SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:O 355.

ÅRSBOK 22 (1928) N:O 5.

A DEEP BORING THROUGH MIDDLE AND LOWER CAMBRIAN STRATA AT BORGHOLM, ISLE OF ÖLAND

BY

A. H. WESTERGÅRD

Pris 1,00 kr.

STOCKHOLM 1929
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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In the year 1900 a diamond boring was made at Borgholm for the purpose of supplying the town with water, and a section was obtained through the Paradoxides ölandicus series and the Lower Cambrian sandstone to a depth of 100 m. below the surface. The core, which has a diameter of 48 mm., was presented to the Museum of the Geological Survey of Sweden, where it has been preserved. I have now subjected it to a scrutiny with the object of obtaining something of stratigraphical interest from it. Though the results are by no means remarkable, I think they may be worth publishing, all the more as the only existing account of this section is a very summary one which was published in the explanation of the map sheet Mönsterås and Högby,[1] and which was based on notes made by G. C. von Schmalensee and the foreman when the core was taken up.

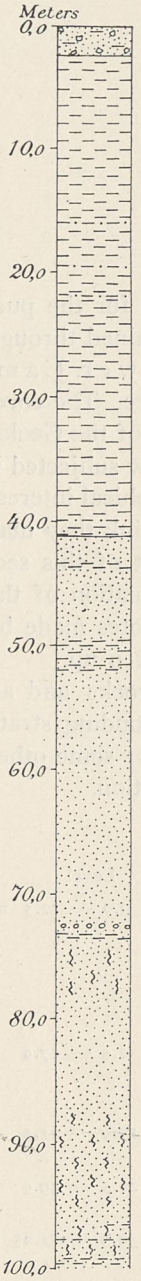
After an account of the petrographical character of the rocks and an enumeration of the fossils found in the core, and in corresponding strata at other localities of Öland, a review of the Lower Cambrian of some other Scandinavian districts will be given for the purpose of correlation.

The succession of the strata of the core is as follows.

	Thickness	Level
Boulder clay	2.5 m.	0.0 — 2.5 m.
Paradoxides ölandicus series.		
Clay shale, greenish grey, commonly somewhat arenaceous and micaceous, not very thinly laminated. A thin layer or lens of a greenish grey, argillaceous and arenaceous limestone, the only one met with in the shale bed, was found at about 17 m.	15.4 »	2.5 — 17.9 »
Clay shale of the kind described above preponderant, with interstratified layers of a dark grey, thinly laminated, soft shale and very thin green seams rich in glauconite	3.6 »	17.9 — 21.5 »
Clay shale, dark grey, thinly laminated, somewhat micaceous and usually arenaceous	18.4 »	21.5 — 39.9 »
Clay shale similar to that immediately above but having interstratified very thin, green seams, rich in grains of glauconite	1.35 »	39.9 — 41.25 »

[1] Sveriges Geologiska Undersökning, Ser. Ac, No. 8. — As to the levels of several strata, the account published in the explanation of the map sheet does not agree with that given in this paper. This being the case the figures published here should be considered correct as they are in agreement with the bore register as well as with notes attached to the core sections when they were packed.

†—*284371. S. G. U. Ser. C. N:o 355. Vestergård.*



0 — 2.5 m.	Boulder clay.
2.5 — 17.9 »	Clay shale, greenish grey, commonly somewhat arenaceous and micaceous.
17.9 — 21.5 »	Clay shale, greenish grey, with interstratified layers of a dark grey, soft shale and very thin, green seams rich in glauconite.
21.5 — 39.9 »	Clay shale, dark grey, somewhat micaceous and usually arenaceous.
39.9 — 41.25 »	Clay shale, dark grey, with thin seams rich in glauconite.
41.25— 41.4 »	Argillaceous sandstone with phosphorite and glauconite.
41.4 — 49.8 »	Sandstone, white, calcareous or non-calcareous, in the lower part glauconitic.
49.8 — 52.3 »	Clay shale, dark, greenish grey, with interstratified thin layers of sandstone.
52.3 — 72.6 »	Sandstone, light grey or greenish grey, infrequently calcareous.
72.6 — 72.65 »	Conglomerate with quartz pebbles and nodules of phosphorite.
72.65— 78.2 »	Sandstone, greenish grey, usually argillaceous and penetrated by winding cylindrical tracks.
78.2 — 87.2 »	Sandstone, white or light grey, seldom calcareous, forming thick banks with argillaceous joints.
87.2 —100.0 »	Sandstone, greenish grey (reddish brown at about 91 m.) argillaceous, with thin layers of pure sandstone and clay shale.

Fig. 1. Schematic succession of strata in the diamond boring core at Borgholm.

