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ÅRSBOK 32 (1938) N:o 5.

DEEP BORING THROUGH THE CAMBRO-SILURIAN AT FILE HAIDAR, GOTLAND

BY

PER THORSLUND AND A. H. WESTERGÅRD

Preliminary Report

WITH FOUR PLATES

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KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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CONTENTS.

Introduction.

Within the Cambro-Silurian sediments of the Baltic basin the occurrence of hydro-carbons has been known for a long time past. During the last years chief attention has been paid to the occurrence of gas in the Lower Cambrian sandstone, and some prospecting work carried out to ascertain whether gas accumulations of economic interest are to be found there. Such investigations, comprising geologic and geophysical surveys as well as drilling, have so far been executed within the Swedish Cambro-Silurian areas of Öland and Östergötland. For both these areas the Lower Cambrian sandstone generally has proved to be gas-bearing. However, in neither case have commercial quantities been found. As regards Öland the explanation might be that this island lies near the border of the Baltic Cambro-Silurian area, while the Cambro-Silurian sediments of Östergötland constitute a relatively small part still remaining in a basin formed by the pre-Cambrian underground and partly surrounded by faults. In both cases the thickness of the gas-bearing beds and that of the impermeable layers is rather small. On Öland the whole sequence of Cambro-Silurian sedimentaries thin out rapidly to the west (Kalmarsund, the Småland Coast). The conditions in this respect ought to be much more favourable on Gotland which is situated more in the centre of the Baltic basin and where the sequence of the Cambro-Silurian beds might be assumed to be two to four times as thick as that of Öland. Sedimentary beds on Gotland, on the whole gently dipping S.E., are deformed by flat folds, the existence of which is indicated by the dipping observations found on the geological maps published by the Sveriges Geologiska Undersökning (Geological Survey of Sweden). In some places there seem to exist dome-like structures, which might be favourable for gas accumulations. Such a structure was supposed to exist in the limestone area of »File Haidar» between Tindstädeträsk and Slite on the north-eastern coast of Gotland.

Skånska Cement A.-B. (The Scanian Cement Co. Ltd.) decided to have a thorough investigation of this structure carried out in order to ascertain whether or not economic gas quantities might be found there. The investigation comprised geologic reconnaisances, geophysical measurements, and drilling.

The rock exposed on File Haidar consists of bedded Silurian limestone and reef limestone of the so-called »Slite Beds». The additional geologic investigations that were carried out as the first point of the programme confirmed the existence of the supposed dome structure. On the sketch, Fig. 1, the limestone

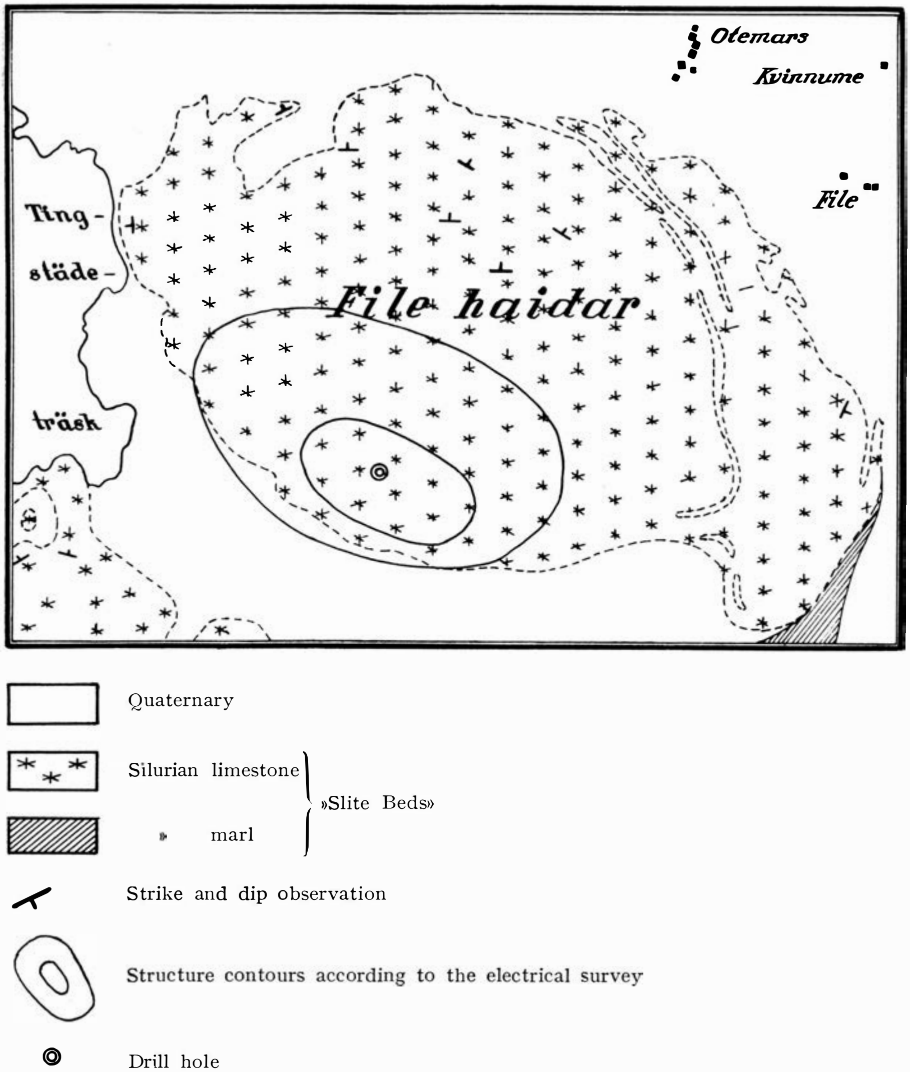


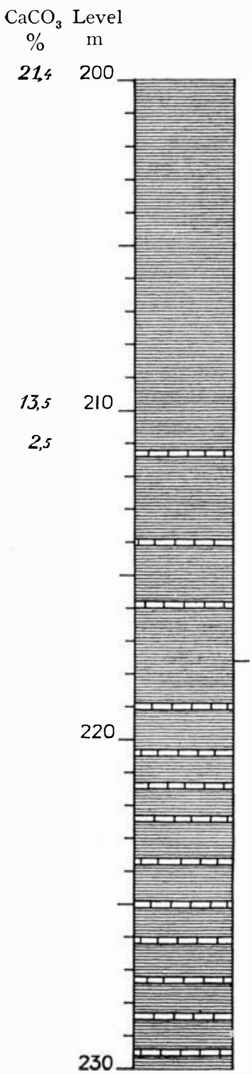
Fig. 1. Map of the File Haidar Structure. Scale 1 : 50,000.

area is shown as well as the dipping observations of the geologic map-sheet Slite supplemented with a few new ones. The geologic observations were, however, not sufficient enough to get a detailed picture of the structure and the location of the top region. Only geophysical investigations could give reliable information in this respect. Furthermore, such investigations should also ascertain whether the surface structure was coincident with that of the underground. An electrical structure investigation was, therefore, carried out by means of the method developed by Karl Sundberg, which method was considered the most suitable in this case. For the principle and procedure of this method please refer to the literature (Sundberg, 1931; Sundberg & Hedström, 1933). By means of electrical investigations contour lines were obtained for the surface of an electric conductor which drilling results disclosed to be identical with the Cambrian sandstone which is salt-water-bearing. It was found that the dome structure was present also in the Cambrian beds, and its contours have been mapped. A drill-hole was placed in the centre of the top region of the dome which is indicated on the sketch (Fig. 1). The place is situated 8 km W. of Slite and 25 km N.E. of Visby. The boring reached a depth of 507.5 m below the surface, which is situated 62.4 m above sea-level, pierces the Silurian, Ordovician, and Cambrian systems, and goes 7.5 m into the Archaean. The upper deposits, to a depth of 200 m, were drilled by percussion drill, and from this level to the bottom diamond drilling was employed. The diameter of the core is 85 mm between the 200 and 304.65 m levels, 70 mm between 304.65 and 412.67 m, and 60 mm below the latter level. The drilling was carried out by the Svenska Diamantbergborrnings Aktiebolaget (Swedish Diamond Drilling Co., Stockholm).

The core was courteously presented by the Skånska Cement A.-B. to the Geological Survey of Sweden where it was subjected to a palaeontological-stratigraphical examination, the Cambrian by A. H. Westergård, and the Ordovician and Silurian by Per Thorslund.

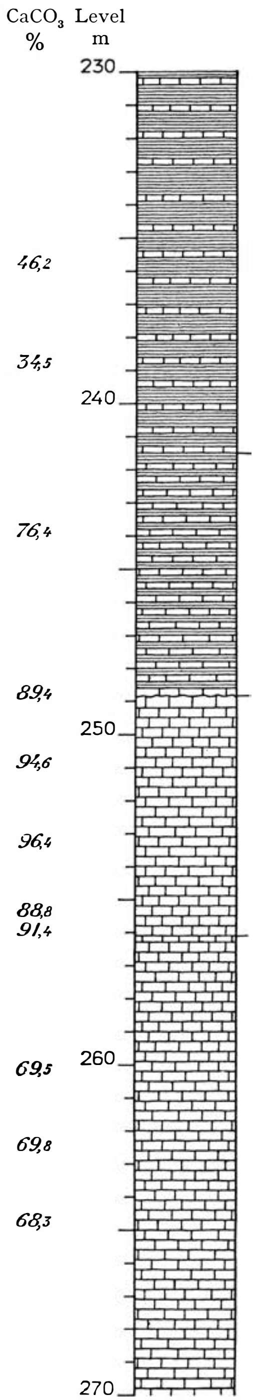
The above-mentioned data as well as the information at the end of this paper concerning the practical results have been placed at our disposal by the Skånska Cement A.-B. with the permission to publish them. For this kindness we express the gratitude of the Geological Survey.

Diagram showing Lithology of the Core.



200.0—217.6 m. Brownish red mudstone, partly slightly marly, containing a few thin intercalations of limestone and, occasionally, thin layers black-spotted by mica.

217.6—241.5 m. Mainly gray-green, partly reddish brown mudstone containing lenses and nodules of limestone, the contents of which become reduced upwards. Thin sandy, micaceous layers



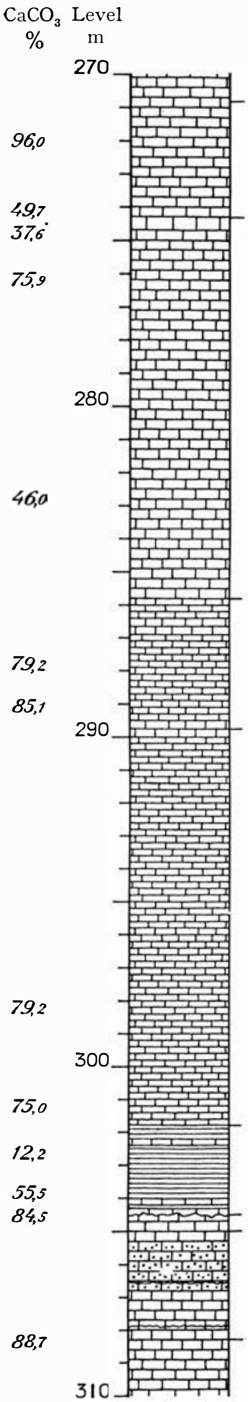
intercalated in the middle portion. — Passage beds. Sliding surfaces fairly common. Graptolites, such as *Monograptus regularis, M.* cf. *convolutus, M.* cf. *lobiferus* etc., were found.

241.5—248.8 m. Gray limestone, mostly argillaceous, in dark-gray and greenish gray calcareous mudstone. The limestone occurs as layers, lenses, and nodules, occasionally indistinctly defined against the mudstone (cf. fig. 5). Sliding surfaces, formed during the induration, common in the mudstone parts.

248.8 m. Silurian-Ordovician boundary.

248.8—256.1 m. Light-gray, in some parts flamy red limestone, partly finely crystalline and partly nearly compact, with shaly, irregular lines of stratification; at the top cut off by a corrosion surface, forming the Ordovician-Silurian boundary. — Algal limestone.

256.1—270.8 m. Dark-gray, slightly bituminous limestone, finely crystalline, with irregular intercalations of darkish marly shales. The limestone is made up of irregularly limited layers, lenses and, occasionally, nodules (cf. fig. 4). Above the 256.6 m level the limestone becomes light-gray and the shaly matter greenish gray. *Orthograptus gracilis* was obtained at the 265.2 m level.



270.8—274.3 m. Light-gray and reddish limestone, partly finely crystalline and partly nearly compact. Algal limestone.

274.3—285.8 m. Beds of the same general type as those of the underlying part, but the intercalated shaly layers somewhat thicker and more separated from each other (cf. fig. 3). Algal limestone. *Dicellograptus* sp., *Mesogr.* sp., and *Dictyonema* sp. were found at the 285.2 m level.

285.8—289.75 m. Gray and dark-gray limestone, finely crystalline or nearly compact, irregularly traversed by thin layers of darker marly shales. Calcareous shells in most cases partly silicified. Algal limestone.

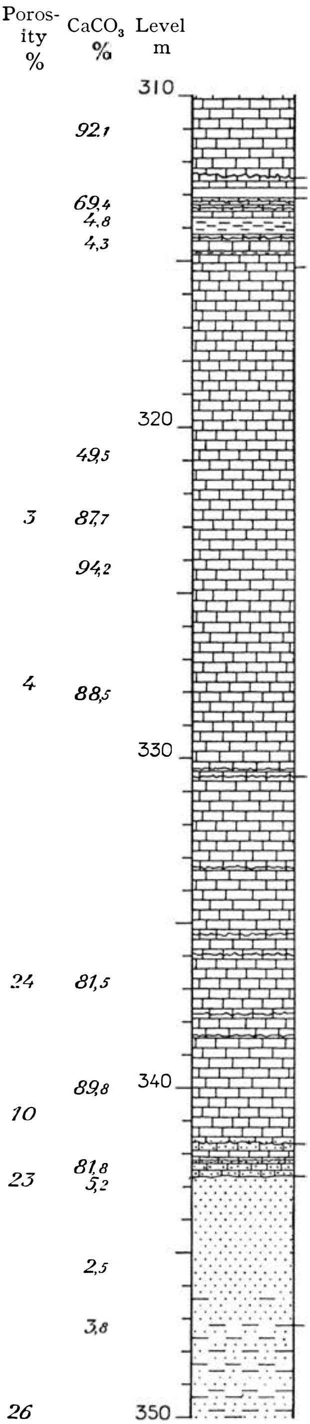
289.75—301.8 m. Beds of light-gray limestone, crystalline — partly coarsely crystalline, with thin intercalations of dark-gray or dark-green (occasionally violet) slightly marly shales. Pieces of pelmatozoic stems abundant.

301.8—304.5 m. Greenish gray, partly red-brown, slightly marly mudstone with lenses and thin beds of gray and — in the lower part — reddish argillaceous limestone. Lithologically sharply marked off from the substratum.

304.5—305.0 m. Beige, nearly compact limestone with very thin irregular intercalations of dark shales.

305.0—308.3 m. Gray, somewhat marly, partly glauconitic limestone with intercalations of grayish green shales. Corrosion surfaces.

308.3—312.4 m. Gray and fawn-coloured, nearly compact limestone, in some parts nodular; with thin irregular intercalations of dark



marly shales. Separated from the substratum by a corrosion surface.

312.4—312.8 m. Light-gray, sandy limestone. — *Macrourus* lmst.

312.8—313.2 m. Core probably missing.

313.2—315.3 m. Beds of limestone of different kinds, light-gray to dark-gray, finely crystalline to nearly compact, partly argillaceous; with intercalations of light- and dark-gray, partly arenaceous shales. 313.75—314.2 m unfossiliferous, light-gray, talky, partly sandy shale, black-spotted by mica. Calcareous shells partly silicified. Several corrosion surfaces in the limestone beds. — *Chasmops* beds.

