The Asaphus Limestone in Northernmost Öland[1]

By

Birger Bohlin

Preface.

The investigations on which the present paper is based were carried on during stays of varying length on Öland during the summers of 1939 — 1948. In 1939 I collected fossils during a week at Böda hamn (the Harbour of Böda), Hälludden, Tokenäse hamn, and Byrum. In 1941 I obtained an OTTERBORG's travelling scholarship, and for an orientation I travelled all over Öland from the south to the north over a period of 5 weeks. Later, I worked chiefly in the northernmost part, from the parish of Föra northwards, after having found that a detailed investigation of this area was necessary to get a correct comprehension of the stratigraphy of the Asaphus limestone. During the summer of 1948 I worked together with three palaeontologists, Mr. V. JAANUSSON and Mr. H. MUTVEI from Estonia and Mr. B. KURTÉN from Helsingfors. Our plan is to write a comprehensive monograph on the Ordovician deposits of Öland. The present paper has to be regarded as a preliminary report and it contains chiefly the results of my own fieldwork and the study of the fossils collected by myself.

When I decided to go back to Öland after my first short visit in 1939, Professsor C. Wiman, who took part in the earlier geological survey of

[1] It has been pointed out that the term "Asaphus limestone" ought to be replaced by the term "Vaginatum limestone" which should be used to designate also the Gigas limestone. As the present paper is mainly a revision of older work at which the former term is the one most commonly used and WIMAN has drawn the limit between the so called Asaphus-limestone and the Gigas limestone on his Solid maps which are discussed below, it might be permissible to use the term Asaphus limestone leaving the question of the most appropriate definition of the units of the section to be dealt with in later more detailed papers.

the island, expressed the wish that I should try to discover why the red Upper division of the Asaphus limestone is not found north of a locality situated on the boundary between the parishes of Föra and Persnäs, i. e. if the red limestone thins out towards the north or if it changes its colour. I think that I have been able to answer this question, thanks largely to several splendid exposures which were not available when WIMAN compiled the Solid map of the region. I am also greatly indebted to Professor WIMAN (†) for the unflagging interest with which he followed the progress of my investigations in Öland.

I have twice had the pleasure of leading excursions from the Palaeontological Institute at Uppsala, which gave me the opportunity to discuss my sections with experienced geologists. Among the members I want to mention Dr. ELSA WARBURG, Dr. I. HESSLAND and Mr. V. JAANUSSON. It has been especially valuable to have a chance of working together with palaeontologists acquainted with the geology of Estonia which, perhaps more than any other Cambro-Silurian area is important for the interpretation of the stratigraphy of the fossiliferous deposits of Öland.

1. Introduction.

The fossiliferous sediments which build up Öland have been the subject of earlier extensive investigations, but what has been published deals chiefly with the Cambrian sequence of strata or with the basal beds of the Ordovician. The Orthoceras limestone has been badly neglected. The literature on its stratigraphy comprises only a few pages, but anyhow if the scattered details are put together one has to admit that those who have travelled on Öland: MOBERG, HOLM, ANDERSSON, WIMAN and others, have seen most of what there is to be seen. As regards Northern Öland HOLM has pointed out (1882) that in the Asaphus limestone, which is the subject of the present paper, a subdivision can be made based on the trilobites occurring in the beds, and in the sea-stacks at Byrum ANDERSSON (1895) has distinguished between a lower glauconite-bearing division and an upper division free from glauconite; and he has observed that there occurs a dark limestone bed with ooids at their base. There has, however, been a peculiar inclination to stop at the fascinating sections at Hälludden, Haget, and Byrum without asking how the richly fossiliferous Asaphus limestone in these localities is separated from the Limbata limestone below and from the Gigas limestone above.

The Solid maps published by WIMAN (1904 a and b) give on the whole a correct picture of the extent of the outcrops of the various divisions of the Ordovician sequence of beds.

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Two circumstances have facilitated my work:

1. During the early forties Northern Öland has been electrified and where the power-lines cross what is in Öland called "alvar" (extensive areas where the limestone lies bare or has only a very thin covering of soil) one had to blast to get the poles down. In the fillings around these poles rich samples of the limestone are available at intervals of between 50 and 80 metres. The depth of the holes is about 1½ metres and the filling must evidently consist of a mixture of limestone fragments from several beds. In reality however, the thickness of beds from which the material is derived is less than 1.5 metres. The hole is namely funnel-shaped and all the larger blocks in the fillings must come from the wider upper part. The lower narrower part is cylindrical and was scooped out in rock which was finely crushed and even burnt at blasting. The series of samples obtained along the lines have proved to be very useful as a complement to the sections in the quarries and along the shore.

2. On the alvar between Stenninge and Sandvik, and near Gunnarslund in the parish of Persnäs, quarries were opened in the Asaphus limestone, which is otherwise poorly exposed in that region. The sections thus obtained comprise together about 12 metres of the sequence of beds. Unfortunately the quarries were soon abandoned and are now filled with water.

2. Field reconnaissances.

Below I am first going to describe a section on the shore west of Haget, which is the locality in the parish of Böda which I know best and where a comprehensive series, from the middle part of the Limbata limestone to the middle division of the Raniceps limestone occurs within a limited area. This section can be easily connected with sections along the shore north and south of Haget (Ölands Norra udde — Byrum). Then the connection will be extended to the parish of Persnäs to get the continuation of the section upwards to the Platyurus-limestone.

I shall go back to the parish of Böda, and using my experiences from Persnäs try to identify higher members of the Asaphus limestone than those exposed in the shore sections.

Then follows a comparison between the sequences of beds in the parishes of Persnäs and Föra (north and south of Hjelmestad in the parish of Föra which is the critical locality where the "Upper red Asaphus limestone" was supposed to disappear towards the north).

Finally in Southern Öland I have made only shorter excursions and I have not yet been able to attack the greater problem of how the Asaphus limestone there with the marked sphaeronite bed at its base may be correlated with the section in Northern Öland where such a bed is not developed. A few observations which might be of importance for the solution of this problem can only be touched upon.

The lists of fossils are preliminary and comprise chiefly the trilobites. Many species of brachiopods will probably turn out to be of importance as index fossils. They have, however, not yet been studied in detail and in the present paper the group is dealt with quantitatively, an abundance of specimens of brachiopods being characteristic of certain parts of the section, whereas in other parts brachiopods are rare.

The same is true about the gastropods, cephalopods, and bryozoans, which were excluded from the lists as the material collected does not give an adequate idea of the occurrence of the representatives of these groups in the sections (so for example are gastropods of the genus *Lesueurilla* very abundant in some beds of the lower part of the Raniceps limestone, but only a few specimens were collected).

Finds of other groups (lamellibranchs, graptolithes and conularias) are so sporadic that they are of no interest for the present paper.

Haget.

This section (figs. 1—3) is situated between Hunderums Sandvik and Hagudden (the map sheet Oskarshamn with Böda). A photograph of the section is reproduced in the Explanation to the sheet as an example of erosion by the sea waves.

Below this section a low shelf extends some tenths of m towards the west. At high water-level, as during the summer of 1948, a great part of the shelf is covered by water.

The beds dip gently (approximately 2:600) towards the north so that lower and lower beds are met with on the shelf when going south. The measurements for the beds forming the shelf were taken during a hurried visit in 1947 and it has not been possible subsequently to check them. They are, however, largely correct; — in such an exposure they can never be absolutely correct, as one has to measure the thickness of the beds one by one and often follow a bed for several m before one reaches a point at which the thickness of the bed on top can be measured. The total thickness of the beds on the shelf (to the bottom of the bed *a* in fig. 2) is the sum of nearly 30 measurements in a distance of about one hundred m.

As one of the starting points for our measurements a very characteristic bed was chosen in the Limbata limestone, known among the workmen in the quarries as "Blodläget" ("the Bloody Layer"). The bed contains within a thickness of about 12 cm three thin layers with "warts" of hematite.[1]

[1] These excrescenses are best developed somewhat above the middle of the bed. Above and below this level they are less conspicuous.

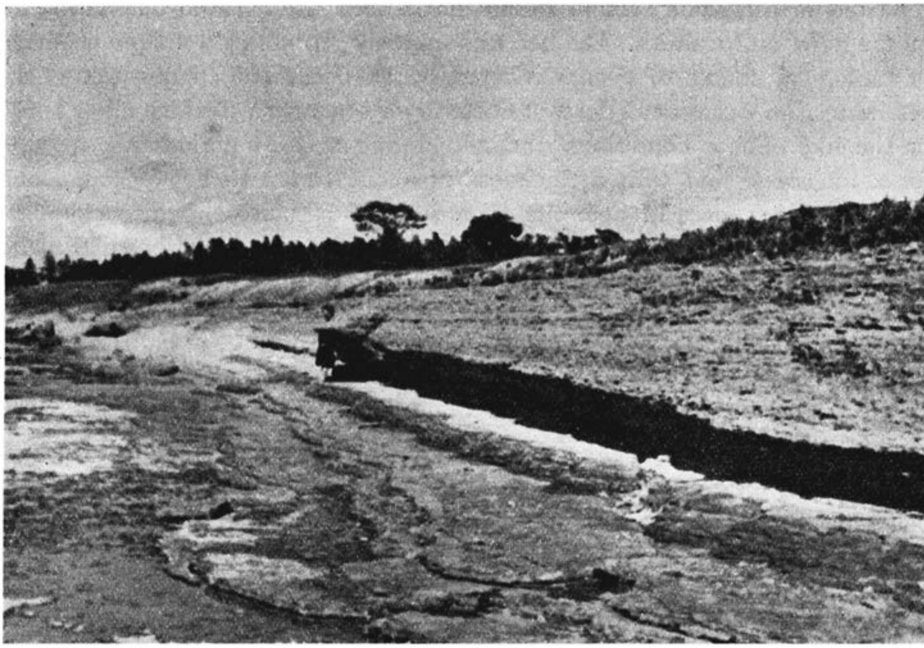

Fig. 1. The northern part of the cliff at Haget from the south. The lady stands on the upper surface of the bed "b" (see p. 536).

These have a diameter of usually 2 or 3 cm and they lie scattered all over the bedding planes at fairly equal intervals (a few cm). At least in some cases the hematite must have accumulated around fossils (remains of the shell of orthoceratites can be completely imbedded in a mass of hematite possibly formed so that a number of warts around the shell fused). Cross-sections through the warts, which one can easily find among the waste from the stone factories at Sandvik, show that they are sharply confined upwards whereas downwards they grade into normal limestone. (The hematite was precipitated on the surface and penetrated to a depth of a few millimetres between the small shell fragments which build up the limestone.)

The "Blodläget" occurs in all quarries, from one situated a few km north of Byxelkrok at least as far as to Sandvik in the parish of Persnäs, a distance of more than 30 km. The bed undoubtedly occurs far north and south of these localities, although it crops out below sea level or is for some other reason inaccessible. (I have not had an opportunity to search for this bed south of Sandvik since its importance for the stratigraphy was discovered). That it is the same bed all the way is beyond doubt. This is sufficiently proved by the experience from the quarries where it fits well into the detailed subdivision of the limestone which has of old been applied by the workmen. Moreover, it is unthinkable that such a peculiar bed which is developed in exactly the same way wherever it is exposed and is never repeated in the same section should have been deposited at different times in the different localities. The bed undoubtedly represents a unique chemical or biological course of events effected by an occasional composition of the sea water, an occasional flora of bacteria (or organisms of some other kind), or the like. These conditions obtained during a short period only, enough for a limestone bed with a thickness of about 12 cm to be deposited and for the excrescenses of hematite to grow during pauses in this sedimentation (see p. 561); they culminated in three or four precipitations of $Fe_2 O_3$, and then nothing similar occurred in the region (unless possibly a coating of red iron oxide on fossils — especially orthoceratites — in the uppermost division of the Raniceps limestone might be due to similar causes). The beds below "Blodläget" are of a deeper red colour than those above, which are to a great extent reddish grey.[1] Higher up the red colour fades, and glauconite which is present already in the uppermost beds of the reddish limestone as minute scattered grains, becomes more abundant. In some parts it occurs in such a great quantity that the beds appear to be of a bright green colour when seen from a distance, especially when they are wet. Single beds in the glauconite-bearing series can, however, be practically devoid of glauconite (see below).