Lower Cambrian sandstone.	Thickness	Level
Argillaceous sandstone, yellowish or dark brownish grey, coarse or fine-grained, with flakes of phosphorite and grains of glauconite	0.15 m.	41.25— 41.4 m.
Sandstone, greyish or yellowish white, hard, somewhat argillaceous, with grains of pyrite	0.5 »	41.4 — 41.9 »
Sandstone, white, very hard, with scattered flakes of mica, sometimes strongly calcareous	1.55 »	41.9 — 43.45 »
Shale, dark, greenish grey, rich in mica, and very thin seams of argillaceous sandstone	0.15 »	43.45— 43.6 »
Sandstone, white, hard, fine-grained, alternating calcareous and non-calcareous, in the upper part devoid of glauconite, in the lower part green-coloured, due to glauconite in varying quantities and often accumulated into seams	6.2 »	43.6 — 49.8 »
Clay shale, dark, greenish grey, micaceous, thin-bedded, with interstratified thin layers of light grey or greenish grey, glauconitic, hard sandstone	2.5 »	49.8 — 52.3 »
Sandstone, light grey or greenish grey, usually glauconitic, infrequently calcareous, alternating with light-coloured sandstone shale, dark greenish grey clay shale, and greenish or yellowish grey, thick-bedded, argillaceous sandstone	20.3 »	52.3 — 72.6 »
Conglomerate, with small quartz pebbles and nodules of dark, brownish grey phosphorite, in a matrix of a slightly calcareous sandstone	0.05 »	72.6 — 72.65 »
Sandstone, light grey, glauconitic, alternating with sandstone shale and dark, greenish grey clay shale	0.65 »	72.65— 73.3 »
Argillaceous sandstone, greenish grey, usually indistinctly stratified and occasionally full of winding cylindrical tubes of white sandstone (fig. 2), with thin layers of light coloured, fairly pure sandstone	4.9 »	73.3 — 78.2 »
Sandstone, white or light grey, fine-grained, not very hard, somewhat kaolin-bearing, seldom calcareous, forming thick banks with argillaceous joints. Pipe rock (*Scolithus linearis*) appears at several levels	9.0 »	78.2 — 87.2 »
Argillaceous, greenish grey sandstone, penetrated by winding cylindrical trails, alternating with white, fine-grained, pure sandstone	3.6 »	87.2 — 90.8 »
Argillaceous sandstone, usually dark, greenish grey, with thin layers and irregular portions of a reddish brown colour	1.0 »	90.8 — 91.8 »
Argillaceous sandstone, greenish grey or grey, partly spotted, partly homogeneously coloured, with interstratified layers of greenish grey, micaceous and somewhat arenaceous shale, and thin beds of a white, fairly pure sandstone, the latter sometimes developed as pipe rock	8.2 »	91.8 —100.0 »

Next below the boulder clay appears a bed of a usually somewhat arenaceous and micaceous clay shale, 38.75 m. thick, which in the upper part is greenish grey and downwards assumes a darker, grey or brownish grey, colour. Fossils are met with mainly in the upper part, to a depth of about 14.5 m. below the surface. Below 16.6 m. no trilobite fragments at all were found. The lower and larger part of the shale bed is almost barren in comparison with the upper one and has yielded only a few brachiopods. In any case, even this lower part of the clay shale bed no doubt ought to be referred to the *Par. ölandicus* series.

The topmost strata of the Ölandicus beds are absent from the core, but they are met with not far from the boring, at Rosenfors (at the south-eastern boundary of Borgholm), where the said beds are covered by the Tessini series. The total thickness of the Ölandicus series at Borgholm may be estimated at a little more than 40 m.

The fossils enumerated below have been found in the Ölandicus shale of the core.

	Level
Paradoxides ölandicus SJÖGR. and undescribed forms nearly related to this species. Numerous fragments: cranidia, free cheeks, thoracic segments and hypostomata	2.5—14.5 m.
Paradoxides quadrimucronatus HOLM in museo (*P.* aff. *ölandicus*), 2 pygidia	12.1—12.3 »
Paradoxides sjögreni LINRS., a cranidium; (a pleura of a thoracic segment, found at a level of 3 m. may possibly belong to this species)	11.3 »
Ellipsocephalus polytomus LINRS., 14 cranidia, 2 free cheeks, numerous thoracic segments	11.8—14.5 »
Solenopleura cristata LINRS., 6 cranidia, 1 free cheek and part of a thorax	7.2—12.3 »
Agnostus regius SJÖGREN, 1 cephalon, 3 pygidia	9.6—12.0 »
Orthotheca teretiusculus (LINRS.), 1 specimen	11.6 »
Hyolithus (s. l.) sp., 2 fragments	12.3—15.0 »
Acrothele (*Redlichella*) *granulata* (LINRS.), numerous dorsal and ventral valves (most common between 12.6 and 17.5 m.)	12.6—39.3 »
Acrotreta socialis v. SEEB., 7 ventral and 2 dorsal valves	27.8 »
Acrotreta sp., about 12 poorly preserved valves	13.7—40.3 »
Lingulella ferruginea SALTER, about 15 dorsal and ventral valves	12.3—40.5 »

The fossils found in the core constitute only a part of the complete fauna known from the Ölandicus series at Borgholm. Especially thanks to collections made by G. Holm from well sinkings at Borgholm in 1889 and later, a very abundant material of the fauna of that series has been assembled. Unfortunately there are no notes concerning the levels at which these specimens are found, but no doubt they originate from the abundantly fossiliferous zone occurring in the upper part of the core. Holm intended to publish a description of this fauna, but he had got no further than making figures of the forms previously unknown at the time of his death. Below is given a complete list of fossils hitherto found in the Ölandicus series of Öland,[1] of which four, marked with an asterisk, have not as yet been met with at Borgholm. The new species I hope to have an opportunity of describing in a projected report on a paleontological-stratigraphical revision of the Swedish Middle Cambrian.

Paradoxides ölandicus SJÖGREN.
» *quadrimucronatus* HOLM in museo (*P.* aff. *ölandicus*).
» *bidentatus* n. sp. (*P.* aff. *ölandicus*?).
» *pinus* HOLM in museo (*P.* aff. *ölandicus*).
» *torelli* HOLM in museo.
» *sjögreni* LINNARSSON.

[1] In the explanation of the map section No. 5 (Sver. Geol. Unders., Ser. A_1 a) *Conocoryphe tenuicincta* LINRS. and *Liostracus aculeatus* ANG. are quoted from the Ölandicus beds, but these species are omitted here because it seems doubtful whether they are found in the said beds or in the lowest part of the Tessini series.

Ellipsocephalus polytomus LINNARSSON.
**Conocoryphe emarginata* LINNARSSON.
Solenopleura cristata LINNARSSON.
Burlingia laevis n. sp.
Agnostus fallax LINNARSSON.
» *gibbus* LINNARSSON, and subsp.
» *regius* SJÖGREN.
* » cf. *integer* BEYRICH.
**Goniodiscus* (?) *ölandicus* n. sp.
Hymenocaris ölandica HOLM in museo.
Orthotheca corneolus HOLM.
» *teretiusculus* (LINNARSSON).
» *affinis* HOLM.
Hyolithus ölandicus HOLM.
» *obesus* HOLM.
* » *socialis* LINNARSSON.
Helcionella pauciplicata n. sp.
Lingulella ferruginea SALTER.
Acrothele (*Redlichella*) *granulata* (LINNARSSON).
Acrotreta schmalenseei WALCOTT.
» *socialis* VON SEEBACH.
Orthoid brachiopod (a non-determinable fragment.)