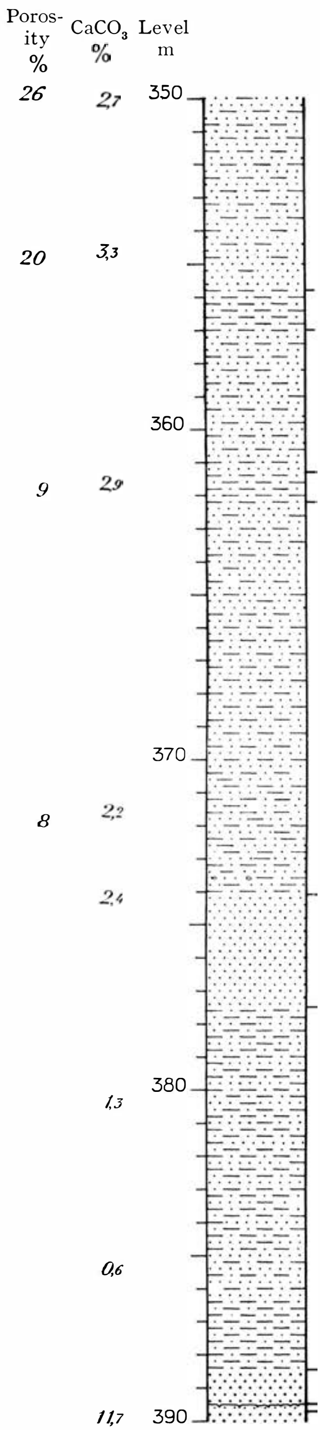
315.3—330.5 m. Light-gray limestone with thin intercalations of darker argillaceous limestone or shales. Corrosion surfaces at the base. — Lower *Chasmops* lmst.

330.5—341.7 m. Gray limestone, partly brownish owing to Fe_2O_3-oolites in two parts, 334.2—334.7 m and 337.9—341.7 m, respectively. Small grains of glauconite sparsely in the basal part. Several corrosion surfaces. — 338.5—341.7 m very likely *Platyurus* lmst; 330.5—338.5 m *Chiron* lmst.

341.7—342.7 m. Light-gray, partly glauconitic limestone with several corrosion surfaces. — *Asaphus* lmst.

342.7 m. Ordovician-Cambrian boundary.

342.7—347.2 m. Grayish white, fine-grained, partly micaceous sandstone, very hard and brown at the very top, decreases in hardness successively downwards and is fairly loose below 344 m. Thin seams of gray shale very rare.



347.2—355.8 m. Rapidly alternating grayish white, or gray and argillaceous, sometimes slightly glauconitic, fine-grained sandstone and gray, soft or arenaceous, shale. Sandstone preponderant.

355.8—357.0 m. Gray arenaceous shale.

357.0—361.3 m. Grayish white fine-grained sandstone preponderant, with thin seams of gray soft or arenaceous shale.

361.3—362.2 m. Gray arenaceous shale.

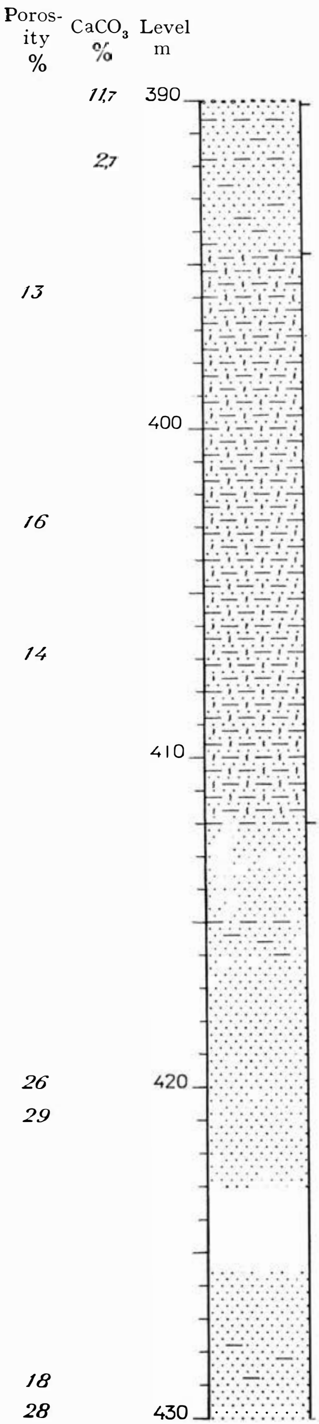
362.2—374.1 m. Rapidly alternating gray argillaceous sandstone, grayish white sandstone, and gray shale. In the lowest portion the sandstone is glauconitic, and at 373.6 m it contains grayish brown phosphorite nodules.

374.1—377.5 m. Light greenish gray, glauconitic, fine-grained, fairly loose sandstone, with argillaceous joints. Dark-brown bituminous spots in the uppermost portion.

377.5—388.45 m. Alternating greenish gray more or less arenaceous shale and light greenish gray glauconitic fine-grained sandstone. *Volborthella* zone.

388.45—389.5 m. Dark greenish gray, slightly glauconitic and phosphoritic, fairly coarse and loose sandstone (average size of the grains 0.5—0.8 mm).

389.5—389.7 m. Grayish white glauconitic fine-grained sandstone (average size of the grains 0.1—0.4 mm). Upper boundary very uneven, lower boundary plain and horizontal.

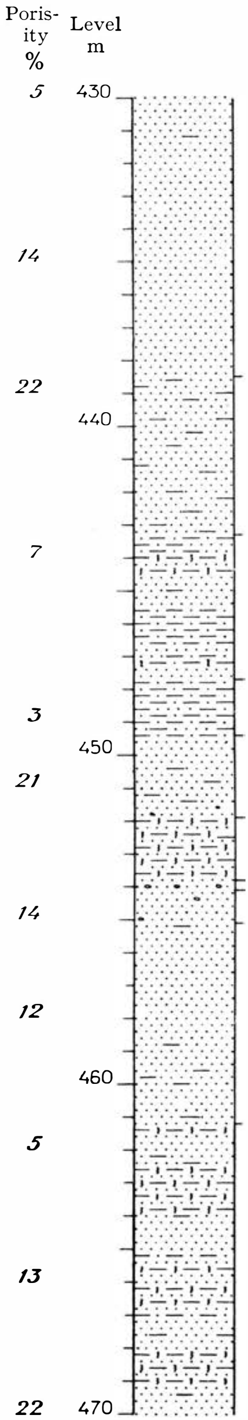


389.7—390.15 m. Dark greenish gray, spotted, slightly glauconitic, fairly coarse and loose sandstone (average size of the grains 0.5—0.8 mm), downwards merging into a conglomerate with pebbles of black or grayish brown phosphoritic sandstone and nodules of phosphorite.

390.15—394.7 m. Grayish white fine-grained, fairly loose sandstone, with scattered seams or laminae of greenish gray shale.

394.7—412.0 m. A spotted rock consisting of greenish gray argillaceous sandstone, white sandstone, and dark greenish gray shale in intimate and irregular mixture and usually rich in burrows and trails (like the »kråksten» of the Kalmarsund region).

412.0—438.5 m. White fine-grained usually loose sandstone, with scattered greenish gray joints and very rare seams or laminae of greenish gray micaceous shale. *Diplocraterion parallelum* fairly common between 413 and 430 m.



438.5—443.3 m. White fine-grained loose sandstone, with numerous thin seams and small lenses of greenish gray argillaceous sandstone and greenish gray shale. *Diplocraterion* and *Scolithus* (a form with sparse 2 mm thick tubes) in alternating layers.

443.3—447.7 m. Variegated and spotted series of rocks consisting of alternating thin layers of sandstone, arenaceous or soft shale, and »kråksten» (see above). The sandstone is white or grayish white, the shales partly dark reddish brown with a violet tinge and partly greenish gray. Mud-cracks common.

447.7—449.4 m. Dark greenish gray soft or arenaceous shale, with thin seams of white sandstone. *Mickwitzia* at 448.6.

449.4—451.9 m. White, relatively coarse, loose sandstone (average size of the grains 0.4—0.6 mm), with sparse thin seams of dark greenish gray shale, in the lower portion slightly glauconitic and containing scattered dark-brown nodules of phosphorite. *Mickwitzia* at 451.5.

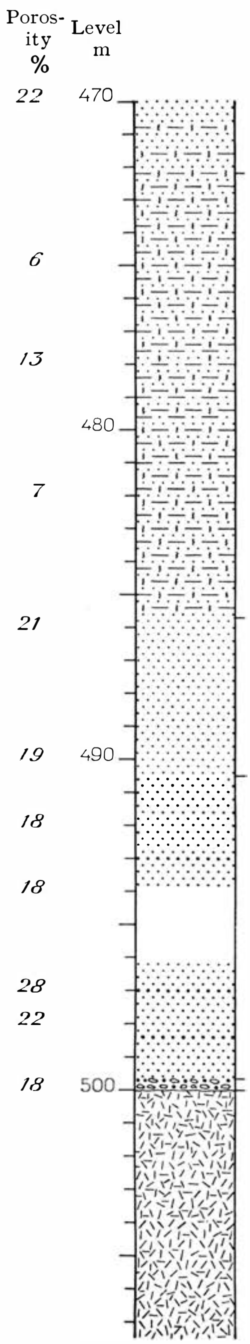
451.9—453.8 m. Spotted greenish gray argillaceous sandstone (»kråksten»), with seams of dark greenish gray shale; the sandstone is slightly glauconitic and contains small and rare dark-brown nodules of phosphorite.

453.8—454.1 m. Grayish white, fine-grained or fairly coarse, slightly glauconitic sandstone, with dark greenish gray shale and a very thin conglomeratic layer, the latter with numerous dark phosphorite nodules and scattered quartz pebbles up to 7 mm in size. *Discinella holsti* fairly common.

454.1—455.1 m. White, or gray-spotted and argillaceous, fine-grained, in part slightly glauconitic sandstone, with very rare phosphorite nodules.

455.1—461.2 m. White, fine-grained, fairly loose sandstone, with scattered thin seams of greenish gray argillaceous sandstone and dark greenish gray shale. *Scolithus* occurs in the whole bed (a form with closely set 2 mm thick tubes).

461.2—472.2 m. Alternating layers of spotted greenish gray argillaceous sandstone (»kråksten»), white, fine-grained, fairly hard sandstone, and thin seams of greenish gray shale. Some layers are, wholly, or in spots, reddish-brown. *Scolithus* (2 mm thick, usually thinly set tubes) in some layers.



472.2—485.7 m. Spotted greenish gray argillaceous sandstone (»kråksten») quite predominant, with scattered seams of dark-gray arenaceous shale and white sandstone.

485.7—490.5 m. White (rarely light-gray and slightly argillaceous) somewhat silty, fairly loose sandstone uneven in grain (fine-grained, with scattered coarser quartz grains up to a size of 1 mm.) *Scolithus* (closely set 2 mm thick tubes) goes through the whole bed.

490.5—499.65 m. Yellowish white, porous and very loose, fairly coarse sandstone (average size of the grains 0.5—1 mm), with a few interstratified very thin conglomeratic layers. *Scolithus* (closely set about 4 mm thick tubes) in the upper portion.

499.65—500.0 m. Conglomerate, very loosely cemented, with the matrix of yellowish white coarse sandstone, crowded with usually well worn quartz pebbles attaining a size of 15 mm.

500.0 m. Cambrian-Archaean boundary.

500.0—507.5 m. Gray veined gneiss, with red pegmatite. The rock is rather strongly weathered (kaolinized) to 503—504 m.

Cambrian.

The Cambrian deposits of the boring profile belong to the Lower Cambrian and the lowest stage of the Middle Cambrian, *i. e.* the Paradoxides oelandicus beds. The lower as well as the upper boundary are very sharp and lie at 500.0 and 342.7 m respectively below the surface; accordingly, the total thickness is 157.3 m. The boundary between the Lower Cambrian and the Œlandicus beds is less conspicuous, but, for reasons adduced below, it may be assigned to 374.1 m. Thus, the Lower Cambrian is 125.9 and the Œlandicus beds 31.4 m thick.

The bedding plane is, broadly speaking, horizontal even though it dips slightly at some levels (maximum 13°). At 365.6 m the strata are strongly folded indicating subaquatic slides.

The basal conglomerate, 35 cm thick, is very loosely cemented and crowded with small pebbles which do not exceed 15 mm in size and, as a rule, are well worn. The bulk of them are formed of light-gray quartz, evidently originating from pegmatite dikes piercing the subjacent gneiss; to a minor extent the pebbles consist of light quartzites. It is remarkable that feldspar is absent. The pebbles and grains are, however, often dotted with an extremely thin coating of a white matter like kaolin which may be decomposed feldspar.

The 9 m thick bed (499.65—490.5 m) immediately above the basal conglomerate consists of a fairly coarse sandstone (average size of the grains 0.5—1 mm) in which are interstratified a few thin layers of still coarser, almost conglomeratic, sandstone. The rock is so loosely cemented that it can often be crumbled with the fingers. As it is practically free from silt it was deposited in fairly agitated water. The bed next in order (490.5—485.7 m), a white sandstone uneven in grain, is, on the other hand, rather rich in silt and was deposited in more tranquil water. This was evidently also the case as regards the overlying »kråksten» and other beds rich in argillaceous matter.

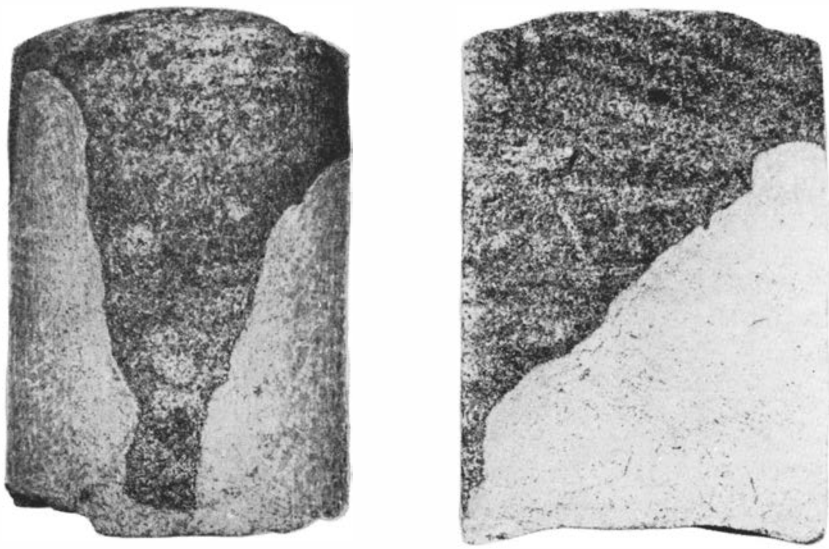
»Kråksten» is a peculiar greenish gray spotted rock, made up of rapidly alternating, very thin layers or small lenses of argillaceous or pure sandstone and shale in which the originally pronounced stratification has been veiled or destroyed by burrowing animals (cf. Pl. III).

