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THE PRE-QUATERNARY SEDIMENTARY ROCKS OF SWEDEN

BY

ASSAR HADDING

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THE PALEOZOIC AND MESOZOIC SANDSTONES OF SWEDEN

WITH 138 FIGURES IN TEXT

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Preface.

Like the author most geologists have no doubt been of the opinion that the sandstones form a relatively uniform group of sedimentary rocks. They have not the abundant and important organic ingredients nor the varying development of the limestones. Their minerals vary little and are not of the same interest as for inst. those of the argillaceous sediments. As a rule the conglomerates also seem to us to offer more tempting problems, especially with regard to their forming conditions and paleogeographical significance.

On devoting a more detailed study to the sandstones, however, we shall find that the supposed uniformity is only apparent. Like other sediments these rocks also are very varying in their character, which reflects the variety of forming conditions.

The account given in the following of a number of Swedish sandstones will illustrate the facts mentioned, at the same time as it shows that the problems connected with these rocks are sufficiently varying and important. The fact that only part of these problems have been discussed here is due to the limitation of the investigation. In the Paleozoic and Mesozoic sediments of Sweden only a few formations are represented and all of them, except the Cambro-Silurian, only in relatively insignificant series of strata. Several genetic types are lacking among these sediments, specially are the continental types remarkably sparingly represented.

To the plan followed by the author in his work at the present material a few explanations are given in the folloving.

In the present work it is not the author's intention to give an account of all the Paleozoic and Mesozoic sandstones in Sweden. He has instead, as in the earlier published investigation on the conglomerates, tried to find the different types represented in the Swedish series of strata.

As the description is not the essence of the task but only a means to illuminate the character and forming conditions of the rock, an equally detailed discussion of all the different kinds of rock has not been necessary nor even desirable. Consequently the irregularity of the treatise in this respect is not due to inadvertency but is quite intentional.

In a couple of cases the author has also given a detailed account of larger parts of the series of strata. In spite of the fact that this account requires more room, its exclusion has not been considered appropriate by the author. For it is only from the series of strata that a correct idea of the mutual connection between the different types of rock is to be obtained. The variations in the character of the rock from bed to bed show the changes in the sedimentary conditions. From this point of view it might seem desirable that a detailed account of the series of strata examined should have been given in each case but the author has found that this would require too much room and in many cases give nothing new, and therefore he has preferred only to illustrate the variations in a few chosen cases. He has specially dwelt on the Lower Cambrian and the Rhaetic-Liassic series of strata.

In order to reduce the size of the treatise the author has entirely foregone the discussion of certain problems in other respects also, or he has confined himself to more summary information. Thus the accessory minerals of the sandstones (zircon, garnet, etc.) and the problems connected with them have been entirely left out of account. These minerals are never so abundantly or so constantly present that they may be said to be characteristic of the one or the other rock. Nor are they of any significance in ascertaining the forming conditions of the rocks.

More characteristic of certain sandstones are glauconite and phosphorite, and the occurrence of these minerals is also of great interest on interpreting the forming conditions of the rocks. However, these minerals will be discussed in the following part of this series of publications and therefore only a short reference has been made to them here.

The tracks in the sandstones are of great value in the investigation of the sedimentary conditions. Our knowledge of them, however, is so imperfect that the author has considered it suitable to make a more detailed examination of them. As the account of this cannot be forced within the compass of this work but must be given elsewhere, the author has contented himself with merely mentioning a few of the more important tracks and their occurrence.

In order to facilitate the comparison between the different sediments the figures generally show the rocks in naturale size and the rock slices enlarged 60 diameters.

To the best of his ability has the author tried to solve the problems that have arisen in the course of the work. That the solutions are always correct is more than he ventures to hope but they may form a basis of discussion. Future investigations will no doubt be able to produce new views of the problems in many cases.

To pupils, colleagues and other friends, who in some way or other have helped in his work, the author wishes to express his sincere thanks. Special thanks are due to Professor K. A. Grönwall, Lund, and the State Geologist Dr A. H. Westergård, Stockholm, for valuable informations and discussions on the Swedish sedimentary rocks.

III.

THE PALEOZOIC AND MESOZOIC SANDSTONES OF SWEDEN

CONTENTS.

A General Survey of the Sandstones.

Before entering on an account on the Paleozoic and Mesozoic sandstones of Sweden it may be appropriate to make a general investigation of the sandstones with regard to their character as seen from their petrographical nature, their content of fossils and the geological occurrence of the rock.

The Petrographical Character of the Sandstones.

The petrographical character of a sandstone is not exclusively evident from the nature of the grains and the structure of the rock. The form (wear) of the grains, their size and crowding, the kind and quantity of the matrix and the nature and occurrence of the cement influence the character of the rock. It may also be characterized by occasional inclusions. Finally the stratification of the rock too may be mentioned as one of its characteristics. This, however, will be discussed in a later chapter, in which the geological occurrence will form the subject of a short survey.

The content of minerals

in the sandstones is often rather lacking in variety, especially in the case of the deposited grains. Among these the quartz dominates always and in the »purest» sandstones practically no other mineral is found. However, it is not possible to find a sandstone in which no other minerals than quartz are present. The predominance of the quartz is of course due partly to its general occurrence among the rocks yielding the material for the sandstones, i. e. principally the eruptive rocks, and partly to the resistance of the mineral to weathering and wear.

The feldspar comes in as a good second among the grains of the sandstones. Several sandstones, *arkoses,* show such a large content of feldspar that they may be said to be characterized by this mineral. Not infrequently are they slightly red in colour but not in the same way as sandstones coloured by for inst. a cement containing ferric oxide. Sometimes the feldspar is so highly kaolinized or muscovitized that the grains are purely white. Even in this case they impart a certain character to the rock.

Of the different forms of feldspar, found in the sandstones, microcline is most common. Remarkably often, however, plagioclase, especially oligoclase, is also found. The grains of microcline are sometimes so fresh that not even under the microscope can any alteration be seen in them.

The marine arkoses are mainly confined to the lower part of the series of strata. They consist largely of a washed but only slightly worn weathering gravel, which has been more or less rearranged during a transgression.

The minerals besides quartz and feldspar, occurring as grains in the sandstones are only accessory components. We can never show that allotigenous grains of a certain kind are confined to sandstones of a certain type of formation.

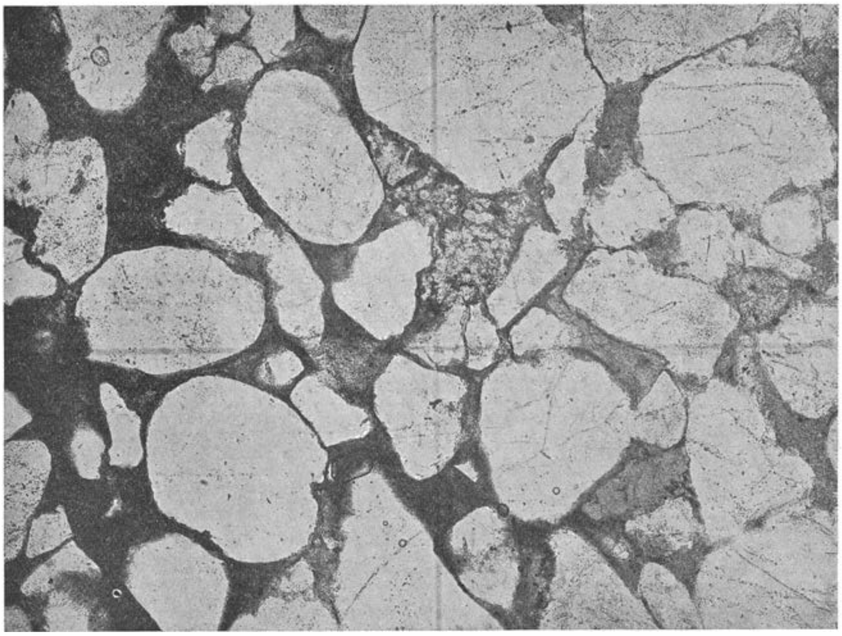

Fig. 1. Sandstone with rounded grains. Matrix silicified. Lower Cambrian. Luopahta, Lappland. (Pr. 2845. Pl. 383.)[1] — 60 ×.

But it is often found that the local conditions play an important rôle for the content of minerals in the sandstone. For inst. in regions with older garnet-rich rock the deposited sand often becomes rich in garnet, and analogically is zircon found in sandstones formed in a region with eruptive rocks containing zircon, and so on. It is obvious that the occurrence of these accessory minerals in the sandstones must be of great interest, especially in determining the origin of the material and the distance of its transport[2] as well as the help it gives us in determining the place from which a sample of sandstone is derived.

[1] Pr. = Preparation, thin section, slice. Pl. = Plate (photographical).

[2] It may suffice here to refer to the investigations made by a number of British students.

The form of the grains

is more instructive than their nature with regard to the formation of the rock. The more rounded grains have obtained their form by wear against other grains, blocks or solid rocks. Only in a lesser degree has a solution by water contributed to the rounding [1]. It is also well known that the wind-transported sand (drift-sand) contains as a rule exceedingly well rounded grains, as does also sand transported a longer distance by running water. The grains washed out from hitherto intact material on a shore, for inst. from weathering gravel or moraine deposits, are on the contrary angular or only slightly rounded.

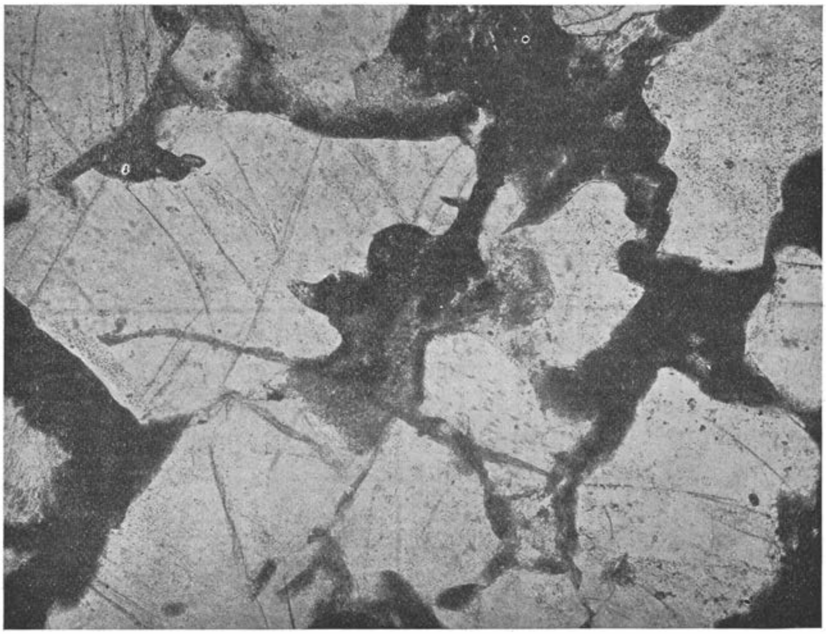

Fig. 2. Sandstone with angular grains. Matrix argillaceous. Keuper. Margreteberg, Höganäs, Scania. (Pr. 2505. Pl. 325.) — 60 ×.

On closer investigation of the sandstones it is generally found that the smaller grains are angular in form, while the medium-sized or larger ones are distinctly rounded. This is obviously bound up with the fact that the smaller grains have remained silted up in water for a longer time during their transport, perhaps throughout the entire transport, while the coarser grains are rolled along the bottom and are thus exposed to continuous wear against this.

The influence of the different conditions of transportation is noticeable not only by the form of the grains but also by their lustre. A wind- or sand-polish is often distinctly visible on the conglomerate pebbles, if the rock has been

[1] In certain sandstones, however, indubitable solution phenomena are visible on the quartz grains.

formed in a region with sand transported by wind. This polish is easily distinguished from that seen on blocks polished during transport in water. Something of the sort may also be found in the grains of the sandstones though as a rule it is less pronounced.

The size of the grains

is seldom fully uniform in a sandstone bed. The bulk of the grains is usually found to be fairly uniform but a minority of them comes outside these size-limits. If for inst. 80 % of the grains in a sandstone are 0.3—0.5 mm in diameter, 5 % of them are perhaps 0.5—1.2 mm and 15 % are less than 0.3 mm in diameter.

This difference in the size of the grains is of course not equally pronounced in all sandstones. It varies with the sorting capacity of the transporting agent. The aeolian sandstones frequently show a very good sorting of the grains according to size, while the arenaceous moraine may be mentioned as an example of the most unsorted material.

The changes in the size of the grains are often of great help in judging the forming conditions. The more coarse-grained parts of the rock indicate a greater, and the fine-grained parts a lesser capability of transportation in the transporting medium. The alternation of coarser and finer portions thus reflects the changes in the transporting capacity of the depositing medium. In some cases these changes follow in close succession, for inst. in the fluvial deposits, in other cases more slowly and at intervals, for inst. in littoral deposits formed during displacement of the shore-line. In both cases, however, the variations of the size of grains give us a great deal of information on the forming conditions and their changes during the period of deposition.

In connection with the discussion on the size of grains in the sandstones we shall also turn to the question of the mode in which the coarseness of the sandstone is to be indicated. Of course the coarsest grains may be chosen as indicating the transporting power of the medium of deposition and the largest diameter of the grains may be used as a gauge of the coarseness of the sandstone. This has also been done in several papers. Though the author fully understands the significance of the fact that the grains do not exceed a certain limit in size, he still does not consider that this limit indicates either the most typical or the most constant feature of the sandstone with regard to the size of its grains. The presence of one or two coarser grains in a sandstone can be due to such a number of occasional circumstances that it would be an error to look upon them as of any greater significance. In the example cited above the bulk of the grains was 0.3—0.5 mm in diameter, while 5 % of them were larger. Possibly 4 % of them are 0.5—0.6 mm and 0.9 % 0.6—0.7 mm in diameter. The remaining 0.1 % of the grains are 0.7—1.2 mm in diameter. Of the latter only very few attain a diameter of 1 mm. In a case like this a size of grains of 0.3—0.5 mm may be stated as characteristic of the rock. In the following description the size of grains has been indicated in this way except when the average value has been stated. Thus in the above case: — grains 0.3—0.5 mm in diameter or grains about 0.4 mm in diameter.

Sometimes, however, more complicated variations in the size of grains are found in the sandstones. The frequency curve can for inst. show two acmes instead of one. In such a case the grains may be grouped according to size in the following manner:

Diameter less than	0.3 mm	15 %
»	0.3—0.5 mm	55 %
»	0.5—0.7 »	8 %
»	0.7—0.9 »	20 %
»	0.9—1.2 »	2 %

Here as in the preceding case it would not be correct to state that the largest grains (1—1.2 mm) are characteristic of the sandstone, nor is a correct idea of the size of grains obtained if the diameter is stated to be 0.7—0.9 mm. According to the author's opinion the size of grains should be indicated as follows: the bulk of the rock consists of grains 0.3—0.5 mm in diameter but grains 0.7—0.9 mm in diameter are abundantly present.