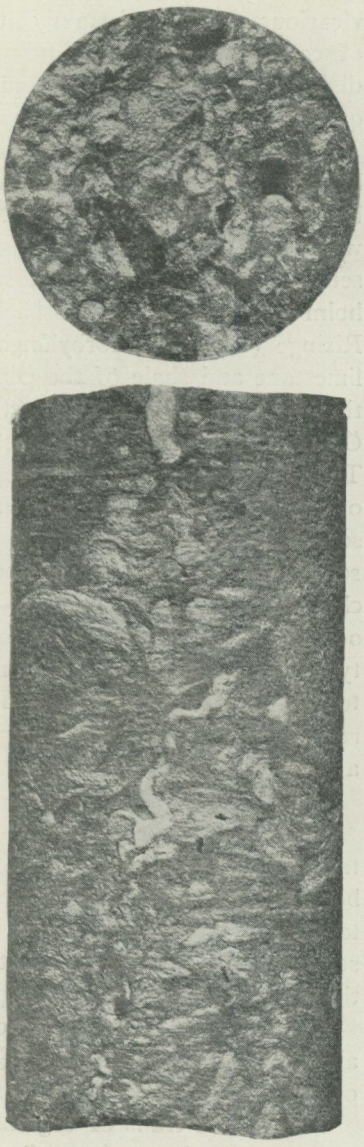


Fig. 2. A part of the boring core of an indistinctly stratified, greenish grey, argillaceous sandstone with winding »worm trails» of white sandstone. Level 74·9—75.0 m. Resembles the »kråksten» of the western coast of Kalmarsund. Nat. size.

Of the above-mentioned new species, *Burlingia laevis,* of which five more or less complete specimens and a couple of fragments are present, deserves special attention. It is very closely related to the geno-type, *B. hectori* WALC., from the Middle Cambrian Ogygopsis shale of the Stephen formation of British Columbia, the only species of that genus hitherto known.[1] The Baltic form seems to be distinguished from the Canadian species mainly by having the cephalon more markedly semi-circular, the glabella entirely without furrows and impressions but provided with a small occipital spine or tubercle (not visible in the Canadian form), the outline of the thorax forming an unbroken (not dentate) line, and by its somewhat larger size — the largest Baltic specimen is 13 mm., the largest Canadian 7 mm. in length. As it would seem, the differences are unimportant and may in part possibly be due to different modes of preservation. In fact, the agreement is great enough to indicate

[1] C. D. WALCOTT, Cambrian trilobites. — Smithsonian Misc. Coll, Cambrian Geology and Paleontology, Vol. 1, No. 2 (1908).

vicarious forms. Certainly it is of great paleogeographical interest and of correlative value to find this peculiar genus represented in the Baltic district, where it is associated with a trilobite fauna, otherwise of a type quite different from that associated with the Canadian form.[1]

The *Paradoxides ölandicus* series is covered by a thin calcareous conglomerate, the so-called *Acrothele granulata* conglomerate, forming the very base of the *P. tessini* beds. It is developed in all localities on Öland wherever the boundary between the Ölandicus series and the Tessini series is met with, viz. at Rosenfors, on the shore half-way between Borgholm and Köping, at Runsbäck (parish of Torslunda), and on the shore at Risinge (south of Mörbylånga). The conglomerate is rich in boulders of limestone and shale of the Ölandicus series indicating erosion and destruction of strata of that series. In consequence the youngest part of the Ölandicus series may be expected to be absent from the sequence on Öland. The conglomerate no doubt represents a hiatus which, however, is probably of minor extent. The size of the break is indicated by a more complete sequence found in Southern Jämtland. From the top of the Ölandicus series of that district we know a zone of a thickness of a few meters characterized by *Par. jemtlandicus* WIM. and *Agnostus* cf. *fallax* LINRS., both of them common, and very rare fragments of a *Paradoxides* of *ölandicus* type. This zone has not been met with at Borgholm, where we might expect to find it developed because of the close paleontological and stratigraphical resemblance as regards the Ölandicus series which these two districts afford.

In the boring the Lower Cambrian sandstone has been penetrated to a depth of 58.75 m. below its upper limit without its substratum being reached. In a deep boring at Visby[2] the sandstone bed has been found to have a thickness of 104.4 m., but probably the total thickness of this series will be somewhat less at Borgholm than at Visby, this being certainly the case as regards its upper part, as proved below.

As is always found in the case of the superimposed shale, the sandstone also is horizontally bedded. Small deviations occurring at several levels are of local nature and due to cross-bedding.

Tracks and trails of organisms are common; mud-cracks were met with at a level of about 76 m. *Scolithus linearis* (pipe rock) occurs in the purer sandstone at different levels of the lower half of the sandstone bed, the

[1] Of the family of *Burlingidae* WALCOTT, of which only one Swedish species has hitherto been described, viz. *Schmalenseeia amphionura* MOBERG from the base of the zone of *Agnostus pisiformis*, we now know, besides the said *Burlingia laevis*, a third species, *Schmalenseeia acutangula* n. sp. from the *Paradoxides tessini* — *P. davidis* series of Scania and Jämtland. It is intermediate between the forms mentioned but, so far as the cephalon is concerned, the only part of the test met with, more closely related to the younger one. It is characterized by having a distinct occipital furrow and three pairs of distinct glabellar furrows, a small occipital spine, smooth preglabellar field lacking a raised longitudinal ridge, and acute genal angles.

[2] H. Hedström, Remarks on some fossils from the diamond boring at the Visby cement factory. — Sveriges Geologiska Undersökning, Ser. C, No. 314 (1923).

pipes being much more sparse than in certain types of the Kalmarsund sandstone. Trails resembling *Scolithus errans* appear in layers of argillaceous sandstone between 74 and 100 meters.