The first appearance of glauconite evidently does not coincide with a change in the fauna. *Megalaspis limbata* still occurs in grey glauconitic limestone.

Only a few of the beds on the shelf have till now been studied in close detail:

In a grey bed containing no or very little glauconite, 1.4 m above "Blodläget", were collected:

Megalaspis hyorrhina
Asaphus cf. lepidurus
Ptychopyge cf. angustifrons

[1] About 2.3 metres below "Blodläget" another peculiar bed occurs in the Limbata limestone which is known among the workmen by the name of "Blommiga bladet" (the "Flowery Sheet") an originally red bed in which funnel-shaped pits were formed by corrosion. These pits are coated with glauconite on their walls and filled with material which forms the bed on top. The limestone has also been influenced chemically in other ways so that large portions have taken on a yellowish brown (ochre) colour. The result is a variegated rock in which the colours (red, ochre and green) are about equally represented, and each forms large patches on the surface. I have seen this bed at Horns udde and not far north of Byxelkrok — about 10 cm thick and in all respects similar in both localities. The quarries near Sandvik have evidently not reached down to this bed; in one of them, however, are beds 2 m below "Blodläget" exposed. Further south the bed must crop out in the cliff between Djupvik and Äleklinta if it stretches that far (the same might be true of "Blodläget")

Below "Blommiga bladet" there lies at Horns udde 2 m of limestone and below that glauconitic limestone, conglomerates and stinkstone which, by a thickness of about one metre separates the Orthoceras limestone from the Paradoxissimus beds (cf. HADDING 1932 p. 36).

In a block of similar limestone found on the shelf by Mr. KURTÉN, the same species were recovered, a pygidium of *Asaphus lepidurus* in such a good state of preservation that there is no doubt about the identification.[1] In a bed rich in glauconite a couple of dm higher up in the section were found:

Megalaspis acuticauda
Asaphus sp.
Ptychopyge cf. angustrifrons

The next bed (c:a 30 cm. thick) has glauconite only in its lower part. In the upper 2 or 3 centimetres glauconite is absent. In its stead there are small pale brown fragments of fossils (limonite impregnation). The limestone itself is in this uppermost part darker than that below and easily recognizable when it occurs as blocks on the shore (north of Haget pygidia of *Megalaspis acuticauda* and an *Asaphus* sp. were collected from such blocks).

Then follows a peculiar bed without glauconite in which three layers can be distinguished:

At the bottom of the bed (3 cm) lies an almost black, soft, marly limestone crowded with small black ooids. The only fossil found in this layer were a few small brachiopods. Other fossils probably occur, but they seem to be rarer than in other beds, which, too, must be characterized as "poorly fossiliferous".

Upwards this soft limestone becomes harder and passes gradually into the middle division of the bed (18 cm). The limestone is still dark but it is so full of small brown pseudooids (small fragments of fossils of an intenser brown colour than those mentioned above from a lower bed) that the bed as a whole has the appearance of being rusty. The bed contains the following fossils:

Megalaspis acuticauda
» *gibba*
Asaphus expansus
Niobe sp.
Ptychopyge cf. *angustifrons*
Pseudocrania sp.

There is also another species of *Asaphus* which is not *A. expansus* and which might be *A. raniceps* (or a member of the *raniceps* group).

The top layer again consists of black soft, ooid-bearing limestone (3—4 cm) exactly like that in the bottom layer and also containing very few fossils.

[1] A Lepidurus zone has been distinguished in Estonia and Mr. JAANUSSON warned me that *Asaphus lepidurus* might occur in the sequence of strata in Öland below the Expansus zone. A rather large material of the species was collected in 1948 and good specimens were also found in earlier collections.

During the field work this bed was designated as the "ooid horizon" (*a* in fig. 2[1]). It is developed in the same way at Hälluden (exposed only for a very short distance near the water-line) and at Byrum, and when possible it was made the starting point for all measurements, the upper surface of the bed being put as $\pm$ 0 m.

ANDERSSON (1896) mentions the bed cursorily. Its great importance for the stratigraphy has not been noticed by earlier writers — the bed being the most obvious part of the Expansus zone which was thought to be wanting in Öland.[2]

The transition from underlying beds to the ooid horizon is, as mentioned above, marked by a layer intermediate in structure. Above follows abruptly a very hard grey, glauconite-bearing bed (*b* in fig. 2), 4—5 cm thick, and identical in structure with several of the glauconite-bearing beds below the bed *a*. This thin bed is resistant to erosion and it forms a shelf about one m wide which can be followed for a couple of hundred m along the base of the cliff. The surface of the shelf is smooth, except in the interior of the deep notch in the section where it is covered by uneven remnants of the soft bed following above.

The bed *b* is the last representative of the type of sediments met with in the lowermost part of the Asaphus limestone and the uppermost part of the Limbata limestone: hard solid beds which form marked steps on the shelf along the shore. Some of the beds are even quarried though the limestone is inferior in quality to the Limbata limestone proper (the red and reddish grey varieties).

The bed is poorly fossiliferous. Only a pygidium of a *Pterygometopus* sp., remains of an asaphid, and a few small brachiopods were collected.

In the sediments above *b* four divisions can be distinguished according to their colour due to a varying amount of silt and glauconite, and their fossil contents. A common feature of the whole series is that the beds easily break up into lenses of varying size and therefore form a valueless overburden wherever they occur in quarries (called by the workmen the "hors").

The bed *c* in the section (fig. 2) is dark green and consists of soft, marly limestone extraordinarily rich in small grains of glauconite and containing occasional lenses of hard, lighter-coloured limestone with a higher percentage of $CaCO_3$. The fossils often occur in nests separated by larger, poorly fossiliferous parts. Large brachiopods (*Iru? zonatus* (DALM.) *Antigonabonites* sp., *Orthambonites* sp., *Lycophoria nucella* DALM. and others)

[1] In the following the letters *a-f* are used to designate certain easily distinguishable beds (or sets of beds) in the upper part of the section forming the cliff at Haget.

[2] MOBERG 1911. REGNELL (1948) mentions *Asaphus expansus* with hesitation from Southern Öland according to a paper by MOBERG in 1880. WIMAN has had several specimens from the neighbourhood of Borgholm (Greby, parish of Repplinge) found in the fields by farmers.

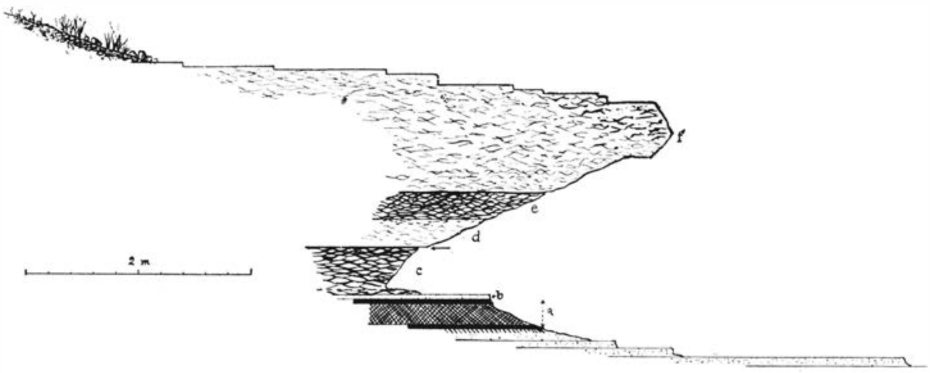

Fig. 2. Section through the cliff at Haget. For the lettering see the text. The arrow shows the position of the smooth bedding-plane above the Expansus zone.

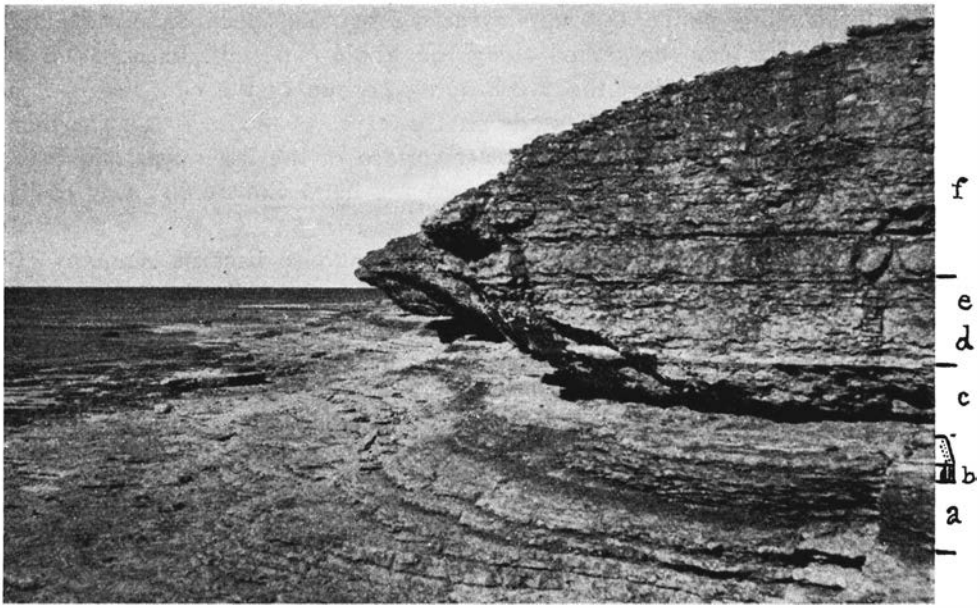

Fig. 3. Part of the cliff at Haget from the south. In the fore-ground a vertical surface along which a portion of the overhanging rock has fallen down.

form a conspicuous element in the fauna. Both shells are often in juxtaposition, in *Lycophoria* usually with a filling of calcite crystals in the space between the shells. Trilobites often occur, or even as a rule, as complete specimens with well preserved chocolate-brown shells. Often they stand on edge in the matrix (see p. 559) and were then mostly deformed when the comparatively soft marly limestone was compressed under the weight of the beds deposited on top.

The bed belongs to the zone with *Asaphus expansus* but also *A. raniceps* seems to occur. Other trilobites from the bed are a *Pterygometopus* sp. and *Ptychopyge angustifrons*. *Megalaspis acuticauda* certainly occurs in the bed but determinable specimens have not yet been collected at Haget. Large, semispheric colonies of a trepostomate bryozoan (*Monticulipora* or a related genus) are quite common. Two specimens of a *Conularia* (most probably *C. aurora* HOLM) were found. See also p. 543, Eskilslund.

The bedding plane between the beds *c* and *d* is remarkable because the contact surfaces are as smooth as natural surfaces can well be. This is, evidently, chiefly the result of a packing and consolidation under water of the surface layers of *c* before the bed *d* was laid down. On the other hand very little of the formation of the surface seems to be due to erosion, either chemical or mechanical. The only influence of this kind that can be demonstrated beyond doubt is that in Cephalopods the part of the shell once protruding above the upper surface of *c* has been dissolved. This smooth surface can be traced along the whole exposure. Its situation in the section, far in below the overhanging portion of the cliff, makes it a rather awkward enterprise to study it. However, as the bed *c* is softer than *d* a narrow strip of the natural lower surface of the latter was laid bare, and one can search for this surface with the hand and in that way easily get an orientation in the section.

This bedding plane seems to be important also because *Asaphus expansus* has not been found above it. More extensive collecting is, however, necessary to make quite sure on this point.

The bed *d* is lighter in colour than *c* because its marly, richly glauconite-bearing component is of secondary importance in comparison with the lenses of harder limestone. Brachiopods are persistently very frequent. The bed passes gradually into the bed *e* which is green and marly and largely a repetition of the bed *c*. Our collections from the section at Haget are as yet available for study only to a comparatively small extent, but they will probably need to be completed in many respects before definite proofs of possible faunistic differences between the facially almost identical beds *c* and *e* can be presented.