The reason why grains of two different groups of magnitude have been enriched in a sandstone is quite obvious, if the coarser grains, as is often the case, are arranged in thin laminae or lenses in the interior of the more fine-grained bed. An occasional increase in the transporting power of the water or the wind has resulted in an occasional deposition of coarser material. The formation is less clear when the coarser grains are more evenly distributed in the fine-grained matter. In this case, however, the mode of formation may have been the same as in the former. The division into coarser layers and finer matter, however, has been spoilt by rearrangement of the material.

The formation can also have been the result of a relatively even supply of coarser grains at a place where mainly finer material was being deposited. This is analogous to certain block-bearing rocks. In this case the supply of the coarser material is not due to changes in the transporting power of the depositing medium but to a favourable store of it. If a relatively coarse sand is enriched on a shore close to the shore-line and finer sand somewhat farther out, the coarser material may be fairly evenly washed out during certain periods (and under certain circumstances).

The sandstones may have been supplied with the sparser, larger grains in some measure under the same conditions. They have often been transported a shorter distance than the grains forming the bulk of the rock and are on that account as a rule less rounded than these. Probably they have partly been rafted (by ice or some other medium) and in this case also they have become less worn than other grains.

The reason why grains smaller than those forming the bulk of the rock always occur in sandstones with well sorted material is partly that a medium, transporting grains of a certain size, is always able to carry and usually does carry finer material as well, partly that smaller grains find shelter behind larger ones, and on that account can be deposited to a certain number together with the latter.

As mentioned above the usual relation between the size of the grains and their roundness is that the middle-coarse and sometimes the coarse grains are best rounded. This does not imply that the middle-coarse (and coarse) sandstones are always composed of better rounded grains than the more fine-grained ones.

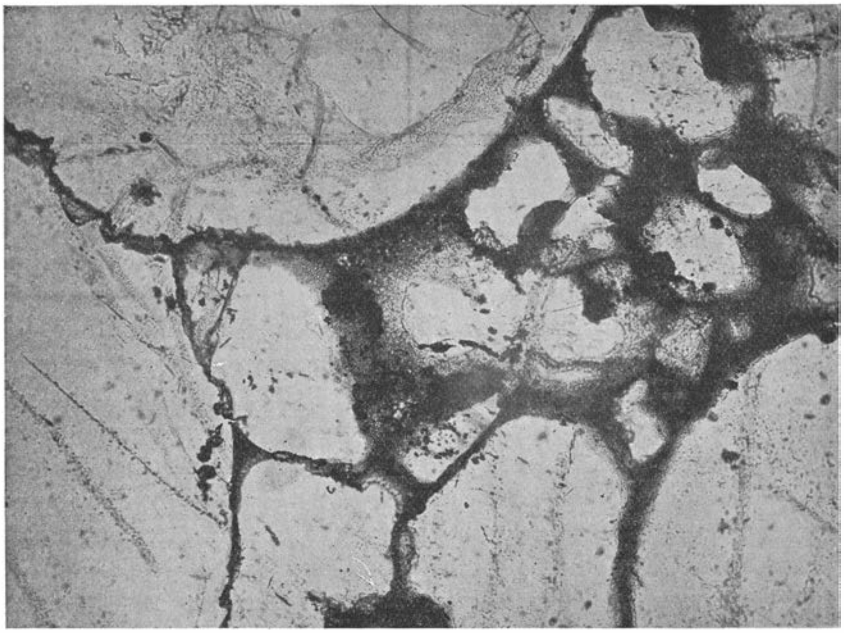

Fig. 3. Sandstone with a matrix of small angular rock fragments between the larger, rounded grains. Cement: calcium phosphate. Lower Cambrian. Simrishamn. (Pr. 2770. Pl. 370.) — 60 ×.

In the following account we find several examples of the contrary. The finest-grained sandstones (diameter of grain > 0.05 mm), however, seldom have, for the said reason, rounded grains.

Besides that, there is a certain connection between the size and the nature of the grains. Heavier minerals occurring together with the quartz grains are usually smaller in diameter than these. Grains of feldspar have often cleaved into small angular fragments, and as a rule the leaves of muscovite are considerably larger in diameter than the grains of feldspar. Thus the cause of the different size in the different minerals can be varying enough, for inst. a difference in specific gravity, in development and in splitting ability. No doubt other factors can also influence the size of grains (for inst. the difference in solubility of the mineral).

The crowding of the grains

may, seemingly at least, vary very greatly. Generally they are as closely packed as possible. No real gaps are found unless part of the material has been carried away by secondary dissolution (for inst. in calcareous sandstones). That the packing in spite of this is of such varying appearance is due partly to the form of the grains, partly to a more or less thorough sorting of the material.

Had the rock consisted of exclusively spherical grains of uniform size, the porosity would have been fairly uniform. Are the grains of a more irregular

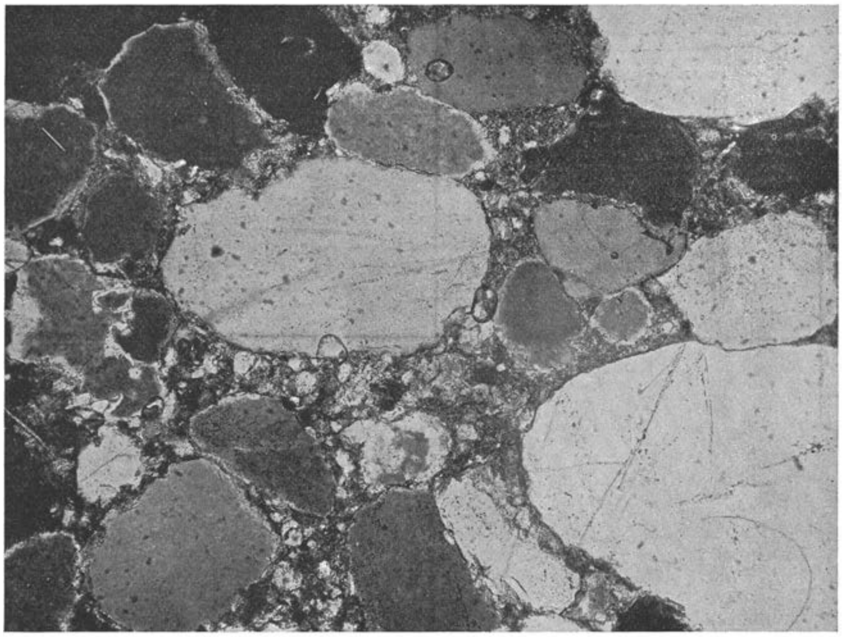

Fig. 4. Sandstone with a matrix of small quartz grains. Cement siliceous. The rock has macroscopically as well as microscopically a pronounced clastic structure. Lower Cambrian. Brantevik, loc. 4, Scania. (Pr. 2794. Pl. 359.) — 50 ×. Nic. +.

form, the pores may be smaller. Angular grains of different size can be crowded so that the pores between them become exceedingly small.

The matrix.

In sand the porosity becomes slighter, if the spaces between the larger grains are filled up with smaller ones. If there is a marked difference in size between the larger grains and the filling between them, one is of course entitled to speak of a *matrix* in the sandstone as well as in the conglomerates. But frequently enough it is impossible to draw the line between the larger and the smaller grains. The fine sandstones are often argillaceous and in these rocks practically all transitions between the clayey substance and the small grains of sand are to be found. It is then impossible to speak of a matrix as distinct from the grains. The rock may appropriately be termed *impure* or argillaceous sandstone.

Together with quartz and clayey substances carbonaceous matter, iron and calcareous compounds occur as a fine *admixture* in the sandstones. The two latter, however, are in a great measure autochthonously formed or diagenetically changed. To a large extent they also form the cement in the sandstones and will be discussed in the following together with other cements.

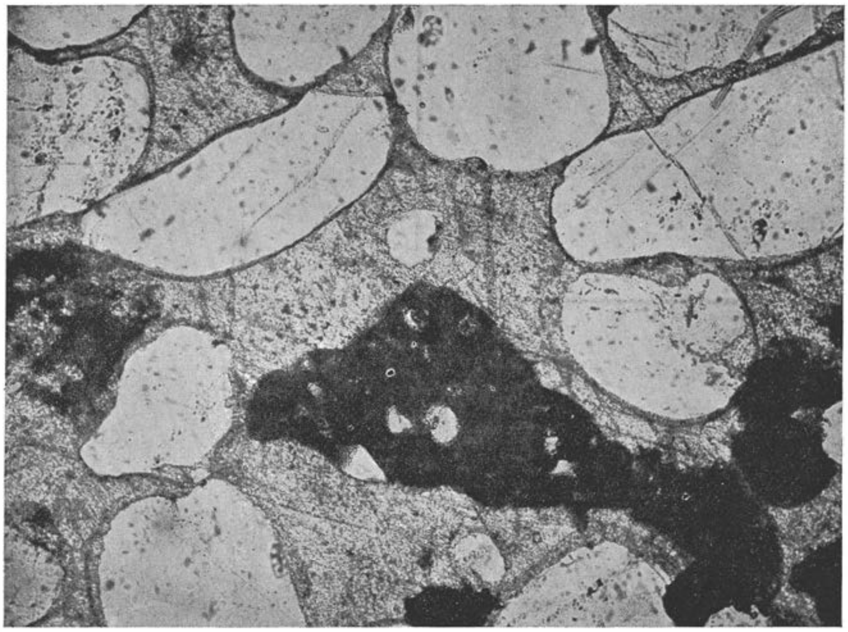

Fig. 5. Sandstone with matrix and cement of calcite, enclosing phosphorite and glauconite. Lower Cambrian. Brantevik, 9 b. (Pr. 2801. Pl. 363.) — 60 ×.

The carbonaceous material is sometimes uniformly spread, enclosing the grains or filling up the spaces between them (see figg. 6 and 7), sometimes more irregularly spread, accumulated in flocks. Not infrequently the sandstone is found in spots free from carbonaceous material. This is the case in certain parts of the sandstone at Munka-Tågarp in Scania and at Mörbylånga in Öland.

The carbonaceous material impregnating the sandstones consists of hydrocarbons, probably of different kinds. Sometimes they are of the character of asphaltum and occur as cement in the sandstone. Coal is not found minutely divided in this but in the form of larger and smaller fossilized fragments of plants. Such are particularly abundant in the Rhaetic-Liassic strata of Scania. In the metamorphosed sandstones the carbonaceous substance may occur in the form of graphite.

The cement

in the sandstones consists as a rule of quartz, calcite or limonite. The last-mentioned mineral is sometimes changed into haematite. Cement of pyrite, siderite and carbonaceous material is less common. The occurrence of the clayey substance and the glauconite as cement may sometimes appear obvious enough but is in fact more problematic.

The cement of silica occurs partly as secondary growth of the quartz grains and partly as a fine crystalline matrix between them. Secondarily formed quartz

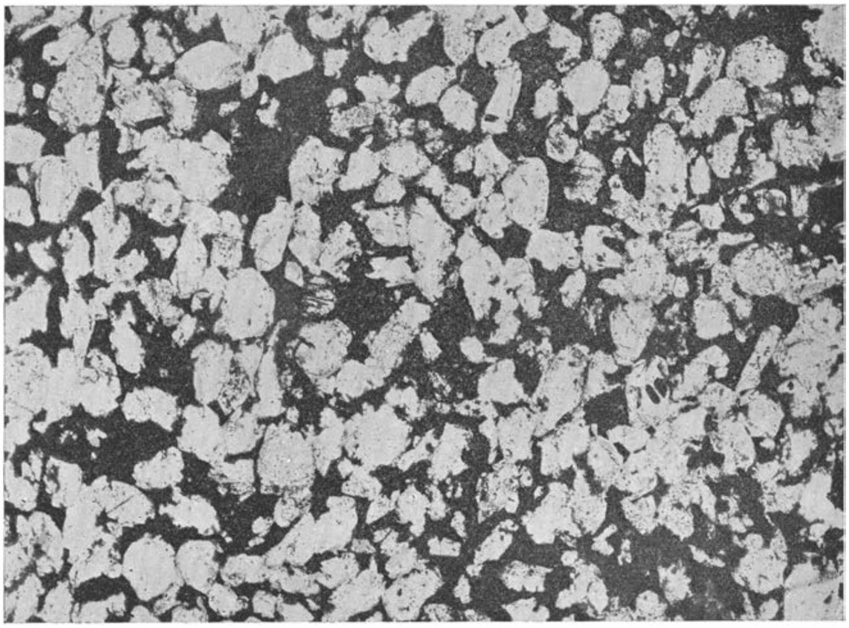

Fig. 6. Sandstone with bituminous matrix. Lower Cambrian. Mörbylånga, Öland. (Pr. 2228. Pl. 334.) 60×.

is often found as outgrowth of the quartz grains, even though the cement mainly consists of other material. Only in the purest sandstones does the secondarily formed quartz entirely fill up the pores between the grains thus giving the rock a crystalline character (»crystalline sandstone»). The limit between an original grain and the crystalline continuity is sometimes difficult to show. As a rule, however, it is distinguished by the coating (of haematite, clayey substance etc.) to be found on the grains, or by the inclusions found in the primary part of the quartz grains. Sometimes the secondarily formed part of the quartz occupies such a large amount of the mass that the original grains do not come in contact with each other. This is for inst. the case in certain forms of the Åhus sandstone. The grains must then have been either secondarily enlarged before their embedding or embedded in another material. In the present case it has obviously been the latter alternative. For in the interior of the secondarily formed quartz there are to be found scattered remains of a calcitic mass, that has enclosed the grains of quartz on the deposition and first cementation of the rock. On the calcareous shells in the same rock crystals of calcite are also present, the points of which are inserted in the surrounding, secondarily formed quartz (see Hadding 1927, p. 28, fig. 7). This often shows a peculiar zonal structure around the original quartz grains. The author has not observed

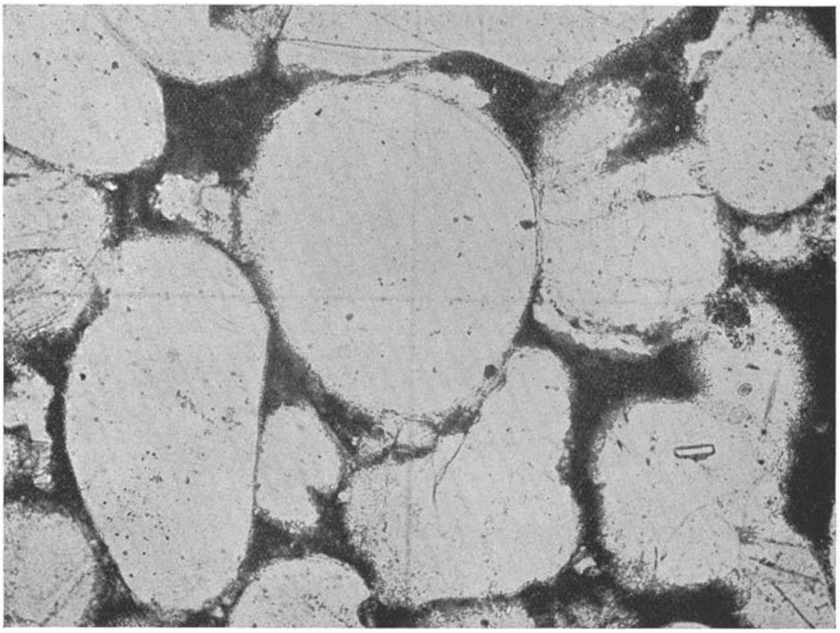

Fig. 7. Bituminous sandstone. Some of the quartz grains show secondary outgrowth. (See also fig. 53, 59 a. o.) Lower Cambrian. Karakås, Scania. (Pr. 2575. Pl. 373.) 60 ×.

a similar phenomenon in the sandstones, in which the secondary formation of quartz has taken place immediately around the quartz grains.