A thin, arenaceous conglomerate, with small rounded pebbles of quartz and nodules of dark brownish grey phosphorite, occurs at a level of 72.6 m. Dr. A. Bygdén has communicated the following analysis of such a phosphorite nodule:

Air-dried matter, when heated to 105°, lost	1.28 %	
In diluted HNO_3 undissolved matter	36.74 »	of matter dried at 105°
P_2O_5	21.23 »	» » » » » »

For reasons quoted below the conglomerate does not indicate any important break in the sequence.

Phosporite is also an important component of the sandstone at the very top of the series, and solitary nodules are found, though very seldom, in the argillaceous as well as in the pure sandstone at different levels. A general sample of the sandstone forming the topmost layer of the series, about 12 cm. thick, has the following composition according to an analysis by Dr. Bygdén:

Air-dried matter, when heated to 105°, lost	0.19 %	
In diluted HNO_3 undissolved matter	57.58 »	of matter dried at 105°
P_2O_5	8.00 »	» » » » » »

The grey or greenish grey, argillaceous sandstone that occupies parts of the core between the said conglomerate and the bottom of the boring, has sometimes a structure indicating disturbed sedimentation. Altogether the character of the sandstone series indicates that it was deposited in very shallow water on a flat sea-bottom lying sometimes beneath and sometimes above sea level, possibly due to the influence of the ebb and flow of the tide.

Apart from the common tracks and trails, including the *Scolithus*, only the following actual fossils were met with in the sandstone of the core.

Hyolithellus (?) sp., a cylindrical fragment, a few mm. in length and circular in transverse section found about 20 cm. below the upper limit of the sandstone.

Bradoria (?) sp., a fragment of a small specimen from about 61 m.

Discinella holsti Moberg, about 10 fairly well preserved specimens and some 20 fragments, occurring between 67.7 m. and 77.6 m. It is most common in and immediately above the conglomerate at 72.6 m.; beneath the latter only one example is met with. In consequence, the conglomerate occurring within the *Discinella*-bearing zone obviously does not represent any important break of sedimentation.

Owing to the poor state of preservation the reference of the said little fragment to the genus *Hyolithellus* is doubtful. However, it resembles a form, *H. micans* (Billings), which is common at the top of the Lower Cambrian at Gislövshammar (see below).

Discinella holsti was originally described by Moberg[1] from boulders found

[1] Om en nyupptäckt fauna i block af kambrisk sandsten insamlade af dr N. O. Holst. — Sver. Geolog. Undersökn., Ser. C, No. 125. Also in Geolog. Fören. Förhandl., Bd 14 (1892).

in Öland. Moberg distinguished five different types of rocks among the boulders with *Discinella* which fairly well agree with the rocks of the *Discinella* zone of the boring core. However, the dark brown, almost black, manganese sandstone described by Moberg (and said to be usually jointed with one of the other types) does not occur in the core, in which moreover the darkest rocks are somewhat lighter coloured than the darkest greenish grey of the boulders. In some boulders *Discinella* is extremely abundant, totally covering solitary bedding planes, but no such surface is met with in the core.

In solid rock *D. holsti* is known from the above-mentioned deep boring at Visby and from the Mjösen area of Norway.[1] It was also met with in a boulder of a rusty sandstone found at Mariehamn, Åland, and unless the boulder was carried thither as ballast — according to Wiman a possibility not to be lost sight of — it would indicate that the *Discinella* zone is developed in the Northern Baltic district too. At Visby it is found 53.0—55.7 m. and at Borgholm 26.4—36.3 m. below the upper surface of the sandstone series. The difference of levels indicates that at least the upper part of the sandstone series decreases in thickness from Gotland to Öland.

No other form of the fauna met with in boulders found in Öland and described by Moberg, of which all cannot be certainly referred to the *Discinella* zone, occurs in the core.

In Öland the Lower Cambrian sandstone is accessible in solid rock only at Mörbylånga. From a well sinking at that place Holst[2] quotes the following sequence.

Moraine	1.8 m.
1. Grey sandstone, the upper part light, the lower part dark with a *Diplocraterion* of large size	2.4 »
2. Black, bituminous (after heating white) sandstone	0.4 »
3. »Black marble sandstone»	0.4 »
4. Sandstone with glauconite and clay seams	2.2 » +

The uppermost strata of the sandstone series are lacking in this section, but a conglomerate with »coprolite-like nodules» (probably phosphorite) occurring as boulders is supposed by Holst to form the very top of the sandstone. Certainly this conglomerate is to be correlated with the phosphoritic layer at the top of sandstone of the core. Strata Nos. 2 and 3 of the said section have no direct parallels but strata Nos. 1 and 4 are of the same petrographical character as the rocks of the upper part of the sandstone of the core.

Petrographically the Lower Cambrian sandstone of Öland corresponds exactly with that under Gotland and in general also with the sandstone of

[1] J. Braastad, Discinella holsti faunaen ved Braastad-elven nord for Gjövik. — Norsk Geolog. Tidskr., Bd 3, No. 5 (1915). — See also J. Kiær, The Lower Cambrian Holmia Fauna at Tömten in Norway. — Videnskabsselsk. Skrift., I, Mat. Naturv. klasse, 1916, No. 10.

[2] Bidrag till kännedomen om lagerföljden inom den kambriska sandstenen. Sver. Geol. Unders., Ser. C, No. 130.

other Baltic districts. In the abundance of glauconite and interstratified seams of clay shale, occurring also in its upper part, it differs from the Lingulid sandstone of Västergötland. It is true that pure white sandstone, non-calcareous and calcareous, occurs also in the Borgholm core, but it is of minor importance and the white sandstone met with is usually glauconite and kaolin bearing.

Among boulders of Lower Cambrian sandstone found in Öland one is of particular interest, because it contains *Mickwitzia monilifera* (Linrs.).[1] It was taken by J. G. Andersson between Eriksöre and Kråketorp (south of Färjestaden) and is composed of a white sandstone connected with a conglomerate with well worn pebbles of quartz, less worn pebbles of a rusty sandstone, and nodules of gray phosphorite. Even if the possibility that it might come from the Northern Baltic district cannot be absolutely rejected, it most probably originated in the Kalmarsund district. This being the case, from what horizon does the boulder come? Our present knowledge of the topmost layer of the sandstone series does not speak in favour of its correlation with that layer, and, for reasons quoted below, it does not seem to belong to the Cambrian basal conglomerate.

