cement capped by sparry calcite. A thin conglomerate or '*Obolus*' conglomerate (named after *Obolus apollinis*, which is present in the matrix) marks the start of Ordovician. The unit is approximately 2 m thick (Fig. 6).

Köpingsklint Formation
The unit is composed of glauconite sand and limestone with a recrystallised limestone at the base. It is 0.60 m thick at this locality.

Bruddesta Formation
This formation is exposed on top of the sea-cliff. The abandoned quarry has not been in use for many years and may be overgrown. The section exposes a green to grey and red limestone with marly interbeds.

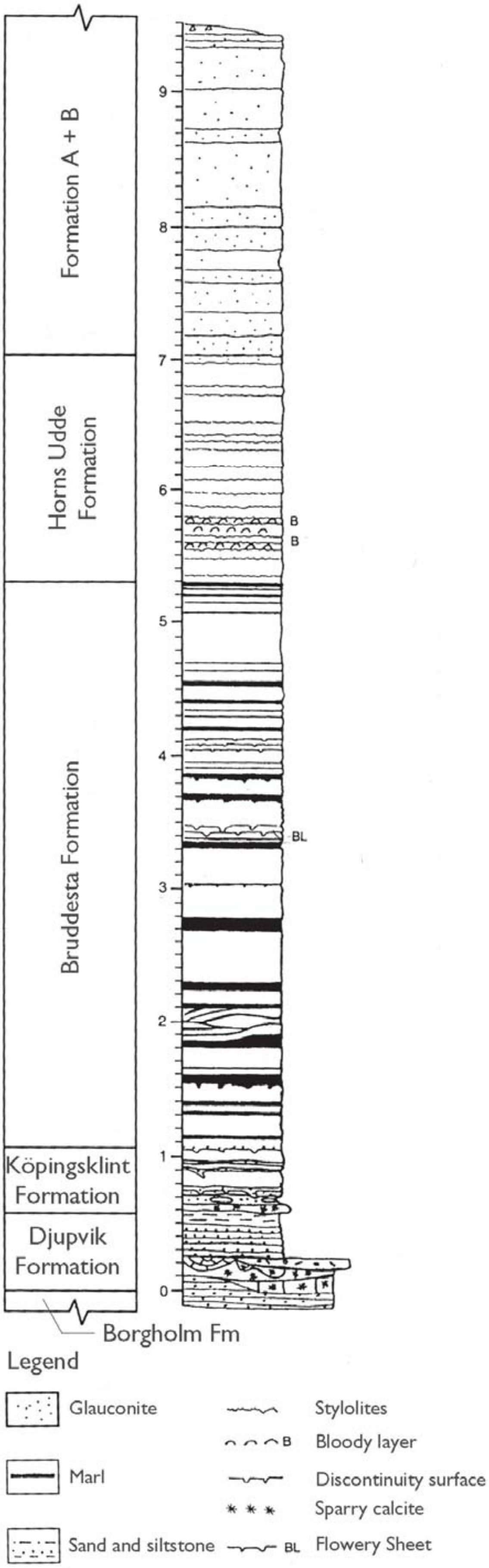

Figure 7: The succession at the north of Horns Udde section (from Bagnoli & Stouge 1997)

Palaeontology and biostratigraphy

The Cambrian System ends at the large antraconite, which is referred to *Agnostis pisiformis* Zone. The '*Obolus*' conglomerate marks the first appearance of the Ordovician beds. The overlying black shale yields *Rhabdinopora flabelliforme*.
Trilobites include the *Megistaspis* (*V.*) *planilimbata* Zone followed by the *Megalaspides dalecarlicus*, *M.* (*V.*) *estonica* and the *M.* (*M.*) *polyphemus* (previously *M.* (*M.*) *lata*, see Nielsen 1995) zones. The *M. armata* Zone (lower Hunnebergian Substage) is missing.
The conodonts from the '*Obolus*' conglomerate are referred to the *Cordylodus angulatus* Zone. The higher beds yield many well preserved conodonts with *Baltoniodus navis* and *Microzarkodina flabellum*.
Acritarch assemblages from the Middle Cambrian Borgholm Formation include *Adara alea* and *Cristallinium cambriense*. The acritarch assemblage from the Upper Cambrian antraconite horizon comprises *C. cambriense*, *Timofeevia pentagonalis* and *T. phorphoritica*. The '*Obolus*' conglomerate did not yield species of biostratigraphic significance as only sphaeromorphs have been observed (M. Tongiorgi pers. comm. 1999).

LOCALITY 3: NORTH OF HORNS UDDE

Main topics. - Bruddesta Formation, 'Blommiga bladet', 'Bloody layer', Horns Udde Formation.

Secondary topics. - Middle Cambrian sandstones (Borgholm Formation), Lower Ordovician '*Obolus*' conglomerate (Alum Shale Formation), Djupvik Formation and Köpingsklint Formation.

Location. - Approximately 1 km north of Horns Udde.

Description. - Horns Udde, together with the coastal cliff immediately to the north of Horns Udde are excellent exposures showing the succession of northern Öland. The locality displays the succession from the Middle Cambrian Borgholm Formation (sandstone) to the Lower Ordovician (Volkhov) limestone of Formation A+B (Fig. 7).

The succession contains significant breaks in the upper Cambrian and early part of the Ordovician. Above this, the succession is complete or almost complete. The lower part of the section may be covered by beach gravel.

Locality 3 is one of the 'classical sections' on Öland and together with the Gillberga section ranks amongst the best sections that display the strata of the '*Orthoceras*' Limestone on northern Öland.

Stratigraphic succession from top to bottom

> 2 m - Formation A+B

Green-grey wackestone to grainstone, bedded to nodular with various amount of argillaceous material and abundant glauconite. Trilobites and orthocones are common allochems.

1.60 m - Horns Udde Formation

Grey, green to violet wackestone. The formation is characterised by numerous discontinuity surfaces and stylolites, which are yellow (goethite). The unit is very fossiliferous and cephalopods are most conspicuous.