The surface between the beds *e* and *f* is not smooth, but it marks a sharp boundary between the marly brachiopod facies of *e* and the more calcareous trilobite facies of *f*. The pack of beds above the surface (*f* in fig. 2) is more than 1 m thick and consists throughout of fairly loosely-jointed small lenses of limestone (compare ANDERSSON 1895, p. 17). At certain levels it is interrupted by more distinct bedding planes marked by a film of limonite. I have not been able to trace such a surface in order to see if it is continuous all along the exposure (about 600 m with varying profile, mostly so that the contact between a pair of beds is very difficult to lay bare to such an extent that one can get a reliable comprehension of its character).

Up till now I have only comparatively small collections from the levels in this complex of beds (*f*): one, 115—125 cm above the upper surface of the ooid bed, the other from the top of the section in fig. 2. The limestone is very fossiliferous and trilobites are the dominating fossils. A list of fossils from the top of the section is found on p. 566.

Higher beds are exposed in a ditch above the terrace seen to the left on fig. 2[1]. The limestone is again more massive and less rich in fossils. It is light grey and contains no glauconite. A good specimen of an "*Acidaspis*" sp. (cephalon and six segments [remnants of the seventh]) was found in a large block at the ditch-side. The following species were identified in material collected in 1941:

Pliomera fischeri (EICHW.)
"*Acidaspis*" sp. [? *Ceratocephala solis* (ÖPIK)]
Megalaspis heros (DALM.)
Megalaspis rudis ANG.
Asaphus cf. *raniceps* DALM.
Illaenus esmarcki (SCHLOTH.)
Antigonambonites sp.
Lesueurilla sp.

Ölands norra udde.

(The northern tongue of Öland.)

According to the Solid map in the Explanation to the map sheet Oskarshamn with Böda (WIMAN 1904 a) the exposure of Ordovician beds on the northern tongue of Öland consists of "Gigas and Platyurus limestone" and according to the text the colour of this limestone is grey. The map is on a very small scale and does not show some interesting details mentioned by ANDERSSON (1896, p. 37) and evident also from HOLM's paper 1882 (p. 63 and 64), where the northern tongue of Öland is mentioned among the localities for *Illaenus esmarcki* ("Denna art är en av den undre grå ortocerkalkens allmännaste" — This species is one of the most common ones in the Lower gray Orthoceras limestone). WIMAN himself has noted in his diary that grey Asaphus limestone occurs between Björnnabben and the extreme point of the northern tongue (see also p. 553).

As will be evident below (p. 553) the Gigas limestone is red at least as far towards the north as to Byxelkrok, and it is difficult to imagine that it should change from the colour which it otherwise bears all over Öland within a few km north of Byxelkrok.

[1] During rainy summers the drainage from this ditch forms a small waterfall at the cliff.

Fig. 4. The Lower (or Middle ?) Raniceps limestone at Ölands Norra udde. The exposed limestone beds dip towards the south and are at high water separated from the shore by a shallow channel.

The exposure on the northern shore (fig. 4) consists of purely grey limestone in some of the collected samples containing scattered small grains of glauconite, but in most of the samples, without glauconite. Its lithic character is similar to that of the upper beds in Tokenäse hamn (see p. 542) and it thus represents a higher level than the beds exposed on Hälludden, where the limestone is fairly rich in glauconite also in the upper part of the low sea-stacks (see p. 541). It represents a high, but not the highest division of the Asaphus limestone.

The material in the Uppsala museum was collected by six members of an excursion in 1944 and comes from a series of beds with a total thickness of perhaps one m. Therefore, no detailed stratigraphy can be based on it. An attempt to collect in the locality in 1948 proved so difficult on account of the high water level that it was thought best to postpone any closer investigation.

For the list of fossils, see p. 566.

Hälludden.

By the name of Hälludden is properly designated a small area on the shore 3 km from the northern tongue of Öland. It consists of a low shelf protruding somewhat towards the north-west (fig. 5). HOLM has used the name also for a low cliff somewhat south of this place. From Hälludden

Fig. 5 The shelf at the southern end of Hälludden showing an incipient stage in the formation of sea-stacks. Above some boulders in the back-ground a slope of shingle (fragments of Lower Raniceps limestone = a).

to the neighbourhood of Byxelkrok a continuous section can be followed downwards from the lower part of the Raniceps limestone almost to the bottom of the Limbata limestone (in 1948 the so called "Blommiga bladet" was just below the water-level, 1 km north of Byxelkrok).

In its lithic character and in its fossil contents the limestone in the low stacks standing on the shelf agrees with the series of beds *f* in the section of Haget. The beds immediately below are, on the other hand, somewhat different. The ooid horizon is similarily developed: it is black and rich in small rust-coloured fragments of fossils, and it contains *Asaphus expansus*. But it seems after a preliminary investigation as if the beds inserted between the ooid bed and those definitely of trilobite facies had a much greater thickness than in the section at Haget. This conjecture is based on the discovery by JAANUSSON of a perfectly smooth bedding plane also in the Hälludden section, but more than 1 m above the ooid horizon (at Haget 45 cm). It is true that there are many other well marked discontinuities in the respective sections but only in one case is the contact surface between the beds smooth. MUTVEI, who worked more at Hälludden than I did, is of the opinion that there is a good agreement as regards the composition of the fauna at least above the smooth surface, if one lets it mark the same level in both localities. The fauna below the surface is also the same but at Hälludden it occurs in a thicker series of beds of another lithic character than the bed *c* at Haget. This bed should then swell towards the north and break up into several beds.

In the Hälludden section "Blodläget" lies nearly 3 m below the ooid horizon (measured by MUTVEI); the variegated bed ("Blommiga bladet") about 2 m farther down.

The fossils in the list on p. 566 were collected in the stacks at Hälludden in 1939 and 1941.

Tokenäse hamn.

(Tokenäse harbour)

The shore south of the harbour is formed by a broad shelf influenced by wave erosion in the same way as at Hälludden. The limestone is, however, free from glauconite and thus it represents a higher level (see also p. 552). Towards the east the shelf is bounded by a low section of the same type of limestone (thickness not more than one m) cropping out from underneath heavy deposits of limestone fragments accumulated by wave action. For fossils collected in this locality, see p. 566.

Further south lower beds are coming up and the shelf consists of glauconite-bearing limestone which in all respects resembles the limestone at Hälludden. Only the following fossils were collected:

Cyrtometopus clavifrons (DALM.), pygidium
Cybele bellatula DALM.
Lichas sp.
Asaphus raniceps DALM.

Large blocks which were deposited on the shelf by ice movements during the winters, contain green beds of the same lithic character and evidently of the same thickness as the beds *c* and *d* at Haget. As they must have come from a lower and permanently flooded shelf, they give us an idea of the continuation of the Tokenäse section below sea level.[1]

Byrum.

The limestone forming the sea-stacks at Byrum is glauconite-bearing only in its lower part. The beds dip towards the north so that at the north-

[1] Such blocks are also found on the shelf at Hälludden. At first sight one would think that they were low sea-stacks formed on the shelf, which had been displaced (compare ANDERSSON 1895 p. 16), as they are approximately of the same size as these. But an examination of the fossil contents (brachiopods dominating) shows that the blocks represent a lower level than the limestone exposed on the shelf. It is difficult to understand how these heavy blocks were heaved over the edge of the shelf from a depth of perhaps more than one m if not by ice accumulating on the shore during westerly storms. In the cold winter of 1946-47 there were such masses of ice on the shore at Byxelkrok that photographs taken at that time could as well have been taken in high arctic regions.

ern end of the area only the upper part is above sea-level (ANDERSSON 1895).

A couple of hundred m south of the area the ooid horizon emerges, and at Byrum, too, *Asaphus expansus* was collected from this bed. The beds following immediately above the ooid horizon are partly full of fairly large ooids consisting mainly of calcite (up to 3 mm in diameter). At Häll-udden and Haget such ooids are comparatively rare.

The following fossils were collected from the non-glauconitic limestone:

Pliomera fischeri (EICHW.)
Lichas verrucosus (EICHW.)
Megalaspis heros (DALM.)
Ptychopyge sp.
Illaenus esmarcki (SCHLOTH.)
Pseudocrania sp.

Eskilslund.

South of Byrum lower beds come up — at Horns udde down to the top of the Paradoxissimus shales. Farther south these beds again disappear below the sea, and at the western end of a drainage ditch at Eskilslund soft, green marly beds lie only about one m above sea level. The composition of the fauna, the state of preservation of the fossils and the lithic character of the limestone agrees with the bed *c* at Haget. Fossils collected at Eskilslund (in site or in blocks on the sides of the ditch) are listed on p. 567.

Persnäs.

To obtain a correlation between the sections in the Persnäs area and those in northernmost Öland one may start from "Blodläget", which is exposed in the limestone quarries between Gillberga and Sandvik. The limestone immediately on top of "Blodläget" (about 125 cm) is greyish red (compare p. 534). Then follows purely grey limestone with gradually increasing amounts of glauconite.

In the highest accessible level (4 ¼ m above "Blodläget") in a quarry near Gillberga the following fossils were collected:

Pterygometopus sp.
Megalaspis acuticauda ANG.
Asaphus sp. (*? lepidurus* NIESZK.)
Ptychopyge angustifrons DALM. (several entire specimens on a bedding plane[1]).
Illaenus esmarcki (SCHLOTH.)
Ampyx nasutus DALM.
Pseudocrania sp.

[1] Complete specimens of trilobites occur also within the beds. The shell is chocolate-brown. The larger fossils very often stand on edge and might then occupy the whole thickness of the bed (see p. 559).

In a block from the waste around the quarry, evidently from a somewhat lower level than the previous, were found:

Megalaspis hyorrhina LEUCHT.
Asaphus lepidurus NIESZK.
Ptychopyge angustifrons DALM.

Above the quarry the section is interrupted by a minor automobile road and about one m of the sequence of beds is not accessible for study. Level with the road, at the base of a series of raised sea-stacks south of Gillberga (the so called "Gillberga hors", fig. 10) a marly, richly glauconite-bearing bed crops out. This bed has been worked by erosion in a way highly reminiscent of the undermining of the Raniceps beds in the cliff at Haget. Nothing has as yet been found in the bed that can with certainty be referred to *Asaphus expansus*, but the species occurs at what is probably the same level and in the same kind of rock in a quarry on the "alvar" between Stenninge and Sandvik, and in the filling around the poles of a power-line between Stenninge and the shore (see p. 545). The limestone which follows above the soft bed at Gillberga also reminds one of the beds above the Expansus zone at Haget. The ooid horizon is not developed in the Persnäs area and therefore the correlation is less evident, but if the sections are put together so that the deep indentations coincide, other parts agree well enough to make it highly probable. The investigation in detail of the Persnäs area is not yet concluded.

The upper part of the stacks at Gillberga corresponds to the bed *f* in the section at Haget. The uppermost bed is variegated (partly grey with a slightly reddish tint, partly brownish-black) and rich in large grains of glauconite; this characteristic limestone I shall call the Hjorthamn limestone. The colour is different from that of the bed *f* (which is light grey), but in both sections fossils are abundant at this level. The collections of fossils from the Hjorthamn limestone are at present more extensive than those from the bed *f* (see p. 539). The fauna is in all essentials the same in both localities, both as regards the species and the percentage of forms referable to various orders.

The thickness of the Hjorthamn limestone is about 90 cm. The bed is a good index horizon in the area around Sandvik in the parish of Persnäs. It is the second bed from the top in the quarry on the "alvar" at Stenninge where it has exactly the same lithic character and the same fauna.

At Stenninge lower levels in the section are best studied in the heaps of blocks piled up around the quarry. In these blocks different horizons can be recognized which are known from other localities: for example, dark green, marly limestone with *Megalaspis acuticauda*, *Asaphus expansus*, *Ptychopyge angustifrons*, and Brachiopods (abundant).

These blocks evidently come from a level in the quarry about 2 m below the lower surface of the Hjorthamn limestone. The sides of the quarry are determined by joints and the lithic character of the different beds is not very obvious on the plane surfaces. I am well aware that the section should be re-measured more exactly, but unfortunately the quarry was filled with water when I returned with the intention of doing this.

The quarry has been worked down to a depth of about 4.5 m below the Hjorthamn limestone, according to the quarry-men down to the beds called "hålögon" (the same beds are exposed high up in the quarries at Gillberga).