Possibly the boulder might belong to the conglomerate of the *Discinella* zone, some boulders of which have been found along the western coast of Öland.[2] In these *Discinella holsti* is very rare. In petrographical character they agree very well with the *Mickwitzia* boulder. However, a supposed coincidence of the *Mickwitzia* and the *Discinella* faunuls does not square with the fact that the faunuls have never hitherto been met with in association.

The boulder under consideration might possibly originate in a conglomeratic layer not visible in the core and occurring either at a deeper horizon than that reached by the boring or at a level penetrated by the boring but at Borgholm not developed as a conglomerate. The former supposition pre-supposes that *Mickwitzia* was older than *Discinella,* a supposition opposed by the facts concerning the vertical distribution and the succession of

[1] Only one specimen is present, in the matrix of the conglomerate. It is far from perfectly preserved, but the characteristic sculpture of the shell seems to warrant the specific reference.

The reader may possibly think it not justifiable to pay very much attention to one single boulder, the origin of which cannot be absolutely ascertained, but, of course, it would be of great interest to gain a positive proof of the mutual succession of *Mickwitzia* and *Discinella*. — It may also be noticed that the former is tolerably rare in our country, except for a thin layer a little above the basal conglomerate at Lugnås. Thus, it is extremely rare at Kinnekulle; at Billingen as well as in Närke only a few specimens have been collected; in Falbygden it seems to have been met with in local boulders south of Tidaholm (according to the explanation of the map section »Tidaholm»), and in the Lingulid sandstone at Oltorp one specimen has been found by R. Lidén; from Östergötland only one specimen is known (occurring in a boulder of a conglomerate at Berg, where boulders of the same petrographical type are not infrequent); and the specimens originating from the Northern Baltic district do not seem to be numerous. In a sandstone dyke in archean rocks on Rävkulteholmen, Dalsland, some fragments were found by Gavelin (Om underkambriska sandstensgångar vid västra stranden av Vänern. — Sver. Geol. Unders., Ser. C, No. 217). In Scania *Mickwitzia* has as yet been sought in vain. In Esthonia, however, *Mickwitzia* is very common at one horizon.

[2] These boulders belong to Moberg's type e. The nodules of »grey clay» mentioned by Moberg are in fact composed of phosphorite or of a rock with a high percentage of phosphoric acid.

the faunistic elements of the Lower Cambrian hitherto known. In Esthonia, *Volborthella tenuis* Fr. Schmidt and *Platysolenites antiquissimus* Eichw. are associated with and appear a little below *Mickwitzia monilifera* (Linrs.) and *Holmia mickwitzi* (Fr. Schmidt),[1] and in the Mjösen district[2] these forms are met with above the zone of *Discinella holsti*. And a thinning out of the conglomerate at Borgholm does not seem to be very probable in view of the wide regional distribution usually characterizing the Swedish Cambrian conglomerates, even in the case of extremely slight thickness.

Consequently, provided that our knowledge of the vertical distribution of the Lower Cambrian fossils, used as index fossils, is satisfactory and that the specific references cited in the literature are true, we have to state only that the *Mickwitzia* boulder in question cannot at present be placed in the Ölandian sequence with any certainty. Maybe correlation with the conglomeratic layer at the top of the sandstone will be more probable than the other possibilities discussed above. (Compare the foot-note 2 on p. 13).

The Lower Cambrian sandstone series of Scania has of old been divided into two main divisions, a lower one, built up by generally light coloured and thick-bedded, hard sandstone — the Hardeberga sandstone proper — and an upper one, in which fairly dark, grey or green, glauconitic, usually thin-bedded, sandstone types predominate. This division seems to be applicable to all Lower Cambrian districts of Scania, also to the district of Torekov, where however the upper division is not accessible but indicated by boulders. The boundary between the two divisions is very sharply marked in the Simrishamn district by an abrupt change of rocks and a thin conglomerate with well-worn quartz pebbles, in which the Hardeberga sandstone terminates. Apart from tracks and trails *(Diplocraterion, Scolithus, Psammichnites, "Cordaites")* the Hardeberga sandstone has yielded actual fossils only at one locality, viz. the harbour of Simrishamn, where Moberg[3] has found poorly preserved *Hyolithus* forms, abundant in a shaly sandstone interstratified between banks of the hard sandstone.

The upper main division has been divided into a lower zone with *Schmidtiellus torelli* and an upper one with *Holmia kjerulfi*. The former species being very nearly related to the Esthonian form *Olenellus mickwitzi* Fr. Schmidt, which is associated with *Mickwitzia monilifera* (Linrs.), Moberg correlated — with some hesitation — the Scanian zone of *Smithiellus torelli* with the *Mickwitzia* sandstone of Västergötland and the zone of *Holmia kjerulfi* with the Lingulid sandstone of the said province. This correlation gains very much in probability through recent in-

[1] Fr. Schmidt, Über eine neuentdeckte untercambrische Fauna in Estland. — Mém. l'Acad. imp. Sci. St.-Pétersbourg, 7. Sér., T. 36, N:o 2. St.-Pétersbourg 1888.

[2] Th. Vogt, Forholdet mellem sparagmit-systemet og det marine underkambrium ved Mjösen. — Norsk Geol. Tidskr., Bd 7, H. 3.

[3] Historical-stratigraphical review of the Silurian of Sweden. — Sver. Geol. Unders., Ser. C, No. 229, p. 196.

vestigations by Schindewolf,[1] who after examination of a better preserved material of the Esthonian form has been able to state that it belongs to the genus *Holmia* MATTHEW and hardly seems to be specifically distinguished from *Schmidtiellus torelli*.[2]

Mickwitzia as well as *Discinella* have never been found in Scania, though they have been eagerly sought, especially in the Simrishamn district. Moberg mentions that he has hunted for *Discinella* particularly in the *Hyolithus* zone at Simrishamn mentioned above. However, in my opinion the *Discinella* zone, if developed in Scania, may appear in the upper main division of the Lower Cambrian, below the *Schmidtiellus torelli* zone. And as it has not been found even there, this need not imply that the zone is totally lacking, but may possibly be due to the fact that the strata in question do not crop out, owing to numerous faults traversing the sandstone.