A series of up to three bright red haematitic wart-like surfaces are present. These comprise the 'Bloody layer' (named by the local stonemasons and introduced into the literature as a local reference horizon by Bohlin 1949). Similar red surfaces are known on southern Öland, but at a different stratigraphic position.

3.40 m - Bruddesta Formation

A mainly red to red-brown argillaceous fossiliferous lime mudstone to wackestone interbedded with marl. The lower 40–50 cm are green to yellow rather than red-brown.

Disconformity surfaces are common and have goethitic coatings.

An interval with two spectacularly well-developed hardgrounds exists 2 m above the base of the formation; it is called the 'Flowery Sheet' (= Blommiga bladet in Swedish and named by Bohlin 1949). Sedimentary 'folds' are well displayed in the lower half of the formation. The 'folds' were described in great detail by Lindström (1963) from this locality.

0.5 – 0.8 m - Köpingsklint Formation

The limestones are composed of limemud, wackestone and grainstone. The limestone is associated with glauconite and interbedded with glauconite sand. The sediments are multicoloured and fossiliferous. The beds in the unit are laterally variable and recrystallised horizons are common to prominent. The horizons are developed as sparry calcite and are arranged in a rosette-like pattern.

Note: The base of the formation is situated at the foot of the cliff and it is not recommended to approach it.

0.25 – 0.45 m - Djupvik Formation

This unit is composed of siltstone with minor shaley intervals.

0.25 m - Alum Shale Formation

A thin layer of black shale may be found.

? m - Borgholm Formation:

Green silt to fine-grained sandstone. This unit is of Middle Cambrian age. The strata are exposed only at low tide and only the top beds may be accessible.

Fossils and biostratigraphy

Upper Cambrian taxa i.e. *Agnostus pisiformis* may be found in the clasts associated with the '*Obolus*' conglomerate.
The base of the Ordovician is exposed near the base of the cliff, but the beach shingle commonly covers the sediments. The base of Ordovician is found at the '*Obolus*' conglomerate.
The thin black shale of the Alum Shale Formation has yielded *Rhabdinopora flabelliforme*.
The Hunnebergian Substage is recorded from the Köpingsklint Formation, but only the *Megistaspis* (*E.*) *armata* Zone has been observed.
The Billingenian Substage i.e. the *Megalaspides* (*V.*) *dalecarlicus* and *M.* (*V.*) *estonica* zones are well displayed in the lower part of the Bruddesta Formation and below the 'Blommiga bladet'. Above the 'Blommiga bladet' and to the top of the section, the strata are referred to the Volkhov Stage. The Volkhovian *Megistapis* (*M.*) *polyphemus*, *M simon* and the lower part of *M. limbata* zones are presumably present in the section, but the precise ranges and the boundaries of the trilobite zones have not been established in this section.
Conodonts are omnipresent in the Ordovician strata and the *Cordylodus angulatus*, *Paltodus deltifer, Oepikodus evae*, *Baltoniodus*? *triangularis*, *Baltoniodus navis*, *Microzarkodina parva* and *Baltoniodus norrlandicus* zones have been recognised from this section (Lindström 1971; van Wamel 1974; Bagnoli & Stouge 1997).
Organic shelled fossils (chitinozoans and acritarchs) are fairly common in the upper grey to green limestones of the Volkhovian Formation A+B (Ribecai & Tongiorgi 1995), whereas the red-brown to red limestones of the Bruddesta and Horns Udde Formations are barren of these fossils. When present, the organic shelled fossils are well preserved.

LOCALITY 4: BYRUM

Main topics. – Formation A+B, Fe-ooids.

Secondary topics. – Formation C.

Location. – South of Byrum and outside the protected area with 'Raukarna' (= sea stacks: erosional remnants caused by the sea waves).

Description. – The section displays a short segment of Formation A+B. It is a low but laterally extensive outcrop and the beds can be traced northwards into the protected area with sea stacks ('Raukarna'). Here higher strata or Formation C are exposed. The area with 'Raukarna' is protected and sampling is not permitted.

The exposures at the coastal section include well-developed Fe-ooid horizons with varied composition in the glauconitic limestone of Formation A+B (Sturesson 1986, 1988). Phosphatic impregnations associated with burrows are present in Formation A+B at the foot of the low sea cliff. The ooid horizons are dark grey to nearly black. The ooids are white, red, yellow or brown.
The appearance of chamosite ooids in the Öland succession and elsewhere in the Baltic Basin (Jaanusson 1982) marks an important change in facies of authigenic silicate minerals (Sturesson 1986). Glauconite is the dominant authigenic silicate in the beds below the ooids whereas in the higher beds the dominating authigenic silicicate is chamosite. The significance of this change is not yet understood, but clearly relates to the upper Volkhov – lower Kunda regressive/transgressive transition.

Stratigraphic succession

>1.75m - Formation C

Yellow to light-grey wackestone.

> 2.75 m - Formation A+B

1.25 m Green grey nodular bedded limestones

0.25 m Horizon of Fe-ooids

0.25 m Green-grey limestone

0.10 m Zone with Fe-ooids

0.90 m Green-grey limestone with phosphatic burrows

(beach)

Fossils and biostratigraphy

The section has not been investigated systematically for fossils. Bohlin (1949) reported the presence of trilobites from the *Asaphus expansus* and *Asaphus* '*raniceps*' Zones. The former zone characterises the ooid horizons.
Conodonts (Stouge unpublished) occur frequently and the succession corresponds to the Haget, Hälludden and Gillberga successions (Stops 5, 6 and 8 in this guide). The Byrum section is the best exposure on Öland, where an interval with both a lower and an upper ooid horizon is displayed.
Acritarchs are present in high numbers (these results have not yet been published) (Ribecai *et al*. in prep.).

LOCALITY 5: HAGET

Main topics. – The upper Volkhov to lower Kunda limestone of Formation A+B and Formation C.