The uncertainty of the observations in the Stenninge quarry are to a certain extent compensated by the following section from a point on the western border of the village of Stenninge (where a minor road crosses the main road) towards the north-west (along a power-line to the northern stone factory; the distance between the poles is approximately 60 m):

1. Grey-darkbrown, variegated limestone (same as the uppermost bed in the "alvar" quarry (see below): *Megalaspis* cf. *rudis* ANG.
2. The same limestone. Among the fossils *Illaenus esmarcki* (SCHLOTH.) is remarkably abundant.
3. The same limestone: *Pliomera fischeri* (EICHW.), *Lichas coelorrhin* ANG. *Asaphus raniceps* DALM., *Illaenus esmarcki* (SCHLOTH.).
4. The same limestone: ?*Cyrtometopus* sp. (see table on p. 576, note); *Illaenus* cf. *ladogiensis* HOLM.
5. "Limestone of the same colour but apparently denser" (translated from a diary): *Pliomera fischeri* (EICHW.), *Lichas coelorrhin* ANG. *Asaphus raniceps* DALM.
6. At least 50 % of the blocks in the filling consist of coarse limestone rich in large grains of glauconite.
7. Hjorthamn limestone: *Lesueurilla* sp.
8. The same limestone: *Megalaspis rudis* ANG. *Ampyx nasutus* DALM., *Iru zonatus* (DALM.), *Lesueurilla* sp.
9. The same limestone: *Pterygometopus sclerops* (DALM.), *Pliomera fischeri* (EICHW.), *Megalaspis rudis* ANG., *Asaphus raniceps* DALM., *Pseudocrania* sp.
10. The colour of the limestone is grey with a rather deep reddish tint. The grains of glauconite are small and comparatively scarce. The blocks are derived from a rather thick bed to judge from their appearance. Within the bed ragged whitish corrosion surfaces occur (compare fig. 9): *Asaphus* cf. *raniceps* DALM.
11. Same limestone. Fossils are rare.
12. Thin-bedded, rather soft limestone, some of the trilobites occur as entire specimens: *Megalaspis rudis* ANG., *Asaphus raniceps* DALM., *Illaenus esmarcki* (SCHLOTH.).
13. Thin-bedded limestone, very rich in glauconite; traces of corrosion within the beds (see above).
14. Green marly limestone: *Megalaspis acuticauda* ANG., *Asaphus expansus* DALM., *Illaenus* cf. *esmarcki* (SCHLOTH.) — the two last mentioned species occur as entire specimens.

The uppermost bed in the quarry consists of variegated limestone lighter in colour than the Hjorthamn limestone and entirely free from glauconite.

The upper limit for the occurrence of glauconite thus seems to have the same position in relation to the Expansus zone as in the section at Haget.

Along a power-line extending from the Stenninge quarry towards the north-east I could follow how the limestone changes its character upwards. The beds soon become more brownish and they then contain more or less regularly small black-brown grains of phosphorite (some of the grains are not amorphous but show well-developed cleavage reminding one of calcite). Finally red colours appear and the series passes over into the Centaurus limestone.

Two very important finds were made in the brown-speckled limestone, namely a cranidium and a pygidium of "*Isotelus*" *stacyi* (Pl. I, fig. 5 and 6) the former from the quarry at Gunnarslund (see below) the latter from the filling around a pole about 1 km north-north-east of Stenninge. The species was not earlier known outside the East Baltic area, where it has a rather small vertical range being restricted to the uppermost division of the Vaginatum limestone (LAMANSKY 1905).

These two finds are of course not sufficient for an appreciation of the stratigraphical value of the species in the sequence of strata in Öland.[1]

They were, however, both made in a limestone which forms a lithologically distinct uppermost division of the Asaphus limestone. The brown-speckled limestone would then be the equivalent of the lower part of $B_{III}\gamma$ in LAMANSKY's subdivision of the Ordovician of the East Baltic area.[2]

In a limestone quarry near the railway halt at Gunnarslund, worked during 1946 but now filled with water, the following section was accessible:

Platyurus limestone, red usually dense (not in the quarry but on all sides of it — the beds form a low cupola with the quarry at its center)	—
Gigas limestone, grey-green and red variegated, usually dense . . .	1.6 m
Centaurus limestone, of the same lithic character as the Gigas limestone	0.6 m
Asaphus limestone, rather dark, greyish brown with black-brown grains. The uppermost part (and sometimes a coating around the fossils) red or reddish. Some beds in the middle of the exposed part are crowded with orthoceratites	1.5 m +

The boundaries between the zones are approximate and partly based on information obtained from the quarry-men as to the origin of some fossiliferous blocks.

The Gigas and Centaurus limestone, especially the latter, are worked in the stone factories, the Asaphus limestone on the other hand, is useless because of its contents of Orthoceratite shells only partially filled with crystals of calcite (the quarry-men call these fossils "saltbassar").

[1] It remains to be seen if the change in lithic character and the appearance of *I. stacyi* in the fauna coincide.

[2] In Estonia "*Isotelus*" *stacyi* occurs together with *Megalaspis centaurus*. (SCHMIDT 1907, p. p. 97 and 98.) The *Megalaspis* in the brown-speckled limestone is *M. rudis*.

For a list of fossils from the brown-speckled limestone see the table on p. 566.

A combination of the various sections described above would give the following standard section for Northernmost Öland:

ZONE WITH:	LITHIC CHARACTER	OTHER FOSSILS
Asaphus platyrus *Megalaspis gigas* *Megalaspis centaurus*	Variegated red and more or less greyish green, dense	
Asaphus raniceps	a. Greyish brown (partially red) with dark brown grains of phosphorite.	*Megalaspis extenuata, heros,* and *rudis* "*Isotelus*" *stacyi*
	b. Light grey without glauconite.	*Brachiopods rare*
	c. Top: Light grey with glauconite.	
	Bottom: Dark grey to green, rich in glauconite, comparatively soft (marly).	*Brachiopods abundant*
Asaphus expansus	Dark grey to green, rich in glauconite: comparatively soft (marly).	*Megalaspis acuticauda,* and *gibba.* Brachiopods abundant at least in the upper part.
	Grey, glauconite-bearing; hard.	
	Almost black with ooids and pseudooids.	
Asaphus lepidurus	Grey beds of varying thickness, usually rich in glauconite; more massive than the glauconite bearing Raniceps beds.	*Megalaspis hyorrhina*
Megalaspis limbata	Greyish red, free from glauconite; dense	
	"Blodläget"	
	Red	
	"Blommiga bladet"	
Megalaspis planilimbata	Red	

(Comparatively soft beds of varying lithic character)
[See HADDING 1932, p. 36 et seq.]

It is evident that the Asaphus limestone in Northernmost Öland is a multiform series both lithologically and faunistically. The subdivision of the zones is mainly based on the character of the limestone, but at least in the Raniceps zone it might be possible to characterize the subzones by index fossils. A quantitative study of the faunas can never be complete as there will always be a great number of indeterminable fragments, and the possibility of getting good specimens especially of the large species much depends on the character of the exposure. So, for instance, is perhaps the difference in number of specimens of *Megalaspis rudis* from the red Asaphus limestone at Marsjö and in other localities entirely due to the splendid exposures along the ditch at Marsjö. It is, however, certain that brachiopods become rarer and rarer from the Expansus zone upwards.[1]

Marsjö

(parish of Föra)

There is an excellent section through the upper part of the Asaphus limestone and higher zones up to the Platyurus limestone in a ditch cut from a point not far south of the railway station of Föra, towards the east, to drain the lake Marsjön. An unlimited amount of rock material is available in the banks along the sides of the ditch. From fossils found in blocks and from exposures in the perpendicular walls of the ditch one gets a fairly good view of the sequence of beds. The thickness of the beds is more difficult to ascertain as the dip is irregular and dislocations along joints occur.

Near the eastern side of the main road[2] the limestone is grey and rich in glauconite. Only a few fossils were collected.

About 1 km farther to the east the ditch is cut in grey limestone free from glauconite. Considerably less time was used for collecting fossils in this division than in the overlying red beds which were met with still a couple of hundred m farther to the east. Therefore the figures for the frequency of the various species in the table on p. 566 are not comparable.

This red limestone contains dark brown grains of phosphorite[3] and is in some beds crowded with cephalopods. It must be noticed that the red colour is not so bright as further south in Öland (for example at Lenstad

[1] In the beds immediately above the ooid horizon at Hälludden the brachiopods are more abundant than the trilobites. In the non-glauconitic limestone at Tokenäs and in the Hjorthamn limestone the brachiopods are still quite common ("3" and "5" in the table on p. 566). At higher levels one may have to search long to find a single specimen (columns 7 and 8 in the table; the lists in the other columns are incomplete as regards the brachiopods — the fossils were collected before the author had realized that not only the species but also the number of specimens of brachiopods might have some stratigraphical significance).

[2] West of the road the ditch is dug in alluvial deposits and it does not touch the solid rock.

[3] WIMAN mentions in his diary reddish grey, speckled limestone with *Illænus esmarcki* from Övre Wässby (a farm on the northern side of the ditch) and remarks that this is "verklig övre Asaphus-kalk" (i. e. true Upper Asaphus limestone).

or even as far north as in the neighbourhood of the railway halt at Stacketorp east of the railway). Smaller portions are sooner grey-brown than red and perfectly like the limestone in the quarry at Gunnarslund, where, on the other hand, smaller portions as red as anything in the Marsjö section can be found.

The lower part of the brown-speckled Asaphus limestone is richly fossiliferous. Farther east, in beds of the same lithic character fossils are less common but those found indicate that we are still in the Asaphus limestone.

Then follows for a distance of a couple of hundred m red and greyish green variegated limestone in which no determinable fossils were as yet found.

The limestone farther east is almost purely red and contains fairly numerous pygidia of *Megalaspis centaurus* (Pl. I, fig. 1).

Then the variegation again becomes more conspicuous and *Megalaspis centaurus* is succeeded by *Megalaspis gigas*. (Pl. I, fig. 4).

The size and the shape of the pygidia of these two species is rather similar as is also the way in which they occur in the rock (their frequency is approximately the same and they were embedded conformably with the bedding planes). Green colours are comparatively rare in the Centaurus limestone but else the lithic character of both zones is very much the same.

The almost barren limestone mentioned above marks a transition from limestone consisting almost entirely of small shell fragments, encrinite stems and so on (best seen on weathered surfaces) to dense limestone in which fragments are of secondary importance or in which they are of considerably smaller size. This dense limestone continues through the zones with *Megalaspis centaurus* and *gigas* up into the Platyurus zone.

The Platyurus limestone underlies the meadows on the eastern shore. It is mostly covered by alluvial deposits of considerable thickness and only a few blocks of it are found on the banks along the ditch.

Djupvik.

A little farther south at Djupviks hamn (The harbour of Djupvik) the lower divisions of the Asaphus limestone can be studied in the fillings around a line of poles extending towards the east from near the harbour to the railway. The poles nearest the shore stand in old beach deposits or in morain, but from the 8th pole on (about 800 m from the shore) the fillings consist of fragments of the local solid rock. The distance between the poles is about 50 m. Between the 8th and the 19th pole the following series was obtained (see also p. 567):

8. Marly limestone. *Illaenus* sp. (fragments). *Ptychopyge* cf. *angustifrons*, *Lycophoria nucella*.
9. Purer, richly glauconite-bearing limestone evidently forming heavy beds. *Megalaspis acuticauda*.