Though a replacement of calcite by quartz is not as distinct in any of the other sandstones as in the Åhus sandstone, similar observations have been made in many cases. It is far more common, however, that calcite occurs as a last formed matrix in sandstones, the pores of which have not been wholly filled up by the secondary growth of the quartz grains. Sometimes these calcitic crystalline sandstones are so rich in calcium carbonate that their cement of quartz is overlooked. Contrary to the calcareous sandstones they remain consolidated even after the dissolution of the lime by weathering. They differ macroscopically from the pure crystalline sandstones by a more granular, typically clastic appearance.

When the quartz cement does not form an enlargement of the quartz grains but an aggregate between them it is generally mixed with clayey substance, iron compounds, calcite or other material. The development of this quartz cement varies in one and the same sample. Fairly large quartz grains are often found in these cement-aggregates. They differ from the allochthonous grains by their diffuse outlines and their inclusions of clayey substance etc. However, the quartz is equally often more finely disseminated but is for the rest of the same character as the said grains. No doubt quartz cement, so minutely divided as not to be optically demonstrable, also exists. This is probably the case in well consolidated clayey sandstones. The clayey substance in itself is not sufficient to give the rock its solidity but we must suppose that it is silicified.

Talking of the quartz cement in the sandstones the author wishes to bring to memory that in the sandstone series siliceous rocks are also to be found, in which quartz grains are almost wholly absent, while secondarily precipitated silica is abundantly present. Such a rock has been found at Brantevik, in the upper part of the Lower Cambrian series of strata. In this rock the silica, in this case chalcedony, is formed after calcite by metasomatism.

The calcite cement is approximately as common as the quartz cement in the Mesozoic and Paleozoic sandstones of Sweden. In certain parts of the series of strata the latter cement dominates, in others the calcite cement.

The last-mentioned is either deposited at the same time as the sand or has been added later to the rock. The former is undoubtedly the case in the rocks where the calcite occupies such a quantity of the rock (> 30 %) that the quartz grains are not crowded. Entirely secondary, on the contrary, is the calcite in for inst. the cross-bedded delta sandstones and the coarse arkoses.

The development of the calcite cement is more varying than that of the quartz cement. This is no doubt due to the fact that the calcite cement has in many cases been secondarily recrystallized. Several examples of different development of the calcite cement might be added to those mentioned below.

The calcite cement is often found as a fine-crystalline mass in the fine-grained sandstones, especially in the impure, argillaceous ones. Sometimes the calcitic aggregate is so fine-grained that not even on high magnification is it possible to distinguish the different crystals.

More distinctly crystalline is the calcite in the pure calcareous sandstones. But in these rocks also the crystals are generally small. If the pores between the grains of sand are small, a single crystal is able to entirely fill up one of them. It is equally common, however, to find a pore space occupied by an aggregate of calcite crystals (fig. 8). Several of the marine calcareous sandstones have a cement of this type.

The calcite cement developed into macroscopically visible crystals is found here and there in the sandstones. Sometimes the crystals of calcite are 1 cm or more in diameter. This development of the cement becomes obvious by the reflection in the large cleavage planes of the calcite. The different crystals of calcite are studded with grains of sand and each of them fills up several pores. Cement of this type is mainly found in coarse sandstones and arkoses. As examples of this the Keuper sandstone at Nyhamn and the arkose at Lugnås may be mentioned. In both these rocks the calcite is secondarily added to the rock.

In the above-mentioned forms of development the calcite cement occurs fairly uniformly mixed with the grains of sand and the finer substance eventually present in the rock. Sandstones are, however, also found in which the calcite

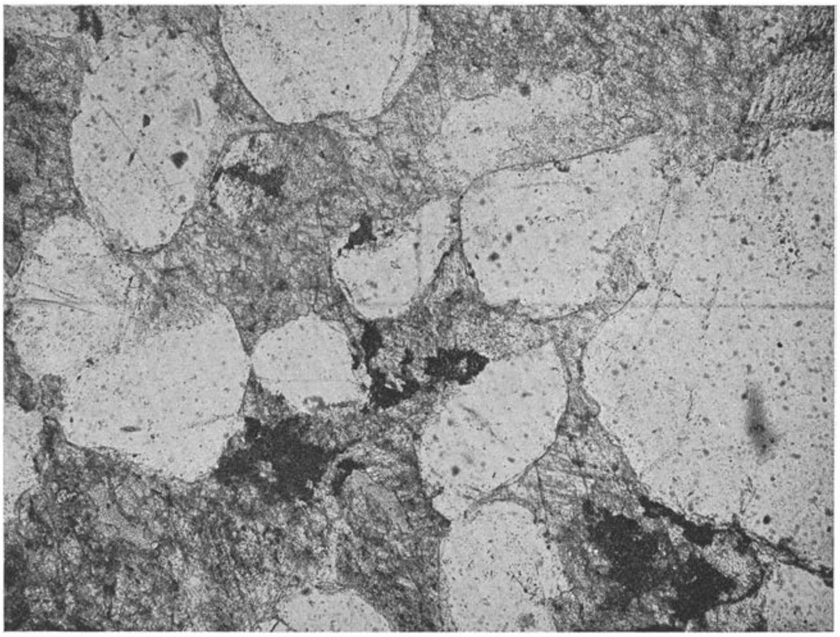

Fig. 8. Calcareous sandstone. Quartz grains cemented by fairly coarse crystalline calcite. Lower Cambrian. Karakås. (Pr. 2576. Pl. 374.) 60 ×.

cement is present more in form of lumps. Certain portions of the sandstone are richer in sand grains and eventual compounds of clay and iron, while others consist of fairly pure calcite.

The content of calcium carbonate in the sandstones is due not only to their calcareous cement but also to enclosed fragments of shells. Sometimes the latter contain an essential part of the content of lime in the rock. On the other hand sandstone beds rich in moulds of bivalves but without calcite cement are not infrequently found. Probably these rocks have had a primary cement of calcite, which has been dissolved at the same time as the shells have disappeared.

Limonite cement occurs in several places in the Paleozoic and Mesozoic sandstones of Sweden, but only in certain parts of the series of strata in larger quantities. Most pronounced is the limonite cement in the Liassic sandstones in SE Scania.

The limonite cement sometimes occurs as a relatively slight coating on the grains of sand, sometimes as matrix. Occasionally the limonite is so abundantly present that the quartz grains lie more or less sparsely scattered in it. The limonitic sandstone has then passed into an arenaceous limonite stone.

Certainly the limonite cement has not been formed in the same manner everywhere. In certain sandstones the cementation has probably been effected by a direct deposition of limonite from water solution (of ferrous carbonate or sulphate). The Keuper sandstones and the cross-bedded Liassic sandstones of NW Scania afford several examples of such a cementation. In other cases the limonite cement has been formed by alteration of an earlier deposited siderite cement. There is ample opportunity of studying this change in the Liassic sandstones of north-western Scania. The limonite is sometimes formed from other iron compounds. On weathering, the pyritic sandstones often show a transition into rust-coloured limonitic sandstones or they contain larger and smaller brown spots, in which a corresponding alteration has taken place.

It is a common phenomenon in the calcareous sandstones that the calcite is dissolved on the weathering of the rock and is partly replaced by limonite. This also occurs in rocks devoid of pyrite or other iron minerals. Thus the content of iron has been added to the rock by a water solution, no doubt of ferrous sulphate. Whether the deposition of iron has been effected by a substitution of calcium for iron in the carbonate and a later formation of the limonite or if this has been formed directly, is not evident from the nature of the sandstones the author has had the opportunity of examining (see p. 27).

Some of the limonite sandstones in the Liassic of south-eastern Scania have obtained their cement by decomposition of an autochthonous iron silicate of greenalitic type. Of this rather peculiar type a more detailed account is given elsewhere.

Several, especially older sedimentary rocks have been exposed to hard pressure and also to a dehydration of their minerals. If limonite sandstones have also been present among these rocks, the limonite has changed into haematite. No doubt many sandstones have obtained their *content of haematite* in this manner. In other cases the iron has perhaps occurred as oxide in the sandstone from the very beginning or the haematite may have been formed directly from siderite and silicates of iron. Not infrequently are haematite and limonite found together, both of them formed by oxidation of an iron compound (for inst. of the greenalite-like mineral in the Liassic strata at Kurremölla).

The development of the *haematite* in the sandstones is practically the same as that of the limonite. It is specially often found as irregular flocks or as a thin coating on the sand grains. It is also present to a large extent as filling in exceedingly fine fissures in the quartz or as impregnation of looser minerals, for inst. of the more or less kaolinized grains of feldspar. Sometimes the mineral is found uniformly spread in the beds, in other cases it is localized to certain laminae. These can be very thin and occur at even intervals and in very great numbers. In the lower Cambrian sandstone at Lugnås haematite-rich bands about 1 mm thick lie interbedded with equally thin, haematite-free ones. Their occurrence is often so regular that a formation by rhytmic precipitation might be imagined. That such a precipitation has really taken place is visible for inst. in the Kalmarsund sandstone. This shows sometimes besides a primary bedding, conspicuous by its varying size of grains, a secondary (false) bedding of haematite-rich bands crossing the real stratification.

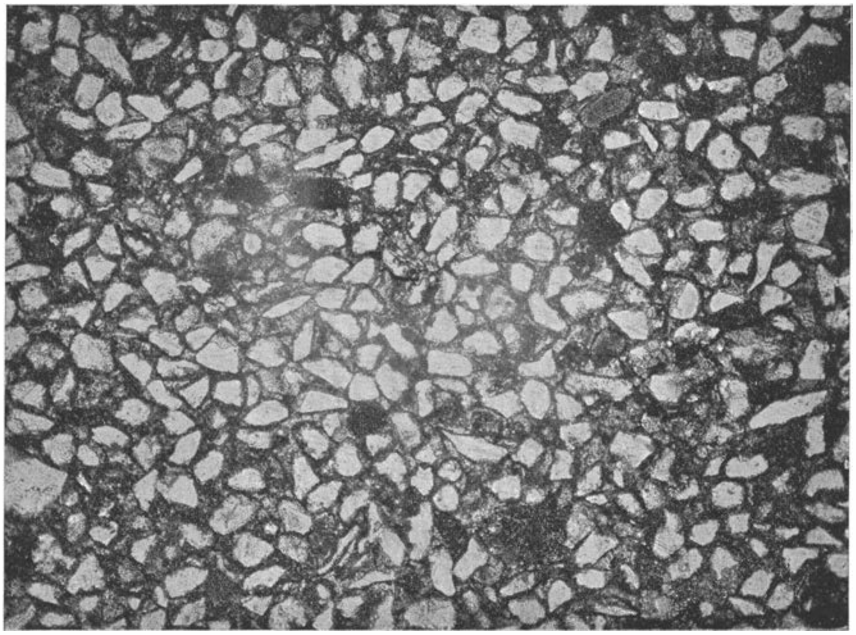

Fig. 9. Ferruginous sandstone. Small angular quartz grains cemented by siderite and limonite. Lias. The zone with Avicula inaeqvivalvis. Kulla Gunnarstorp, Scania. (Pr. 2549. Pl. 321.) — 60 ×.

Hitherto sufficient attention does not appear to have been paid to the importance of the *siderite* as cement in sandstones. The mineral is said to occur principally together with calcareous and clayey sediments (cf. for inst. Cayeux 1916, 223, Twenhofel 1926, 331, Clarke 1924, 581 and 544). Among the Swedish sediments the author has found a well developed series of sandstones in which the siderite is present as sole cement. These sandstones belong to the upper part of the Lower Lias. They are marine (contain a marine fauna), are remarkably even-bedded, fine- and even-grained and relatively free from mud but occur together with highly argillaceous strata.

In the above-mentioned sandstones the siderite is developed in the same manner as the calcite in the majority of the calcareous sandstones, i. e. as a fine-crystalline aggregate (see figg. 9 and 10). Contrary to the calcite it seldom shows distinct cleavage or twinning lamellae. In ordinary light it appears under the microscope as a slightly yellow fine-crystalline matter, with considerably stronger refraction than quartz. Between crossed nicols it shows a very strong double-refraction. Of course, it is evident already from a simple test with hydrochloric acid that the rock is not cemented with calcite.

An analysis of the siderite sandstone from Kulla Gunnarstorp gave the following result: FeO 16.48 %, Fe_2O_3 4.07 %.

On weathering the siderite sandstones change into limonite sandstones, sometimes so red that some haematite must also be present in them. The outcropping

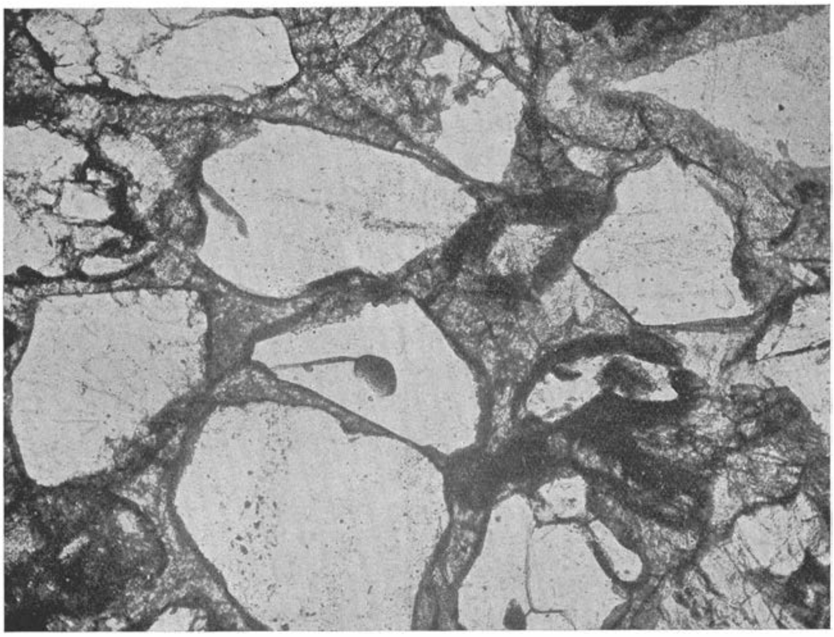

Fig. 10. Siderite sandstone. Angular quartz grains cemented by siderite. Lias. Fyledal, Scania. (Pr. 2859. Pl. 312.) — 60 ×.

beds of siderite sandstone in the shore sections at Kulla Gunnarstorp are only superficially weathered.