Secondary targets. - Local D-surface and Fe-ooids in

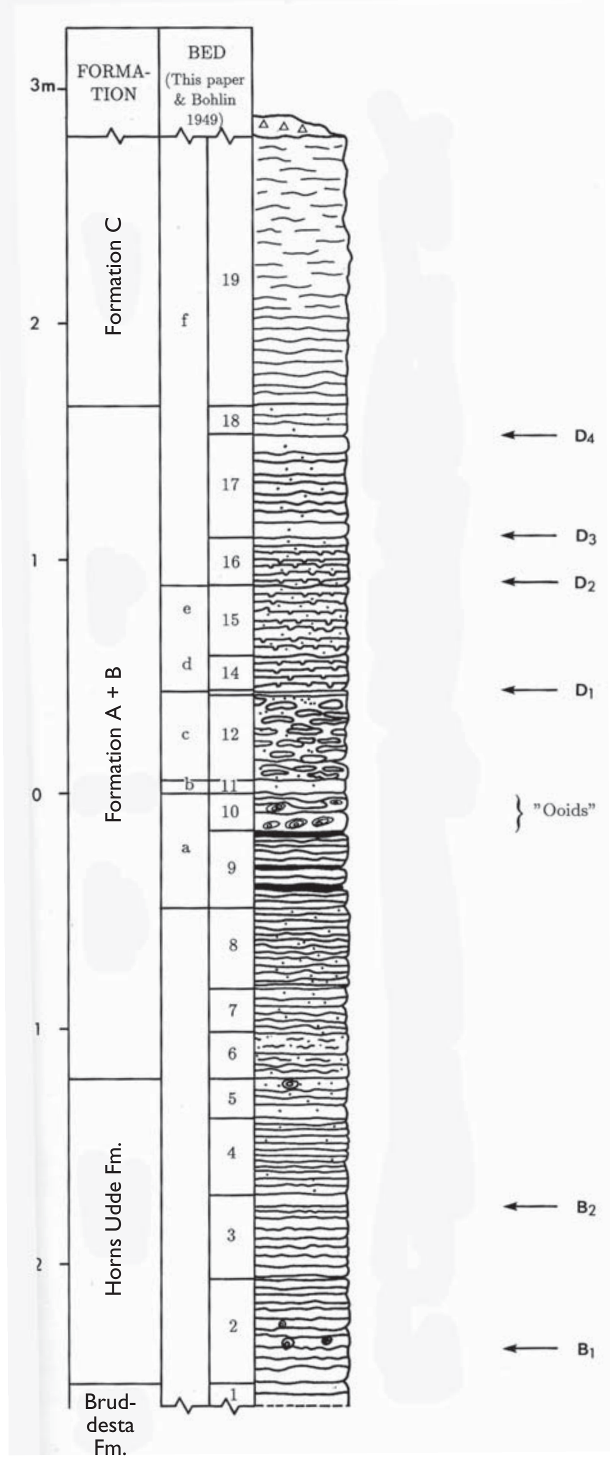

Figure 8: The succession at Haget (from Stouge & Bagnoli 1990). Formation A and B are now combined into one or Formation A+B.

Formation A+B.

Location. – West coast, between Byrum and Byxelkrok.

Description. – The upper Volkhov to lower Kunda beds are exposed in the sea cliff at the Haget section (Fig. 8), which also displays the erosional morphology caused by the sea waves. The lower part of the section is an almost flat surface that is commonly covered by seawater. The foot of the low cliff lies approximately 30 cm below the Fe-ooid bed.

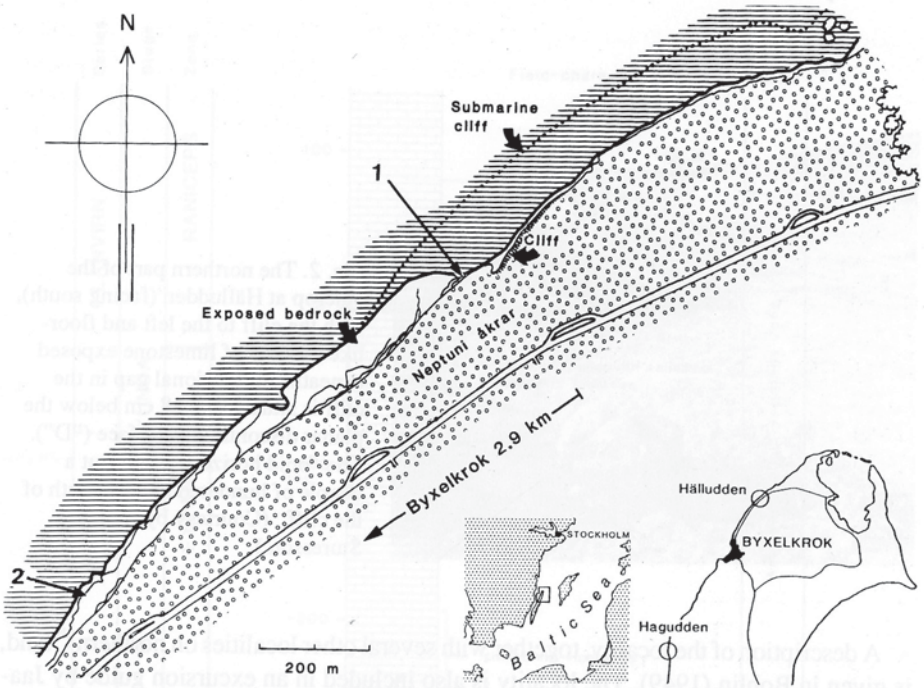

Figure 9: The Hälludden locality showing the location of the main section and the Neptuni åkrar (from Nordlund 1989a). The 'ooid' horizon (1) situated about 100 m to the south of the cliff-section. (2) is a cephalopod-rich level in Horns Udde Formation (from Nordlund 1989a).

Stratigraphic succession

>1.15 m – Formation C

Grey to beige wackestone with undular bedding. Trilobites are the most common allochems.