The *Holmia kjerulfi* zone is known of old from two localities of the Simrishamn district, about 1 km. south of Brantevik and 600 m. north of Gislövshammar. The latter may, on this occasion, deserve of a more detailed account.

On the shore line, along a length of fully 125 m., is seen a bank of a coarse quartz sandstone, according to Grönwall petrographically resembling the Rispebjærg sandstone of Bornholm, and having the upper as well as the lower surface larded with nodules of phoshorite and pyrite. This bank has a fairly wide distribution in South-eastern Scania and seems always to be directly covered by a light coloured greenish grey greywacke shale with interstratified calcareous layers. As early as in 1877 G. v. Schmalensee collected from this bed the following fauna (kept in the Museum of the Geological Survey).[3]

Holmia (*kjerulfi* [LINNARSSON] ?)[4].
Ellipsocephalus nordenskiöldi LINNARSSON.
Strenuella primaeva rotundata KIÆR.

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[1] Eine neue Rekonstruktion von Holmia mickwitzi (Schm.) (Fam. Mesonacidae Walc.) aus dem Unterkambrium Estlands. — Zeitschr. Deutsch. Geol. Ges., Bd 79 (1927), pp. 112—120. — In 1897 already G. Holm emphasized the fact that the Esthonian form may be referred to genus *Holmia*. See Geolog. Fören. i Stockholm Förhandl., Vol. 19, pp. 169—171.

[2] The correlation of the *Holmia kjerulfi* zone with the Lingulid sandstone is less evident. It may also be noticed that *Mickwitzia monilifera* has a wider vertical distribution than usually seems to be supposed. Thus, one example met with at Oltorp was — according to Lidén — found associated with a *Lingulella* in the upper part of the Lingulid sandstone, and in Närke the species is — according to G. Holm — encountered only in the upper part of the Lower Cambrian, in a white sandstone petrographically identical with the Lingulid sandstone of Västergötland.

Between the Vestrogothian Lingulid sandstone and the superimposed strata we have a considerable hiatus. The *Paradoxides ölandicus* series is probably lacking, and moreover the break is marked by a thin conglomerate with pebbles of a brownish grey phosphoritic sandstone, in which the Lingulid sandstone terminates. This conglomerate has a very wide distribution; it has been found in Kinnekulle, Billingen, Falbygden (Djupadalen), and also in Halleberg (Överdalen) and Hunneberg (between Munkesten and Mossebo).

[3] Compare Sver. Geol. Unders., Ser. Aa, No. 109, p. 16. — It is somewhat doubtful whether v. Schmalensee collected this fauna at the locality north of Gislövshammar or at that south of Brantevik.

[4] The poor preservation does not allow of a safe specific reference.

Strenuella aff. *linnarssoni* KIÆR.
Hyolithellus micans (BILLINGS) (or a closely related form).[1]
Helcionella rugosa acuticosta WALCOTT.
Scenella sp.[2]

Some indistinct brachiopods are also present, which in general form and size recall *Obolella mobergi* WALCOTT or *O. rotundata* KIÆR.

In an impure, greenish grey limestone lying about 0.7 m. above the Rispebjærg sandstone and cropping out just at the shore line, where it is seen above sea level only in case of extremely low water, the present writer has found the following fauna.

Strenuella aff. *linnarssoni* KIÆR, very common but difficult to get out of the rock.[3]
Hyolithellus micans (BILLINGS)[4] (or a closely related form), common.
Lingulella sp., very rare.
Acrothele bellapunctata WALCOTT (?), one fragmentary valve.
Obolella (?) sp., a few indistinct casts.

The first mentioned fauna, at least most of it, was probably collected from the beds between the said limestone bed and the Rispebjærg sandstone.[5] The limestone band with *Strenuella* and *Hyolithellus* consequently seems to be somewhat younger than the *Holmia kjerulfi* zone proper, but as the Scanian *Strenuella* form is distinguished from *S. linnarssoni* — the index fossil of the topmost zone of the Lower Cambrian of Norway (see below) — the Scanian *Strenuella* zone cannot, at least for the present, be parallelized with the Norwegian zone of *Strenuella linnarssoni*. However it may be noticed that Störmer (l.c.) has found *Hyolithellus micans* associated with *S. linnarssoni* in Western Norway.[6]

The superimposed stratum of the *Strenuella* limestone is not found in solid rock, but most probably it is formed by a grey limestone abundant in fossil-fragments and in places rich in black phosphorite nodules, which at the locality south of Brantevik covers the greywacke shale, and which in numerous boulders is also met with at the locality under consideration. South of Brantevik the fragment limestone is covered by a thin bed of alum shale, which according to Moberg has yielded *Agnostus fissus* LUNDGREN, *Liostracus aculeatus* ANG. and *Conocoryphe tenuicincta* LINRS., indicating the lowest part of the Tessini series, and which is superimposed by the *Conocoryphe exsulans* limestone.

[1] One fragmentary specimen which was depicted and described by G. Holm under the name *Hyolithus* sp. No. 3. — Sveriges kambrisk-siluriska Hyolithidae och Conulariдae. Sver. Geol. Unders., Ser. C, No. 112, p. 108, pl. 1, figs. 14—15.

[2] The poor preservation does not allow of a safe specific reference.

[3] Professor Kiær of Oslo has had the kindness to examine a couple of specimens and states that this Scanian form is distinguished from *S. linnarssoni*.