Siderite also occurs as clay-iron-stone and similar highly arenaceous, concretionarily occurring formations. Such are found, *inter alia* at Kulla Gunnarstorp, enclosed in the shale underlying the siderite sandstone proper.

The origin of the siderite in the sandstones mentioned is evident in so far as it has been formed either simultaneously with the deposition of the sand or by the metasomatism of another mineral deposited simultaneously with the sand. The necessity of this supposition is evident from the sand-grains being relatively scattered (see fig. 10).

If the siderite has been formed directly as matrix and cement, it may have been deposited from a solution of ferrous bicarbonate by loss of carbon dioxide.

In this case the formation has been analogous to the precipitation of calcite from a solution of calcium bicarbonate. There is however reason to ask oneself if such a ferrous carbonate formation is possible in the surroundings in which the sandstone has been deposited. The purity and even-grainedness of the sandstone show that it has been deposited in a basin where the material has been well sorted according to the size of the grains. Consequently it could not be a closed basin with still water. On the other hand the fine-grainedness, the even bedding, and the absence of tracks and ripple marks show that the deposition has not taken place in a more moving water, for inst. on an open shore or in a region with strong tidal currents. Bearing in mind these facts and the contents of marine fossils in the beds we may infer that the rock has been formed in a marine region, with relatively even bottom and a rather slight but constant current. Fossil fragments of plants are wholly absent in the siderite sandstone and it has an entirely different character from that of the rocks in the series of strata formed in shallow water regions with abundant vegetation. According to Twenhofel (1926, 331) ferrous carbonate is deposited under conditions that »are thought to abundantly obtain in the marshes and shallow waters of sea and coasts and river flood plains where the growing vegetation extracts the carbon dioxide from the water and the decay of the vegetation uses up the oxygen». However, the siderite sandstone at Kulla Gunnarstorp must be formed under other conditions.

It is not out of the question that the siderite has been formed by substitution of the calcite but no traces of such a replacement have been observed. The slight content of lime present in the rock is not localized to the central (not changed) portions of the beds but to the more weathered limonite-rich bedding surfaces. No doubt the calcite is here a later infiltration product formed after the alteration of the siderite into limonite.

The conditions of the sediments at Kulla Gunnarstorp do not allow a direct inference of the mode of formation of the siderite. It is therefore of interest that siderite sandstones of a partly different type are found at still another place in Scania and in the same series of strata (Liassic). At Kurremölla in SE Scania these rocks occur together with limonite-rich sandstones and iron oolites. In the freshest parts of these rocks the cement consists of a green, optically isotropic substance, according to analysis mainly consisting of ferrous oxide. Its character and formation will be discussed elsewhere (see also p. 21). The green mineral is readily altering. In the sandstones it is mostly changed into ferrous carbonate (siderite), ferric oxide (haematite) and above all into ferric hydrate (limonite). Of greatest interest here is the quite distinct grading into siderite. This mineral then is a secondarily occurring cement in these rocks.

On summarizing our observations on the siderite as a cement in the sandstones we may say that it plays a greater rôle than has hitherto been imagined. In certain cases the formation of the mineral is distinctly secondary (after isotropic mineral rich in FeO) but in other cases it may be primary, autochthonous. On the weathering of the rock the sideritic cement mainly changes into limonite.

Cement of pyrite is sometimes found in the sandstones but as a rule it is confined to smaller portions in the beds. These pyrite-cemented portions are usually rounded in form, just as the normal concretions. Their size varies from a couple of millimetres to several centimetres.

Besides in these concretion-like formations the pyrite is sometimes found fairly evenly distributed in sandstone beds. The mineral has then been formed simultaneously with the sandstone. Its cementing character is somewhat dubious in certain cases, especially when the pyrite occurs as a black, cryptocrystalline powder. But in other cases its cement nature is distinct enough.

Sometimes *the phosphorite* may occur as cement in the sandstones, but as a rule the mineral is present in the same limited form as the pyrite. Where the phosphorite occurs primarily in a sandstone it is so studded with grains of sand that it (the nodules) may be termed phosphoritic sandstone. (The author prefers to reserve this term for sandstone with phosphoritic cement in contradistinction to »phosphorite-bearing sandstone» containing phosphorite independent of the occurrence of this mineral as cement or in the form of pebbles.) Sometimes the content of sand is so much larger than the content of phosphorite that this can only be designated as a sandstone with scanty cement. Nodules of this type from Gothland have recently been described by HEDSTRÖM (1928) and the author has often found similar ones in the Cambrian sandstones.

The phosphorite may also be fairly evenly distributed in a sandstone bed. Thus the black Lower Cambrian sandstone in NW Dalecarlia contains a fairly constant content of phosphorite in some of the beds. As far as the author knows it does not occur as pebbles in these beds but as a minutely divided matrix and cement between the grains of sand. Judging from the samples at the author's disposal, the formation cannot have occurred in such a manner that a number of nodules have grown together into a bed (as is the case for inst. at Brantevik; see p. 31) but the phosphorite has instead, judging from its occurrence and the nature of the rock, originally been fairly evenly deposited in the sand as a mass more or less completely cementing the whole bed.

To count the *glauconite* as one of the minerals forming cement in the sandstones might perhaps be erroneous. It is more correct only to state its occurrence as cement-like in certain cases. In the cases in question here the glauconite is not developed into rounded grains but into a mass of irregular form squeezed in between the grains of sand. It has, however, a distribution of only one or two millimetres. The impression is easily gained that the glauconitic substance has been accumulated in grains which have been squeezed out by the sand-grains and thus filled up the pores between them. The procedure is quite natural if we imagine the glauconite to be formed as small lumps of a gelatinous mass and in such a state embedded in the sand. By supposing the said formation we also obtain a natural explanation of the fact that the glauconite never occurs cementing larger portions but only scattered in the same manner as when it is developed into undeformated grains. A deposition of more extended portions of glauconite is sometimes found but in the Swedish sediments it has only been observed as a coating on shells and blocks.

The colour.

The colour of the sandstones is dependent on the nature of minerals and above all of the matrix and the cement.

Just as the pure quartz sand is *white*, the purest sandstones are of the same colour. As a rule the white colour remains unchanged even though the sandstone contains light mica and a smaller amount of feldspar, especially if the latter is somewhat kaolinized, as is usually the case. But sometimes the grains of quartz may give the rock a darker, gray colour, as is often the case in coarse sandstones, for inst. in certain of the sandstones at Hardeberga. The cement in the white sandstones consists of quartz or calcite.

When dark mineral particles occur in the matrix or the cement the sandstone obtains a *gray* colour. A perceptible content of dark sand-grains may of course also have this effect but no examples of this type are found among the sediments examined. If the dark substance increases, the colour changes into darker gray or *black*. The substances observed as giving the sandstone a gray or black colour are: clayey substance, pyrite (in form of powder), bitumen, phosphorite and in certain cases glauconite. The colour is seldom a pure gray but shows as a rule a bluish, greenish or brownish tinge. Thus the sandstones coloured by clayey substance are often bluish or greenish gray. If the colouring matter consists of phosphorite or bitumen, the rock sometimes shows a slight brownish tinge quite distinct by transmitted light.

The *green* colour may be derived from chloritic or clayey substance, glauconite or ferrous compounds. In the series of strata examined the colouring by glauconite is most common. The marked variations in colour shown by the grains of glauconite will of course also effect variations in the green colour of the rock.

The *red* sandstones are either rich in relatively fresh feldspar or they contain ferric oxide. An exceedingly good example of red arkose coloured only by the feldspar is the basal bed of the Lower Cambrian sandstone at Gislöv in Scania. Sandstones coloured by iron oxide are found everywhere in the series of strata, and red rocks dominate entirely in certain parts of these. This for inst. is the case in the youngest Silurian and parts of the Keuper. The pigment of iron oxide can be present in such abundance that it forms an essential part of the filling between the grains. But it is often found in relatively small quantities, sometimes only as a thin coating round each quartz grain. Occasionally the iron oxide occurs in very thin layers separated by more iron-poor ones. In such cases the content of iron can be due to secondary infiltration (see p. 22). This is obviously the case in several sandstones also, for inst. in the red *Scolithus linearis* sandstones. By the admixture of the iron oxide with some other substance variations arise in the red colour.

The *brown* colour in the sandstones is in most cases derived from an admixture of ferric hydroxide. On an abundant and compact occurrence this is of a dark brown, sometimes blackish brown colour. When present only in smaller quantities or in a looser, earthier form it gives the rock a lighter brown colour.

Brown sandstone coloured by limonite is found partly as limited portions in certain beds and partly in whole beds, sometimes even in several successive ones. In the Swedish pre-Quaternary sediments the limonite sandstones are most widely spread in the Liassic series. The brown spots coloured by limonite that are often found in the white or light gray sandstones, are frequently formed by weathering of pyrite nodules. This is, however, not always the case. The author has made the observation that in several sandstones where the weathered rock contains brown limonite-coloured spots, the fresh rock contains small lumps of calcite or a concretionary enriched calcitic cement in a sandstone otherwise quartz-cemented. The brown colours in these rocks have no doubt arisen in this manner, the calcite has been replaced by limonite by metasomatism when the rock has been broken up by weathering and begun to be percolated by water with dissolved salts of iron (see also p. 21). The more wide-spread the calcitic cementation, the larger the brown spot. In the brown spots the sand-grains are less well cemented than in the surrounding parts of the rock. There is reason to suppose that part of the calcite has been dissolved and carried away without being replaced by limonite. Has the rock been wholly calcite-cemented (= calcareous sandstone), the alteration will produce a brown, porous, somewhat loose sandstone.

In the siderite sandstones a brown colour is also found, not so much owing to the light brown or straw-colour of the siderite but rather owing to new limonitic and haematitic products of alteration. By reflected light the rock usually shows a relatively dark colour, by transmitted light on the contrary it becomes light brown or slightly yellow.

As mentioned above phosphoritic and bituminous sandstones also show a brown colour by transmitted light.

Yellow colours are rare in the sandstones. A local colouring, arisen on the weathering of the pyrite, from free sulphur is sometimes found in the pyrite-bearing Lower Cambrian sandstones. Sometimes the ferric hydroxide can also give the rock a more yellow than brown colour. This is especially the case when it occurs in only small quantities. In the siderite sandstone, on the contrary, the author has never observed a yellow colour. The fact is remarkable, as the siderite-rich limestones are intensely yellow in colour (for inst. in the Orthoceras limestone).

The inclusions of Mineral aggregates.

Together with the grains of sand and the matrix and cement enclosing and binding them, the sandstones often contain inclusions of one kind or another distinctly limited in size and character. Not infrequently they are characteristic to the rock and give us good guidance in judging its forming conditions.

Often the inclusions are concretionarily formed mineral aggregates generally without the radiate and concentric structure of the crystalline concretions. Their size varies from a fraction of a millimetre to several centimetres. They can be either autigenous or allotigenous. The latter have earlier been embedded in older sediments, in which they have been autochthonously present.

The commonest inclusions in the sandstones are pyrite, calcite, siderite, phosphorite, and glauconite. As mentioned above these minerals also occur as cement or matrix in the sandstones. In the following their occurrence as occasional, more or less characteristic inclusions will be illustrated.

The pyrite is common in the sandstones both in the form of small loose crystals and concretionary nodules. (Its occurrence as a fine dust is mentioned above; see p. 25). The concretions are mostly from 1 to 5 cm in diameter. As a rule they are fine-crystalline, seldom distinctly radiate. They are most abundant in the calcareous sandstones. In all cases observed by the author the pyrite nodules have been autigenously formed. Generally they only contain a small amount of the grains of the rock and differ in this respect from certain other autigenously formed mineral aggregates, for inst. calcitic concretions and phosphorite nodules. Attention has already been called to the fact that the pyrite can also be studded with grains of sand (pyrite cement, p. 25).

Concretions of calcite[1] are mostly known from highly argillaceous rocks but they also occur in arenaceous sediments. Sometimes these concretions are so numerous that they give the rock a conglomerate-like appearance (cf. Hadding 1927, 161). In some cases they are best visible on the weathering of the rock (see p. 27). The lumps of calcite are always studded with grains of sand, unless they are formed as fillings of fissures and cavities in an earlier consolidated rock.

The calcite has been deposited from water solution after the deposition of the sand. Consequently it has practically been formed in the same manner as the secondarily deposited cement of several calcareous sandstones.

The difference is that the calcite has, in the one case, been deposited around certain centres and so sparingly that the rock has not been cemented in its entirety, while in the other case the deposition has probably taken place simultaneously around a great number of the sand-grains which have thus been bound

[1] Here as in the following the author uses the term concretion of a closed aggregate arisen by deposition from a water solution. Where a growth has taken place it has been from within outwards. As a rule growth-layers are not seen in the smaller aggregates.

together. There are also examples of a formation of calcite along both these lines in one and the same sandstone, for inst. in certain of the Keuper sandstones in Scania.

Siderite nodules are present in the sandstones occurring together with beds of siderite sandstone. With regard to their formation these nodules are analogous with the nodules of clay-iron-stone in highly argillaceous sediments. Like these they are sometimes rich in material from the surrounding rock (grains of sand or clayey substance), in other cases on the contrary they are fairly free from

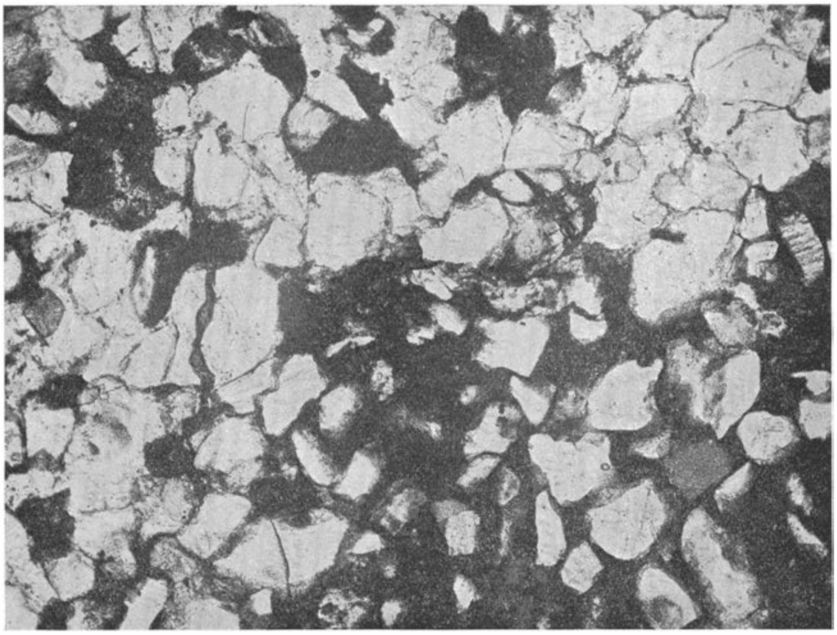

Fig. 11. Sandstone with phosphorite on primary deposit. The quartz grans are locally cemented by phosphorite. The lower right part of the fig. shows a small part of a phosphorite nodule containing an abundance of quartz grains of the same size and shape as in the surrounding rock. Lower Cambrian. Brantevik, 6. (Pr. 2796. Pl. 364.) — 60 ×.

such admixture. The smaller concretions are rarer in the sandstones than in the clay beds. As a rule the siderite is found in the interior of the sandstones in the form of larger or smaller nodules of siderite sandstone, unless the mineral is evenly distributed in whole beds of this rock. Practically the siderite as well as the calcite is more frequently found as concretionary aggregates in the sediments of clay than in the sandstones. As a rule the deposition of carbonate has been more evenly distributed in the coarser sediments (more permeable to water) than in the finer ones.