10. Marly limestone. *Pterygometopus* sp., *Nieszkowskia* cf. *tumidus* (a form with comparatively low glabella), *Asaphus expansus*, *A.* cf. *raniceps*, *Ptychopyge* cf. *angustifrons*, *Illaenus* cf. *esmarcki*, *Lycophoria nucella*, *Pseudocrania* sp., Trepostomate bryozoans.
11. Marly limestone. *Pterygometopus* sp., *Lichas erici*, *Asaphus expansus*, *A.* ? *raniceps*, *Ptychopyge* sp., *Ampyx* cf. *nasutus*, *Antigonambonites* sp., *Lycophoria nucella*, Trepostomate bryozoans.
12. Marly and more compact limestone. *Asaphus raniceps*, *Illaenus esmarcki*, *Lycophoria nucella.*
13. Marly limestone. *Asaphus expansus*, *Ptychopyge* sp.
14. Marly limestone. *Asaphus expansus*, *A.* cf. *raniceps*, *Ptychopyge* cf. *angustifrons*, *Antigonambonites* sp.
15. Marly limestone. *Asaphus expansus.*
16. More compact limestone. Trepostomate bryozoan.
17. Marly limestone. *Cybele* sp., *Asaphus expansus.*
18. Compact, richly glauconite-bearing limestone with *Asaphus raniceps*, *Pseudocrania* sp., Trepostomate bryozoans.
    Marly limestone with *Illaenus esmarcki* and *Iru zonatus.*
19. More compact limestone, rich in glauconite. *Pliomera fischeri*, *Asaphus raniceps*, *Ptychopyge* sp., *Ampyx nasutus*, *Iru zonatus.*

These notes were made when studying samples taken during a hurried excursion along the line. Only a few fossils were found at each pole but the series shows beyond doubt that marly, soft limestone with *Asaphus expansus* (and another species of the *raniceps* type) occurs also in this part of Öland. The lower boundary of the Expansus zone is not exposed. In the harbour a series comprising the lowermost Ordovician down to the top of the Paradoxissimus-shales crops out, partly below the water-level (see HADDING 1932).

There is probably a gap between the sections at Djupvik and Marsöj comprising the middle part of the glauconite-bearing division of the Raniceps limestone.

Korntorp.

Farther south entire specimens of *Asaphus expansus* were found in deeply weathered Alvar soil not far (110 m) west of the main road along the small road to Korntorp. Rather further to the west at the farm house of Korntorp blastings were made for a drainage ditch. There *Megalaspis acuticauda* was found on the bedding surface of blocks of thick-bedded richly glauconite-bearing limestone. This sequence of beds may be compared with that at Hjorthamn and Gillberga where *M. acuticauda* was found on the surface of massive limestone blocks from levels below the soft Expansus limestone[1].

[1] The best pygidia of *Megalaspis acuticauda* found by me come from such blocks in Hjorthamn.

The uppermost division of the Asaphus limestone north of Persnäs.

In Föra the uppermost division of the Asaphus limestone is red to a much greater extent than in Persnäs, further the Hjorthamn limestone was not found outside Persnäs, yet the same divisions of the Asaphus limestone can easily be distinguished on both sides of the point where earlier the attempts to trace the red Asaphus limestone towards the north were given up.

One may then ask how the uppermost part of the Asaphus limestone has developed in the parishes north of Persnäs. A few exposures along power-lines, in cuttings for roads and in water-holes give an answer to this.

I. Power-line crossing the "alvar" (somewhat in zig-zag) from a point on the main road to Högby about 1 km east of Alvidsjöbodar towards the north-east to Berget on the southern side of Horns udde (the name is not found on the ordnance map but the place is marked with the sign for a harbour). The distances given below were paced. The figures give the numbers of the collected samples:

1—5. The first 1350 m from the S. W. end: Platyurus limestone, usually one-coloured red but in some places variegated (red and green). Somewhere between 1 300 and 1 400 m the Gigas limestone probably occurs but no determinable fossils were found.
6. (1 410 m) Red dense limestone in which a large fragment of a pygidium of *Megalaspis centaurus* was collected.
7. (1 460 m) All the blocks in the filling are of the same type (variegated, about half red and half green).
8. (1 720 m) Grey brown speckled limestone. Some parts greyish green. *Lichas coelorrhin* ANG., *Megalaspis rudis* ANG., *Megalaspis extenuatus* DALM., *Pseudasaphus* sp., *Niobe frontalis* DALM.
9. (1 770 m) Same limestone. *Pliomera fischeri* (EICHW.), *Megalaspis rudis* ANG., *Illaenus esmarcki* ? SCHLOTH. (hypostoma).
10. (1 820 m) Same limestone. *Cyrtometopus clavifrons* (DALM.), *Megalaspis rudis* ANG., *Pseudasaphus* sp.
11. (1 870 m) Same limestone. *Pliomera fischeri* (EICHW.), *Megalaspis rudis* (ANG.).
12. (1 920 m) Grey limestone without grains of any kind. No fossils found.
13. (1 970 m) Limestone similar to nr. 12. *Lichas coelorrhin* ANG., *Megalaspis rudis* ANG., *Ampyx* cf. *nasutus* DALM.
14. (2 020 m) Reddish grey limestone with grains of brown phosphorite. *Megalaspis rudis* ANG., *Pseudasaphus* sp.
15. (2 200 m) Same limestone. *Megalaspis extenuatus* DALM.
16. (2 250 m) Same limestone. *Megalaspis rudis* ANG.
17. (2 300 m) Same limestone. *Ceraurus* sp.

The presence in this section of the zone with *Megalaspis gigas* is not confirmed by fossils, but there is, on the other hand, no reason to suppose that it is entirely missing. The samples 6 and 7 represent the Centaurus limestone (and evidently also the poorly fossiliferous limestone underlying it in the Marsjö section). The samples 8—17 belong to the uppermost division of the Raniceps zone. The light grey poorly fossiliferous limestone of the 12th sample probably comes from a small inclusion in which phosphorite grains are missing. When I studied this section in 1941 I did not know at all what results could be expected from my investigations in Öland. I had observed the brown grains but I did not suspect that they should turn out to be of importance for the stratigraphy. I would therefore think it quite likely that a large part of the filling at the pole where the sample was taken consists of the brown-speckled limestone. The division of the Asaphus limestone which especially interested me in 1941 — the zone with *Asaphus expansus* — is as well as the lower divisions of the Raniceps limestone covered by old beach deposits (see p. 565). The highest level accessible in the cliff at Horns udde seems to be the same as in the quarries between Gillberga and Sandvik ("hålögon", see p. 545; ? zone with *Megalaspis hyorrhina* and *Asaphus lepidurus*).

II. Byrum. In a small ditch which debouches at the northern end of the low dissected cliff red, dense limestone with *Lichas coelorrhin* and a large *Megalaspis* is exposed not far from the shore. The brown-speckled limestone of the upper division of the Raniceps limestone is evidently covered by drift-sand. The uppermost beds exposed on the shore belong to the middle division.

III. Tokenäse hamn. The beds exposed in the harbour consist of light grey limestone without glauconite (see p. 542). At the bottom of a pit somewhat above the natural exposures, where the beach deposits were cut away to be used as road metal, it was possible to dig up fragments of brown limestone with grains of phosphorite and to make sure that they came from the solid rock. No fossils were found at this preliminary investigation. On the alvar south-east of the harbour, beds a couple of m higher up in the sequence are available at the eastern end of a powerline. Along this line the following samples were taken from fillings around the poles:

1. Approximately 100 m east of the road along the shore (where a road is forking off to Enerum): Variegated greyish green and red limestone, a mixture of dense limestone with limestone composed of small fragments. Scattered grains of phosphorite. *Megalaspis* sp. (*centaurus* or *gigas* ?), *M. heros*, (DALM.), *Asaphus* cf. *raniceps* ANG., *Nileus armadillo* DALM., *Illaenus* cf. *esmarcki* (SCHLOTH.).
2. 170 m from the road. Same limestone. *Megalaspis gigas* ANG., *Illaenus esmarcki* SCHLOTH.
3. 250 m from the road. Same limestone. *Lichas coelorrhin* ANG., *Megalaspis gigas* ANG., *Illaenus esmarcki* SCHLOTH.
4. 300 m from the road. Same limestone. *Megalaspis gigas* ANG., *Ampyx* cf. *nasutus* DALM.

Farther east follows the Platyurus limestone, some parts of it purely greyish green but most of it with the usual red colour.

The pole at which the first of these samples was collected evidently stands in the uppermost part of the Asaphus limestone so close to its upper boundary that forms typical of higher beds have already entered the fauna (one may have to count with the possibility that the blasting touched two distinct zones and that the fossils were mixed). Fossils which can with certainty be referred to *Megalaspis centaurus* do not occur in the scanty material. At the other poles good specimens of *Megalaspis gigas* were found. *Megalaspis gigas* was also collected by Dr WARBURG from red limestone near Byxelkrok.

IV. The area north of the line Byxelkrok—Maderna. The Solid map compiled by WIMAN shows that the boundaries between the divisions of the Orthoceras limestone north of Byxelkrok are rather irregular. As put forth on p. 539 the exposures on the northern tongue of Öland are, at least the main part of them, grey limestone with scarce glauconite. According to WIMAN's diaries "Gigas limestone, partly grey, occurs less than 100 m from the extremity of the tongue". He also remarks that there seems to be no room for a red Upper Asaphus limestone. But as the grey limestone belongs to a rather high level of the Raniceps limestone (there is almost no glauconite) and the dip is rather steep the outcrop of what might be inserted between it and the Gigas limestone must form a quite narrow strip and there is little doubt that the uppermost division of the Raniceps limestone exists underneath the beach deposits.

An important point on the boundary between the areas occupied by the Asaphus limestone and the "Gigas and Platyurus limestone" is met with at Maderna approximately in the middle of the island, east of Byxelkrok. In a cutting of the main road compact grey limestone occurs in some parts containing black-brown grains of phosphorite. In the greater part of the limestone such grains are missing but instead smaller portions are of a finer grain and greyish green in colour. The beds dip somewhat towards the south (about 10°). In the filling around some poles not far north of the road grey limestone with phosphorite grains occurs, very similar to the uppermost division of the Raniceps limestone in the parish of Persnäs. The few fossils which were collected from this limestone are characteristic of the Raniceps limestone (*Pliomera fischeri, Megalaspis rudis, Asaphus* cf. *raniceps, Pseudasaphus* sp.).

The so called "Långalvaret" (the "Long Alvar"), which stretches with its south-eastern corner within 500 m NE of Maderna, consists chiefly of the Platyurus limestone, but also half way between its northern and southern ends grey, brown-speckled limestone reaches its western border. From there it has been followed towards the west for about 1 km.

This kind of limestone has been traced as far north as to a fork in the small roads on the "Alvar" 600 m south-east of Hälludden (see the Geological map and the old Ordnance map). About 75 m north of the fork variegated, red and greyish green limestone begins ("Gigas and Platyurus limestone").

These (and other) observations indicate that the uppermost Asaphus limestone has been raised in a flat anticline so that it is now exposed as a narrow wedge with its point approximately at Maderna (fig. 6)[1]. The map

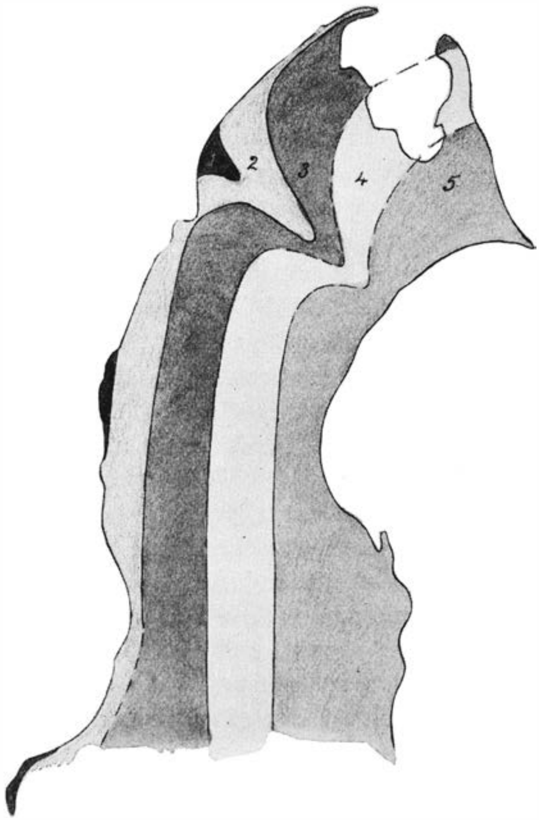

Fig. 6. The Ordovician horizons in Northernmost Öland. Diagrammatic map. 1. Limbata limestone; 2. Asaphus limestone; 3. Gigas and Platyurus limestone; 4. Schröteri limestone; 5. Chasmops limestone.

also shows that the configuration of the northern extremity of Öland is probably due to a general diversion of the strike of the beds towards the east combined with an increase in the dip, in accordance with what can

[1] The map is diagrammatical. An exact plotting of the boundaries between the various divisions of the Ordovician cannot be made without an extensive collecting work in beds which are not very well exposed. This must wait until the investigation of the important sections on the shore has been completed. One cannot reckon with the colour only as is evident from the section east of Tokenäse hamn where the Raniceps fauna seems to occur in beds of the same colour as the Gigas limestone.

be directly demonstrated in the exposures of the Raniceps limestone on Öland's norra udde.