The beds between 472.2—461.2 and between 447.7—443.3 m are heterogenous, spotted, and variegated — dark reddish brown, greenish gray, and white. Mud-cracks are common, and the sandstone layers are often rich in pieces of shale indicating that the bottom was intermittently laid dry when these beds were deposited. The reddish brown, often spotted, layers may have got their colour during the dry phases when processes of oxidation took place.[1]

[1] A sample of shale from 446.9 m, partly greenish gray and partly reddish brown, was analysed by Dr. A. Bygdén with the following result:

	Greenish gray shale	Reddish brown shale
Fe_2O_3	3.36 %	6.63 %
FeO	2.84 »	3.59 »
MnO	0.04 »	0.04 »

Around the 390 m level repeated emergences and submergences are indicated. At 390.15 m there is a lithologically sharply marked boundary, a white fine-grained sandstone being immediately covered by a dark conglomerate crowded with pebbles of phosphoritic sandstone, the largest 6 cm in diameter, and nodules of phosphorite, which upwards merges into a dark-green, fairly coarse sandstone (average size of the grains 0.5—0.8 mm). At 389.7 m this rock is cut



a *b*

Fig. 2. The core portion between 389.5 and 389.6 m displaying a very uneven surface of a grayish white, fine-grained sandstone covered by a dark greenish gray coarse sandstone. — a, the outside of the core. — b, the core cleft. The surface seen in b is perpendicular to the plane touching the middle line of a. — $^2/_3$ of the nat. size.

by a horizontal plain surface and covered by a white fine-grained sandstone, the upper limit of which is, on the contrary, formed by an uneven, eroded surface, with up to 8 cm deep steep grooves (Fig. 2). Then follows again a dark-green, somewhat glauconitic and phosphoritic, fairly coarse sandstone, like that beneath the 389.7 m level, which at 388.45 m merges into a greenish gray shale.

Burrows and trails excluded, the Lower Cambrian is extremely poor in fossils, which, when they do occur, usually are in an imperfect state of preservation, and consequently a division of the sequence into palaeontological zones is possible to a certain extent only. An 11 m thick zone with *Volborthella tenuis* F. SCHMIDT appears a few metres below the top (377.5—388.45 m). *Mickwitzia monilifera* (LINNARSSON), the index fossil of the lower zone of the Lower Cambrian of Västergötland and occurring at a relatively high level of the Lower Cambrian in Esthonia, is represented by but three specimens from the vicinity of the 450 m level. *Discinella holsti* MOBERG — according to our present knowledge the oldest real fossil of the Scandinavian Lower Cambrian — is confined to, but fairly common in a 30 cm thick layer at 454 m. In addition to these, only few fossils have been found in the core: *Strenuella obscura* sp. n., *Torellella laevigata* (LINNARSSON), Obolidae, spicules of spongiae, and a doubtful *Indiana* (see p. 22).

Burrows and trails of different kinds, on the other hand, are common in nearly the whole sequence. *Scolithus linearis* HALDEMAN appears some few metres above the basal conglomerate — the bed between 498 and 486 m is developed as a true Scolithus sandstone crowded with these tubes — and it occurs at different levels up to 427 m at least. A form with 2 mm thick tubes — usually closely set but sometimes sparse — is predominant; in the lowest bed the tubes have about twice that thickness, however. In the white sandstone the *Scolithus* tubes are easily overlooked but in argillaceous, gray sandstone the tubes differ in colour from the matrix and are thus conspicuous.

Diplocraterion parallelum TORELL (Pl. II, figs. 3—5) occurs at various levels; the typical form has been observed between 463 and 413 m at least. It is common in the white sandstone between 430 and 413 m and it probably occurs in the »kråksten», too. The form occurring in the former rock is rather uniform in size, the length of the pocket in a horizontal direction being 45—60 mm and the tubes 6—8 mm thick.

In the »kråksten», burrows and winding trails of different types are, as a rule, very common. There often occurs a vertical U-shaped burrow with a continuous pocket (»Spreite») between the tubes (Pl. II, figs. 6 a, b). The average diameter of the tubes is 5—7 mm, and the pocket is 20—30 mm in length; the tubes as well as the pocket are usually filled with non-argillaceous white sandstone. Obviously this burrow is a *Diplocraterion* but it differs from the typical *D. parallelum*, having crooked instead of straight tubes, and consequently the pocket is irregularly curved instead of being plain. Nevertheless the former was possibly made by the same species as built the latter, and, if this be so, the differences in shape are only due to the differences in matrix, the typical *D. parallelum* having been built in pure sand and the form with crooked tubes in a sediment of alternating thin layers of sand and clay. — Another structure forms single, irregularly curved, vertical tubes, 4—6 mm in diameter and usually filled with white sandstone; it resembles the single stipe of the above-mentioned *Diplocraterion*.

Winding trails are common at the argillaceous joints throughout the whole sequence.

The boundary between the Lower Cambrian and the Œlandicus beds is not sharply marked in the core. At 374.1 m a light greenish gray glauconitic fine-grained sandstone, resembling the sandstone seams of the Volborthella zone, is overlain by a rock of alternating thin layers of gray shale and grayish white sandstone which is the predominant rock of the Œlandicus beds, and at 373.6 m there appears a very thin layer with pebbles of dark-brown phosphoritic sandstone and nodules of phosphorite. In all probability the boundary coincides with one of these two levels. In the layer between them there have been found fragments of *Acrotreta*, however, which is not infrequent in the overlying strata but has not been observed below 374.1 m. Thus the latter level may be regarded as the boundary between the Lower and Middle Cambrian.

The fauna of the Middle Cambrian is remarkably poor, and the specimens are in an imperfect state of preservation. Only the occurrence of *Ellipsocephalus polytomus* LINNARSSON — the most common index fossil of the Œlandicus beds in other Swedish regions — has made possible the identification of this portion of the core with the unit mentioned. At least four cranidia of this species occur between 367.45 and 353.6 m. Otherwise there have only been found a few fragments of *Paradoxides* sp., *Hyolithes oelandicus* HOLM (?), and some specimens of *Lingulella* and *Acrotreta*,which, however, are of minor stratigraphic value (cf. p. 24). It may be noted that no specimen of *Acrothele granulata* LINNARSSON has been discovered, one of the most common fossils in the Œlandicus beds of other regions in Sweden.

Winding trails are often seen at the joints in this unit as well as in the Lower Cambrian. Burrows occur more sparsely. Scattered, 3 mm thick, very short, vertical tubes resembling *Scolithus* have been observed at 358.9 m.

Lithologically the Œlandicus beds of the core differ from the unit in Öland and other Scandinavian regions, sandstone predominating in the former but shale in the latter. Moreover, calcareous layers are very rare in the core, whereas lenses and discontinuous layers of arenaceous and argillaceous limestone are often found in the Œlandicus shale of Öland. The above-mentioned scantiness of the fauna may to some extent depend on the sandy facies prevailing in the core, but it should be kept in mind that the Œlandicus beds of the core probably correspond only to the lower portion of the unit in Öland, also comparatively poor in fossils.

It may be emphasized that there are no reasons for the presumption that the uppermost portion of the sandstone in the core belong to the *Paradoxides tessini* beds or to some still younger unit. The uniform character of the sandstone and the appearance of some fragments of *Ellipsocephalus*, probably *E. polytomus*, 2 m below the Ordovician limestone, as well as the conditions in the Middle Cambrian of the boring at Visby mentioned below, make valid objections to such a presumption. The Œlandicus beds end in a 4.5 m thick layer of a fine-grained sandstone nearly free from argillaceous matter, indicating an emergence which laid the area dry possibly even before the Œlandicus phase had come to an end. The uppermost portion of the sandstone is very hard and to some extent quartzitic, and at the boundary against the Ordovician it is dark-brown in colour. Obviously this slight metamorphosis took place during the late Cambrian or early Ordovician periods when the area was above sea level.

The Œlandicus beds are immediately overlain by the Asaphus limestone, but it does not seem probable that the area was continuously above sea level during the whole of this interval, for in such a case one would expect the not very resistible Œlandicus beds to be lacking. There are, however, no traces of a conglomerate at the boundary, from which we might draw some conclusion as to the supposed deposits that may to some extent have filled the gap and may have been destroyed during the period of land preceding the submergence in the Asaphus phase.

Finally it may be mentioned that pyrite in small quantities is fairly often found throughout the Cambrian sequence. At 349.5 m a druse of marcasite was observed, and galena forming very small impregnations sometimes occurs in the Lower Cambrian as well as in the Œlandicus beds.

Comparisons with the Cambrian of Surrounding Regions.

No thorough comparison can be made between the core under consideration and the one from Visby described by Hedström in 1923 since the latter core is incomplete: because of the small diameter, 21 mm, and the loosely cemented rocks predominant in the Cambrian, the borer has crumbled many layers, of which no core but only sand samples were obtained. The following facts may be advanced, however.

In the Visby section as in the section at File Haidar the Cambrian System is represented only by the Lower Cambrian and the Paradoxides œlandicus beds. At Visby the boundary between the Archaean and the Cambrian lies 382.3 m and the boundary between the Cambrian and the Ordovician 241.4 m below the surface, which approximately coincides with the sea level; both are very sharp. Also the boundary between the Lower Cambrian and the Œlandicus beds is lithologically sharply marked and lies at 276.5 m.[1]

The lowest portion of the Lower Cambrian at Visby, 382.3—375 m, consists of a light, faintly yellowish, fairly coarse sandstone with interstratified very thin layers of coarser or, sometimes, even conglomeratic sandstone. No basal conglomerate is to be seen (possibly it was crumbled by the borer; from the beds in question, more than 7 m thick, only small pieces of core with a total length of 0.8 m were obtained). From the layers between 375—364 m there is almost nothing but a fine white sand. Between 364—358 m a spotted greenish gray argillaceous sandstone (»kråksten») predominates, and a similar rock is found also at some higher levels. In the upper portion of the Lower Cambrian a white fine-grained sandstone is by far the predominant rock even though there occur scattered thin layers of gray argillaceous sandstone and greenish gray shale. No layer can be found that can be definitely correlated with the dark coarse glauconitic sandstone at 388.45—390.15 m in the core from File Haidar, possibly due to the defectiveness of the Visby core. It may be noted, however, that several thin layers of a fairly coarse light-gray sandstone occur between 298 and 292 m. *Discinella holsti* is found in the Visby core at 331.6—344.3 m, *i. e.* about in the middle of the Lower Cambrian; at File Haidar it occurs at a comparatively lower level, 80 m below the top and 46 m above the base, and in a boring at Borgholm (Westergård, 1929) it ap-

[1] Owing to an error in writing Dr. Hedström happened to give the level 278.6 as the boundary between Lower and Middle Cambrian.

pears in a 10 m thick zone, 26—36 m below the top and, probably, about 40—50 m above the base of the Lower Cambrian.

Volborthella is not recorded from the Visby boring but it can scarcely be doubted that the zone of this species is developed in the Visby section too. A re-examination of the core has given no positive result, which, however, may be due to the fact that between 278.6 and 293 m where *Volborthella* may be expected to occur, the boring yielded but very few pieces of core, mainly sand and shale fragments.

At 276.5 m the light fine-grained Lower Cambrian sandstone in the Visby core is covered by a 3 cm thick layer of a greenish gray glauconitic sandstone, with dark phosphorite nodules, which may be considered the basal stratum of the Œlandicus beds. It is overlain by a greenish gray, usually arenaceous, shale which is the preponderant rock of this unit, but includes, at some levels, rather thick layers of a light fine-grained sandstone. The very top is formed of such a sandstone which, as in the core from File Haidar, is very hard and quartzitic. At the 241.4 m level this bed is covered by gray glauconitic Ordovician limestone.

As regards their lithological character, the two sections broadly speaking agree in the Lower Cambrian but differ in the Œlandicus beds, in which shales are very predominant in the Visby core, sandstones, on the other hand, in the File Haidar core.

The total thickness of the Cambrian at Visby is 140.9 m — the Lower Cambrian 105.8 m, and the Œlandicus beds 35.1 m. The corresponding figures for the section at File Haidar are 157.3, 125.9, and 31.4 m, respectively. Considering the remarkably even sub-Cambrian surface prevailing in Fenno-Scandia, we may infer from the above figures that under Gotland the Lower Cambrian decreases in thickness in the direction from NE to SW whereas the Œlandicus beds increase slightly in the same direction. This is quite in accordance with the known facts as regards the thicknesses of the units in Esthonia and Öland. Thus, in Esthonia the Lower Cambrian attains an estimated maximum thickness of about 180 m and the Œlandicus beds (as well as younger Cambrian deposits) are entirely lacking, whereas in the neighbourhood of Borgholm, Öland, the Lower Cambrian is proved to be 78 m and the Œlandicus beds 57 m thick (deep borings).

For the Lower Cambrian of Esthonia (Estonium) Dr. Öpik (1929, 1933) gives the following sequence:

5.	*Diplocraterion* and *Scolithus* zone	8— 10 m.
4.	*Scenella* zone	3— 5 ».
3.	*Volborthella* zone	8— 9 ».
2.	*Hyolithes* zone	10— 15? ».
1.	»Bluish clay», lower sandstones, and conglomerates	100—140 ».

In the core from File Haidar there are no strata correlative with the above Zones 4 and 5 except a 3.4 m thick layer of sandstone without characteristic fossils. The latter is underlain by the *Volborthella* zone, with a thickness of about 11 m (377.5—388.45 m). *Mickwitzia monilifera*, which occurs in the above Zones 3 and 4, is found in the core at a relatively much deeper level, 448.6—451.5 m. The »Bluish clay» — established by a recent deep boring at Bönan, 12 km NE of Gävle, to exist also in the Northern Baltic region, where it attains a thickness of more than 11 m — is under Gotland replaced by sandstone with intercalated thin shale layers, the former sometimes so loose that it approaches a non-consolidated sand.

For the sake of completeness also the sequence of the Lower Cambrian in the Mjösen area of Norway (according to Vogt, 1924) may be quoted.

Middle Cambrian.
Lower Cambrian.
4. Green shale and limestone with *Strenuella linnarssoni*.
3. Green shale with *Holmia kjerulfi*.
2. Green shale with *Volborthella tenuis* (western facies). Sandstone and green shale with *Platysolenites antiquissimus* (eastern facies). Total thickness c. 50 m.
1. Basal conglomerate and sandstone with *Discinella holsti* (= *D. bråstadi* POULSEN, 1932). Thickness 1.2—4.6 m.

Hiatus.
Upper part of the Sparagmitian.

Only Zones Nos. 1 and 2 of the above scheme can be definitely pointed out in the section from File Haidar. It may be noticed that *Discinella*, which, however, is not represented by quite identical forms in the Mjösen and Baltic regions, is found about 46 m above the base of the Lower Cambrian at File Haidar, and appears but 1 m above that base in the Mjösen area. This may indicate that the Lower Cambrian submergence which advanced from the east to the west in the Middle Baltic region and in about the reverse direction in the Mjösen area, may have reached the latter later than it did Gotland.

Comments on the Cambrian Fauna.

Lower Cambrian.

Strenuella obscura sp. n. — Pl. I, fig. 3.

Three imperfect and poorly preserved internal casts of the cranidium, the best of which is seen in fig. 3, have been found between 393.9 and 394.25 m. The form is clearly distinct from *S. primaeva* (BRÖGGER), zone of *Holmia kjerulfi*, and *S. baltica* (WIMAN), from boulders in the Northern Baltic region, *inter alia* by broader glabella (cf. Kiaer, 1916).

Indiana (?) sp. — Pl. I, fig. 16.

An imperfect, very small — 1.1 m long — moderately convex valve is present. Test smooth, thin, dark-brown, glossy. No ocular or other tubercles discernible. — Level: 446.8 m.

Volborthella tenuis F. SCHMIDT, 1888. — Pl. I, figs. 4—13.

About 400 specimens have been found between 377.5 and 387.9 m, the bulk between 377.5 and 380.0 m. In general shape and size as well as in the indication of a central tube and a very faint transverse striation on the outer surface, visible in the best preserved specimens, they agree completely with the Esthonian species as described and illustrated by Schmidt, 1888, and Schindewolf, 1934. The angle of divergence varies between 8° and 11° in intact specimens, and only in those disfigured by pressure is the angle found to be larger (up to 18° at least). The form described by Schindewolf under the name of *V. conica*, with an angle of divergence of 15°—20° in non-compressed specimens and according to him more common in Esthonia than is the former, has not been observed in the present material. Specimens with the broader end exactly circular in transverse section are comparatively rare, most of the specimens having this section more or less elliptical (cf. figs. 8—10).

The latter characteristic may be secondary and due to compression, however, as the circular transverse section is found in specimens more or less perpendicular to the bedding-plane and sometimes in those parallel to that plane, but the elliptical section exclusively in specimens with the latter orientation. Usually the cone is straight but sometimes gently curved (figs. 11—12). Nor is this difference believed to imply specific distinction, and, thus, all the forms mentioned are here included in Schmidt's species.