As mentioned above, (p. 25) the *phosphorite* sometimes occurs as cement fairly evenly distributed in a sandstone. Far more frequently, however, it is found in form of nodules enclosed in sandstone or limestone. The great sediment-petrographical interest connected to this mineral and to the glauconite, its appendage in several rocks, is the reason why the author wishes to spare a special part of the series already begun for these two minerals. This also seems the more well-grounded as a very rich and varying material of them is contained in the Swedish sediments. For the said reasons it might seem unnecessary to say anything more now of the two minerals but the author thinks that he ought already here to give a short survey of their development and occurrence in the sandstones.

The phosphorite occurs in the sandstones not only as an autigenous but also

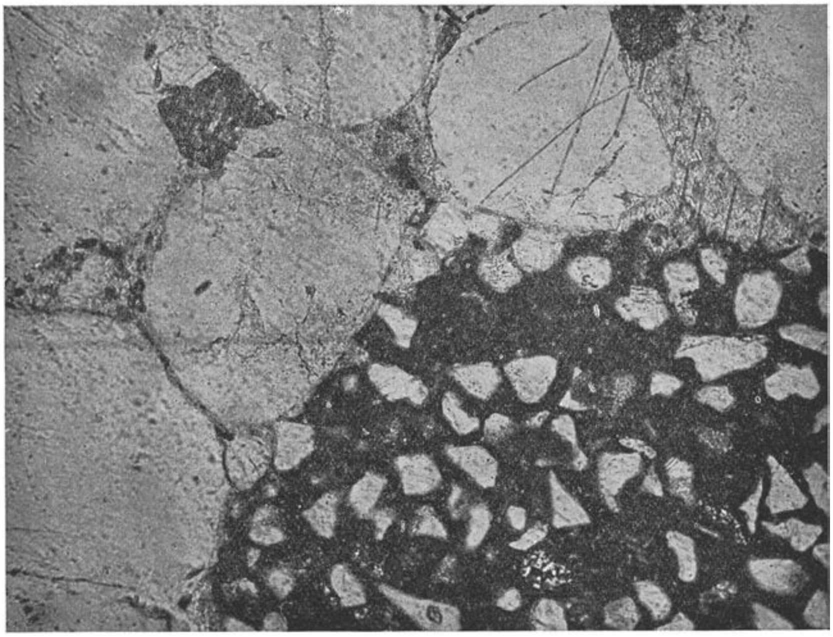

Fig. 12. Sandstone with phosphorite on secondary deposit. Phosphorite nodule, containing small angular quartz grains, embedded in a coarse-grained calcareous sandstone with well rounded quartz grains. Lower Cambrian. Hardeberga. (Pr. 2683. Pl. 341.) — 60 ×.

as allotigenous mineral. The author infers this from the fact that phosphorite nodules of different kinds can be seen in one and the same sandstone bed. Where the phosphorite occurs autigenously it is, like the concretions of calcite, studded with sand-grains of the same type as those in the rock. As a rule these nodules are irregular in outline, sometimes with a somewhat diffuse demarcation. The rounded, worn pebbles can also contain grains of the same character as the surrounding rock but as a rule their grains are of a different size, kind and wear. Usually the worn phosphorite nodules in a sandstone contain finer, less rounded grains than those found in the surrounding rock. This shows, according to the author's opinion, that these phosphorite pebbles have been formed at a place where finer, more angular sand-grains have been deposited. Consequently their occurrence in the coarser sandstone is secondary. The fact that the phosphorite contains grains of glauconite even when grains of this kind are absent in the phosphorite-bearing sandstone further supports this opinion.

Where the phosphorite nodules occur secondarily enriched they form a real conglomerate, where they occur autigenously they form at most a pseudoconglomerate, next comparable to one formed from concretionarily enriched calcitic cement.

Like other conglomerates the secondarily enriched phosphorite is confined

Fig. 13. Phosphorite bed in Lower Cambrian sandstone. Brantevik, 11.

to certain horizons, denoting a change in the sedimentary conditions. Generally this change is otherwise also conspicuous in the character of the rock.

The primarily occurring phosphorite is also confined to certain horizons, but not for the same reason as the former. No change worth mentioning is noticed in the horizon where the autigenously formed phosphorite is found. The occasional deposition of the calcium phosphate may take place without any other change in the sedimentary conditions to be seen in the rock.

In certain quarters the opinion has been expressed that the phosphorite has been formed in the littoral zone. No doubt this opinion has been based on observations on secondarily occurring nodules of phosphorite, without any knowledge of this character in them. The phosphorite can be formed where a fairly coarse sand is deposited, as is found from certain occurrences of phosphorite at Hardeberga and Brantevik, but in none of the cases known by the author can this deposition be said to have taken place in the littoral zone or in its immediate neighbourhood [1]. The characteristics indicating a deposition in very shallow water and found in so many of the other sandstone beds in the phosphorite-bearing series of strata, are absent in the beds with autigenously formed phosphorite. On this account we may suspect that the phosphorite has been formed at a somewhat greater depth than the said sandstones. Another reason to place the formation of the phosphorite at a distance from the shore is the fact, called attention to above, that the phosphorite nodules generally contain a considerably more fine-grained material than the coarser rocks in which they have been embedded by secondary enrichment and which are formed closer to the shore.

The above proposition to place the formation of the phosphorite nodules wholly outside the littoral zone and at greater depth than several phosphorite conglomerates apparently indicate, must not be interpreted as a wish to place the formation in very deep water. No doubt the entire Lower Cambrian series of strata in for inst. Scania is formed at a slight depth, probably not exceeding 100 m. Within this limit, then, the formation of phosphorite must also have taken place. However, the author wishes to emphasize that the formation of phosphorite can not be counted among the phenomena typical to elevations of land and regressions. In this respect, on the other hand, the secondary enrichments are of the same importance as the intraformational oscillation-(regression-) conglomerates.

The phosphorite nodules vary somewhat in colour. The black or blackish brown nodules are most common but even lighter grayish brown and gray are not infrequent. They have a dull lustre even on a fresh fracture surface. Worn, polished grains have often a glossy surface. Even the small phosphorite grains regarded as coprolites and abundantly present in certain rocks have a high lustre.

Like the phosphorite the *glauconite* is a mineral confined to certain parts of the series of strata. It never occurs, as the phosphorite, in larger lumps but only in the form of small grains, seldom exceeding 2 mm in diameter. The grains are sometimes distinctly rounded in form, sometimes irregular and dependent on the surrounding grains of sand. In the latter case is the mineral cement-like in its occurrence (see p. 25). Here the glauconite must be supposed to have been formed at approximately the same time as the sandstone and to be a primary deposit (autigenous component). Obviously the rounded grains, on the contrary, have in many cases been worn during transport. In these cases they are somewhat older than the layer in which they lie embedded, and are then secondary deposits in it (allotigenous components). Consequently the glauconite may occur as allotigenous or autigenous mineral in a sandstone. On judging its sediment-petrographical importance this circumstance must of course be taken into consideration.

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[1] Littoral zone is the term used by the author for the shore between high and low water level.

We shall not dwell here on the different types of sandstones, in which the glauconite occurs. We shall be content to ascertain, that the Swedish rocks further support the prevalent opinion that the glauconite is wholly connected to the marine sediments. In the rocks in question the mineral is formed at a slight depth but occurs only as a secondary deposit (allotigenously) in the sandstones of the littoral zone.

As a rule the glauconite is distinctly crystalline but is seldom developed into so coarse aggregates that optical determinations can be made on the separate

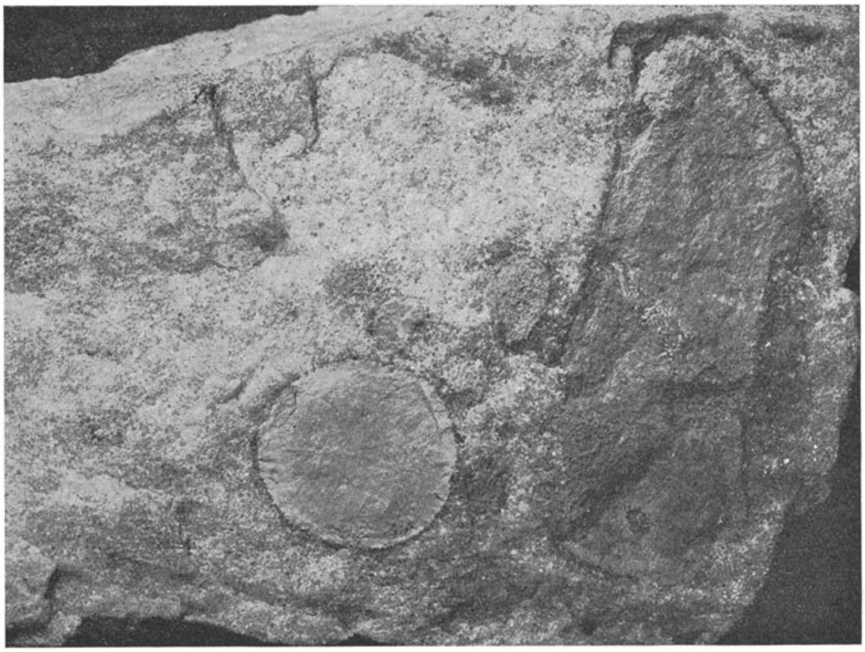

Fig. 14. Rounded clay slabs in Lower Cambrian sandstone. Plane parallel to the bedding surface. Hardeberga. — $^1/_1$. (Pl. 258.)

crystals. These have either a prismatic or a fibrous development. The colour varies from blackish green to pale grayish yellow, but is usually distinctly green.

Clay pebbles and clay galls. Rounded clay pebbles or thin clay galls are not infrequently found in the sandstones. They occur sometimes in occasional samples, sometimes accumulated in great quantities.

The material in the clay galls is entirely of the same character as the material in the clay layers interstratifying the sandstone beds. Consequently the clay galls must be broken-up more or less rounded parts of such clay layers. In the Lower Cambrian standstone at Hardeberga clay galls and slabs occur, from 1 to 20 cm in diameter or even larger. Galls from 2 to 4 cm in diameter are, however, most common. Such are found in most sandstone series, for inst. in the Lower Cambrian sandstones in Scania, Vestergötland and Lapland, in the sandstones of the

Visingsö series, in the Silurian sandstones at Klinta, Öved and Ramsåsa, and in the Scanian Keuper-Liassic sandstones.

The formation of the clay galls implies that the clay bed from which they have been derived, has been somewhat consolidated before being broken up. The consolidation may have been effected by drying up when the bed was elevated above the water level, and it may of course also have been effected by the bed for some time being buried beneath sediments deposited on it. In both cases the formation has taken place on a shore in or close to the littoral zone. A subaerial formation

Fig. 15. Clay flags in Lower Cambrian sandstone. Plane transverse to the bedding surface. Hardeberga. — 1/1. (Pl. 273.)

of clay galls is of course also a possibility to be thought of but is out of question in all the cases which the author has had the opportunity to study. Recent clay galls of subaerial as well as subaquatic formation are known (see for inst. WALTHER 1894, 847 and RICHTER 1926, XVI.).

The lumps of clay found in the sandstones are sometimes accumulated in such abundance that they give the rock the character of a conglomerate. The pebbles are always well rounded, often of an elliptic longitudinal cut. They are varying in size, mostly from 2 to 6 cm in length.

The material in the clay pebbles varies somewhat. Sometimes they consist of a soft, plastic gray clay, in other cases of harder clay or of clay-iron-stone. Possibly the harder pebbles have in some cases been firmly cemented before being broken loose and rounded but in other cases the cementation has taken place after the embedding. This is evident from the fact that the pebbles are, in these cases, studded in the surface with coarse sand-grains, while such grains are absent in their interior. On the weathering of the pebbles the grains have sometimes been detached so that only their impressions are visible on the pebbles.

The clay pebbles have been formed analogously with the clay galls but from thicker layers of clay. Where the pebbles are derived from partly already cemented deposits their wear and enrichment have been effected in the same manner as the formation of certain intraformational conglomerates (Hadding 1927, 74 and

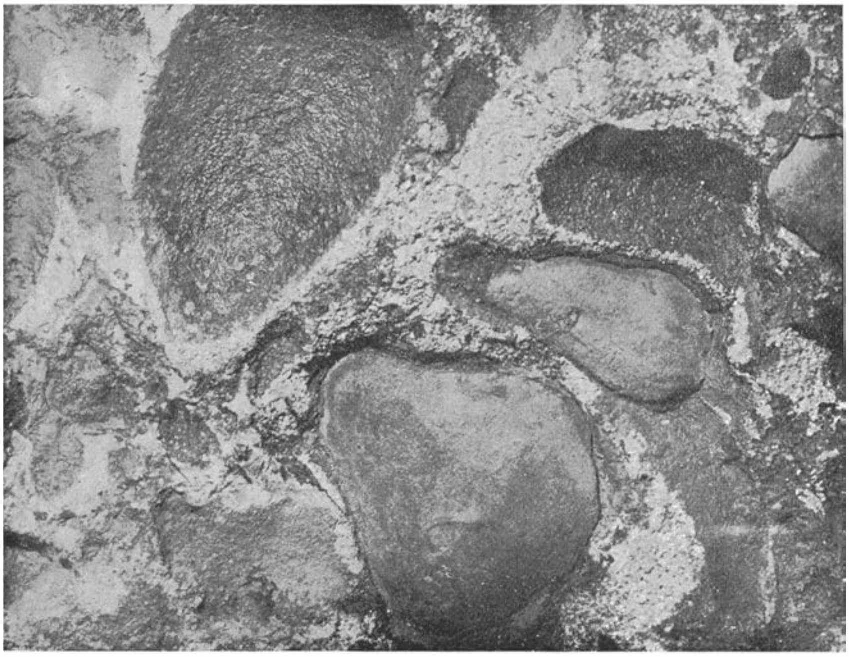

Fig. 16. Rounded fragments of clay ironstone in Liassic sandstone. Kulla Gunnarstorp. — $^1/_1$. (Pl. 228.)