2.80 m - Formation A+B

Grey to dark grey wackestone with glauconite.

Grey to green wackestone with glauconite and glauconitic sand. Phosphatic burrows are common. Ooids in the formation are limonitic/goethitic.

1.30 m - Horns Udde Formation

Lime mudstone to wackestone with grey to violet and red stringers. The 'Bloody layer' is present at the base of the formation. Cephalopods are the most common allochems. This formation may be covered by seawater.

> 0.10 m - Bruddesta Formation

Red-brown, argillaceous lime mudstone with trilobites.

Palaeontology and biostratigraphy

Bohlin (1949) outlined a detailed stratigraphy of the Haget section. He reported the *Asaphus lepidurus*, *A. expansus* and *A.* '*raniceps*' zones from the section.
Graptolites (Arenig–Llanvirn) have been found in the green limestones (Skevington 1963, 1965a).
Conodonts are present in all beds. The conodont zones from the *B. navis* Zone to the *Lenodus pseudoplanus* Zone are recorded (Stouge & Bagnoli 1988).
Acritarchs are well represented in the green glauconitic limestone of Formation A+B and exceptionally high numbers of specimens have been recorded from this locality (C. Ribecai in prep.)
Stop: Byxelkrok for lunch, shopping etc.

LOCALITY 6: HÄLLUDDEN

Main topics. – Formation A+B; D-surface.

Secondary topics. - Fe-ooids (if exposed).

Location. – North of Byxelkrok.

Description. – The Hälludden section is part of the long and extensive exposure that extends to the north of Byxelkrok as a narrow strip along the coast for several kilometres (Fig. 9). It starts just to the north of Byxelkrok and continues almost to the very tip of the island. The succession begins with the Billingenian limestone and the strata gradually become younger northwards and end with limestone of Kundan age (Bohlin 1949).
Inland from the cliff section, the beach ridges are composed of shingle. Linnaeus (1745) named the elevated beached 'Neptuni åkrar' (the fields of Neptune) and this name has gained general usage. Linnaeus also noted the fossiliferous exposures along the shore including cephalopods ('Ölandsspikar') and figured a pygidium of *Megistaspis* (*M.*) *limbata*.
The Hälludden section was the target in Project Hälludden (Jaanusson & Mutvei 1982). These workers used index horizons for determining the level of the succession. The index horizons are the top of the oolitic bed (0) at the base of the Hunderumian Substage, and a conspicuous, smooth

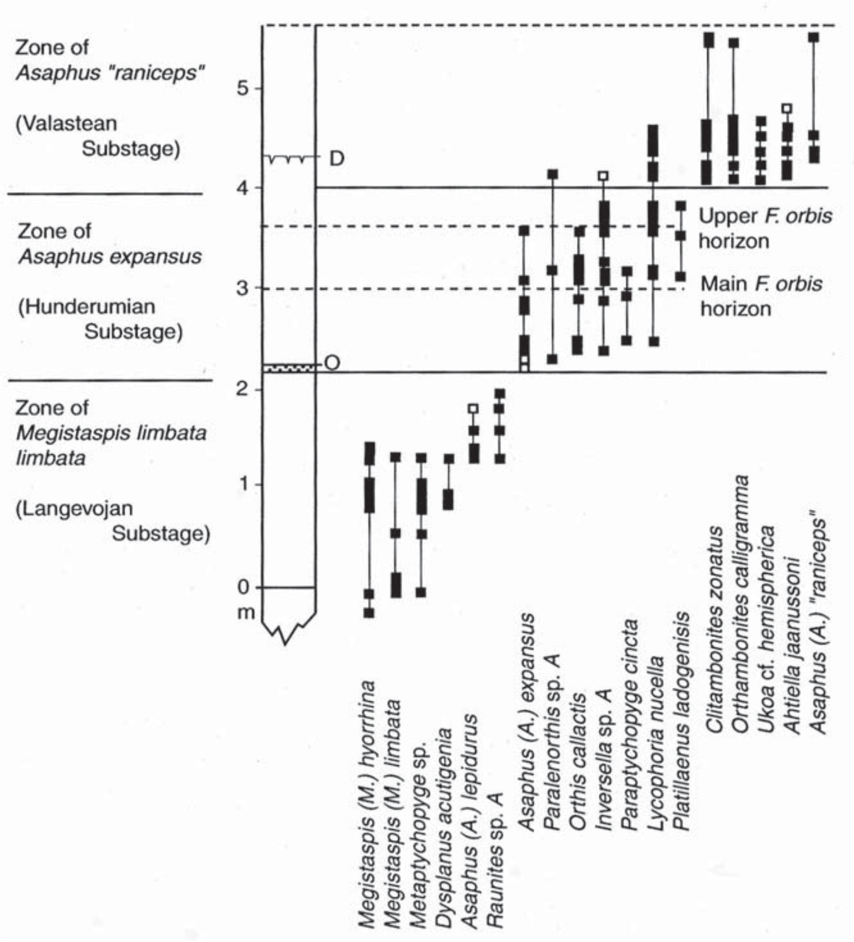

Figure 10: Biostratigraphy at Hälludden and the lower (main) and upper horizons with *Fisherites orbis*. D is the local discontinuity surface used as reference level. O marks beds with limonitic 'ooids' at the base of *Asaphus expansus* Zone (from Nitecki *et al.* 1999).

discontinuity surface (D) in the basal Valastean Substage. The levels above D were designated as + D, and those between D and the upper surface of 0 as – D.

The boundary between the upper Volkhov Stage and the Hunderumian Substage of the Kunda Stage is placed at the base of the oolitic bed, and that between the Hunderumian and Valastean substages, is at about - 30 D i.e. 30 cm below the index discontinuity surface (Jaanusson 1957).