In Sweden *V. tenuis* is recorded from the Mickwitzia sandstone at Lugnås, Västergötland, where it seems to be rare, however. Some specimens have been found in a boulder of a light greenish gray sandstone from the northern point of Öland, and possibly also in boulders from other localities in the Kalmarsund region (cf. Moberg, 1892, p. 118).

Discinella holsti MOBERG, 1892.

About 25 shells, a few well preserved and displaying 14 muscle scars, *i. e.* the number characteristic of Moberg's species, have been found between 453.8 and 454.1 m.

Torellella laevigata (LINNARSSON, 1871), and var. — Pl. I, fig. 14.

There are four fragments, the largest 4.7 mm long, from a loose and relatively coarse sandstone between 449.0 and 451.85 m, and possibly also a fragment from 387.4 m. The test is glossy, gray, bluish gray, or black, and shows very faint transverse striae. There is no doubt that the fragments belong to Linnarsson's species taken in a wide sense but three of them are too imperfect to allow of it being determined whether they agree better with the typical form than with some of the varieties described by Holm (1893) and Kiaer (1916). The most complete specimen, fig. 14, which rapidly increases in breadth in the part preserved and whose transverse section is nearly circular at the narrow end but flattened elliptical (ratio of breadth and length 1 : 2.3) at the broad end, may be identified as var. *falcata* HOLM.

Torellella (?) sp. — Pl. I, fig. 15.

Only the specimen figured is present. General form subcylindrical, transverse section circular or nearly so. Shell black, about 0.04 mm thick, without traces of striae; composition doubtful, probably phosphoritic. It recalls *Hyolithellus micans* BILLINGS but differs by a markedly thicker shell. In this respect it seems to agree better with *Torellella*. — Level: 384.4 m. Associated with *Volborthella tenuis*.

Mickwitzia monilifera (LINNARSSON, 1869).

Three imperfect valves from 448.6 and 451.5 m agree with this species as regards sculpture as well as form, judging from the parts preserved. (As regards the occurrence of *Mickwitzia* in Sweden cf. Westergård, 1929, pp. 11—12).

Lingulella (?) sp.

A few fragmentary specimens of Obolidae have been found between 375.4 and 384.4 m, possibly belonging to more than one species. A ventral valve has the beak greatly elongated (even longer than in *L. acuminata* CONRAD).

Protospongia sp. — Pl. II, figs. 1—2.

In a few bedding-planes between 377.6 and 379.9 there are found numerous very small spicules with thread-like rays which seem to consist of pyrite more or less completely changed into limonite. The spicules are irregularly scattered over the shale surface, are different in size, the largest having 3 mm long rays, and cruciform, with the four rays at right or acute angles. The spicules are distinct from those of *P. fenestrata* SALTER — recorded from the Middle and Lower Cambrian of Europe and North America — by smaller size and proportionally more slender rays (cf. Walcott, 1920, p. 304).

Problematicum. — Pl. I, fig. 17.

One specimen has been found. General form subcylindrical. Surface black, greatly callous. Consists of dark-brown phosphorite. — Level: 449.0.

Paradoxides œlandicus Beds.

Ellipsocephalus polytomus LINNARSSON, 1877. — Pl. I, figs. 1 (and 2?).

Four cranidia and three associated thoracic segments from 353.6—367.45 m may safely be identified with Linnarsson's species. — Also two imperfect cranidia and an associated thoracic segment from 344.53—344.6 m agree in so far as they are preserved with this species, save that the antero-lateral corner of the cranidium is slightly more angulate. In this characteristic they approach to some extent *E. lejostracus* (ANGELIN) (= *E. muticus* ANGELIN) from the

Paradoxides tessini beds, but are clearly distinct from the latter by the entirely or nearly obsolete occipital furrow. Moreover, the pleural terminations of the associated thoracic segment are blunt (not spined). Both the cranidia are 22 mm in length, and thus the size exceeds the average size of *E. polytomus* but is not larger than in the largest specimens of the latter.

Paradoxides sp.

Some few fragments — cranidium, free cheek, rostrum, hypostoma, and thoracic segments — occurring at different levels between 356.9 and 371.9 m are referable to some *Paradoxides* but are too imperfect to allow of a specific identification. The thoracic fragments have relatively short pleural spines, and consequently do not belong to any species of the *P. œlandicus* group.

Hyolithes œlandicus HOLM, 1893 (?).

A very imperfect specimen in shale, lacking its proximal portion, with the apertural width 11 mm and the angle of divergence about 13°, may tentatively be identified as *H. œlandicus.* — Level: 360.2 m.

Lingulella spp.

Of about 20 poorly preserved specimens from different levels between 344.1 and 371.9 m some probably may be identified as *L. ferruginea* SALTER whereas a few belong to a distinct form characterized by a long pointed beak.

Acrotreta spp.

About 15 dorsal and 20 ventral valves occurring between 357.1 and 373.7 m are present, the latter as a rule crushed and compressed and consequently not safely identifiable. A few seem to be referable to *A. socialis* v. SEEBACH.

Ordovician and Silurian.

The bulk of the upper part of the core, dealt with in the following pages and including Ordovician and Silurian beds, consists of limestone of different textures and compositions. Only in the uppermost, Silurian part do argillaceous beds dominate, as that part is built up of slightly marly mudstone with intercalations of limestone, the latter diminishing in thickness and becoming more and more separated from each other towards the top of the core.

The Ordovician begins with a light-gray glauconitic limestone. Its contact with the underlying Cambrian beds is very distinct, and — to judge from the core-section — almost horizontal. Thus, the upper surface of the Middle Cambrian sandstone is only slightly rugged. There is no conglomerate at the base of the limestone, in which only a few rounded grains of quartz have been observed close above the Cambrian strata (Pl. IV, Figs. 1—1 a.)

In the following description the limits between the divisions distinguished are drawn mainly at levels where the rocks of the core alter in essential lithological respects or, exceptionally, where faunistic evidence has been revealed for dividing adjacent, petrographically but slightly dissimilar series of strata. Thus in a few cases the divisions correspond to stratigraphic units.

As to the fossils found and listed in the following account it must be noted that the figures after such species as are of stratigraphical importance denote the levels of the core at which specimens of these species were obtained.

General Description.

The following strata in the series of the core above the Cambro-Ordovician boundary have been distinguished (see p. 11).

1. *342.7—341.7 m.* Light-gray limestone transversed by several corrosion surfaces[1], most distinct in the basal and the uppermost parts. Small grains of glauconite occur fairly abundantly in the lower portion, disappear by and by above the 342.2 m level, but reappear towards the upper boundary, which corresponds to or consists of a corrosion surface.

Fragments of fossils, especially of cephalopods, are fairly common; they are sometimes cut off by the corrosion surfaces. Amongst the fossils obtained from this division it has been possible to identify specimens of *Ceraurus* sp., *Pliomera fischeri* (EICHW.), 341.65, *Remopleurides* sp., *Megalaspis* cf. *acuticauda* ANG. 342.2, 342.56, *Asaphus* sp., *Nileus* sp., *Illaenus* sp. (cf. *esmarki* SCHLOTH.), *Illaenus* n. sp., *Ampyx* sp., *Gonionema* sp., *Lycophoria?* sp., *Orthis* sp., *Pseudocrania* cf. *antiquissima* EICHW., 342.35, and cephalopods.

From this fauna it is evident that this limestone represents a stratigraphic unit which must be correlated with the Asaphus limestone in Sweden and with the East Baltic Vaginatum limestone (BIII of Lamansky a. o.). It cannot as yet be said what is an adequate correspondence to the zones of the latter, although the Asaphus limestone of the core would appear to have been deposited contemporaneously with the middle and upper ones ($B_{III}\ \beta+\gamma$ = Kunda formation of Raymond), or parts of them only (cf. p. 33).

2. *341.7—330.5 m.* Mainly gray limestone containing small oolites with a maximum diameter of 1 mm, within two different parts, 341.7—337.9 m and 334.7—334.2 m, respectively. The oolites are similar to those occurring in the Aseri formation in Esthonia, described by Orviku (1927). In the lower part there are only brownish Fe_2O_3-oolites; they also occur in a large middle portion of the upper part, separating thinner portions containing white $CaCO_3$-oolites. The iron oolites are sometimes highly abundant, giving the limestone a brownish tint.

Close above the base of this division the limestone also contains some very small grains of glauconite. As mentioned the lower boundary is marked by a corrosion surface, and the basal limestone with grains of glauconite and iron

[1] This expression is used in the same sense as the German »Korrosionsfläche».

oolites fills the superficial pits of the substratum. The surface itself appears in sections or on the outside of the core as a thin undulating band, distinguishable from the adjacent limestone by its dark-brown colour. There are such surfaces also within the limestone of this division, especially close together between 338.5 and 337.7 m.

The following fossils have been found in the lower part, to the 338.5 m level: *Asaphus* cf. *platyurus* ANG., 341.45, *A. cornutus* PANDER, 340.80, *Christiania* cf. *semiglobulosa* (PANDER), and fragments of cephalopods.

The upper part of this division is much more fossiliferous, especially the light-gray, oolite-free limestone. The list below is a very preliminary one, as six metres of the core have not yet been submitted to a minute examination; *Asaphus plicicostis* TQT, 337.2, *Asaphus* sp., *Pseudasaphus tecticaudatus* (STEINH.) — several pygidia between 338.1 and 335.45 m, *Illaenus chiron* HOLM — several pygidia between 338.1 and 335.45 m, *Remopleurides* sp., *Nieszkowskia* sp., *Raphistoma obvallatum* (WAHLENB.), *Hyolithus* sp., *Climacograptus scharenbergi* LAPW., 337.4, some badly preserved specimens of brachiopods and cephalopods.

From the lists of fossils detected it seems probable that the lower part corresponds to the Platyurus limestone and the upper part to the Chiron limestone in Sweden. The correlative strata in the East Baltic are to be found in C_{1b} of Fr. Schmidt, or to be more exact, this limestone was evidently deposited contemporaneously with the beds of the Echinosphaerites-zone and the »Baukalkstein»-zone (according to Orviku 1927 and 1929). Thus it appears as if the surface that bounds this division to its substratum, can be looked upon as a westerly extension of the corrosion surface between the »Oolithen»-zone and the Echinosphaerites-zone of the Aseri formation in Esthonia (cf. Orviku 1927, Pl. V).

3. *330.5—315.3 m.* Beds of light-gray limestone with thin intercalations of darker argillaceous limestone or shale. The contact with the substratum is indicated by a corrosion surface (Pl. IV, figs. 2—2 a), and there are also a few similar surfaces in the basal part. There is, however, no lithologic difference between the limestone on the two sides of the contact surface, but faunistic evidence has proved that it denotes a distinct stratigraphic boundary.

Lithologically and faunistically the limestone of this division appears to agree fairly well with the Lower Chasmops limestone of the North Baltic District (= the Gulf of Gävle and adjacent parts of the Baltic Sea).

Although the following list of the fossils obtained seems to indicate the presence of a rather rich fauna, it should be mentioned that this is hardly the case. This opinion of the author's does not refer to the brachiopods, but the specimens of this group are preserved in such a manner as to make the identifications difficult. It is a remarkable fact that ostracodes are almost absent, although they occur richly in the corresponding beds in Sweden and the East Baltic; in this respect the limestone of the core agrees with that of the Lower Chasmops beds of the North Baltic District. A preliminary examination disclosed the following fossils: *Ceraurus* sp., *Illaenus crassicauda* (WAHLNB.), 326.75, *Ill. parvulus* HOLM, 325.20, *Illaenus* sp., *Chasmops* sp., 324.9, *Stygina* (*Holometopus*) *nitens* WIMAN, 324.9, *Asaphus fennicus* WIMAN, 321.3, *Asaphus* sp., *Ampyx* sp., *Pterygometopus* cf. *exilis* (EICHW.), 319.55, 316.10, *Remopleurides* sp., *Steusloffia* aff. *rigida* ÖPIK, 325.2, *Platystrophia* sp., *Leptelloidea* cf. *musca* ÖPIK, 319.8, *Sowerbyella* spp. (belonging to the *liliifera*-group), *Leptaena* sp., *Christiania* sp., *Cliftonia* cf. *dorsata* (HIS.), 329.6, *Kullervo* cf. *lacunata* ÖPIK, 323.25; several species of Bryozoa; *Echinosphaerites* sp., *Haplosphaeronis* sp., 316.9, *Diplograptus uplandicus* WIMAN, 327.35, *Climacograptus* cf. *kuckersianus* HOLM and *Cl.* cf. *bekkeri* ÖPIK, 316.2, *Dendrograptus* ? sp.

4. *315.3—313.2 m.* Beds of limestone of different colours and compositions, changing from light-gray to dark-gray, finely crystalline to nearly compact, and beds of light- to dark-gray argillaceous limestone intercalated by arenaceous shales. Between 314.20 and 313.75 m the rock consists of non-fossiliferous light-gray shale, talky to the touch, with black spots caused by small scales of mica and partly rich in small sharp-edged grains of quartz, the latter less than 0.5 mm in diameter.

Finely crystalline pyrite is not uncommon in different parts of the limestone.

The lower limit of this division has been drawn almost arbitrarily, *i. e.* just at this level there is no obvious alteration in lithologic or faunistic aspect, and no corrosion surface is present.

The limestone of this division is transversed by several corrosion surfaces (See Pl. IV, fig. 3); their positions are indicated in the section, p. 11. Pyrite is often concentrated to these surfaces.

As to the fossils it is characteristic of this division, that the calcareous shells are partly silicified. The following fossils were observed: fragments of trilobites; several though mostly badly preserved specimens of brachiopods such as *Nicolella* sp., *Platystrophia* cf. *lynx* (EICHW.), *Leptelloidea* sp., *Rafinesquina* aff. *bekkeri* ÖPIK, *Sowerbyella* aff. *undosa* ÖPIK, *Sowerbyella* sp., *Leptaena* sp.; several specimens of Bryozoa; spicules of sponges; fragments of dendroid graptolites.

5. *313.2—312.8 m.* No core was obtained.

6. *312.8—312.4 m.* Light-gray arenaceous limestone, lithologically similar to the Macrourus limestone found as loose blocks in Öland, but slightly sandier. The fossils obtained also indicate that true Macrourus limestone is present. Thus, a complete pygidium and a fragmentary cranidium of *Chasmops macrourus* SJÖGR. have been found. Besides, specimens have been observed of *Remopleurides* sp., *Orthis* (*Hesperorthis*) *inostrancefi* WYSOG., *Leptaena* sp. and *Dictyonema* sp.

Lithologically, this limestone is sharply separated from that of the superimposed division and its upper boundary is uneven, possibly consisting of a corrosion surface.

7. *312.4—308.3 m.* Gray and fawn-coloured limestone, almost compact, partly nodular, partly thick-bedded, containing thin irregularly limited inclu-

sions of darkish marly shales. This limestone resembles the so-called Masur-Limestone (also called »Knyckelkalk«) and like that it is intersected by fine fissures filled with calcareous spar.

As pointed out above, this limestone is sharply limited at the base. This is, however, by no means the case with the upper limit of this division, the limestone there presenting a transitional appearance.

Except members of Dasycladaceae (*Vermiporella* sp. and *Rabdoporella* sp.), occurring rather abundantly, no identifiable fossils have been observed.

8. *308.3—305.0 m.* Beds of gray argillaceous limestone with thin intercalations of dark-green shales. Small grains of glauconite occur between 306.75 and 305.40 m. A corrosion surface is developed at the 306.55 m level. A similar surface, though indistinct, can be traced at 307.9 m. Fossils observed: *Illaenus* sp., *Amphilichas?* sp., *Stygina* sp., 306.3, *Remopleurides* sp., *Nicolella* sp., *Sowerbyella* sp., *Platystrophia* sp., *Leptelloidea* ? sp., *Conularia* sp., *Leptograptus* ? sp.