Outside the straight coast line between Öland's norra udde and Ängegärdsudden the sea is comparatively shallow and full of shoals. It is possible that the straight coast line is caused by a fault, but this can evidently not be a very large one as a continuation of Öland towards the north-east as a submersed plateau is indicated by soundings (Pl. II).

Lenstad.

About 500 m west of the railway halt at Lenstad (7 km SE of Färjestaden) a drainage ditch was blasted in the Asaphus limestone. In Uppsala there is a rather large collection of fossils from this locality, the only one in the museum from Southern Öland which as regards its size is comparable with the collections from the northernmost part of the island.

The limestone is as purely red as is ever the limestone of the Platyurus zone and the zones immediately below it in the north. It is sometimes composed of larger grains ("coarsely crystalline") and it is then often paler in colour (partly greenish). The beds are rich in fossils: At one level the limestone is crowded with Orthoceratites. In another level most of the fossils are small specimens of trilobites, which otherwise attain a more considerable size, associated with trilobites which are normally small-sized (the pygidia and cranidia have an average size of less than 1 cm). Thus, together with *Trinodus* cf. *glabratus*, a small finely tuberculate species of *Cyrtometopus* (?), a species of *Remopleurides*, there are small specimens of *Megalaspis heros*, *Asaphus* cf. *raniceps*, *Ptychopyge* sp., *Nileus armadillo*, *Illaenus esmarcki* and others. MOBERG (1904 p. 7) mentions that red-coloured Ordovician beds very often contain such dwarfed faunas and gives as an example of this just the Upper Asaphus limestone in Öland. There are, however, horizons with a fauna of trilobites composed of individuals of normal size. In all cases the fauna is on the whole the same as in the Raniceps beds in northern Öland (see the table on p. 566).[1] The following

[1] The section exposed in the ditch is only about 75 cm high. The sequence of beds is (from above):

Variegated, pale and greyish green limestone. No orthoceratites	7—9 cm
Red brown limestone, rich in orthoceratites. Other fossils common	14 cm
Variegated, red brown and green limestone	4 cm
Red brown limestone. Orthoceratites comparatively few	19—20 cm
Red brown, coarsely crystalline limestone. Rich in small trilobites	4 cm
Greenish, coarsely crystalline limestone. Rich in small trilobites	not measured
	76 cm

pecularities are worthy of notice: *Megalaspis rudis* does not seem to occur at Lenstad — if it does it must be very rare. Instead a species of about the same size was found. In the pygidium of this form (Pl. I, fig. 3) the rhachis is more pronounced than in *M. rudis* (Pl. I, fig. 2). The pygidium itself is more triangular and in consequence the distance from the posterior end of the rhachis to the posterior end of the pygidium is greater (1/5 of the total length of the pygidium against 1/6 in *M. rudis*). Otherwise it resembles *M. rudis* in many respects and both species probably belong to the same group (see also the explanation to the plate). There is a number of fairly good cranidia and before these have been properly studied and compared with the material from other localities a definite specific determination cannot be made.

Megalaspis heros occurs with the same frequency as in other localities.

Nileus armadillo and species of the genus *Niobe* (at least the greater part of the material seems to belong to *N. frontalis*) are much more common than in the northern localities. *Ampyx*, on the other hand, is comparatively rare.

Brachiopods are very rare like they are in the uppermost division of the Raniceps limestone in Northern Öland.

*

Lenstad is situated approximately in the middle part (in an east-westerly sense) of the area occupied by the so-called Upper Asaphus limestone. My experiences from Persnäs and Föra lead me to believe that it is reasonable to assume that lower horizons of this red series of beds correspond to higher horizons of the thick grey series in northern Öland. The lithic character of the limestone must appear to be very different: in the north light grey matrix containing bright green grains of glauconite, in the south red limestone with small rust coloured specks. One would think that these two types of limestone were deposited under very different conditions (different depth, chemical composition of the seawater and so on). But in a small ditch crossing a road between the church of Föra and Uggletorp a heavy limestone bed is exposed which bridges over this difference in a rather astonishing way. The bed is on the surface underneath a thin covering of soil, it is well delimited downwards and in its whole extension (as far as it is of interest in this connection) well exposed and easy to follow. Immediately south of the road it is grey and contains large, fresh grains of glauconite (fossils: *Pterygometopus sclerops, Cyrtometopus* cf. *clavifrons, Lichas coelorrhin, Megalaspis rudis, M. heros, Asaphus* cf. *raniceps* — all more or less characteristic representatives of the Raniceps fauna). A couple of tenth m towards the south the same bed consists in its whole thickness of purely red limestone without a trace of glauconite (the glauconite was probably oxidized and gave rise to small rust coloured specks). In a series of samples taken with short intervals the transition between the two types of limestone can be studied. It must be pointed out that the red limestone is fresh and that it can hardly be the question of a deep weathering in very late times (if that were the case one may ask why the extensive exposures of grey glauconite-bearing limestone in Northern Öland have not everywhere been subject to the same change).

I have not tried to look for the "Lower grey Asaphus limestone" between Lenstad and Färjestaden but to judge by the literature the Sphaeronite bed reaches at least thus far towards the north and it probably represents the entire (or almost the entire) grey limestone in that area.

In the parish of Köping where the "western road" climbs the cliff (not very pronounced in that place) the following trilobites were found in blocks of grey glauconite-bearing limestone at the sides of a large ditch: *Megalaspis acuticauda* (at least 6 specimens). *Ptychopyge* cf. *angustifrons*, *Symphysurus palpebrosus.* The fossils indicate a low level of the Asaphus limestone as do also exposures of Limbata limestone in the same ditch. Further east the ditch is dug in morain and it is as yet unknown to me if there are at this locality grey beds belonging to the Raniceps zone. Still farther east, at Källingmöre (two km east of Köping), WIMAN found "blocks of the Upper Asaphus limestone only" in field walls and mounds ("more coarsely crystalline than the Platyurus limestone and full of brown specks" — quoted from WIMAN's diary).

West of the railway halt at Stacketorp grey limestone with *Pterygometopus sclerops, Pliomera fischeri, Asaphus* cf. *raniceps, Illaenus* cf. *esmarcki* (hypostom) and *Ampyx nasutus* is exposed in a draining ditch close to the main road. A couple of hundred m west of the road the following fossils were collected around a water hole near the same ditch: *Megalaspis acuticauda, Pseudasaphus* sp., *Ptychopyge* cf. *angustifrons, Symphysurus palpebrosus* and *Iru zonatus* (evidently the same level as at Köping; also at Stacketorp the Limbata limestone crops out not far below). On the eastern side of the railway bright red limestone, probably belonging to the Raniceps zone, is exposed. The fossils (*Asaphus* cf. *raniceps*, *Pseudasaphus* sp., *Illaenus* sp.) are, however, too few and not sufficiently well preserved to give full certainty.

3. Correlations.

The problem of the correlation of the Asaphus limestone in Northern and Southern Öland is far from solved with what has been displayed above. At the most, one would dare to assume that gradually higher beds of the series in Southern Öland through their northerly extension change their colour into grey. It is, however, quite certain that the old designations of "Upper" (red) and "Lower" (grey) Asaphus limestone have an entirely different meaning when applied to sections in Northern or Southern Öland (as must have been generally suspected). They are, in fact, so inadequate that they ought to disappear from the future discussion.

Like the old subdivision of the Raniceps limestone in Northern Öland that proposed above is based mainly on lithic characters but less on the colour than on the various kinds of grains disseminated through the stone.

One might expect that the change from one type of limestone to another would have taken place at different times in places far apart. The following facts contradict this: Grains of glauconite and phosphorite never occur together in the same bed, the beds containing the one kind or the other are even separated by a zone of limestone free from inclusions. From what is said below about the sedimentation it is evident that the grains are allochton and that they probably were carried by waves or currents from the area where they were formed and deposited simultaneously on vast areas together with shells and shell fragments. Their value as stratigraphical indicators should therefore not be underrated.

The subdivision is applicable to the region around Uggletorp and Stacketorp and perhaps even farther south, but the section at Lenstad shows that the difficulty of correlation with the sections in Northernmost Öland increases southwards.

With our present knowledge a fairly complete correlation with the sequence of strata in Estonia is possible. Some elements of the faunas do not appear or disappear strictly at the same level (compare the fossil lists from Öland with those of LAMANSKY 1905 p. 53—60), a difference which may be partly removed when the faunas from Öland have been thoroughly revised. Gotland (THORSLUND 1938) is not as one would expect intermediate between Öland and Estonia. The whole Asaphus limestone is only 1 m thick. The fossils seem to indicate that it comprises the Expansus zone (*Megalaspis* cf. *acuticauda* ANG in its middle part; also in Estonia this species occurs at rather low levels: $B_{III\alpha}$ and $B_{III\beta}$). The Asaphus limestone in Dalarna has been studied by HESSLAND and a subdivision corresponding to that in Öland has been made (several papers now in print). Our knowledge of other Ordovician areas on the Swedish mainland are at present too deficient for a correlation with Öland. Reference to a section from Östergötland in MOBERG 1911 (p. 153) may be sufficient to demonstrate the difficulties met with (Limestone with *Megalaspis heros* below the Expansus limestone!).

4. The Sedimentation.

It is a well-known fact that the lithic character of the Orthoceras limestone is not the same all through. So, for instance, the limestone with *Megalaspis limbata* is fine grained, and on fractures comparatively few sections through larger fragments of fossils as for instance encrinite stalks can be seen. The grey glauconite-bearing limestone which follows above, is, on the other hand to a great extent composed of larger fragments of fossils held together by a cement of calcite. The following discussion of the sedimentation starts with the glauconite-bearing beds between the Limbata zone and the Expansus zone which I have studied in the quarries at Gillberga and at Haget.

As mentioned above (p. 537) in these limestone beds one often finds large fossils which do not lie conformably with the bedding planes but very often stand on edge extending through the whole thickness of the

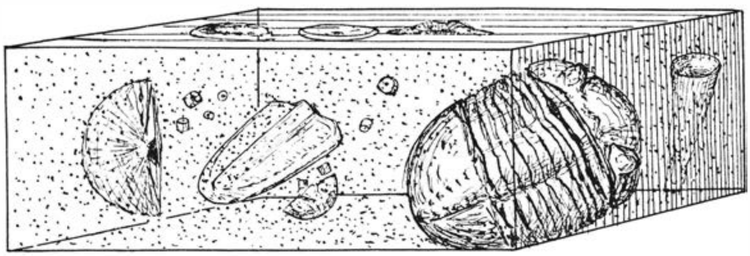

Fig. 7. Diagram showing the position of the fossils in a limestone bed. See the text.

bed. Fig. 7 is a diagram showing a block of a thin limestone bed with a few fossils in their present orientation at different angles to the bedding planes. (The fossils lying on the bedding planes are horizontal.)