149). The loose, unconsolidated, argillaceous material has been washed away and only the hardest lumps have been left embedded in the coarser strata of sediments that have been deposited.

The Content of Fossils in the Sandstones.

One of the most specific characteristics of the sedimentary rocks is their content of fossils. The fossils in a rock always deserve the greatest attention, as also in judging the rock's petrographical character and conditions of formation. It is then not only of interest to study the nature of the fossils (the faunistic character of the rock), which to a certain degree reflects the conditions under which the sedimentation has taken place (for inst. marine — shallow water) but also their state of preservation and their general occurrence. These often give valuable information as to the formation and diagenesis of the rock.

The state of preservation of the fossils.

Well preserved fossils can be found in the sandstones but they are far from common. As a rule only fragments are found in these rocks and they are also frequently worn or deformed by dissolution. The state of preservation is not

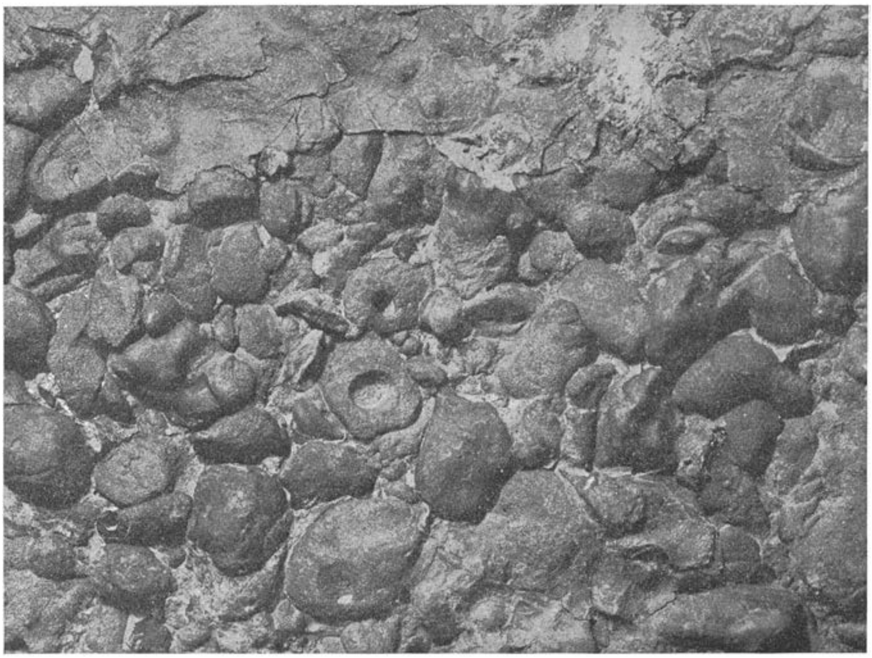

Fig. 17. Intraformational conglomerate with pebbles of clay ironstone in Rhaetic sandstone. Helsingborg. — $^1/_1$. (Pl. 234.)

only dependent on the conditions of sedimentation but also on the fossils' own nature. Thin shells are easily broken and therefore they are only present in a fragmentary state in coarser sandstones. But in more fine-grained sandstones richer in matrix (for inst. the highly calcareous or clayey sandstones) brittle fossils are also found preserved.

Fossils built up of calcium carbonate have suffered most severely from the dissolution.

Sometimes they have been entirely removed by solution, in other cases their nucleus remains. On the whole the dissolution of fossils is for obvious reasons stronger in the sandstones, especially in those poor in lime, than in the more fine-grained sediments of clay and in the limestones. The fossils built up of silica should form an exception to this rule but they play no rôle whatever in the sandstone in question.

If the fossils embedded in the sand are dissolved before the cementation of the sand they are entirely obliterated. But usually the dissolution takes place in connection with the consolidation, and the cavity left by the fossil may then remain. Instead of the fossil we find a mould of its different sides, and in this is often seen a reproduction even of fine details in the sculpture.

The cavity formed after a dissolved fossil (the mould) can have been filled up

Fig. 18. Moulds of lamellibranchs in red sandstone. Upper Silurian. Klinta, Scania. — $^1/_1$.

afterwards by a later deposition from water solution. Calcite is mostly found in relatively coarse aggregates in such casts. A new formation or change of substance can also take place, without previous formation of a cavity. However, the author has seldom observed this in the sandstones but the more frequently in the limestones, and on that account he does not think it necessary to enter on the different possibilities of such a change, exemplified in the Swedish sediments. As examples only a phosphatization of calcite shells in certain Cambro-Silurian sandstones, a siderite pseudomorph of calcitic lamellibranch shells in Liassic strata and a chalcedony pseudomorph of sepula tubes in the Tertiary sandstones may be mentioned here.

The general occurrence of the fossils in the sandstones.

In the sandstones as well as in the other sediments the distribution of the fossils is very irregular. While certain beds may be full of fossils, they can be wholly absent in both over- and underlying strata. An irregular distribution is often found in one and the same bed also, so that certain parts of it, either the bedding surfaces or (a part of) a certain horizon in the bed, contain an abundance of fossils, while other parts have none or only few. The reason of this irregular distribution is partly variations in the development of fauna and flora during the deposition and partly varying conditions of sedimentation. When the oyster-banks during the Lower Lias underwent a period of powerful development on the western shore of Scania, an abundance of shells were embedded in

Fig. 19. Casts of *Pullastra elongata*. The shells were buried when the animals were alive and the shells already half buried in clay. Lower surface of sandstone bed. Rhaetic. Ramlösa, Scania. — $^1/_1$.

the sand. Later on under changed conditions when no molluscs could thrive any more in that region, though a deposition of sand continued, the embedding of shells in the sand naturally ceased. Such examples of the influence of the biological factors on the distribution of fossils are found everywhere in the fossiliferous series of strata.

Approximately the same factors influence the horizontal distribution of the fossils as well. In the so-called *Ostrea*-bed in the Lias of Scania the shells are by no means as equally abundant in the one place as in the other. The variations are still more noticeable in horizontal directions in other beds or zones. If these can be followed over larger distances a complete change in the faunistic as well as the petrographical character of the rocks is sometimes found. In such cases the local conditions characterize both the fauna and the formation of sediments. In the zone with *Belemnitella mucronata* in the Senonian of Scania we find a typical example of this. In SE Scania this zone is developed as a glauconite-bearing calcareous sandstone or sandy limestone with sparse, scattered fossils (cephalopods, lamellibranchs, echinids), in NE Scania as a shell limestone almost wholly built up of fragments of shells (mostly lamellibranchs), while in SW Scania it consists of chalk poor in macroscopical fossils (mostly siliceous sponges) but rich in microscopical ones (coccolites). Similar variations are found in every zone, even though they are not always as great in a smaller region as in the case related. On analysing the paleographical conditions during the different sedimentary periods it is of the greatest importance to be acquainted with these variations. In the concluding part of this series the author intends to give an analysis of the said facts and will then essentially dwell on the reflection of the local conditions in the development of the fossils and the rocks.

Of course, a local and sporadic occurrence of fossils of a certain kind or an occasional accumulation in great quantities must not simply be connected with a general change in the biological conditions of the basin of deposition. Occasional changes in the conditions of deposition can sometimes be noticeable both in the content of fossils and the petrographical character of the rocks.

The position of the fossils in the sandstones.

Practically the fossils occupy the same position in the sandstones as in other sediments. If they are extended in one or two directions, they usually lie with these directions in or parallell with the bedding surface. But there are exceptions to this rule. Shells of bivalves are occasionally found huddled together in all positions. Sometimes all the shells can be found in an upright position, as for inst. in the *Pullastra* bed at Ramlösa (fig. 19). The small bivalves (*Pullastra elongata*) have been embedded in the sand and half buried in clay, while the animal was still alive. The shells are closed and are found in the same position as they occupied when alive. The shells are now completely dissolved and only the moulds of their lower, formerly buried part remain.

Most valves lie as is usual with the convex side upwards. The importance of this in determining the foot-wall and hanging-wall of a bed is well known (see below).

Fossils of plants may occupy a primarily upright position. This is for inst. the case in certain of the Rhaetic sandstones. Sometimes the trails and burrows have also a primary vertical position (see p. 43).

Fossils typical of the sandstones.

If we wish to discover which fossil forms of animals and plants are characteristic to the sandstones, we must first determine which of them occur primarily in these rocks and which have been added to the rock by secondary rearrangement or more occasional embedding. Pure plankton forms sometimes occur but they cannot be regarded as characteristic. Other elements equally foreign to the sand fauna may on the other hand be typical to the sandstone-series in so far as they are only found in them. This is true of for inst. the medusae. No markings (moulds or casts) of these are found, unless they have been embedded in the sediments under certain favourable conditions. As these conditions only occur in the littoral zone in an open region with deposition of sand and clay the casts of medusae are confined to the argillaceous sandstones.

No doubt shells of lamellibranchs are the most usual in the Swedish sandstones. They can not however be said to be derived from forms living in areas

Fig. 20. *Medusina.* Lower surface of a sandstone bed. Lower Cambrian. Lugnås. — $^1/_1$. (Pl. 241. S. Hjelmquist foto.)

with sand deposits. As a rule the shells are not to be found at the place where the animal lived. In many cases we can also infer that the animal would not have thrived and developed under such conditions as those which existed on the formation of the sandstone.

From these and other similar examples we may infer that the fossils in the sandstones to a large extent are forms that have not lived on or in the sand in which they have become embedded. Concerning a great number of them, however, we may conclude that they have not been transported any longer distance. There are then good grounds to consider them as typical admixtures in the sandstones, even though we prefer to term them »littoral forms», »shallow-water forms» or the like. Real sand forms, however, are not lacking (see below on the tracks) but their occurrence is limited and in many cases no doubt difficult to demonstrate.

The groups of animals mostly found in the Swedish sandstones are lamellibranchs, brachiopods, hyolithes, gastropods, ostracods and trilobites. Other groups are not so well represented, for inst. cephalopods (a. o. ammonites), echinoderms, foraminifera (fairly common in the Tertiary sandstones), and graptolites.

The fossils of plants are essentially preserved as carbonized fragments or as impressions. Sometimes the latter show an exceedingly well preserved surface sculpture.

The Tracks and Trails and Burrows in the Sandstones.

In several sandstones tracks and markings of different kinds form a characteristic feature. Like the fossils they are of importance for the interpretation of the forming conditions of the rock. On that account we can hardly forbear to pay some attention to them. A description of the different tracks, trails and burrows, however, just as a description of the fossils of the sandstones is out of question here. Only of the most important types and their occurrence will a short illustration be given.

With regard to the mode of formation we can distinguish the following among the tracks or track-like formations observed in Swedish sandstones:

a. *Trails*: formed when a body has been moved by for inst. waves or currents and then been dragged against the bottom;

b. *Trails and tracks*: formed when an animal has moved dragging its body on or in the deposited sediments;

c. Track-like tubes, *burrows*, built by animals in the sand;

(d. *Foot-prints* formed when animals have walked on the sand).

To these markings others of purely inorganic formation may be added, as for inst.:

Mud-cracks and casts of such;

Rain prints and rain-drop impressions.

These and others will be mentioned in the following account of the character of the bedding surfaces (p. 46).

The trails of type *a* are present almost everywhere in the sandstones deposited in shallow water, if these are fine-grained and contain some clayey substance. These trails are specially numerous in the Lower Cambrian sandstone in Västergötland. The commonest type of trails in this sandstone has been termed *Eophyton* and the lower part of the sandstone where these tracks are particularly abundant has been called Eophyton sandstone. According to Nathorst the tracks are probably formed by algae, driven in the water, dragging against the bottom. Other trails in the same rock have probably been formed by the medusae, common in the water, dragging their arms against the bottom while the animal was driven by the waves.

As a rule the trails form a system of parallel lines (fig. 22). Sometimes they show depressions (in the casts elevations), enlargements or other irregularities. These have been formed when the object by the heaving of the waves has been thrust against or lifted from the bottom.

The trails and tracks of type *b* can be with or without transverse striation. The latter are principally worm tracks. They occur in the interior of the sandstone beds as well as on the bedding surfaces. The tracks with transverse striation are formed by different kinds of animals. Some tracks consist almost exclusively of transverse grooves, marks after some part of the animals. Among them we may mention the *Cruziana* in the Lower Cambrian sandstones, possibly formed

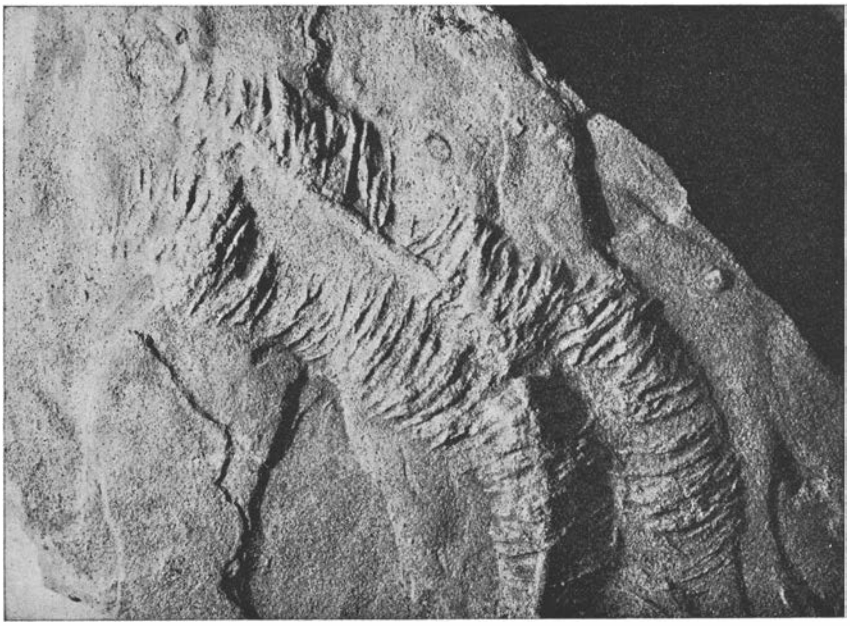

Fig. 21. *Cruziana*. Lower surface of a sandstone bed. Lower Cambrian. Lugnås. — $^1/_1$. (Pl. 419. Orig. in the Museum of Geol. Surv. of Sweden, Stockholm.)

by trilobites. Others also show longitudinal lines. In such the body has partly been dragged. In the adjoining fig. 21 an example of these trails is shown.