9. *305.0—304.5 m.* Beige limestone, nearly compact, with very thin intercalations of dark shaly matter. This limestone is intersected with calcareous spar in the same manner as that of item 7 above, with which it shows very great resemblance. The boundary to the underlying division is indistinct, and the basal part consists of irregularly bounded lenses or nodules of limestone in dark-gray marly shales. The upper limit is lithologically very sharp, probably a corrosion surface. Only a few indeterminable fossils were observed.

10. *304.5—301.8 m.* Mainly greenish gray, but partly brownish red mudstone, slightly marly, with intercalations of gray or (in the lower part) reddish, argillaceous limestone. Lithologically, this limestone transits into that of the superimposed division without any distinct boundary.

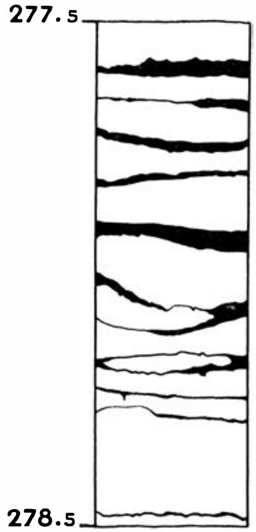
Fossils are rather rare and mostly badly preserved. There were observed a few smooth-tested ostracodes, *Conularia* sp., *Platystrophia* sp., *Sowerbyella* cf. *schmidti* TQT, 302.4, *Sowerbyella* sp., *Streptelasma* ? sp.

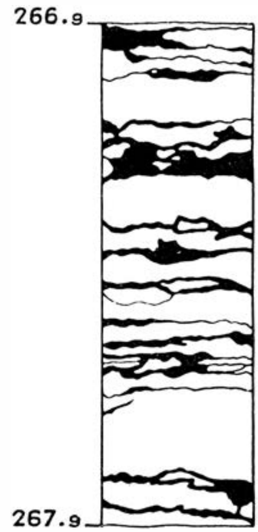
11. *301.8—289.75 m.* Beds of light-gray limestone, crystalline and in part coarsely crystalline, intercalated with dark-gray or dark-green (occasionally violet) shales, occasionally slightly marly. In the lower part there is more shaly matter than in the upper, which contains small, sparse grains of glauconite. The limestone beds are rich in stems of pelmatozoans. Otherwise only a few brachiopods, as *Kullervo* sp., *Orthis* cf. *lyckholmiensis* WYSOG., *Sowerbyella* spp., and *Propora* sp., 290.0, have been found.

12. *289.75—285.8 m.* Gray and dark-gray limestone, finely crystalline or nearly compact, including thin slices or layers of marly shales, darker than the adjacent limestone, placed relatively close together and irregularly bounded. Algal limestone. Some fossils are partly silicified. The following have been

observed: *Illaenus* sp., *Aparchites* sp., *Primitiella* sp., *Coelochilina* aff. *distans* (KRAUSE), *Bythocypris* sp., *Bairdia* cf. *cuneata* KUMMEROW, *Diplotrypa* sp., *Bilobites* sp., *Halysites parallela* FR. SCHMIDT, 286.2, *Dictyonema* sp., *Paleoporella variabilis* STOLLEY, *Vermiporella* sp., *Rhabdoporella* sp.

13. *285.8—274.3 m.* This division is built up of material similar to that of the substratum, but the shaly parts are somewhat thicker and not so close together as in that division (Fig. 3). Algal limestone. Amongst the fossils found





Figs. 3 and 4. Schematic sections illustrating the distribution of limestone (white) and shaly matter (black) between the levels stated.

there are specimens of *Illaenus* cf. *parvulus* HOLM, *Illaenus* sp., *Remopleurides* sp., *Proetus* cf. *densistriatus* KUMMEROW, *Platylichas* ? sp., *Acidaspis* sp., *Isochilina frequens* STEUSL., *Primitiella elongata* (KRAUSE), *Apatochilina* cf. *plana* (KRAUSE), *Eurychilina* (?) cf. *umbonata* (KRAUSE), *Bythocypris incurvata* KUMMEROW, *Bairdia cuneata* (STEUSL.), and of other species of Ostracoda; *Dalmanella* sp., *Vellamo* sp., *Sowerbyella* sp., *Dicellograptus* sp., 285.2, *Mesograptus* sp. and *Dictyonema* sp., 285.2, *Paleoporella variabilis* STOLLEY and *Vermiporella* sp.

14. *274.3—270.8 m.* White and reddish limestone, partly finely crystalline, partly compact, with very thin shaly lines of stratification, which, when seen in vertical sections, often transverse the limestone in zig-zag manner, occasionally wedging out to nothing. This limestone has an appearance typical of that of »Östersjökalk». It contains small hollows, the walls of which are covered by crystals of calc-spar. These hollows often contain dark oil.

Transitional kinds of rocks appear towards the substratum and the following division.

This limestone has not yet been submitted to any complete examination with a view to finding fossils. Besides types of Siphoneae verticillatae — *Paleoporella variabilis, Dasyporella* sp. — pygidia of *Illaenus* sp. and *Encrinurus* sp. were observed.

15. *270.8—256.1 m.* Dark-gray limestone, finely crystalline or nearly compact, with irregular inclusions of dark marly shales. Algal limestone. The limestone constitutes at least 90 % of this division of the core; it is somewhat bituminous and appears to form beds or lenses with irregular limits, sometimes small nodules in the marly shale (Fig. 4). Vugs almost filled with crystals of calc-spar are found also in this limestone. Occasionally there occur sliding surfaces; they are restricted to the shaly parts and were evidently formed during the induration.

The limestone above the level 256.6 m gradually grows light-gray though darker parts sometimes appear, and the intercalated marly shales have a greenish tint. These are in reality transitional beds to the limestone of the superimposed division. Fossils observed, *Illaenus* sp., *Proetus* cf. *ramisulcatus* NIESZK. 259.6, *Proetus* sp., *Remopleurides* or *Caphyra* sp., *Platylichas* ? sp., *Hemiarges* n. sp., *Isochlina frequens* STEUSL., *Primitiella elongata* (KRAUSE), *Apatochilina* cf. *plana* (KRAUSE), *Coelochilina* cf. *distans* (KRAUSE), *Macronotella* sp., *Bythocypris* sp., *Bairdia* cf. *cuneata* (STEUSL.), *Kullervo* (?) sp., *Platystrophia* sp., *Heliolithes interstinctus* (L.), 259.3—259.5; *Orthograptus gracilis* (ROEMER), 265.2, *Paleoporella* sp., *Vermiporella* sp.

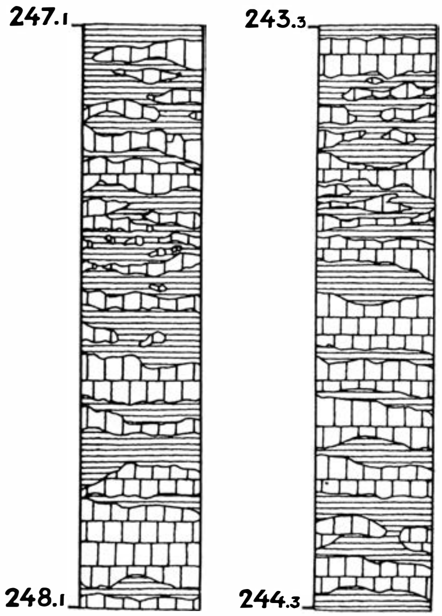


Fig. 5. Schematic sections showing the contents of limestone and mudstone (horizontally lined) between the levels stated.

16. *256.1—248.8 m.* Light-gray and faintly reddish — in part flamy red — limestone, finely crystalline and nearly compact, with very thin shaly lines of stratification interwoven in the limestone in the same manner as those of item 14 above. Algal limestone, resembling »Östersjökalk».

There is a corrosion surface at the top of this division; it separates limestones of different appearances and compositions.

The following fossils were found: *Proetus* sp., *Isochilina frequens* STEUSL., *Platystrophia* sp., *Sowerbyella* sp., *Halysites catenularia* (L.), *Vermiporella* sp., the latter sometimes very abundant, forming the main constituent of the rock.

17. *248.8—241.5 m.* Gray, somewhat argillaceous limestone, intercalated with greenish gray or dark-gray, slightly marly mudstone. The limestone appears to form beds, lenses and nodules, irregularly limited and often indistinctly bordered towards the mudstone (Fig. 5). Sliding surfaces are fairly common in the mudstone.

As mentioned above, the boundary to the underlying division is very sharp (Pl. IV, fig. 4). At and immediately above the corrosion surface there are incrustations of pyrite, giving the adjacent limestone a dark colour. The upper boundary of this division has been drawn arbitrarily.

Fossils occur rather abundantly, but, as far as the writer has been able to ascertain, most of the specimens appear to belong to undescribed species, so that in such cases only a generic determination can be given at present. The following list is very incomplete: *Illaenus* sp., *Bumastus* sp. (aff. *macallumi* SALT.), *Bumastus* sp., *Proetus* spp., *Cheirurus* sp., *Encrinurus* sp.; several species of smooth-tested ostracodes and of bryozoans; *Plectodonta* sp., *Parmorthis* sp. and other species of brachiopods; *Favosites gotlandicus* (L.), *Halysites* sp., *Heliolites interstinctus* (L.), *Aulopora* sp., *Climacograptus* ? sp.

18. *241.5—217.6 m.* Greenish mudstone, partly marly, with indistinctly bordered inclusions of gray limestone, forming thin beds or lenses. In parts the colour of the mudstone changes to reddish brown, especially in the upper part (above 219.7 m) but also between 231.6 and 229.3 m. Between 235.95 and 332.5 m there are portions in which the mudstone displays a dark mesh-like pattern, fragmentary specimens of graptolites occurring in the meshes. Very thin layers of finely-grained micaceous sandstone are observed in the middle portion of this division, *e. g.* between 229.8 and 229.9 m and between 225.3 and 225.4 m. Sliding surfaces are found also in the mudstone of this division.

The content of limestone successively diminishes towards the top of this division, which in other respects, too, appears to form passage beds between the adjacent divisions of the core. — List of fossils: *Illaenus* sp., *Encrinurus* sp., *Proetus* sp., *Cheirurus* sp., *Calymene* sp., *Leperditia* spp., *Beyrichia* sp., *Parmorthis* sp., *Plectodonta* sp., *Triplecia* cf. *insularis* (EICHW.), *Meristina* sp., *Pentamerus oblongus* (SOW.), 236.2—235.95, *Atrypa reticularis* (L.), *Spirifer* cf. *exporrectus* (WAHLNB.), *Leptaena* sp., *Bilobites* sp., *Halysites* sp., *Favosites* sp., *Alveolites* sp., *Aulopora* sp., *Heliolites* cf. *barrandei* PENECKE, *Climacograptus scalaris* (HIS.), 236.0, *Monograptus* cf. *concinnus* LAPW., 236.2, *M. regularis* TQT, 233.5, 233.2. *M.* cf. *convolutus* (HIS.), 233.5, *M.* cf. *lobiferus* MC COY, 233.5, *Rastrites* sp., 233.2.

19. *217.6—200.0 m.* Mainly chocolate-coloured mudstone, in parts slightly marly; with rare, usually thin, inclusions of limestone. A greenish colour predominates between 209.6 and 208.9 m.

Thin layers with small scales of black mica in abundance occur at different levels, *e. g.* at 216.2, 206.8 and 205.7 m. — List of fossils: *Illaenus* sp., *Phacops* sp., *Encrinurus* cf. *punctatus* (BRÜNN.), *Beyrichia* sp.; species of bryozoans;

Parmorthis sp., *Plectodonta* sp., *Bilobites* sp., *Atrypa reticularis* (L.), *Barrandella* or *Clorinda* sp., *Skenidiodes* (?) sp., *Eospirifer* (?) sp., *Spirifer* cf. *exporrectus* (WAHLNB.), *Halysites* sp., *Heliolites* sp., *Aulopora* sp.

Stratigraphical Considerations and Correlations.

Summarizing what has been said above concerning the lithological composition — the facies — of the Post-Cambrian strata of the core it may be stated that the abundance of limestone in the Ordovician indicates a general agreement with the conditions of the Ordovician of the East Baltic. The stratigraphical results gained from the examination of the core appear to corroborate this opinion. As regards the lowest 35 metres of the Ordovician of the core we are also there able to find several points of correspondence with the series of strata to the west, especially with that of Öland. The beds of the uppermost portion of the core (above 248.8 m) seem to take up, both lithologically and faunistically, a median position between their correlative strata on both sides of the Baltic Sea.

It may be added that the various limestones of the core are not dolomitic. In Esthonia the limestones of the Ordovician formations at least appear to become successively more dolomitic from the west to the east.

Ordovician.

As far as can be learnt from the sequences of the two hitherto available cores of the deep borings (cf. also Hedström 1923), the Ordovician of Northern Gotland is rich in stratigraphical gaps, and thus comparatively incomplete. This is evident already from the fact that the Ordovician begins with beds corresponding to the Asaphus limestone (= Lower Gray Orthoceratites limestone) in Sweden. Accordingly, not only the Dictyonema-Ceratopyge series is missing but also the whole lower part of the Orthoceratites limestone, viz. the Planilimbata-zone and the Limbata-zone. As the Asaphus limestone of the core is comparatively thin (about 1 m) and also contains several corrosion surfaces, it would very likely prove to be fairly incomplete if detailed comparisons could be made with the different zones of the Asaphus limestone on both sides of the Baltic Sea (cf. p. 26).

From the statements above it is evident that there is a considerable stratigraphical break underneath the Asaphus limestone in the sequence of strata of the core. A break at the corresponding horizon of the East Baltic series of strata was long ago discovered (Lamansky 1905) though it is comparatively small and in Esthonia hardly comprises more than the basal part of the Vaginatum limestone (= B_{III}) which latter may be considered to correspond to the Asaphus limestone in Sweden. As shown by Lamansky this break increases from the east to the west in Esthonia. Towards the north-western part of that country the Vaginatum limestone is successively replaced by a calcareous sandstone, the Rogö Sandstone, which (according to Öpik, 1927, p. 57) corresponds only to the middle part of the Vaginatum limestone. These beds are superimposed on the Megalaspis limestone from which they are separated by a corrosion surface.

Loose blocks of conglomeratic beds derived from the Middle Baltic District[1], W and NW of Gotland and Gotska Sandön, have proved, by faunistic evidence, to belong to strata of the same age as the Rogö Sandstone (J. G. Andersson 1895, Öpik 1927). These are the blocks with »*Strophomena jentzschi*». According to J. G. Andersson's investigations they contain, *inter alia*, pebbles with Upper Cambrian index fossils, amongst them *Agnostus pisiformis* (L.). The conclusion drawn by him (1895, p. 213), that the »*Strophomena jentzschi*»-beds form the basal Ordovician of the Middle Baltic District and are here in contact with Middle or Lower Cambrian strata, may be said to be confirmed by the sequence of strata of the core at File Haidar.

Deposits corresponding to the Gigas limestone of the Swedish Orthoceratites limestone seem to be lacking in the core. Thus, the existence of a stratigraphical break between the Asaphus limestone and the superjacent beds is very likely. In this respect there exists agreement with stratigraphical conditions within the Aseri formation of Esthonia, where — as pointed out by the present writer (1935 a) — it is evident from Orviku's investigations that there is a break between the »Oolithen»-zone and the *Echinosphaerites*-zone of this formation (cf. p. 27). These zones are separated by a very distinct corrosion surface, which Orviku (1927, Pl. V) has been able to follow from Narva in the east to Ojaküla in the west and which has been recognized at some localities farther west in Esthonia and also on the island of Odensholm (Öpik 1927). Thus, the corrosion surface of the core limiting the Asaphus limestone at the top very likely forms a part of the westerly extension of that mentioned above.