Stratigraphic succession

< 1.5 m – Formation C (only seen to the north of the section)
Grey to yellow wackestone with some or no glauconite.
The smooth reference surface D with borings and ooids is seen - 0.40 m from the base.
2.9 m - Formation A+B
Grey to green wackestone with glauconite. The amount of glauconite decreases up through the section. The lower part of the section comprises green to grey glauconitic wackestone-grainstone and glauconite sand.
A 10 cm thick ooid horizon has been reported from the southern end of the section (Jaanusson 1957; Janusson & Mutvei 1982), but this interval may be covered by seawater.

Palaeontology and biostratigraphy

Gerhard Holm collected cephalopods and graptolites at Hälludden for many years (e.g. Holm 1882). Additional years of collecting under the Hälludden Project has yielded many additional fossils. So far, illaenid trilobites Jaanusson (1957), graptolites (Bulman 1936; Skevington 1963, 1965a), chitinous hydroids (Skevington 1965b), acritarchs (Eisennack 1976; Ribecai & Tongiorgi 1999), chitinozoans (Grahn 1980, 1982) and two horizons with receptaculitids (= *Fisherites orbis*) have been recorded and described from the section (Nitecki *et al.* 1999), but many more undescribed taxa including brachiopods are present, especially in Formation A+B (Jaanusson & Mutvei 1982; Fig. 10).
Additional trilobites to those described by Jaanusson (1957) have been listed (Jaanusson & Mutvei 1982; Nitecki *et al.* 1999) and the *M. limbata*, *A. expansus* and *A. 'raniceps'* zones are present (Fig. 10).

The graptolites are Darriwilian in age; those recorded between – 1.00 m and – 0.60 m in the middle of the *A. expansus* Zone are Arenig, whereas the fauna at + 0.20 i.e. *Asaphus* '*raniceps*' Zone is Llanvirn.
Conodonts are present in the whole section with a moderate yield and preservation in the lower part to good yield and preservation in the upper part. The fauna is currently being investigated (Stouge in prep.) and the fauna is referred to, from base to the top, the *Lenodus antivariabilis*, *Lenodus variabilis* to *Yangtzeplacognathus crassus* conodont zones.

Depositional environment. - The depositional environment has been debated for some time, especially for the sediments

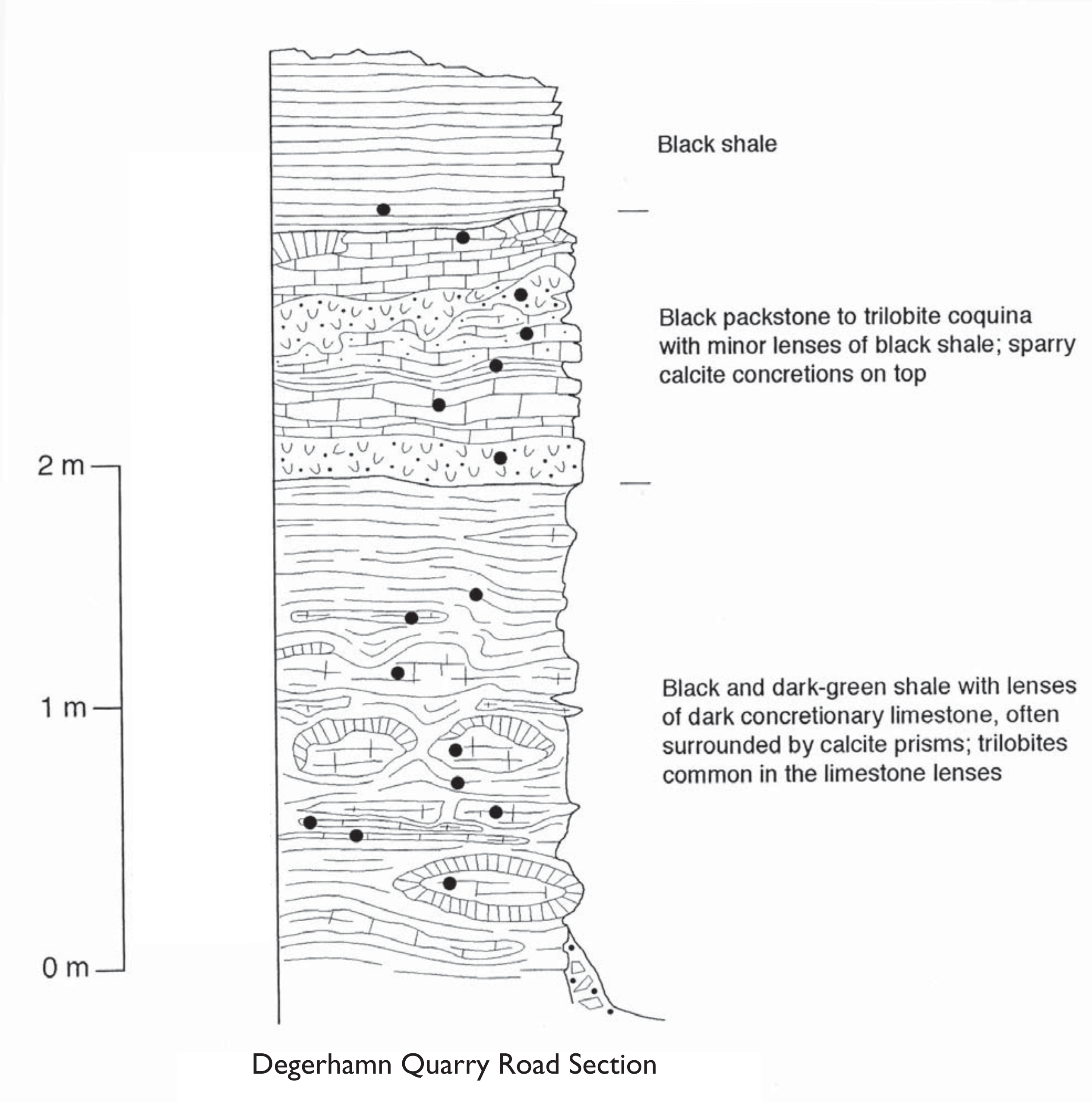

Figure 11: Degerhamn quarry road section – a road cut showing the Alum Shale Formation with the *Olenus* horizon (Upper Cambrian) characterized by antraconites in black shale overlain by shale with *Clonograptus tenellus* (Lower Ordovician). Trilobites are very

of Formation A+B at Hälludden. Chen & Lindström (1991) found that the deposition took place in a fairly deep sea, i.e. between 150–200 m. In contrast Bohlin (1949), Grahn (1982, 1986), Jaanusson (1982), Sturesson (1986, 1988 and Nordlund (1986, 1989a, 1989b) all argued that the strata of Formation A+B accumulated in a comparatively shallow sea and were storm generated deposits or tempestites. The arguments are equivocal and the debate is not yet settled.