The tracks, especially the worm tracks, are sometimes cylindrical in form. They can occur both on the bedding surfaces and in the beds. As they have been preserved in the loose sediments their walls must have had a certain solidity, i. e. the animal has constructed a tube. Part of the forms of tubes found in the sandstones may also have served as the animal's dwelling for some time. To these track-like tubes or burrows belong *Scolithus linearis* as well as *the U-shaped tubes.*

Scolithus linearis is fairly abundantly present in the Lower Cambrian sandstones. Several different forms have been observed. After the investigations made by Richter (1920, 1927) there is hardly any doubt that these tubes are built by sand worms. The tubes are at right angles to the bedding surfaces and almost always straight. Diameter and length are different in different forms. Sometimes the tubes are so closely packed that they can have formed a reef above the sand bank. In other cases the long, thin tubes are so scattered that they must have been built in the sand in such a manner that only their openings have stuck up above it (fig. 23). The wall has often been so dense that no solutions have penetrated it. For a strong pigmentation by oxide of iron deposited from ferruginous water solutions, is often found in the interior of the cylinders but not in the surrounding rock, in other cases in the rock but not in the cylinders.

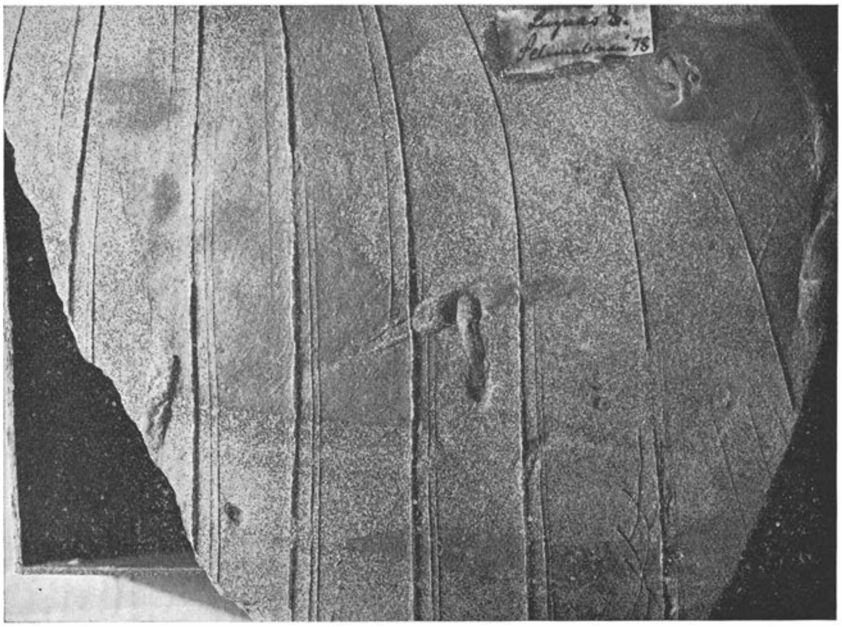

Fig. 22. Trails produced by some object dragged along over the surface of a clayey layer. Cast on the lower surface of the overlying sandstone bed. Lower Cambrian. Lugnås. — $^1/_1$. (Pl. 418. Orig. in the Museum of Geol. Surv. of Sweden, Stockholm.)

The U-shaped burrows occur, as *Scolithus linearis*, only in relatively pure sandstones free from mud. Thus all the animals that have lived in these tubes have been plankton-eaters just as the sand worms mentioned by Richter. But o determine by what kind of animals the tubes have been built is more difficult. Similar burrows are known from recent strata but they are either built in muddy rocks or are otherwise of more occasional significance, hardly to be compared with the fossil burrows, which have obviously been relatively solid in their structure.

The U-shaped burrows in the Swedish sandstones are of two different types. One of them, *Arenicolithes*, consists of single U-shaped tubes, the other of U tubes with connecting arches between the two vertical limbs. The latter form, *Diplocraterion*, is by far the most common. A third form of U-shaped tracks, *Corophioides*, with several U tubes of different width surrounding each other, has been described from Great Britain but hitherto it has not been found in Sweden.

Diplocraterion tubes are found both in the Lower Cambrian and in the Rhaetic-

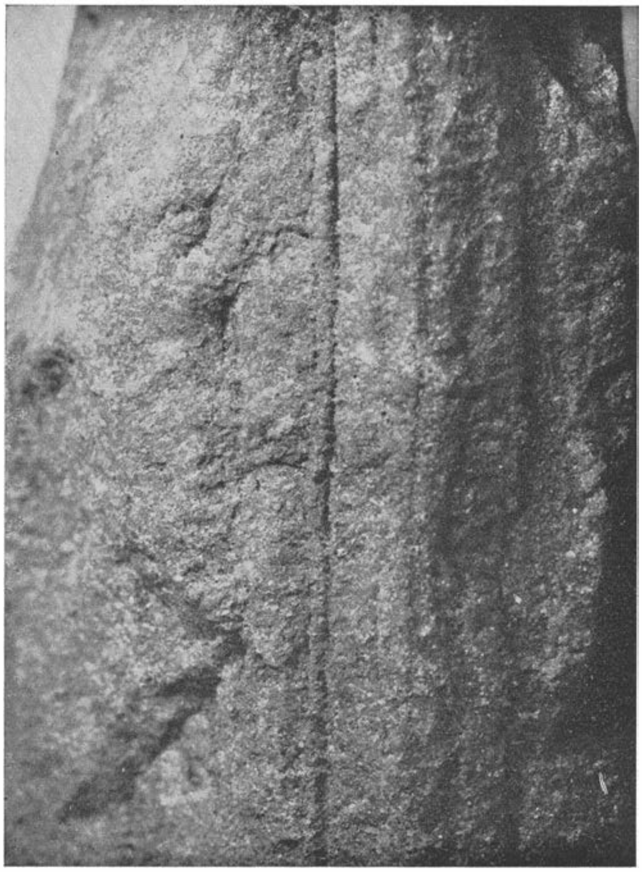

Fig. 23. *Scolithus linearis.* Transverse to the bedding surface of Lower Cambrian sandstone. Rekarekroken. Scania. — $^1/_1$. (Pl. 39.)

Liassic sandstones. Several different forms occur. They are easily seen on the bedding surfaces on account of the openings of the tubes often being enlarged by weathering. Two tube openings belonging to one another are as a rule connected by a grove. Sometimes the tube is weathered to a depth exceeding 1 cm. In a vertical section the rock shows a vertical striation, but the striae do not lie as close as in Scolithus linearis. The walls in the *Diplocraterion* tubes contain an abundance of clayey mud, though such does not occur in any noticeable quantity in the surrounding rock. It has obviously been caught by the animal itself and added to the wall.

Sometimes the *Diplocraterion* forms occur as real reefs, as for inst. in the Lower Cambrian sandstone at Torekow (fig. 26).

All the trails, tracks and burrows mentioned above are formed in shallow water. On their occurrence together with ripple marks, mud cracks, and the like, see below (p. 53).

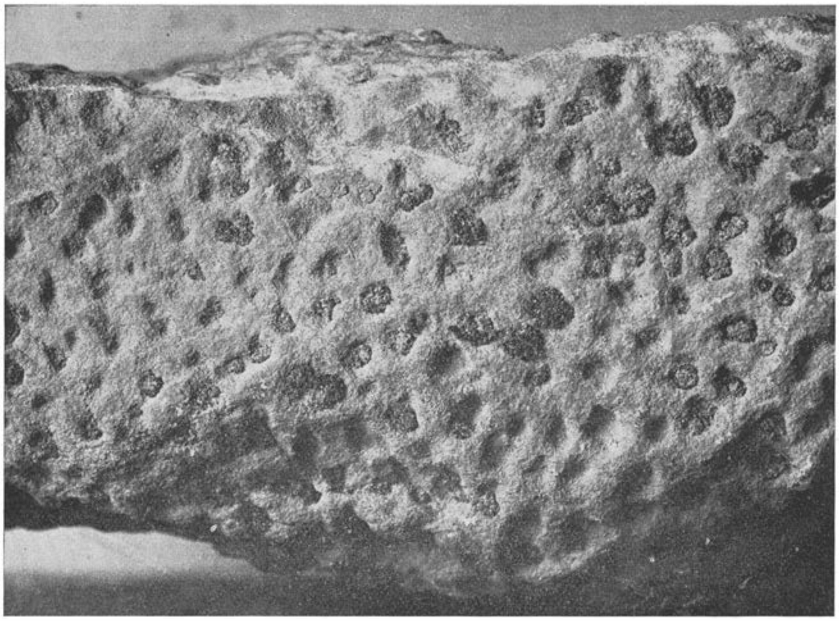

Fig. 24. *Scolithus linearis.* Bedding surface of Lower Cambrian sandstone. Erratic boulder. Scania. — $^1/_1$. (Pl. 61.)

The Stratigraphical Occurrence of the Sandstones.

To the petrography of the sandstones we must of course not only take into account the sand-grains, the character of the cementing matter and the inclusions but also the occurrence of the material. Stratification and bedding, the character of the bedding surfaces and the relation to other sediments must not be disregarded. In the following account of the Swedish sediments we have often occasion to call attention to observations or problems concerning the circumstances mentioned. Only a short orientation on them will be given here.

Lamination and bedding in the sandstones.

On weathering, the sandstones may be divided into flags that are usually from a couple of centimetres to a metre thick. The unweathered rock splits along the same surfaces. In his description the author has termed these flags bounded by bedding surfaces *beds* or *strata*. By *laminations* are meant the thin layers which not infrequently occur in the rock parallel or transverse to the bedding surfaces. There are no distinct cleavages along the laminations or the planes, that are not bedding surfaces.

Thus the stratification of the rock comprises both beds and laminations. Before proceeding to discuss the causes of development of lamination we shall investigate the character of the bedding surfaces.

Fig. 25. Diplocraterion sandstone. Weathered bedding surface. Lias. Hittarp, Scania. — $^1/_1$. (Pl. 225.)

The character of the bedding surfaces.

Sometimes the bedding surfaces in a sandstone are almost perfectly plane with no tracks or markings whatever. The author has seen such in flags a couple of square metres large, quarried in the silurian sandstone at Burgsvik in southern Gothland. It is, however, much more common to find the bedding surfaces irregularly curved or showing tracks and markings of some kind. Some tracks have already been mentioned; some other markings will be discussed here, such as rain impressions, mud-cracks, and ripple marks.

Ripple marks have been observed in the Swedish sandstones at a great number of places. In the Lower Cambrian sandstones at Hardeberga they have been exposed and well known for more than 30 years. During the last few years new markings have been exposed in several different beds. Some of these markings have been described by TROEDSSON (1927). At Jerrestad, Brantevik, Vik and other places in SE Scania ripple marks also occur. They are especially remarkable at Brantevik. In other occurrences of Lower Cambrian sandstone ripple marks have been exposed at least periodically.

Second to the Lower Cambrian sandstone the Liassic sandstones in NW Scania show the most remarkable ripple marks[1]. They can be observed in several sandstone beds outcropping along the shore N of Helsingborg at Sofiero and Kulla Gunnarstorp.

Fig. 26. Diplocraterion reef. Lower Cambrian sandstone. Torekow, Scania. — $^1/_1$.

The ripple marks vary somewhat in structure. Symmetrical and unsymmetrical, uncomplicated as well as anastomosed or checkered ones, ripples with long and short waves, with sharp or rounded crests are to be found. They also occur in sandstones of varying nature. To include an account here of all the material the author has collected on the ripple marks would carry us too far from our subject especially as such an account would necessitate a discussion of the different conditions under which the different ripple marks have been formed. It is obvious to everyone that the form, size and direction of the marks is of the greatest importance for the interpretation of the paleographic conditions, and therefore the author will return to them later.

[1] Remarkable ripple marks are also present in the pre-Cambrian sandstones, for inst. in the Dala sandstone.

A tabular summary only will be given here on some of the ripple marks in Scania at present (1928) easiest of access.

Occurrence	Age		Direction	Length	Depth	Leeward steep
Hardeberga	Lower	Cambrian	N 37° E	35—45 cm	4 cm	SE
»	»	»	N 20° E	15 »	2,5 »	—
»	»	»	E—W	60 »	—	S
Brantevik	»	»	N. 78° E	112 »	10 »	N
»	»	»	N 80° W	65 »	5 »	N
»	»	»	N 55° W	145 »	15 »	NE
»	»	»	N 58° W	100 »	10,5 »	NE
Jerrestad	»	»	N 70° E	55—65 »	—	NW
»	»	»	N 80° W		—	N
»	»	»	N 30° E		—	NW
Simrislund	»	»	N 60° E	81 »	—	—
			N 20° E	7—11 »	—	—
Rekarekroken	»	»	N 35° W	100 »	—	—
Sofiero	Lias	»	N 20° E	8—10 »	—	—
			N 40° E		1—1 1/2 »	—
			N 68° W		—	—

The ripple marks may be considered to indicate a formation in shallow water or, if they are formed by wind action, an aeolian formation. In most cases the latter possibility is wholly excluded in the series of strata in question. The ripple marks often occur together with other markings in sediments with unquestionable marine or lacustrine forming conditions (for inst. mud cracks) or in a series of strata with such markings. In no case have the ripple marks been observed in those parts of the sandstone series, which could have been supposed to be formed at a greater depth. On the contrary, the ripple marks seem to have been especially preserved in the sandstones deposited at a very slight depth.

The author cannot forbear to call attention to the risk of an uncritical use of the observations that can be made on the direction of the wave-ridges. It lies temptingly close at hand to draw conclusions from this direction as to the direction of the shore-line or of the currents. No doubt such conclusions are possible but they must not be overrated. The author will only call attention to the fact that ripple marks with their ridges in different directions can be formed near each other. On a surface of some tens of square metres the author has observed uncomplicated ripple marks formed at the same time and at one part of the place at right angles to those at another part (fig. 31). The configuration of the bottom and the shore plays an important rôle in the development of the markings. In order to draw any conclusions as to for inst. the general course of the shore-line we ought to be able to follow the ripple marks over larger areas.

The connection between the wave-length and the size of the sand-grains is not as clear as might perhaps be expected. The author has observed the formation of ripple marks with a wave-length varying from 6 to 70 cm at one and the same place on a sandy shore (the shore at Engelholm). The material (the sand) was on the different occasions practically the same.