In this connection a few words may be said of the geological significance that must be attributed to the corrosion surfaces, a problem which has been discussed by the writer before (1937). These surfaces were evidently formed during intervals of non-sedimentation, and moreover, during changes of sea-level. The probability of the latter assertion can easily be shown in the case concerned. As pointed out above there is a stratigraphical break above the corrosion surface at the upper limit of the Asaphus limestone and the Vaginatum limestone of Gotland and Esthonia, respectively. At least the Gigas-zone of the Swedish Orthoceratites limestone is missing. As indicated by faunistic evidence the beds close above this surface must be correlated with the Platyurus limestone in Sweden. In the Lockne district of Jemtland the Platyurus limestone begins with a conglomerate containing rounded fragments (pebbles, cobbles and rare boulders) of gray and red Orthoceratites limestone and also of Archaean granite and Pre-Cambrian dolerite. As far as the writer has been able to ascertain the limit between the Gigas limestone and the Platyurus limestone is marked only by a corrosion surface in the adjacent Brunflo district.

Similar corrosion surfaces are fairly common in the part of the core which

[1] The Middle Baltic District includes Gotland, Gotska Sandön, Kopparstenarna and adjacent parts of the bottom of the Baltic Sea (cf. J. G. Andersson 1895, pp. 153 and 237).

can be approximately correlated with the Platyurus-zone + the Chiron-zone of the Swedish Orthoceratites limestone and with the Echinosphaerites-zone of the Aseri formation + the »Baukalkstein»-zone of the Tallinna formation in Esthonia ($C_1 \beta+\gamma$ according to Öpik 1930, p. 48). It is impossible at present, however, to draw any conclusions as to the stratigraphical evidence of these surfaces. Very likely, they indicate breaks of comparatively short though varying duration. The surface that limits the Chiron limestone and the Chasmops limestone from each other, on the other hand, can with a great degree of probability be said to have been developed during changes of sea-level. Arguments in support of the existence of such changes can be quoted from several places in Sweden and also in Esthonia. The most conspicuous data can in this case be obtained from the eastern part of the Jemtland Cambro-Silurian district, where the Chasmops beds in some places rest immediately on the Archaean, in others on different zones of Cambrian or older Ordovician strata; the basal beds are always built up of indisputable transgression deposits (sedimentary breccias, conglomerate, sandstone). — Examinations of loose blocks have proved that the basal Chasmops beds consisted of similar rocks at Tvären, off the coast of Södermanland, about 73 kilometres SSW of Stockholm. — According to Öpik (1937, p. 3), there is evidently a break between the Uhaku formation and its substratum at Tallinn in Esthonia. The Uhaku formation constitutes the basal zone ($C_1\delta$ of Öpik 1930, p. 48) of the East Baltic Chasmops-series, and part of its lower half is said to be without corrrespondence in this locality.

The fossil material obtained is not sufficient to permit an exact determination of the limits between different zones of the Chasmops beds of the core. It is evident, however, that the main part of them corresponds to the lower Chasmops-series in Sweden and thus approximately to the Esthonian formations denoted $C_1\delta$, C_2 and C_3, while the uppermost part, at least the sandy limestone containing *Chasmops macrourus*, must be correlated with some part of the D-series in Esthonia, very likely only D_1 or the Jewe formation. The corrosion surfaces observed in the upper half of the Chasmops beds of the core and the comparatively small thickness of the true Macrourus limestone indicate the existence of several breaks, but probably not very large. The comparatively large contents of arenaceous matter in these beds are notable, as similar conditions are unknown in the corresponding strata on both sides of the Baltic.

The Ordovician part of the core, dealt with above, has permitted a rather close correlation with known series of strata in the east and the west. Unfortunately, the same cannot be said of the divisions of the core following close after, a circumstance mainly due, of course, to the weak correlation value of the fossil material obtained. Nor has the lithologic appearance caused any definite comparisons to be drawn, even if it might be said that the predominance of limestone indicates a closer general agreement with the conditions of correlative strata in the East Baltic than with those of the corresponding Trinucleus beds in Sweden.

On account of the stratigraphical position it is evident that the strata between 312.4 and 289.75 m of the core at least partly correspond to the Wesenberg (E) in Esthonia and that they were deposited contemporaneously with a great (lower) part of the Trinucleus beds in Sweden, approximately those below the red Trinucleus shales of Dalecarlia. As far as can be judged from the sharp contact with the Chasmops beds there seems to exist a break close above the Macrourus-limestone. Although it is impossible to determine just how large is this break, it is very likely, however, that at least the upper part of the Esthonian D-series has no equivalent in the sequence of strata of the core.

As mentioned in the general description, a few corrosion surfaces have been observed within the portion of the core concerned but nothing can at present be said of their stratigraphical significance. Only at the surface of the 304.5 m level is there a sudden and obvious change in lithologic respect, although this merely refers to limestones of different textures that are in contact with one another. As to the fossils listed it may be pointed out that the cranidium of *Stygina* sp. found is very like that of the *Stygina*-species, previously referred to *St. latifrons* PORTL. which occurs in the red Trinucleus shale of Västergötland. The fragmentary *Sowerbyella*-species, compared with the holotype of *S. schmidti* (TQT.) recorded from the upper Ordovician of Dalecarlia, presents an externally great resemblance to that species.

On account of palaeontological evidence the beds between 289.75 and 248.8 m of the core must be correlated with stage F — including the Lyckholm (F_1) and the Borkholm (F_2) formations — of the East Baltic district or with a great part of it at least. It must be pointed out, however, that the level of 289.75 m by no means forms a definite lower limit as it has proved impossible to fix any limits of correlatable stratigraphical units within the series of strata of the core above the true Chasmops beds. Thus in the case concerned the lower limit has been drawn only tentatively.

As far as the writer has been able to ascertain there are no corrosion surfaces or the like in this portion of the core. Lithologically there are always passage beds between the different divisions distinguished, as also towards the substratum. Thus, there are no indications of breaks during the sedimentation of the beds from 304.5 m upwards to 248.8 m, and I am not able to determine if the sudden lithologic change at the former level can be ascribed such a significance.

The fossils found also indicate that from a stratigraphical point of view, the divisions concerned are closely related to each other. In this connection we may but notice the algal contents and the ostracodes; amongst the latter *Isochilina frequens* STEUSL. has thus been encountered between 284.2 and 251.6 m.

Leaving the algae out of consideration, it is true that only few of the fossils hitherto found are known from the East Baltic stage F; these are *Halysites catenularia* (L.), *H. parallela* FR. SCHM. and *Heliolithes interstinctus* (L.). But none of these species occur in strata older than those of the Lyckholm. Some of the trilobites obtained from the core are very similar to species of stage F, and further investigations very likely would prove at least some of them to be identical with an East Baltic species. Unfortunately the rich fauna of Ostracoda is at present of little value as regards correlation as the identifiable species are as yet only described or known from loose blocks in Germany. Most of these glacial drift boulders have evidently come from outcrops on the sea-bottom of the Middle Baltic District, thus from the westerly to the north-westerly extension of the strata under consideration. This is obviously also the case with the drift boulders at Öjle Myr, Gotland, which have been subjected to a thorough investigation by Wiman (1901). A preliminary examination of Wiman's collection of Ostracoda from these blocks has proved that there are several species identical with those obtained from the part of the core now dealt with, *inter alia Isochilina frequens* STEUSL. and *Coelochilina* cf. *distans* (KRAUSE). Amongst other fossils common to both we are at present able to note *Proetus* cf. *ramisulcatus* NIESZK., *Halysites catenularia* (L.) and *H. parallela* FR. SCHM.

From the above it would appear that the correlation of the strata of the core under consideration is intimately connected with the question of the age of the beds, of which the Öjle Myr blocks are debris. Wiman has tried to demonstrate that the latter are Borkholm of age, but as far as I am able to determine, Wiman's result is in this case open to discussion. And it may be pointed out at once, that the writer himself is inclined to question whether there actually are strata of the Borkholm age represented amongst the Öjle Myr boulders examined. This conclusion owes its origin mainly to later information in the literature concerning the occurrence of some in this case stratigraphically important fossils listed by Wiman.

It is a fact pointed out by several authors, and clearly shown in Wiman's paper on the subject concerned, that the fauna of the Lyckholm is closely related to that of the Borkholm and that there are several species common to both. A number of such species were obtained from the Öjle Myr blocks, but in addition there were also species, the occurrence of which was known formerly either from the Lyckholm or from the Borkholm exclusively. As Wiman attached importance to the latter fossils it is necessary to call attention to the fact that two of them, *Pachydictya bifurcata* (HALL) (= *Rhinidictya* ? *Borkholmiensis* WIMAN) and *Glauconome plumula* (WIMAN), have later been found also in the Lyckholm formation (Bassler 1911). — As to the trilobites obtained Wiman (1901, p. 208) has discussed their occurrence in detail and thus their stratigraphical importance with reference to the age of the strata of the Öjle Myr boulders. Amongst them there are two species mentioned as index fossils of the Borkholm formation; these are *Lichas cicatricosus* LOVÉN and *Proetus ramisulcatus* NIESZK. Recent investigations have proved, however, that the former species does not — as appeared very likely from Fr. Schmidt's works — occur in the Borkholm. The specimens of that formation, on which that author founded his identification and description, thus have proved to belong to two different genera, »*Trochurus*» and *Amphilichas* respectively (Öpik 1937). The species obtained from the Öjle Myr blocks greatly resembles »*Trochurus*» *mastocephala* ÖPIK, a Borkholm species, formerly referred to *Lichas cicatricosus* by Fr. Schmidt, but Öpik remarks in his description of this species: »Ob das Wiman'sche Exemplar hierher gehört, ist, trotz der Zustimmung Fr. Schmidt's, noch zweifelhaft . . .». With reference to *Proetus ramisulcatus* it may be pointed out that this species by several authors (very likely after Fr. Schmidt) has been stated to occur not only in the Borkholm but also in the Lyckholm (cf. Wiman 1902, pp. 171 and 201). I have seen the material which Wiman had attributed to this species. It appears to embrace two different species, one of which — also represented by material obtained from the core — is very like *Pr. ramisulcatus*.

Thus, it is probable that at least the bulk of the Öjle Myr boulders arose from beds of the Lyckholm age, and very likely this is also the case with the part of the core under consideration. In support of this view it may be pointed out that the Lyckholm has a considerable thickness compared with that of the Borkholm and that representatives of the latter formation are said to be missing in some localities in western Esthonia (Fr. Schmidt 1882, p. 39; Teichert 1928, p. 77). An obvious corrosion surface occurs at the 248.8 m level of the core (Pl. IV, fig. 4), indicating the existence of a break between the Ordovician and Silurian series of strata in the Middle Baltic District. In the writer's opinion this break includes, of Ordovician, the Borkholm or at least a great (upper) part of that formation.

As regards the correlation between the core-portion in question and the Ordovician strata of other Palaeozoic districts round the Baltic, it seems as if the graptolites found in the core might give some valuable information. This is possible owing to the fact that *Orthograptus gracilis* (ROEMER), formerly recorded only from loose blocks, has recently been found in solid rocks on the island of Bornholm, where, according to Poulsen (1936, p. 57), this species occurs in the uppermost Trinucleus Beds, very likely belonging to the zone of *Staurocephalus clavifrons* ANG. The loose blocks, in which this graptolite was obtained, have been assumed to derive from beds of the Wesenberg or the Lyckholm ages (cf. Bulman 1932, p. 21). According to F. Roemer (1885, p. 313) specimens were found associated with *Chasmops eichwaldi* FR. SCHMIDT, an index fossil of the Lyckholm.

Also the *Dicellograptus* sp. of the core appears to be informative for the correlation, in spite of the preservation of the specimen detected not premitting a reliable identification with any described species. However, it has been possible to determine that the thecae are of the *complanatus*-type and very like those of *D. anceps* (NICH.), but the proximal end (badly preserved) appears to be different. As to the vertical range of the genus *Dicellograptus* it is of importance that it be established that no species of it has been found above the Trinucleus Beds in other Palaeozoic districts in Sweden, and thus never in the Dalmanites Beds that are considered basal Silurian. As far as the writer knows *Dicellograptus anceps* has not hitherto been found in Sweden[1].

[1] Probably, the statements of Törnquist and other authors concerning the occurrence of this species in the Black Trinucleus Shales of Dalecarlia are due to mistakes. Material (also Törnquist's collection) of Dicellograptids from these shales has been examined by Dr. O. M. B. Bulman, of Cambridge, who was able to establish the occurrence of *D. morrisi* HOPK. only (cf. Thorslund 1935 b, pp. 47—48).

A variety of this species has been described from the Trinucleus Beds of Bornholm, where it occurs together with *Orthograptus gracilis* (cf. Poulsen 1936, p. 57).

As far as can be judged from the above it is quite natural at present to correlate some (upper) part of the Trinucleus Beds of Sweden and Bornholm with the Lyckholm, and also to regard the part of the core containing the graptolites just mentioned to be Ordovician of age.

As to the stratigraphical position of the limestone formerly known from blocks and called »Östersjökalk», the lithologic examination of the core has proved that this limestone represents a facies restricted to the Ordovician of the Baltic Sea area where it occurs above the true Chasmops beds. This result is in accordance with the conclusions drawn by Wiman (1906) in his work on the North Baltic Ordovician. Thus, the »Östersjökalk» does not represent a distinct stratigraphical unit but a facies of limestone developed within the limits mentioned above.

Silurian.

The upper part of the core, above the 248.8 m level, belongs to the part of the Silurian series of strata that cannot be studied in outcrops on Gotland as it is below the level of the Baltic Sea. That is the main reason for this part not having been described formerly in reports on the Middle Baltic area.

As pointed out above the Ordovician and Silurian strata of the core are marked off by a very distinct corrosion surface (Pl. IV, fig. 4). Above this surface there are no signs of stratigraphical breaks in the series of strata.

Lithologically these beds appear to take up a middle position between those of the richly calcareous Tamsal formation in Esthonia (cf. Teichert 1928) and the Rastrites Shales in Sweden. The correlation with some part of the latter is proved by the graptolites obtained from the middle division of the Silurian portion of the core. Thus these graptolites indicate the presence of the zone of *Cephalograptus cometa* (GEIN.) in Sweden or the zone of *Monograptus convolutus* (HIS.) in Great Britain. This is the only conclusion that can be drawn with certainty at present in regard to the correlation with the Rastrites Shales, as the latter and the Silurian strata of the core mainly exhibit two different facies, graptolitic and shelly, respectively.

According to O. T. Jones' classification (1925) in his work on the geology of the Llandovery district the *Monogr. convolutus*-zone forms the uppermost part of the Middle Llandovery. From this and the position in the core of the graptolite-bearing strata belonging to that zone it is probable that at least a great part of the Middle Llandovery occurs in the Silurian of Gotland. It must as yet be left open whether or not there is any equivalent to the Lower Llandovery in the basal Silurian part of the core. This question may be answered by further investigations of the fossils when a close comparison with the fauna of the Lower Llandovery of the Oslo district can be made. As far as the writer is now able to determine, however, there are probably no strata corresponding to the Lower Llandovery, nor to the Dalmanites Beds of Scania and Dalecarlia.

<table>
<tr><th></th><th>ESTHONIA</th><th>GOTLAND</th><th colspan="2">DALECARLIA</th><th>SCANIA</th></tr>
<tr><td rowspan="3">Silurian</td><td>Tamsal</td><td>Mudstone and Limestone</td><td colspan="2">Rastrites Shales</td><td>Rastrites Shales</td></tr>
<tr><td rowspan="2">Hiatus</td><td rowspan="3">Hiatus</td><td>Upper Boda</td><td>Dalmanites Beds</td><td>Dalmanites Beds</td></tr>
<tr><td colspan="2" rowspan="2">H i a t u s</td><td rowspan="2">Hiatus</td></tr>
<tr><td rowspan="3">Ordovician</td><td>Borkholm</td></tr>
<tr><td>Lyckholm</td><td rowspan="2">Algal Limestone</td><td>Lower Boda</td><td>T r i -</td><td rowspan="2">Trinucleus Shales</td></tr>
<tr><td>Wesenberg</td><td colspan="2">n u c l e u s Beds</td></tr>
</table>

Fig. 6. Table of tentative correlation.