To explain the orientation of the fossils within the beds one is forced to assume that the bed is composed of material which was carried away by the water during a violent storm or some other natural catastroph and then rapidly settled on the bottom. Large shells of trilobites and other animals were swept away at the same time; they sank to the bottom and were locked between the comparatively large sedimental particles which formed the matrix, and fixed in the position in which they happened to have been swept down to the bottom. They are thus found within the beds in positions which they could not possibly have had if they had sunk down one by one, independently of the material forming the matrix (or if they were part of a fauna living on the bottom) and then been inbedded under slow sedimentation of the material which forms the bulk of the limestone. Single instances of angular orientation could perhaps be explained by assuming that a shell (a pygidium or the like) lying on the surface of the bottom sediments had been tilted by currents sweeping along the bottom and supported in this position by sediment particles which were stirred up at the same time and settled underneath the shell. But when the fossils as a rule lie at an angle to the bedding planes such an explanation is not satisfactory. A reworking by currents on a large scale of the uppermost sediments on the bottom would hardly have left the delicate spines on the "*Acidaspis*" pygidium of fig. 8 unbroken. Further the thin bed "b" at Haget which has the same thickness for hundreds of m along the base of the cliff and is very homogenous in its structure could not possibly have been laid down on a bottom disturbed by currents strong enough to stir up the sediment and rearrange the fossils now found within the bed. The fossils can hardly have sunk into the bottom sediments. The small "*Acidaspis*" in fig. 8 weighed practically nothing in water, and even if it had a weight

Fig. 8. *Acidaspis* sp. Pygidium. Riksmus. Palaeoz. Avd. Stockholm. N: r ar 9800. Light from the right and from below; vertical section through a bed. See the text. × 4.

worth mentioning the long fine spines would have effectively prevented it from sinking.

The conclusion must be that limestone beds with a thickness of up to one dm (and perhaps even more) were laid down in a space of time which can be best measured in hours. The few dozens of beds which interest us here (total thickness about 3 m) would then have been deposited in a time which together amounts to say only a few days of the hundreds of thousands of years which this series of sediments might represent.[1]

[1] A similar sudden deposition of limestone beds but in alternation with a deposition of shales, evidently took place also in other formations. During the XVIIIth Geological Congress I saw an example on an excursion in the Lower Lias of Pinhay Bay, Devonshire. In limestone beds with a thickness of at least two dm large Ammonites were seen standing vertically in the matrix. They were probably at first kept in this position by

During the time interval which passed between the deposition of one bed and the next, the first bed seems to have been subject to corrosion ("negative sedimentation").[1] Very little new material, if any at all, was deposited during these periods. The greyish green lamellae with a high percentage of glauconite separating two beds of limestone are so thin that they are best explained as a residue from the dissolved limestone (glauconite is insoluble in hydrochloric acid and was probably still less influenced by the very dilute acids (phosphoric acid and others), which were present in the sea water.

Fig. 9 shows how the corrosion worked. The 15 cm thick limestone bed represents four sedimentations. During the periods when no sedimentation took place the corrosion produced a very irregular surface bleached under the influence of chemical agentia. On the section through the bed the corroded surfaces are seen as light coloured zig-zag lines (broader at the convexities of the curve) which run roughly parallel to the bedding planes. It is quite possible that beds which were once deposited were again entirely dissolved.

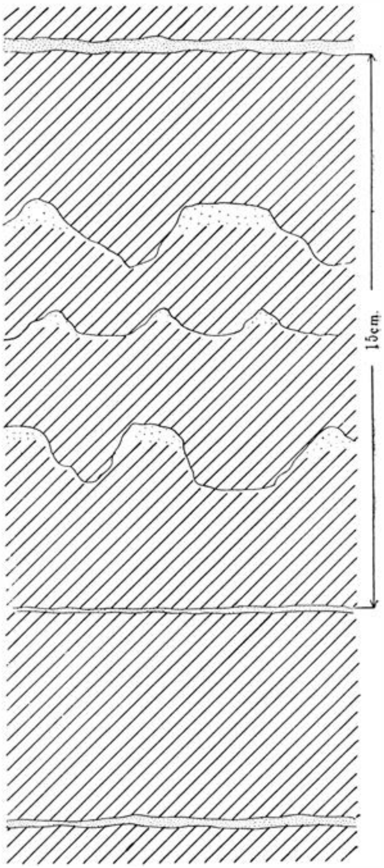

Fig. 9. Section through a limestone bed with irregular corrosion surfaces. See the text.

The fossils occurring in the loose sediment between the limestone beds are usually poorly preserved. A large number of fossils were certainly dissolved in the same way as the limestone. The fossils lie conformably with the bedding planes.

gas filling the chambers of the shell as the matrix accumulated around them. The imbedding cannot have taken long time also for the reason that if it had, the portions of the Ammonite not yet protected by the sediments would needs have been etched by the sea water or attacked by boring organisms. It is evident that these limestone beds cannot have been formed secondarily (as concretions in the shales), as in the shales the fossils lie horizontally. It seems reasonable to assume that the whole sequence of beds were deposited under the same bathymetric conditions, the shales representing the "normal" sedimentation and the limestone intercalated "storm beds". A photograph of a cliff of Blue Lias somewhat east of Pinhay Bay is reproduced in CHATWIN 1948 (Plate II, B).

[1] HADDING (1927, p. 86) signifies as negative sedimentation the denudation and removal of deposited, mostly unconsolidated material, which often leaves the coarser fragments on the place. The term is applicable to the case discussed here though the "denudation and removal" were evidently accomplished by chemical means. The corrosion ("halmyrolysis"?) illustrated in fig. 9 must have occurred in consolidated limestone.

The rapid deposition of each limestone bed (or part of one — cf. fig. 9) and the long periods of "negative sedimentation" are phenomena which must be reckoned with when trying to interpret the Ordovician sediments of Öland. But there are other problems connected with the sedimentation which must be left unsolved, such as the question of the source of the material forming the matrix in the beds, the means of transportation of this material to its present site and the very uniform development even of rather thin beds over wide areas. There is a certain similarity with the chalk deposits in Skåne, as for instance that at Båstad, where the chalk consists of small fragments of shells of about the same size as those composing some Ordovician beds. In both cases the beds contain comparatively few determinable fossils. The Ordovician beds in Öland were, however, undoubtedly deposited farther from the shore as boulders of older rocks are never found in them, which, on the other hand, is more or less the case at all the levels in the quarry at Båstad.

I am inclined to assume that the different layers in the "packs" of the *Limbata* limestone were also formed suddenly — though not so suddenly as the beds above them as the material forming the sediment is finer. I have not made a detailed study of the fossils as to their orientation, but large fossils, as for instance the pygidia of *Megalaspis limbata* lie horizontally (which is what one would expect as such fossils cannot on account of their weight be fixed in a labile position by the fine slowly settling sediment).

One would get the same difference of sedimentation as between the coarser limestone and the *Limbata* limestone if one poured a shovel full of small disks of glass and glass beads into water or the same disks together with finely powdered glass.

In the upper part of the *Expansus* zone and in the lowermost part of the *Raniceps* zone well defined continuous beds can still be distinguished (the beds "c" and "d + e" in the section fig. 2) but these beds are composed of lens shaped portions of limestone separated and cemented by soft marly sediments rich in glauconite. In "c" and "e" the soft component dominates so that it determines the colour of the whole beds (dark greyish green). In "d" and in the beds above "e" the limestone lenses determine the colour (light grey).

In the limestone lenses the orientation of the fossils is irregular as in the beds described above. The lenses are, however, comparatively thin, and therefore larger fossils like the pygidia of *Megalaspis* and *Asaphus* lie horizontally. The deposition of the limestone lenses must have taken place at short intervals as neither the limestone nor the fossils have suffered much from corrosion.

The Expansus limestone and the Raniceps limestone were probably deposited nearer the shore than the limestone on lower levels. This is especially true of the uppermost part of the Expansus limestone which contains a very high percentage of terrigeneous material.[1] It is possible that the lenticular structure indicates deposition in so shallow water that turbulence caused by storm waves could catch and rework the bottom sediments.

ANDERSSON (1896, p. 78) wanted to correlate the "Conglomerate with *Strophomena jentzschi*" with the "Lower *Asaphus* limestone" in Öland which is supposed to be the equivalent of the "s. g. Expansuskalk Östergötlands and Nerikes". Since the "Lower *Asaphus* limestone" has turned out to be very heterogenous, comprising at least three faunistically distinct zones the exact position of the conglomerate in the Lower Ordovician sequence of strata remains to be ascertained (see HESSLAND 1949). The most probable is that the "Conglomerate with *Strophomena jentzschi*" corresponds to the uppermost Expansus beds or the lowermost Raniceps beds (c—e at Haget) which were evidently deposited in comparatively shallow water. HOLM is also right in assuming (1895) that the isolated siphons found in the "Undre grå" are proofs of a deposition near the shore. The storms which I have postulated might have broken the shells of the orthoceratites to pieces and carried away the siphons.

Above the glauconite-bearing division of the Raniceps limestone the beds again become more compact. As an example one may mention the light grey limestone in the small ditch above the cliff at Haget (see p. 539).

In the uppermost division of the Raniceps limestone the orientation of the fossils and the structure of the beds has not been especially studied, but upwards from the Raniceps limestone we get a gradual change both in the colour and in the grain of the limestone which is the reverse of the change observed in the series below the Raniceps limestone from the Limbata limestone upwards. The Limbata beds were probably deposited in deeper water than those containing *Asaphus lepidurus*, *expansus* and *raniceps*. The red beds with *Megalaspis centaurus* and *gigas* and *Asaphus platyurus* mark a return to sedimentation in greater depth.

The black ooid-bearing bed in the Expansus zone ("a" in fig. 2) must have been deposited under unusual conditions, possibly in a depression of the shelf with stagnant water, or perhaps in a lagoon. The onset of this

[1]

	unsolved in cold HCl
Eskilslund (Expansus limestone = Haget "c")	20.3 %
Hjorthamn limestone	7.0 %
Byrum (bed with calcite ooids above the ooid horizon proper)	7.0 %
Haget ooid horizon, upper part	12.7 %
Haget (beds below the Expansus Zone?)	5.1 %
Platyurus limestone Stenåsa (NÖRREGAARD 1911)	6.5 %
Ancistroceras » » » »	4.5 %
Upper Asaphus limestone Resmo » »	6.3 %
Lower » » » » »	9.2 %
Planilimbata » » » »	10.5 %

sedimentation is foreboded by a change of the lithic character of the bed below the ooid-bed (see p. 535) towards the contact. The ooid bed is followed abruptly by a thin but very compact and resistent limestone bed ("b" in fig. 2) which is in all respect like the bulk of the beds laying below the ooid-bed. This bed might have been formed when the barriers confining the supposed depression were removed.

5. The erosion of the Asaphus beds.

In 1895 ANDERSSON published an interesting paper on the sea-stacks at Byrum. He points out that the formation of sea-stacks is connected with a regression of the sea (p. 21) and that it is favoured a). by the presence of vertical joints traversing the limestone, b). by a restricted tendency of the limestone to separate along horizontal planes (p. 25) and, finally, c). by the rock being of the same hardness within the same level (p. 6). ANDERSSON also mentions as characteristic of the limestone that it tends to split into fragment about one dm in length as the weathering proceeds which of course facilitates the work of the waves along the joints.

ANDERSSON's paper only deals with Byrum. An incipient formation of sea-stacks can, however, be seen also on Hälludden and in Tokenäse hamn, at both these localities in the same kind of limestone as at Byrum. There may be several reasons why the sea-stacks are not equally well developed in all these places:

There may exist some small differences in the structure of the limestone, not noticeable, however, when one collects fossils.

The exposure to the waves may be different. This is, however, not very likely as the coast faces approximately in the same direction (northeast) at all three localities.

The appearance of the coast when the Raniceps beds came within the reach of the waves may have been deciding. At Byrum it was probably protected by superimposed drift. The waves could cut into the edges of the beds, but the resulting stacks protruded comparatively little from the covering alluvial deposits and could therefore not be destroyed by the ice accumulating on the coast during the winters. The sea-stacks at Byrum lie, as a matter of fact, at the southwestern corner of the vast forested dune sand area occupying almost the whole of the parish of Böda, and the sand could very well have formed such a protective covering. At Hälludden and Tokenäs the shelf along the shore is bare, so that the ice can remove the tops of the sea-stacks successively (see p. 542).

At the same time the supply of sand (and also of pebbles of silicate rocks) at Byrum assisted at the grinding and polishing action of the waves.