[4] This form is probably identical with the Norwegian form recently described by L. Störmer (On a Lower Cambrian fauna at Ustaoset in Norway. — Fennia, Vol. 45, No. 1, Helsingfors 1925) and also with that occurring in the Protolenus and adjacent beds of Comley in England, described by E. S. Cobbold (The Cambrian horizons of Comley, and their Brachiopoda, Pteropoda, Gastropoda etc. — Quart. Journ. Geol. Soc., Vol. 76, pt. 4, 1921).

[5] According to K. A. Grönwall (Bornholms Paradoxideslag of deres Fauna, Danm. geol. Unders., II. Raekke, No. 13, p. 176) the greywacke shale at the locality south of Brantevik has a thickness of about 1 m.

[6] A zone with *Strenuella* and *Hyolithellus* has been met with at the top of the Lower Cambrian also at Hardeberga, according to an oral communication by Dr. Troedsson.

In the Mjösen district of Norway, the upper zones of the Lower Cambrian seem to be more fully developed than anywhere else in Scandinavia, and so far as at present known it is the only Scandinavian area where the Lower Cambrian appears to pass over into the Middle Cambrian continuously and without any traceable break. According to Kiær (l.c.) and Vogt (l.c.) the succession of strata is the following:

1. Zone with *Paradoxides ölandicus.*
   Transition bed with a fauna of Middle and Lower Cambrian forms (*Paradoxides*, *Torellella* etc.).
2. Zone with *Strenuella linnarssoni* (by Kiær regarded as a parallel of the *Protolenus*-fauna of England and the Atlantic province of North America).
3. Zone with *Holmia kjerulfi.*
4. Zone with *Volborthella tenuis* and *Platysolenites antiquissimus.*
5. Zone with *Discinella holsti.*
   Hiatus.
   Sparagmite-formation.

This scheme is incomplete, inasmuch as it does not directly show the horizon of the zone with *Mickwitzia-Holmia mickwitzi-Schmidtiellus torelli,* but for reasons quoted above it is by Vogt parallelized with the zone No. 4 of the above scheme.

A correlation of the Ölandian Lower Cambrian with that of Norway indicates that only zones No. 1 and No. 5 of the above scheme are certainly developed in Öland. But the probable occurrence of a *Hyolithellus,* a genus which appears to be restricted to zones Nos. 2 and 3, at the top of the sandstone makes a correlation of the uppermost part of the Ölandian sandstone bed with one of the said zones imaginable, though it requires however to be confirmed by further finds of fossils. If this correlation is correct, the break between the Lower and Middle Cambrian of Öland, indicated by the petrographical character of the topmost part of the sandstone and the abrupt change of rocks, cannot be very important and suggests an emergence corresponding mainly to the age of the Norwegian transition bed between the Lower and Middle Cambrian and, probably, the topmost zone of the former.

In a recently published report Dr. B. Asklund,[1] misled by the very summary account of the bore section at Borgholm cited in the explanation of the map sheet Mönsterås and Högby, has suggested that the red-coloured layers of the lowest part of the core under consideration may be correlated with the red Kalmarsund sandstone of the eastern coast of Småland, which he is inclined to look upon as being of pre-Cambrian age. However, the thin red-coloured layers of the core are of a type quite different from the red Kalmarsund sandstone. The types of rocks of the lowest part are

[1] Om Fennoskandias algonkiska geologi och formationsindelning. — Geolog. Fören. Förhandl., Bd 49 (1927).

not distinguished petrographically from those above the lowest *Discinella* level, and consequently the whole sandstone series of the core indicates one formation only. Thus, if the red Kalmarsund sandstone is developed at Borgholm, it is to be looked for at a deeper level than that reached by the boring.

As regards the probable age of the Kalmarsund sandstone, the following may be adduced. In the formation supposed by Asklund to be of pre-Cambrian age he includes the »kråksten», a greenish grey, micaceous and argillaceous sandstone of peculiar structure. Now, a sandstone (see fig. 2) which, so far as I can see, is not distinguished petrographically from the »kråksten» — for instance that occurring in solid rock about 6 km. W. of Kalmar and 2 km. S.E. of Dörby — appears in the core at several levels between 74 and 100 m. below the surface. As shown above the lowest part of the sandstone series of the core also no doubt belongs to the Cambrian, and, consequently, the »kråksten» W. of Kalmarsund may also be of Cambrian age. A small percentage of phosphoric acid in the latter speaks also in favour of its belonging to the Cambrian. Thus, a sample of »kråksten» from the above-mentioned locality S.E. of Dörby which was analysed by Dr. Bygdén yeilded 0.08 % P_2O_5.[1]

According to Asklund, the »kråksten» and the red *Scolithus* sandstone must belong to o n e formation, as the former is said to occur interstratified in the latter on Runnö. This being the case the red *Scolithus* sandstone too evidently must be included in the Cambrian, and not only the said bed but also the bottom layers of the sandstone series, as these are in part developed as *Scolithus* sandstone, according to the explanation of the map sheet Mönsterås and Högby.

Asklund lays particular stress upon the occurrence of rounded fragments of a hard red sandstone, resembling a sandstone of the bottom layers on Runnö, found in a conglomerate or rather a sedimentary breccia on Runnö Rödskär, the matrix of which is a loose sandstone and which is thereby distinguished from the very hard basal conglomerate on Runnö. The breccia is supposed by Asklund to be much younger than the latter and to be correlated with the Cambrian basal conglomerate. However, the conditions under which the breccia and the conglomerate were formed were evidently different, and it does not seem to be quite inconceivable that these deposits are contemporary. It may also be noticed that loose and hard rocks alternate in the bottom layers on Runnö, according to the explanation of the map sheet Mönsterås. And the occurrence of fragments of hard sandstone in a loose conglomeratic sedimentary breccia need not necessarily imply that the former is derived from layers essentially older than the breccia itself.[2] Be this as it may, provided that Dr. Ask-

[1] A grey *Scolithus* sandstone from Runnö has proved to contain traces of phosphoric acid.