As this paper is not the place further to enlarge upon particulars of correlation, reference is made to the subjoined table (fig. 6) which represents an attempt at a solution of the correlation problems of the Ordovician-Silurian boundary in the Scandinavian-Baltic region.

The uppermost division of the core, *i. e.* the brownish red mudstone, very likely belongs to the Upper Llandovery, the boundary between the Upper and Middle Llandovery being drawn by O. T. Jones (1925, p. 370) immediately above the *Monograptus convolutus*-zone.

An examination of the small samples of rocks taken at intervals during the drilling down to the 200 m level has proved that »red beds» — i. e. the continuation upwards of the brownish mudstone below the 200 m level — are found at 173 m and that the beds at and above the 170 m level have a grayish colour. As the »red beds» begin at an approximate level of 218 m they have a thickness of at least 45 m at File Haidar. From the deep boring at the Visby Cement Factory it is evident (cf. Hedström 1923) that the »red beds» at this locality are about 54 m thick and that their upper limit is situated abt. 62 m below the level of the Baltic Sea. The Lower Visby Beds (the »Stricklandinia-marl»), exposed on the coast south and north of Visby to a maximum height of 9 m above the sea-level (Hede 1921, p. 28), have by some authors been considered to belong to the top of the Upper Llandovery; others stating them to be Wenlock of age (cf. Hede 1921, and Teichert 1928).

Remarks on the Stratigraphy of the Visby Core — a Preliminary Comparison.

The sequence of strata of the core obtained from the deep-boring at the Visby Cement Factory was briefly described by H. Hedström in 1923. The core is in the collections of the Swedish Geological Survey, and for the purpose of comparison it has been subjected to a superficial examination during the work on the core from File Haidar. This examination concerned the lithological appearance only, and special attention was paid to the boundaries between different recognizable units. A closer comparison will be possible when the fossils obtained from the Visby core are available.

However, the lithological comparison alone has produced several facts indicating a general agreement between the stratigraphical successions of the cores, a result which certainly was not unexpected.

The Visby core has a diameter of 21 mm and owing to the boring, parts of the sedimentary rocks are presented as gravels only, this of course making the comparison less complete.

The boundary between the Cambrian and Ordovician rocks is about 241,4 m below the level of the Baltic Sea. As at File Haidar the basal Ordovician strata consist of glauconite-bearing limestone, about 1 m thick. It contains several corrosion surfaces, and at the top it is bounded by such a surface, which constitutes the lower limit of a limestone containing Fe_2O_3-oolites (Fig. 7). Thus, the agreement with the corresponding part of the File Haidar core is striking.

It has not been possible to establish the boundary between the Chiron limestone and the Chasmops limestone in the Visby core, very likely owing to the poor state of preservation of the part in which this boundary must be expected. The Chasmops limestone appears to be thicker — approximately 28 m — in this core than in that of File Haidar (about 18 m). This may be due to a wedging out of some parts of the (upper) Chasmops beds from Visby towards File Haidar, but also, at least to some degree, to circumstances connected with the boring at the latter locality. The portion between 202.75 and 202.25 m of the Visby core consists of micaceous shales similar to those occurring between 314.20 and 313.75 m at File Haidar. Light-gray arenaceous limestone, very likely Macrourus limestone, occurs below the 200.8 m level, which constitutes the lower limit of a light-gray (fawn) nearly compact limestone, about 4 m thick. The superimposed gray limestone and its intercalations of darkish green shales contain small grains of glauconite between the 194.5 and 193.7 m levels. (Corresponding levels of the File Haidar core are 306.75 and 305.4 m). The portion between 192.2 and 186.0 m consists mainly of red-brown, occasionally greenish mudstone with relatively thin intercalations of limestone. Light-gray and dark-gray algal limestone, in parts with thin irregularly limited intercalations of marly shales, occur from the 185 m level upwards to the Ordovician-Silurian boundary. This is situated at the 142.6 m level and appears as a corrosion surface similar to that of the File Haidar core. Pyrite occurs in profuse quantities at this surface and in the mudstone close above it.

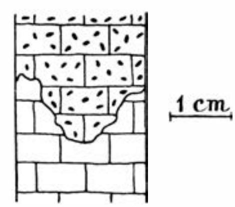


Fig. 7. Schematic section through the Visby core illustrating the boundary (corrosion surface) between the glauconitic basal Ordovician limestone and the oolithic limestone (black-spotted).

The basal Silurian strata have an appearance and a composition similar to those of the corresponding part of the File Haidar core.

Practical Results.

During the drilling the following investigations and tests were carried out in order to collect data which could be useful with regard to the possible occurrence of hydro-carbons.

1) Examination of the lithological character of mud samples from 0 to 200 m depth and of core from 200 to 500 m, whereby the $CaCO_3$ content was determined from 0 to 392 m.

2) Determination of porosity from 323 to 500 m depth.

3) Determination of the NaCl and SO_3 contents of water from several levels.

4) Examination of the core with regard to traces of hydro-carbons.

5) Electrical measurements in the drill-hole (»electrical logging») between 438.5 and 503.5 m.

6) Gas tests.

The lithological character of the strata between 200 m and 500 m is shown in detail on the stratigraphical profiles, by the side of which the $CaCO_3$ values are also given (pp. 8—15).

From 0 to 200 m there exists a sequence of Silurian limestones and marly shales; the following table (I) on the percentage of $CaCO_3$ gives an approximate idea of the nature of these layers.

Table I.

Level metres	$CaCO_3$ %	Level metres	$CaCO_3$ %	Level metres	$CaCO_3$ %
6	98.7	75	92.8	140	40.8
11	97.6	80	92.6	145	35.7
16	96.4	85	86.2	150	32.1
21	93.9	90	90.5	155	36.2
26	93 4	95	84.9	160	30.6
31—32	84.6	100	84.7	165	33.4
36	90.7	105	75.3	170	39.3
41	86.8	110	78.2	173	32.3
46	70.5	110	52.6	175	33.4
50	88.8	115	68.3	180	48.3
55	65.5	120	65.3	185	38.4
60	73.8	125	65.0	190	18.5
62—63	79.0	130	49.3	195	27.0
65	77.2	135	58.7	200	21.4
70	84.7				

The porosity of the beds between 323 and 500 m determined on core samples is shown close to the profiles (pp. 11—15). The figures illustrate clearly the frequent change of porous sandstone and compact shale within the Cambrian layers. The porosity of the Cambrian sandstone varies between 13 and 30 %, and the shales have a porosity of 2—6 %. The thickness of the compact shale beds, however, does not exceed 1—2 dm.

The chlorine and sulphate contents of waters struck on various levels of the drill-hole are shown in the following table (II).

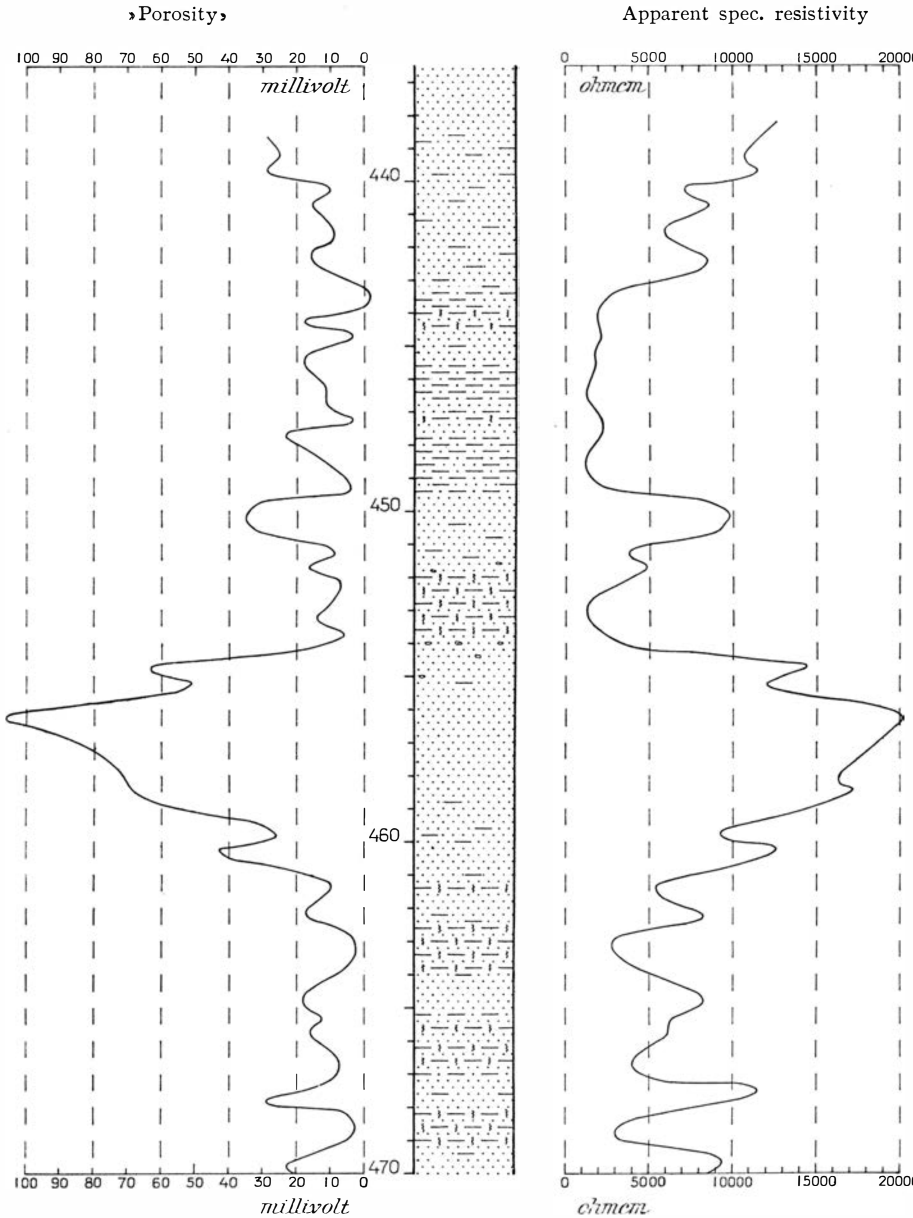
Table II.

Level	Cl mg/l	NaCl mg/l	SO_3 mg/l
36 m.	161	265	14.4
88 m.	554	912	18.3
150 m.	3,089	5,090	2.9
180 m.	4,885	8,050	3
304 m.	960	1,580	0
304—390 m.	2,100	3,500	0
339—346 m.	32,000	53,000	0
346—412 m.	23,500	39,000	0
427—429 m.	19,000	31,000	0
431—433 m.	21,000	35,000	0
438.90—446.50 m.	1,160	1,920	14
452.70—459.50 m.	820	1,350	14
455.10—457.50 m.	4,000	6,600	13

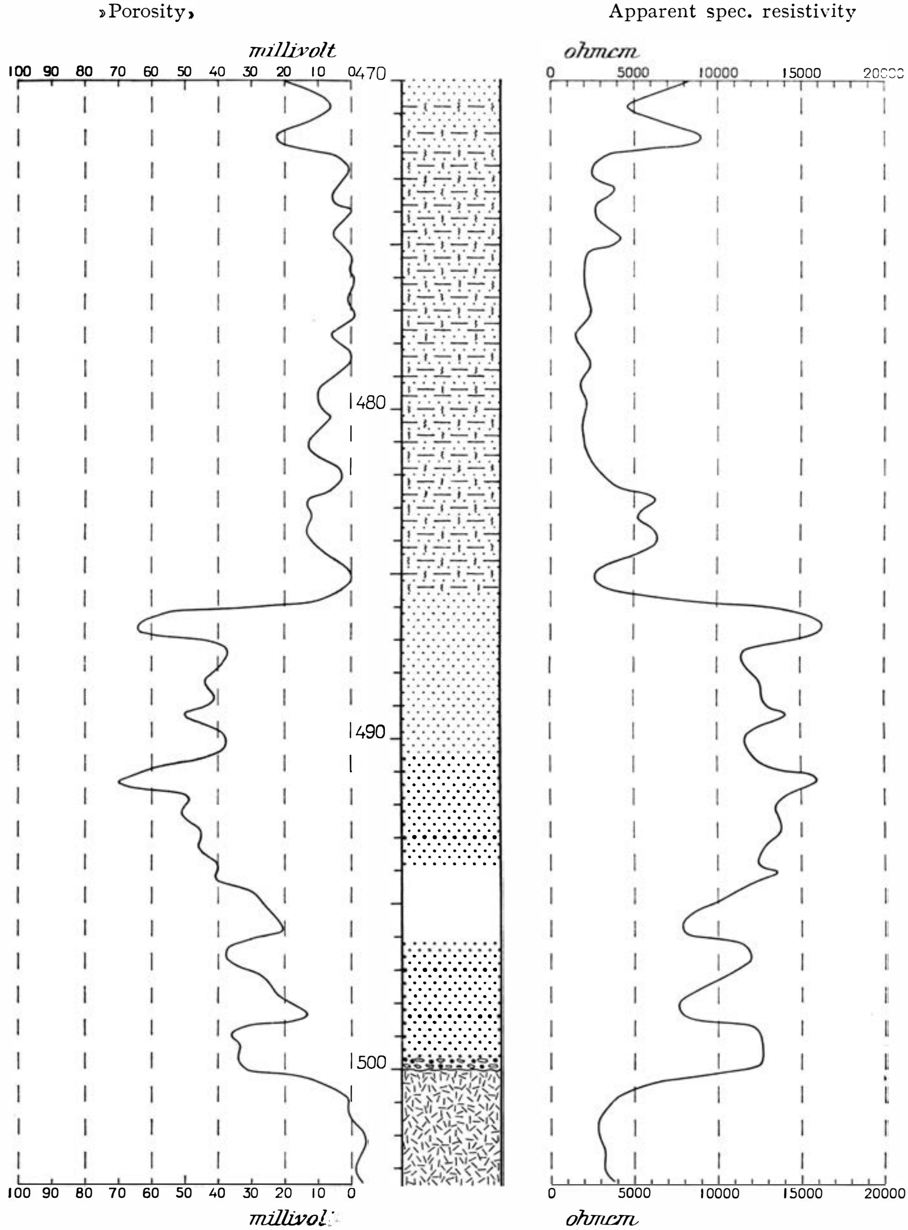
From this table it will appear that three categories of waters were obtained. The first category corresponds to the two waters from 36 and 88 metres' depth. Their NaCl and sulphate contents are normal for ordinary subsoil water. The second category is represented by eight water samples from 150 to 433 m. These have a NaCl content varying between 0.16 and 5.3 % and contain no or very little sulphate. These waters have thus the qualities that characterize the oil field waters. The third category is illustrated by water taken from 438 to 457.5 m with a NaCl content varying between 0.135 and 0.66 % and a sulphate content approximatively the same as that of the first category. The most probable explanation of the composition of these waters is that they originally have been salt waters of the second category, which have been diluted with ordinary fresh-water having found its way there along fissures from the upper layers.

Regarding the search for hydro-carbons in the core traces of oil only have been found in the upper part of the Ordovician limestone between 260 and 270 m.