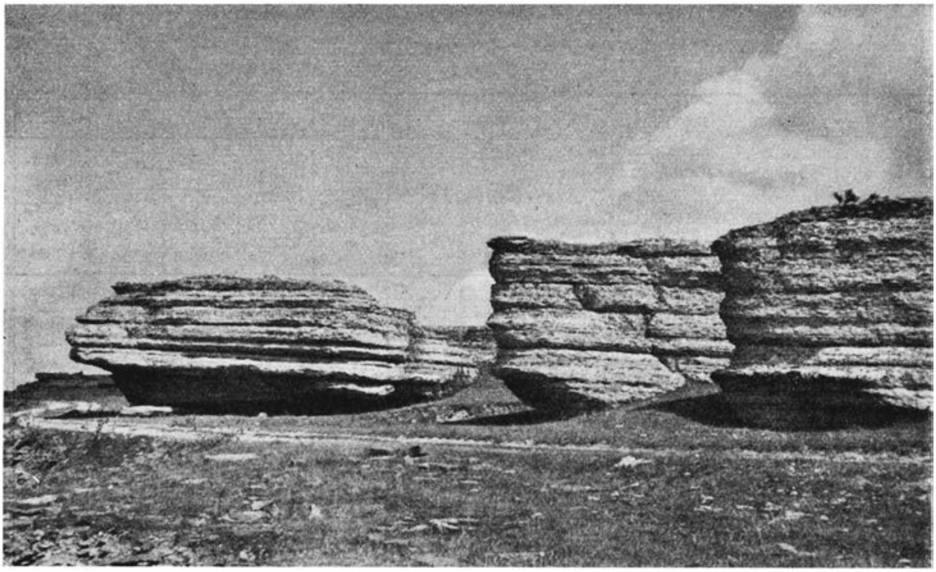

Fig. 10. The raised cliff at Gillberga. See p. 544 and p. 567.

ANDERSSON indicates without attaching great importance to it, that the small brook debouching at the northern end of the dissected cliff at Byrum had taken part in the formation of the sea-stacks.

How ever the sea-stacks were formed, one thing is certain, namely that if large or small they are only found where the Raniceps limestone forms the nearly submerged part of the shore. On the shore between Grythamn and Alvidsjöbodar (more than 6 km) the Limbata limestone and higher levels up to the Expansus Zone form a low flat shelf without even traces of sea-stacks. The structure of the limestone does not allow it to be picked by small pieces like the Raniceps limestone but the eroding forces break off large flags along the bedding planes. These flags are then by and by broken into small ones. The shingle thus formed is very much coarser than that formed from the Raniceps limestone.

The enormous accumulations of limestone fragments which are called "Neptuni åkrar" (the "Fields of Neptune") derive from the lower Raniceps limestone which was broken up with a speed that there was no time for the fragments to become properly rounded before new masses were deposited which protected the first ones from further action of the waves. These fragments can be used as a natural macadam whereas the shingle from the Limbata limestone is far too coarse for that purpose.

It is quite possible that sea-stacks once were developed at Haget but when the shore was raised so far that the soft beds at the boundary between the Expansus and the Raniceps zones came within the reach of the waves the sea-stacks were doomed. The present undercut cliff represents a later

List of fossils I.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
	Norra udden	Häll-udden	Toke-näs	Haget	Hjort-hamn lime-stone	Marsjö grey	Marsjö red	Pers-näs Upper Rani-ceps	Len-stad
Pterygometopus sclerops (DALM.)	—	10	1	1	19	—	—	—	2
Ceraurus ingricus F. S.	—	2	—	—	9	—	1	—	1
» *ornatus* DALM.	—	—	—	—	6	—	—	—	—
Cyrtometopus affinis ANG.	×	1	1	—	2	—	5	1	1
» *clavifrons* (DALM.)	—	3	—	—	4	—	1	—	—
? *Cyrtometopus* sp.[1]	×	3	—	—	14	—	2	—	2
Nieszkowskia tumidus (ANG.)	—	—	—	—	2	—	1	—	1
Sphaerocoryphe sp.	—	—	—	—	1	—	—	—	—
Pliomera fischeri (EICHW.)	×	13	11	6	22	2	3	2	2
Cybele bellatula (DALM.)	—	3	—	—	—	—	—	—	—
Ceratocephala solis (ÖPIK)	—	2	—	—	—	—	—	—	—
Lichas coelorrhin ANG.	×	2	1	5	15	5	6	2	1
» *verrucosus* (EICHW.)	—	1	—	1	—	—	1	1	—
Harpes sp.	—	—	—	—	—	—	—	1	—
Remopleurides sp.	×	4	—	1	2	—	—	1	2
Megalaspis extenuata DALM.	×	2	7	—	14	1	13	3	—
» *heros* (DALM.)	—	11	1	2	8	1	10	5	6
» *rudis* ANG.	—	6	4	2	14	1	60	13	?
» sp. cf. *gibba* F. S.	—	—	—	1	—	—	—	—	—
» sp. (see p. 556)	—	—	—	—	—	—	—	—	13
Asaphus raniceps DALM.	×	67	31	19	83	14	13	28	21
Pseudasaphus sp.	—	—	1	2	1	—	16	2	2
Ptychopyge sp.	—	?	—	—	2	3	3	—	4
Nileus armadillo DALM.	—	—	—	—	3	—	—	—	15
Niobe frontalis DALM.	—	—	1	—	2	1	3	—	12
"*Isotelus*" *stacyi* F. S.	—	—	—	—	—	—	—	2	—
Illaenus esmarcki (SCHLOTH.)	×	8	16	4	10	9	16	13	20
» cf. *ladogiensis* HOLM	—	1	—	1	2	—	—	—	2
Ampyx nasutus DALM.	×	9	1	—	9	1	5	1	1
Trinodus cf. *glabratus* (ANG.)	—	2	—	1	1	—	—	—	3
Brachiopoda var. sp.	×	×	49	11	55	1	3	9	4

[1] Small verrucose cranidia; the generic determination is uncertain but the whole material undoubtedly belongs to the same species.

List of fossils II.

	Number of specimens	
	Eskilslund[1]	Djupvik[2]
Pterygometopus sp.	2	2
Cyrtometopus clavifrons (DALM.)	3	—
Nieszkowskia cf. *tumidus* (ANG.) see p. 550	—	1
Lichas erici WARB.	1	1
» aff. *coelorrhin* ANG.	1	—
» *platyrrhinus* F. S.	1	—
Conolichas? oelandicus (ANG.)	1	—
Megalaspis acuticauda ANG.	2	1
» cf. *hyorrhina* v. LEUCHT.	1	—
Asaphus expansus L.	18	9
» cf. *raniceps* DALM.	2	3
Ptychopyge cf. *angustifrons*	3	4
Niobe sp. (hypostoma)	1	—
Symphysurus palpebrosus DALM.	1	—
Illaenus sp. (? *esmarcki*)	3	2
Ampyx cf. *nasutus* DALM.	2	3
Antigonambonites sp.	2	—
Lycophoria nucella DALM.	4	5
Pseudocrania sp.	7	1
Orthis callactis DALM.	2	—
Colonies of Trepostomate bryozoans (*Monticulipora*)	3	2

[1] The fossils collected from a certain level or from a certain block were numbered separately. The list gives the total of 8 such collections.

[2] The total of the collections 8—17 on pp. 549—550 which all except 9 and 16 come from the same kind of marly limestone.

stage in the evolution of the shore. Still in a later stage the protruding parts fall down as for instance at the northern and southern end of the cliff at Haget, perhaps also south of Hälludden and south of Byrum. The so-called sea-stacks at Gillberga (fig. 10) now raised to a height of about 8 m above sea level probably correspond to a stage somewhat later than that represented by the cliff at Haget.

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Explanation of plate I.

Figs. 1—4. Pygidia of some stratigraphically important Megalaspids. In some of the specimens the limbus is partly broken away but part of the background on which the specimen was photographed is left for a reconstruction. All 2/3 nat. size.

1. *Megalaspis centaurus* DALM. Narrower than the specimens figured by SCHMIDT from Estonia (ratio width/length 0.78 instead of 0.88). However, a wide range of variation is allowed in this respect (SCHMIDT 1906, p. 59). — Marsjö.

2. *Megalaspis rudis* ANG. Ratio width/length 1.0. Considered by SCHMIDT and others to have "höchstens die Bedeutung einer Varietät von *M. centaurus* oder *grandis*" (l. c. p. 61). In Öland the two species (or varieties) never occur in the same beds, at least not in the rather well investigated localities in Persnäs and Föra. — Marsjö.

3. *Megalaspis* sp. Ratio width/length almost as high as in *M. rudis* (0.97), but the shape of the pygidium is distinctly more triangular reminding one somewhat of *M. extenuata* in which, however, the number of segments in the rhachis and that of distinguishable costae is considerably smaller; in this respect the species reminds one more of *Megalaspis rudis*. — Asaphus limestone (red), Lenstad.

4. *Megalaspis gigas*. ANG. Ratio width/length 0.9. — Gunnarslund.

The species of *Megalaspis* from Öland will be the subject of a monography later. The figs. 1—4 are published to make clear the signification of the various specific names in the present paper.

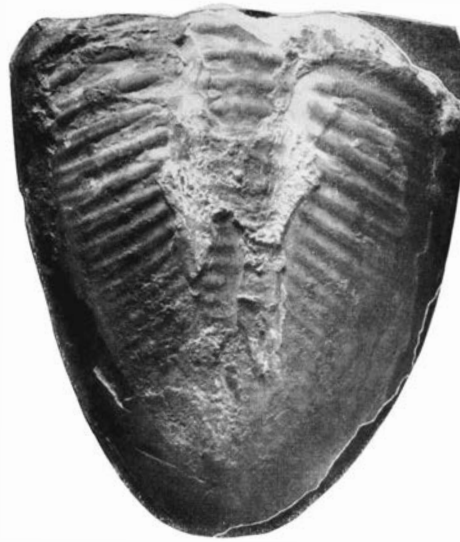
Fig. 5 and 6. *"Isotelus" stacyi* F. S. 2/3 nat. size.

5. Partial cranidium without the shell. The portions in front of the irregular white line are reconstructed (cf. SCHMIDT 1901, p. 97). Posteriorly the right half is complete. — Upper Raniceps limestone, Gunnarslund.

6. Fragmentary pygidium, shell partly preserved. — Upper Raniceps limestone about 1 kilometer N. N. E. of Stenninge.

Photos N. HJORT.

1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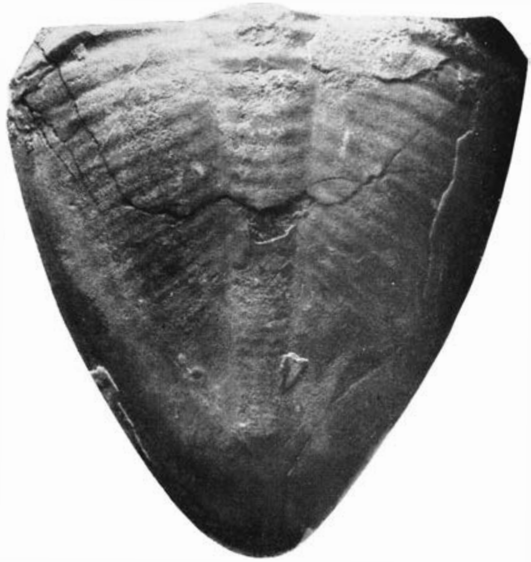
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5



6

Map of the northernmost part of Öland (Ordnance map reduced to the scale 1:300000).

The Contour-lines in the sea of the north mark depths of less than 10 metres.

The approximate extensions of the sections at Marsjö and Djupvik are indicated with lines in Indian ink.

A.	Alvidsjöbodar
B.	Byxelkrok
Be.	»Berget» (see p. 551)
By.	Byrum
Dj.	Djupviks hamn
E.	Eskilslund
Gi.	Gillberga
Gu.	Gunnarslund
Ha.	Haget
Hjh.	Hjorthamn
Hjs.	Hjelmestad
H. u.	Horns udde
Hä.	Hälludden
K.	Korntorp
M.	Maderna
Ma.	Marsjö
N. u.	Norra udden
Sa.	Sandvik
St.	Stenninge