LOCALITY 7. - KÄLLA – TYPE LOCALITY FOR THE KÄLLA LIMESTONE

Location. – South-west of Källa Church.

Main topic. – Källa Limestone (Viru – Middle Ordovician).

Description. – The locality is mostly overgrown but approximately 1.5 m of strata can be seen. The sediment is a lime mudstone or wackestone with argillaceous interbeds and with some macrofossils.

Palaeontology and biostratigraphy

Macrofossils i.e. trilobites are not frequently found, but brachiopods are fairly common in the argillaceous layers. The conodonts are well preserved and the fauna represents the *Baltognathus robustus* Subzone of the *Pygodus serra*

Zone (= *Glyptograptus teretiusculus* graptolite Zone, Uhakuan Stage) (Stouge unpublished). Acritarchs are present and well preserved. These are currently under investigation (Ribecai in prep.).

LOCALITY 8. – GILLBERGA QUARRY

Location. - Approximately 200 m to the south-west of the village of Gillberga.

Main topics. – Formation A+B and the formations above, C and D.

Description. – The locality is presently being quarried and thus the description given here may not quite correspond to its appearance on the day of our visit.
This locality is the northernmost of a series of large quarries located between Gillberga and Sandvik and up to the coast. Most of the quarries reveal the upper part of the Bruddesta Formation down to the 'Blommiga bladet', which often forms the bottom of the quarry and the Horns Udde Formation, but the top of the Gillberga Quarry succession displays the youngest exposed Kunda sediments on this part of the island.
Bohlin (1949) described the Hjorthamn Limestone from the Gillberga quarry. The Hjorthamn Limestone is a unit approximately 0.9 m thick and is part of Formation A+B. The base and the top of Formation A+B are well displayed in the quarry. The strata referred to as Formations C and D lie above Formation A+B and Formation D concludes the succession.

Stratigraphic succession.

>2.50 m – Formation D

Grey to red and green undular bedded wackestone with argillaceous partings. Cephalopods and trilobites are common.

2.90 m – Formation C

Light grey, mottled grey to dark grey or violet wackestone to grainstone with abundant stylolites. Cephalopods and trilobites are frequent. Pyrite is present.

8.20 m – Formation A+B

Wackestone with glauconite and glauconitic sand. This unit has a green appearance. Glauconite becomes more rare in the upper part of the unit. Several spectacular discontinuity surfaces, especially at the bottom of the formation can be traced to the section north of Horns Udde. Hjorthamn Limestone occurs within the upper one meter of this unit.

1.65 m – Horns Udde Formation

Wackestone with many disconformity surfaces. This unit is developed with the 'Bloody layer' at the base. The top is a prominent surface. Cephalopods are common.

2.5 m – Bruddesta Formation

Red micrite with silt or marl beds. The 'Blommiga bladet' is exposed at the base of the quarry and is often covered by water.

Palaeontology and biostratigraphy

The section has not been investigated for fossils.
The conodont biostratigraphy of this section was described by Löfgren (2000). The succession is almost complete and reaches up to the *Microzarkodina ozarkodella* Zone (Kunda Stage).

Table 1

North Öland	
Upper Grey *Orthoceras* Limestone	*Centaurus* Limestone
Upper Red *Orthoceras* Limestone	*Platyurus* Limestone
	Gigas Limestone
Lower Grey *Orthoceras* Limestone	*Asaphus* Limestone (=*Vaginatum* Limestone sensu Holm 1882)
Lower Red *Orthoceras* Limestone	*Limbata* Limestone and *Planilimbata* Limestone (pars)
South Öland	
Upper Grey *Orthoceras* Limestone	*Centaurus* Limestone
Upper Red *Orthoceras* Limestone	*Platyurus* Limestone
	Gigas Limestone
	Transition beds
Middle Red *Orthoceras* Limestone	Upper *Asaphus* Limestone
Middle Grey *Orthoceras* Limestone	'Sphaeronites bed'
Lower Red *Orthoceras* Limestone	Lower *Asaphus* Limestone
	Limbata Limestone
Lower Grey *Orthoceras* Limestone	*Limbata* Limestone and *Planilimbata* Limestone