As mentioned in the introduction the occurrence of gas-bearing horizons has been anticipated within the Cambrian sandstone. As soon as the sandstone was encountered gas tests were therefore carried out and continued as the drilling in the sandstone proceeded. However, enormous water quantities soon occurred, and even when testing small sections between rubber packings the water could not be excluded. In order to localize within the deeper part of the sandstone those horizons that were especially worth a thorough testing an electrical measurement (electrical logging) was carried out in the uncased drill-hole between 438.5 and 503.5 m, in the ordinary way often



described in the literature. The result of this measurement is shown by two curves at the parts of the profile that correspond to the drill-hole section electrically examined. The right curve indicates the apparent specific resistivity of the strata traversed by the drill-hole, and the left curve the potential differences existing inside the drill-hole. These potential differences depend on



the porosity of the various beds, it therefore being said that one measures the »porosity». As shown by the curves, an indication was obtained between 454 and 461, where the resistivity as well as the »porosity» are greatest. The following tests were therefore concentrated on this section of the drill-hole, but the water flow here proved to be still worse than higher up.

Methane determinations were made in all the gas samples obtained, and in some cases also complete analyses. However, for one sample only traces of methane could be found, all the others consisting of air only.

The practical final result of the drilling was thus negative. The explanation of this might be the considerable permeability of the Cambro-Silurian layers in vertical direction on account of numerous fissures intersecting the sediment series. The rich flood of water increasing towards the depth, while at the same time the chlorine content decreases considerably, confirms this assumption. Even the indications obtained when measuring in the drill-hole — high porosity together with high specific resistivity — might be explained by the fact that fresh water from the surface limestone beds has penetrated through fissures into the Cambrian sandstone and, above all, into the most porous beds, where it has highly diluted the primary salt-water.

The most important conclusion that may be drawn from these circumstances is, however, that, due to the permeability of the Cambro-Silurian layers at File Haidar, most of the liquid and gaseous hydro-carbons which no doubt once existed in these layers leaked out long ago.

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EXPLANATION OF PLATES

PLATE I.

Ellipsocephalus polytomus LINNARSSON. Page 24.

Fig. 1. Internal cast of cranidium. Level: 353.6 m. — $^2/_1$.
» 2. Imperfect cranidium; this species? Level: 344.6 m. — Nat. size.

Strenuella obscura sp. n. Page 22.

» 3. Internal cast of cranidium. Level: 394.25 m. — Nat. size.

Volborthella tenuis F. SCHMIDT. Page 23.

Figs. 4—5. Intact specimens. Level: 379.9 m. — $^6/_1$.
» 6—7. Inconsiderably compressed specimens, with the broader end slightly elliptical in transverse section. Level: 379.9 m. — $^6/_1$.
» 8—10. Three more strongly compressed specimens in different aspects. Level: figs. 8—9, 378.0 m; fig. 10, 379.9 m. — $^6/_1$.
» 11—12. Gently curved specimens. Level: 377.6. — $^6/_1$.
Fig. 13. Part of shale slab relatively rich in specimens. Level: 378.0 m. — $^4/_1$.

Torellella laevigata falcata HOLM. Page 23.

Figs. 14 a—b. Specimen in different aspects. Level: 451.85 m. — $^4/_1$.

Torellella (?) sp. Page 24.

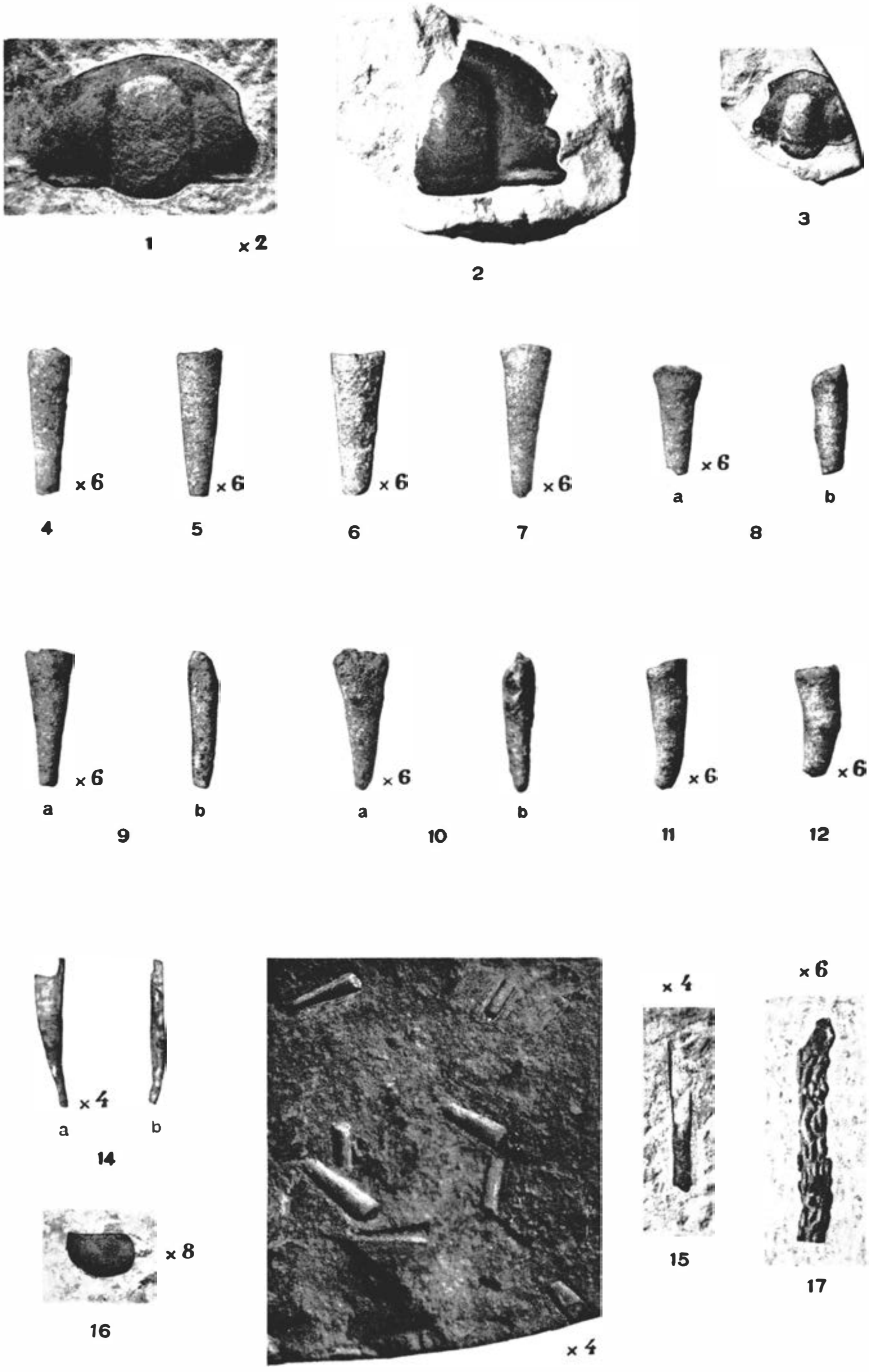
Fig. 15. Imperfect specimen. Level: 384.4. — $^4/_1$.

Indiana (?) sp. Page 22.

» 16. Interior surface of a right valve. Level: 446.8. — $^8/_1$.

Problematicum. Page 24.

» 17. Subcylindrical, with callous surface; consists of dark-brown phosphorite. Level: 449.0. — $^6/_1$.



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Figs. 1—2 Paradoxides oelandicus beds
Figs. 3—17 Lower Cambrian

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PLATE II.

Protospongia sp. Page 24.

Figs. 1—2. Spicules of different size, in shale. Level: 377.6 m. — Fig. 1 magnified six times, fig. 2 eight times.

Diplocraterion parallelum TORELL. Page 18.

» 3—4. Horizontal sections of two specimens. Level: 429.6 m. and 426.5 m respectively. — Nat. size.

Fig. 5. Vertical section showing nearly the entire pocket. Level: 413.0—413.1 m. — Nat. size.

The burrows of figs. 3—5 are filled with greenish gray argillaceous sandstone; matrix of white or light-gray pure sandstone.

Diplocraterion sp. Page 18.

Figs. 6 a, b. Specimen with crooked and unevenly thick tubes, in »kråksten». a, horizontal section showing the pocket connecting the lateral tubes; b, vertical section showing one of the tubes. Tubes and pocket filled with white sandstone; matrix consisting of alternating greenish gray shale and argillaceous sandstone of the same colour. Level: 480.3—480.4 m. — Nat. size.

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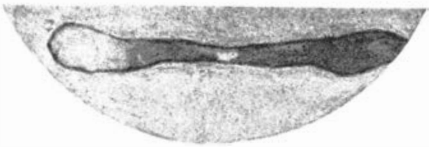

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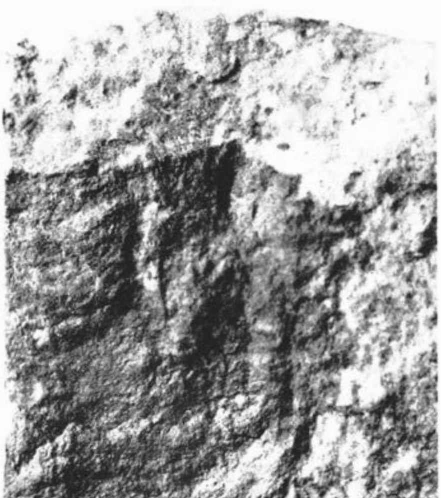

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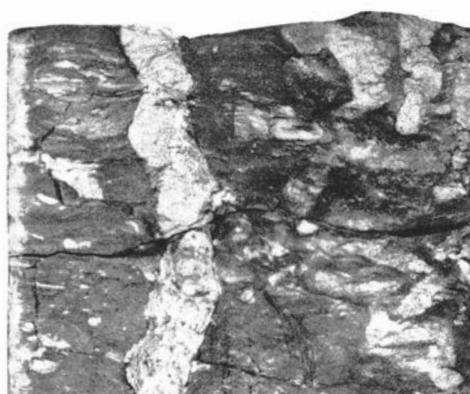

6 b

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Lower Cambrian

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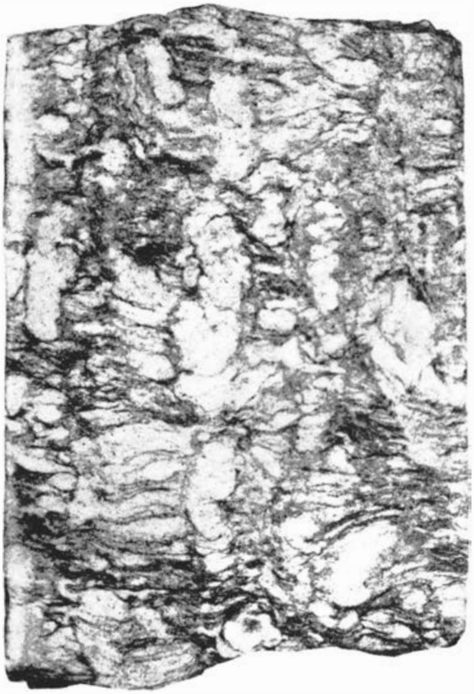
PLATE III.

Different types of greenish gray argillaceous sandstone, »kråksten».

Figs. 1 a, b. Vertical and horizontal sections of a sample of the typical »kråksten» crowded with burrows. Level: 484.65—484.75. — Nat. size.

Fig. 2. Level: 452.0—452.1. — Nat. size.

» 3. Greenish gray argillaceous sandstone and shale, with thin seams and small lenses of light-gray sandstone, practically lacking burrows and trails and having the original stratification well preserved. Forms an 8 cm thick layer in typical »kråksten» like that in fig. 1. Level: 480.95—481.03. — Nat. size.



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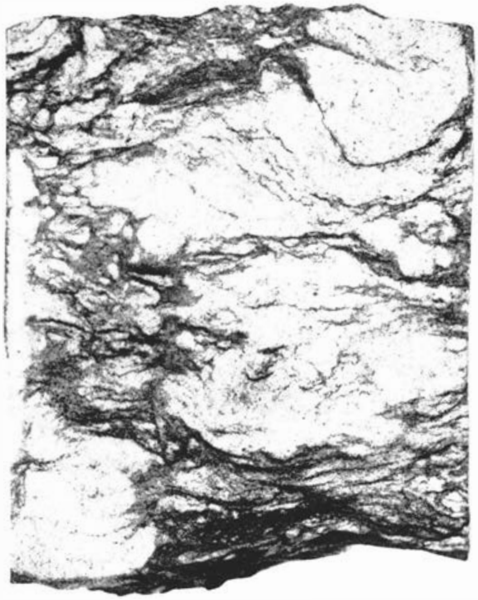

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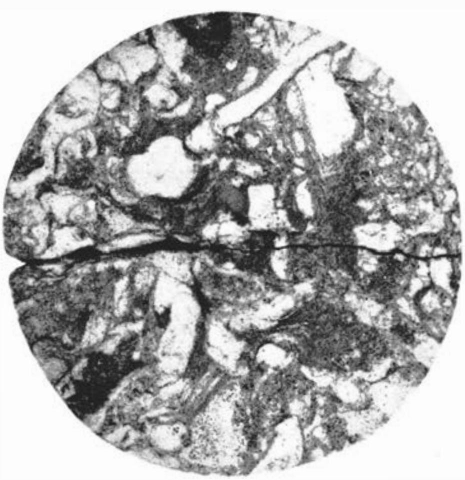

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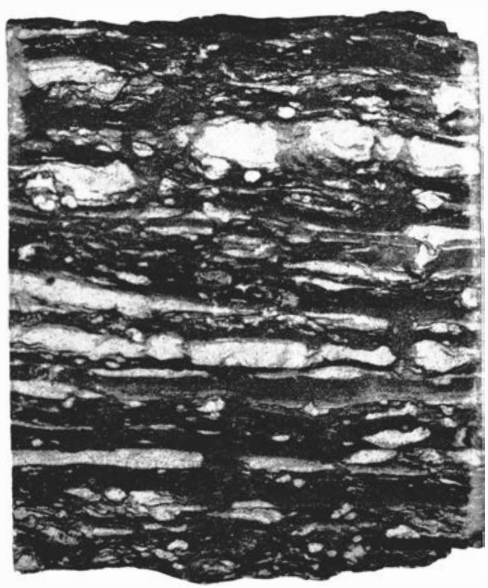

3

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Lower Cambrian

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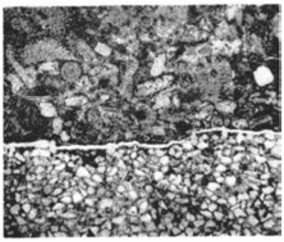
PLATE IV.

Figs. 1—1 a. Vertical sections showing the contact between the Middle Cambrian sandstone and the Ordovician Asaphus limestone. The sandstone is covered by a film of siliceous matter. A single grain of quartz is seen in the limestone to the right in fig. 1. — Enlarged about 10 × and 36 ×, resp.

Figs. 2—2 a. A portion of the core and vertical section showing the corrosion surface that marks off the *Chiron*-limestone from the *Chasmops*-limestone. — × $^2/_3$.

Fig. 3. The outside of a core-portion from the Upper Chasmops beds showing sections of three corrosion surfaces. — × $^2/_3$.

Fig. 4. Vertical section of the core at the Ordovician-Silurian boundary. The Ordovician algal limestone is mainly gray but flamy red. The dark colour at and above the boundary indicates the presence of pyrite. — × $^2/_3$.



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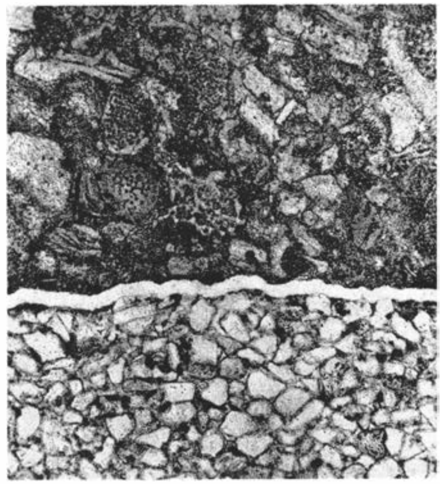

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2 a

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Ordovician and Silurian

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