[2] In the Cambrian basal conglomerate of Kinnekulle appear slightly rounded fragments of a quartzitic sandstone which originated in layers in all probability formed in connection with the Cambrian transgression. — Compare A. G. Högbom und N. G. Ahlström, Über die subkambrische Landfläche am Fusse vom Kinnekulle. Bull. of the Geol. Instit. of Upsala, Vol. 19, p. 77.

lund's above-mentioned claim that there is no break between the »kråksten» and the *Scolithus* sandstone is correct, the sandstone series of the Kalmarsund district constitutes one formation only.

In spite of the difference in petrographical character between the lower part of the Kalmarsund sandstone and the Hardeberga sandstone, the former does not seem to be older than the latter, the Cambrian age of which is established *inter alia* by the occurrence of *Hyolithus*, and probably they may be approximately contemporary. According to Holst, the lowest *Diplocraterion*-bearing layer of the Kalmarsund sandstone occurs at a low horizon, possibly below the »kråksten». This track-form is also known from the Hardeberga sandstone of the Simrishamn district, where it probably occurs at different horizons, and at Torekov *Diplocraterion* appears a few meters above the basal conglomerate. Consequently, our present knowledge of the sandstone beds under consideration seems to justify the assumption that the Lower Cambrian transgression may have inundated Scania and the Kalmarsund district approximately simultaneously and, possibly interrupted by an uplift of short duration, it subsequently reached the middle part of Sweden. At any rate the earlier phase of the transgression cannot be traced in Västergötland, as already stated by Moberg.

Finally a few words concerning the Middle Cambrian under Gotland, as revealed by the deep boring at Visby described by Dr. Hedström in a paper quoted above. On the Archean there rests directly a Lower Cambrian bed of sandstone alternating with shales, 104.4 m. thick (278.6—383.0 m. beneath the mouth of the boring). On this follows a bed of bluish-grey shale, 36.6 m. in thickness (278.6—242.0 m.), which is directly covered by a glauconitic limestone of Ordovician age. The shale is stated by Hedström to belong to »the zones with *Paradoxides tessini* and *P. ölandicus*». However, judging from the fossils described and depicted by him from the topmost part of the shale, the Tessini series is, so far as I can see, totally lacking in the Visby section, — an opinion in which Dr. Hedström now agrees with me — and, moreover, the uppermost part of the Ölandicus series, represented in the sequence at Borgholm, does not seem to be developed at Visby.

With *Ellipsocephalus polytomus* Hedström identifies two cranidia from 242.7 m. and 242.8 m. resp. and though they are very fragmentary there can be no doubt as to their specific reference. To the same species also two unnamed free cheeks from 242.3 m., reproduced in figs. 8 and 9 of plate 2, can now be referred. Young individuals of this species have the free cheek provided with a small spine, which, as the animal grows, decreases in length and finally becomes obliterated without leaving any trace behind, as shown by a series of specimens at different stages of development from Öland and Jämtland.

Even the small cranidium from 243 m., described by Hedström under

the name of *Anomocare balticum*, in all probability belongs to *E. polytomus*, an immature form of which it may be. I have arrived at this result by studying the abundant material of the species from the Ölandicus shale at Borgholm, where several specimens — one of them complete — of quite the same form has been found. Be this as it may, the said immature form is as yet met with only in association with *E. polytomus*.

Consequently, all fragments of *E. polytomus* known from the Visby core have been found in a 1 m. thick layer forming the top of the shale. But the species in question is an index fossil of the upper part of the Ölandicus series and it does not seem to ascend into the topmost part of the series, at least not in Jämtland. It is true that it is met with not only in pebbles but even in the matrix of the *Acrothele granulata* conglomerate, forming the base of the Tessini series at Borgholm, but in the matrix it may reasonably occur secondarily. From what is cited in the geological records, and judging from my own field researches, this species is replaced in the Tessini series by a related form, *E. lejostracus* (ANG.),[1] readily distinguished from *E. polytomus* by its having a marked occipital furrow.

Hedström describes some more fossils, trilobites and brachiopods, from the upper part of the shale, a few of which, owing to poor preservation, seem to be difficult to identify and are consequently of less stratigraphical interest. At all events none of them indicate the topmost part of the shale to be younger than the Ölandicus series.

As mentioned above, the thickness of the Ölandicus series is about 40 m. at Borgholm and 36.6 m. at Visby. The zone yielding *Ellipsocephalus* occurs at Borgholm about 27—29.5 m. and at Visby about 36 m. above the base of the shale. It is evidently a matter of mere chance whether fossils are met with in a narrow boring core,[2] but nevertheless numerous fragments which can certainly be referred to *Ellipsocephalus* — at Borgholm about 40, at Visby at least 4 — have been found in the cores, all restricted to a thin zone. This fact seems to justify a supposition that the zone in question in both of the cores represents one and the same stratigraphical horizon. This view admitted, we conclude that the uppermost fourth of the Ölandicus series at Borgholm has no direct equivalence at Visby, indicating an earlier uplift or a more deeply advanced erosion of the sequence of the Visby district than on Öland. The hiatus between the shale and the covering glauconitic limestone of the sequence at Visby consequently corresponds to a very long period, lasting from a

[1] This species was at first described by Angelin in 1851 (Palæontologia Suecica) under the name of *Calymene lejostraca*, which was in 1854 (Palæontologia Scandinavica) amended by the author himself into *Liostracus muticus*. It was more closely defined and limited from kindred forms by Linnarsson in 1877 and later in the literature has been quoted under the name of *Ellipsocephalus muticus*. A good figure of the cranidium and a revised description were given by Wiman in 1906, (Bull. Geol. Instit. Upsala, vol. 7, p. 289). However, the first specific name, as being the older one has priority, even if it has been rejected by the author himself. — *E. granulatus* LINRS., also belonging to the *P. tessini* series, does not seem to be specifically distinguished from this species.

[2] The core of the boring at Visby has a diameter of but 21 mm.

late phase of the Ölandicus age until an undetermined phase of the (younger?) Ordovician period.

As has been proved to be the case with the Lower Cambrian sandstone (at least its upper part including the *Discinella* zone) also the part of the Ölandicus shale which is developed at Visby decreases in thickness from Gotland to Öland.

Geological Survey of Sweden, December 1928.

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