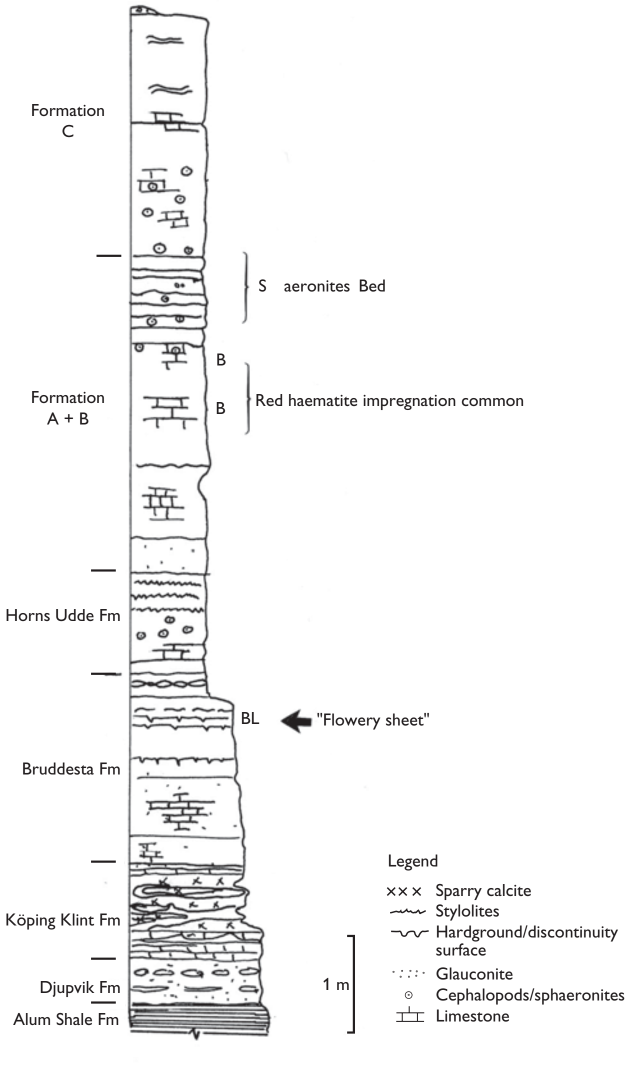

Figure 12: A log for the Degerhamn quarry section (it is also valid for Grönhögen see text). The '*Sphaeronites*' bed lies near the top of Formation A+B.

SOUTHERN ÖLAND: LOCALITIES 9–13

LOCALITY 9. – DEGERHAMN HARBOUR

Location. – In the harbour at Degerhamn.

Main topic. – Green Limestone with '*Sphaeronites.*'

Description. – The stop is in the small harbour where loose blocks with '*Sphaeronites*' are easy to investigate. The purpose of this stop is to show the parts of the facies of Formation A+B, which are not found on northern Öland. The unit is easy to recognise in the sections as it appears as a 'green unit' beneath a red limestone. The 'green unit' is intensively quarried in the Degerhamn Quarry (Stop 10) due to its low content of clay material. The 'green unit' is a marker horizon that can be traced from Kinnekulle, Väster Götland, central Sweden in the west to southern Öland and further on and across the Baltic Basin to Estonia in the east.

The unique fossils at the Degerhamn Harbour locality are the diploporite cystoids or '*Sphaeronites*'. The conodont fauna is typical of the Volkhov – Kunda transition (*Lenodus variabilis* Zone) in the Baltic Basin.

LOCALITY 10. – DEGERHAMN QUARRY

Location. – East of the main road and approximately 2 km south-east of Degerhamn.

Main targets. – The unit with '*Sphaeronites*' of Formation A+B and the overlying Formation C.

Additional targets. – The Bruddesta and Horns Udde formations.

Description. – This is an extensive quarry and permission to enter the quarry from the owner is required. The entrance to the quarry is at the factory in Degerhamn village aproximately 2 km north-west of the quarry, but parts or even all of the quarry may not be accessible if production is taking place.
In this quarry the succession from the Alum Shale Formation to Formation C is well exposed (Fig. 11). The succession in southern Öland is largely the same as the succession on northern Öland, but differences are found in the thickness of the units and colour of the sediments. The most prominent colour change is that the Bruddesta Formation is brown-red on northern Öland but grey in southern Öland and the colour of Formation C is red in the Degerhamn quarry rather than being light grey to yellow as it is typically on northern Öland.
On Öland the *Orthoceras* Limestone was first divided into units according to colours as shown
in Table 1.
Comparison between northern Öland and southern Öland using the colour system however appeared to be difficult and is now abandoned.

Stratigraphic succession

> 1.90 m – Formation C

Red to brown grain- and wackstone with occasional green partings. Cephalopods are present.

1.25 m – Formation A+B

Green, grey and red wackestone with some glauconite. Cephalopods and trilobites are common in the formation and '*Sphaeronites*' mark the top of the formation on southern Öland. In the upper part, several bedding planes are encrusted by haematite.

1.50 m - Horns Udde Formation

Grey to violet wackestone with many disconformities developed as stylolites.

Cephalopods are common.

1.70 m – Bruddesta Formation

Grey to light grey lime mudstone and wackestone with green marly horizons. Beds usually 5-7 cm thick. Rusty weathering pyrite nodules are common at bedding planes.

1.05 m – Köpingsklint Formation

Glauconitic lime mudstone with green stringers and limestone nodules and glauconite sand. The middle part is strongly recrystallised at certain levels. Slump structures are present within the formation.

0.40 m – Djupvik Formation

Green silt with silty limestone nodules. Glauconite is common in the sediments.

> 1.30 m – Alum Shale Formation

Dark grey and black shale with occasional limestone lenses; rusty weathering is characteristic and pyrite nodules are present.

Palaeontology and biostratigraphy

The section has not been investigated for macrofossils. However the trilobite zones recorded from Ottenby (Tjernvik 1956; Stop 13) can be correlated with the section.
All conodont zones from the *Paltodus deltifer* Zone, which is found in the Djupvik Formation to the *Lenodus pseudoplanus* Zone, which is present in Formation C, have been recorded in the section (Stouge unpublished and in prep.).

LOCALITY 11. – DEGERHAMN QUARRY ROAD SECTION

Location. – At the bridge on the main road approximately 1.5 km to the north of Degerhamn.

Target. – The Cambrian–Ordovician system boundary in the Alum Shale Formation.

Description. – The Degerhamn quarry road provides an excellent section of the Alum Shale Formation and the Cambrian – Ordovician boundary. The section is a road cut in the private road to the Degerhamn quarry on both sides of the road and of the bridge.

Stratigraphic succession.

See Figure 12 for a description of the section.

Palaeontology and biostratigraphy

The antraconite nodules are very fossiliferous and consist exclusively of trilobites. Olenids are the dominat trilobites and *Olenus gibbosus* and *O. truncatus* are present. *Peltura scarabaeoides* and *P. minor* are present in the uppermost beds. Acritarchs and conodonts also occur frequently and are well preserved. The graptolite *Clonograptus tenellus* (*Rhabdinopora flabelliforme* Zone) is recorded from the shale at the top of the section.

LOCALITY 12. - GRÖNHÖGEN QUARRY

Location. – In Grönhögen village with the main entrance on the east side of the road and across the entrance to Grönhögen camping place (= old quarry in Alum Shale).

Main target. – The succession from the Bruddesta Formation to Formation C.

Description. - The quarry is large and the exposures are fairly good. The exposed succession is less complete than in the large Degerhamn quarry and the stratigraphically lower units i.e. the Alum Shale, Djupvik and Köpingsklint formations are not exposed in the quarry.

Stratigraphic succession

The exposed succession at this locality is identical to the succession in the Degerhamn quarry (Stop 10) and is not repeated here.

Palaeontology and biostratigraphy.

Biostratigraphic studies have not been published on the exposed succession. Conodonts extracted from the section are currently being investigated. To date, the results are similar to those from the Degerhamn section.

LOCALITY 13. – OTTENBY SECTION

Location. - Small sea-cliff west of Ottenby, the southernmost village of Öland.

Main target. – Köpingsklint Formation.

Additional targets. – Alum Shale and Djupvik formations.

Description. - Ottenby is a natural exposure along the shore of Kalmarsund. The cliff at Ottenby is the best exposure of the Köpingsklint Formation on Öland.

Stratigraphic succession

The section comprises the Alum Shale Formation, the Djupvik Formation, the Köpingsklint Formation and ends with the Bruddesta Formation. The section is shown in Figure 13 (from Tjernvik 1956).

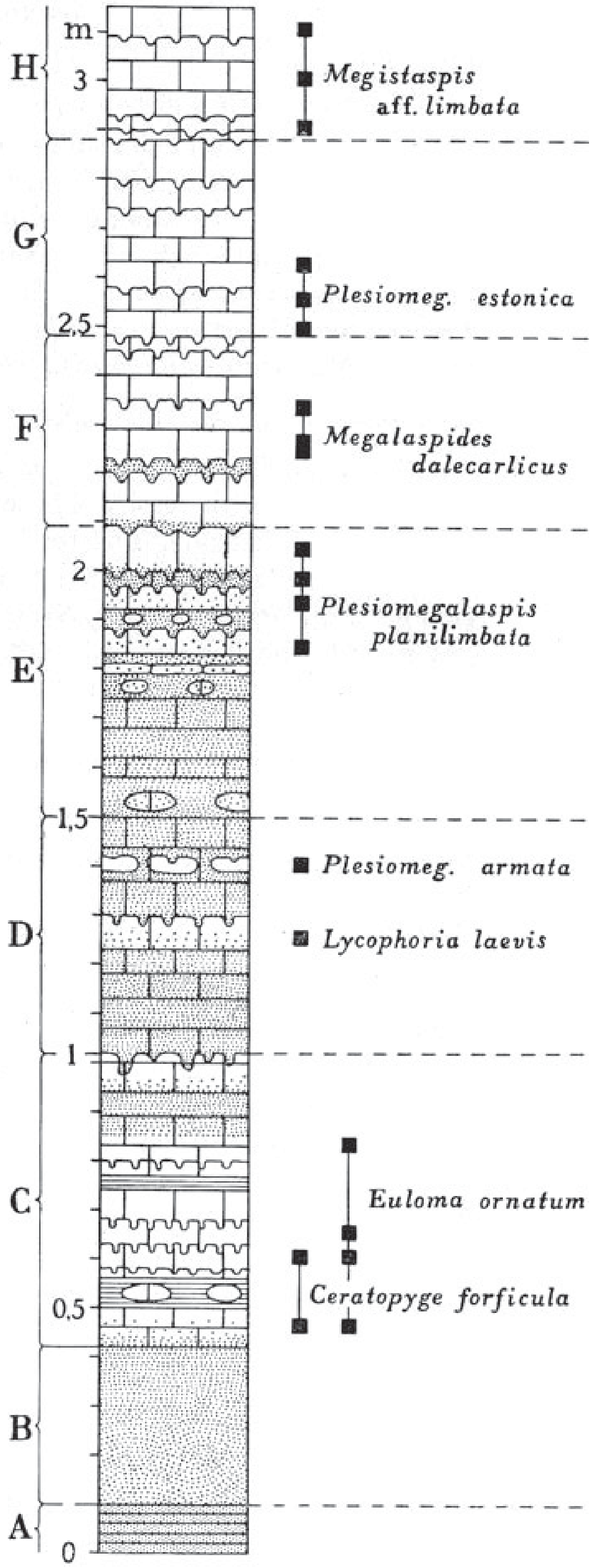

Figure 13: The section at Ottenby with trilobite data (from Tjernvik 1956). The *Ceratopyge* and *Dictyonema* shale are now referred to the Alum Shale Formation. The Djupvik Formation is 30–36 cm thick and the Köpingsklint Formation is about 2 m thick at this locality.

Palaeontology and biostratigraphy.

The Ottenby section has yielded around 20 trilobite species. The most common forms are *Ceratopyge forficula* (Sars), *Euloma ornatum* Angelin, *Orometopus elatifrons* (Angelin), *Niobe insignis* Linnarsson, *Niobella obsoleta* (Linnarsson), *Varvia longicauda* Tjernvik, *Ottenbyaspis oriens* (Moberg & Segerberg), *Symphysurus angustatus* (Sars & Boeck) and *Nileus limbatus* Brögger.

Conodonts are common and the basal limestone nodules and beds of the Köpingsklint Formation contain a *Paltodus deltifer* Zone fauna. The *Paroistodus proteus* Zone begins about 0.2 m above the base of the Köpingsklint Formation. It is complete except for a break at the base of the Billingen Substage 1.3 m above the base of the limestone. The *Oepikodus evae* fauna appears 1.55 m above the base of the limestone section. The uppermost layer of the section is basal Volkhov in age.

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