Mud-cracks may be considered a certain indication that the rock in which they occur has been formed in the littoral zone or for some reason has been occasionally drained. Their formation implies a shrinkage of the sedimentary

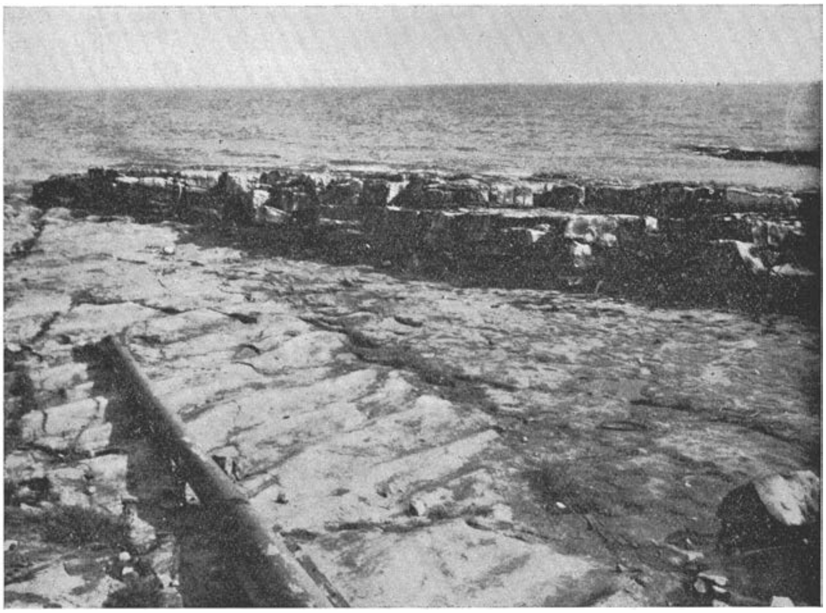

Fig. 27. Ripple marks. Lower Cambrian sandstone. Brantevik.

mass owing to the decrease of its content of water. As far as we know this drying up of the sedimentary strata causes a formation of cracks only if the strata have been elevated above the water level. If drainage takes place below the surface of the water, for inst. owing to the pressure of the overlying sediments, the decrease in volume caused by the expulsion of the water will be noticeable only by the decreasing thickness of the strata. In certain cases, however, a decrease in volume may result in a formation of cracks under the water surface also. We have examples of this both in the septaria and in the grains of glauconite. In these cases also the cause of the shrinkage in the mass is probably a decrease in the content of water. This decrease, on the other hand, is not due either to the evaporation of the water or to its expulsion by outside pressure. In the author's opinion it is due to crystallization in the sub-crystalline or amorphous and gelatinous, highly watery mass. A formation of cracks for similar reasons in an unconsolidated bed may not be excluded but in no case has the author been able to find any evidence of it.

As the mud-cracks are formed by shrinkage of a rock during its desiccation, they cannot be formed in pure sand. They only occur in more or less clayey or muddy rocks. The reason why they should, in spite of that, be mentioned in connection with the account of the sandstones is that the cracks themselves

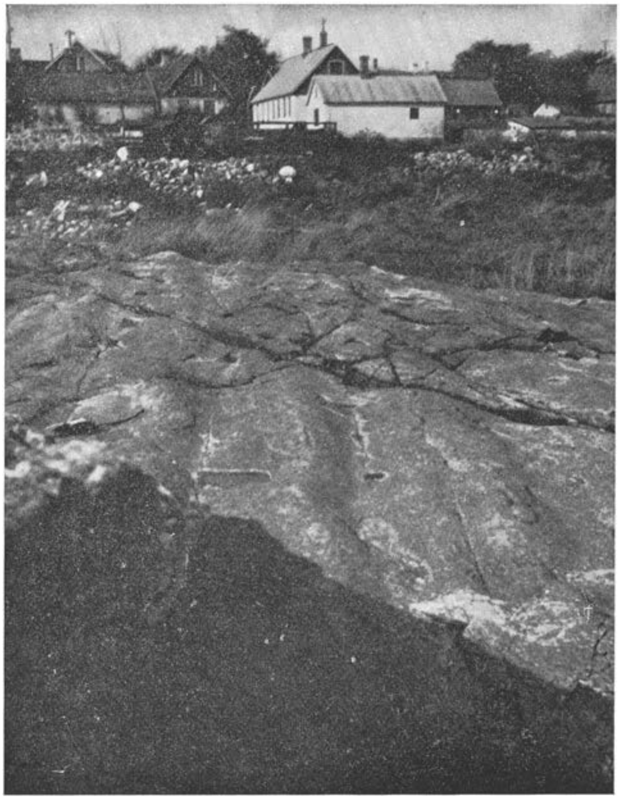

Fig. 28. Large ripple marks. Lower Cambrian sandstone. Brantevik.

are usually not accessible to a study but only their casts, and these casts have, as a rule arisen in sand. The cracked clayey rock often crumbles but in the overlying sandstone the entire system of cracks is found in the cast as elevated lines.

As the mud-cracks are formed on a periodically drained shore their occurrence in the sandstone series is quite natural. For reasons mentioned above they are confined to the bedding surfaces in which highly argillaceous sediments occur. For obvious reasons the casts are principally found in the foot-wall of the sandstone-bed. The author has also found sandstones showing distinct mud-cracks (casts) in the upper bedding surface. They have formed the foot-wall of the cracked clay-bed. The sand below the clay layer has then run together with that supplied from above so that the filling of the cracks has been connected with both sandstone beds. On a cleavage along the clay-bed the mud-cracks have appeared as elevated ridges on the hanging-wall surface of the lower bed as well as on the foot-wall surface of the upper bed. Of course a formation of casts in the underlying bed implies that the clay bed has been so thin that the

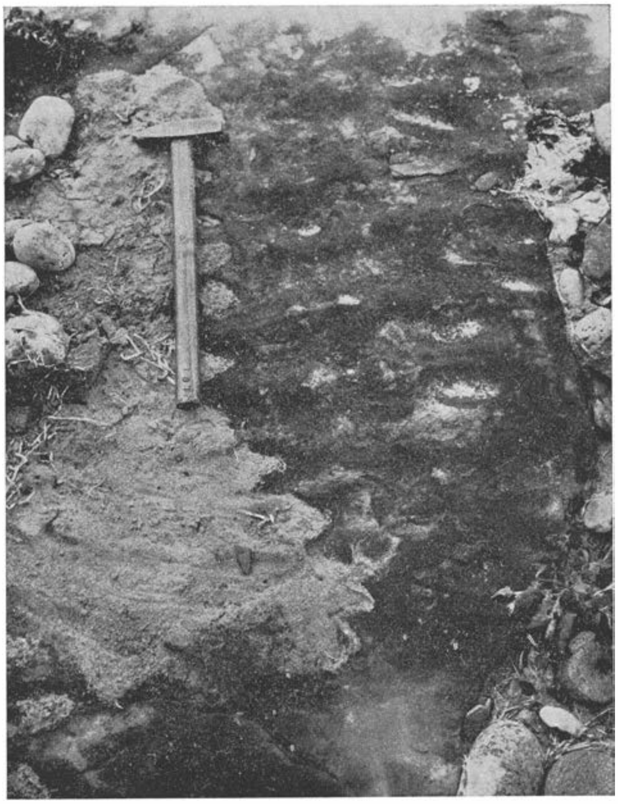

Fig. 29. Small ripple marks. Liassic sandstone. Gravarna, Scania.

mud-cracks have gone clean through it. It is often seen from the casts in the hanging-wall that the cracks have thinned out downwards.

As a rule the mud-cracks form an irregular checkered pattern, in which the size of the polygons and the breadth of the cracks may vary widely. Polygons a few millimetres in diameter and separated by narrow cracks (less than 1 mm broad) as well as polygons exceeding 30 cm in diameter and separated by cracks from 3 to 5 cm broad have been observed (cf. Hadding 1927, p. 20 and 64, fig. 4 and 18).

A regular checkered net-work implies an uniform drying. Has the clay bed a curved surface, the humidity remains as a rule longer in the lower parts.

The cracking begins on the elevated parts of the surface and the crack net-work is often better developed there than in the depressions or grooves. It may also happen that the drying does not proceed so far that the clay cracks in the lower parts. Frequent opportunities of observing such a state in recent formations are given and the author has also seen the same phenomena in certain sandstones (especially in the Lower Cambrian sandstone at Brantevik). Mud-cracks

Fig. 30. Interference ripples. Liassic sandstone. Gravarna.

confined to certain parts of the bedding surface are of special interest, when occurring together with ripple marks. A crack with short out-thinning branches can then be found along the wave-crest. In the lower surface of an overlying sandstone bed it appears as an elevated ramified »track» on the bottom of the grooves (fig. 32). Similar »tracks» may arise if the surface is irregularly curved, and part of the tracks ascribed to an organic formation have no doubt arisen in the said manner. To them belong among others a track from the Lower Cambrian sandstone at Lugnås described under the term *Archaeorrhiza* TORELL. The track-like mud-cracks differ from the trails and crawling tracks by their characteristic ramification and from the same as well as from eventual impressions of plants by their usually precipitous, vertical walls.

Worm tracks and other tracks of animals are frequently found on the bedding surfaces (fig. 33—36). In several cases we may infer that they have been formed above the water surface. If a track is only visible on the most elevated parts of the uneven bedding surface it shows that the track has been obliterated when the animal has moved across the lower portions. The same observation may be made when for inst. an earth-worm moves across an uneven surface of moist, soft clay with water in the depressions. On evaporation of the water in the depressions the tracks may be formed in these only, as the clay in the more

Fig. 31. Recent ripples on the shore of Skelderviken, NW Scania. The ripples in the foreground are transverse to those in the background. The two systems are formed simultaneously

elevated parts has then become so hard that the animal moves across it without leaving a track. Thus the limitation of the tracks in the manner described above shows that the bedding surface has been above the water level at the time of their formation. This, however, does not entitle us to infer that all tracks limited in a similar manner have arisen under the same conditions. At different places in the sandstones the author has found tracks mainly confined to the wave-troughs in a bedding surface with ripple marks. As the tracks are cylindrical in form with a nucleus of pure sand and a clayey wall, they have no doubt been built by the animal as burrows in the mud. The reason why these tracks principally follow the wave-troughs, often in 8-shaped coils (fig. 34), is probably that the mud has been more abundantly accumulated in them than on the wave-crests. The occurrence of the tracks on the bedding surfaces cannot be schematically interpreted, no more than the occurrence of other markings.

Rain impressions. Here and there in the sediments we find small round impressions in the bedding surfaces which have been interpreted as marks made by rain-drops. The formation of these rain-drop impressions implies that the bedding surface has been above water. The interpretation of these markings

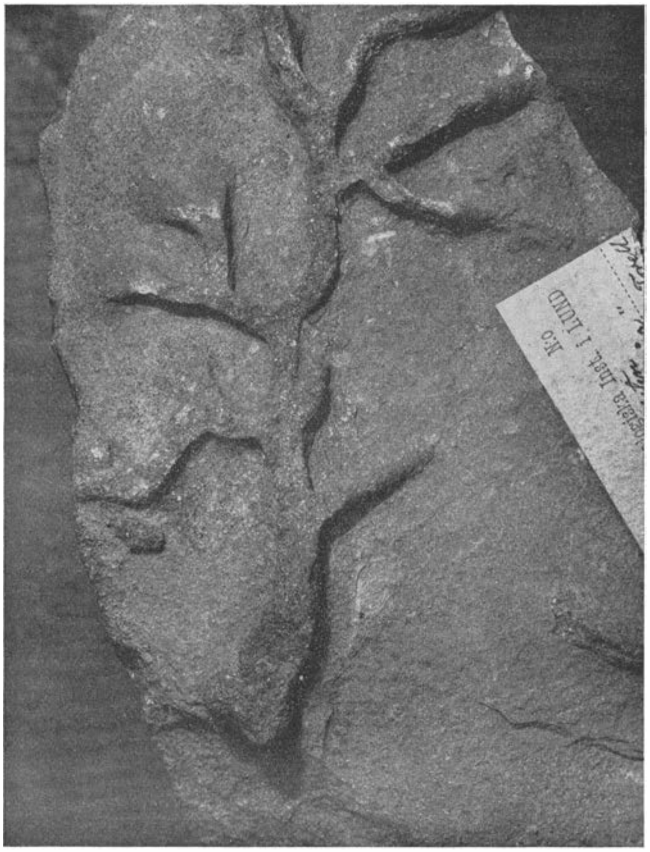

Fig. 32. Mud cracks resembling a branched trail. Lower surface of the overlying bed. Mickwitzia sandstone, Lower Cambrian. Lugnås. — $^1/_1$. (Pl. 238.)

is no doubt correct. The author has in vain looked for such markings in the Swedish sandstones. The requisite qualifications for their formation (clayey layers between the sandstone beds and their occasional drying) have no doubt been present in several of the rocks examined. Only a few uncertain markings have been found.

In a remarkable development on the other hand some markings occur, which the author with every reserve designates as rain impressions. As the term indicates they are not marks of single rain-drops but of rain, during which the impressions of the single drops run together. The entire bedding surface is greatly torn. It shows larger and smaller grooves separated by sharp crests intersecting at acute angles. Exactly the same formation is found in moist sand that has been exposed to heavy rain. (A further description is to be found on p. 104). If the author's interpretation is correct, such markings give us another means of ascertaining that the bedding surface has been above the water surface during the formation.

The rain impressions occur together with rill marks formed by rain water

Fig. 33. Narrow winding trails. Lower surface of a sandstone bed. Upper Silurian. Klinta, Scania. $^1/_1$. (Pl. 239.)

running off. These rill marks occur in certain grooves in the bedding surface. Several smaller ones run together into a larger. In the author's opinion these grooves show that the sand has been covered by a thin layer of clay on the formation of the marks. The supposition of this layer of clay may also explain the fact that the rain impressions have not been obliterated when the rain has ceased to fall and the sand has dried. A thin layer of clay is always present at the bedding plane with rain impressions, but it is always so loose that its character allows no direct conclusions to be drawn of its contribution to the formation of the markings.

The change of material at the bedding surfaces and lamination planes.

At the bedding surfaces as well as at the lamination planes in a sandstone a certain change is as rule found in the material of the rock. Usually the bedding surfaces contain clayey substance even though the rest of the sandstone is free from clay. Not infrequently real layers of clay occur between the sandstone beds, and the bedding surface then forms a juncture between sediments of different kinds.

Sometimes the bedding surfaces show an abundance of mica. In other

Fig. 34. Winding, 8-shaped trails in the mud between the ridges of a bedding surface with ripple-mark. Lower Cambrian sandstone, Hardeberga. — $^1/_1$. (Pl. 264.)

cases hardly any change in the content of mineral is noticeable on passing from one bed to another.

The lamination planes or the laminations appear principally in cross-sections of the beds, as the rock does not cleave along these planes. The lamination is often conspicuous by changes in the size of grains but equally often by inclusions. Layers with pigment of clayey substance, limonite, haematite, glauconite, and pyrite are common. Not infrequently the stratification is indicated by fossils.

Causes of stratification.

Stratification is always due to disturbances or changes in the sedimentation. Changes in the dimensions of the material, in its nature and content of inclusions or accessory constituents may be causes of stratification. Whether this results in the formation of bedding surfaces or not is equally due to the qualitative and the quantitative variations in the sedimentation. If the cementation of the deposited layers is not obstructed in a vertical direction (for instance by variation in the material) no bedding surfaces are as a rule formed in the sandstones.

Fig. 35. Worm trails. *Scolithus errans.* Lower Cambrian sandstone. Hardeberga. — 1/1. (Pl. 35.)

Where a noticeable weakness in the cementation is to be found a change *can* have occurred and a bedding surface been formed.

The disturbances in the sedimentation are often reflected in an *alternation of positive and negative sedimentation.* These disturbances may also result in the formation of bedding surfaces, even though they, as is seldom the case in the sandstones at least, show no change in the material. A lower stratum, laid bare during negative sedimentation, has often been fairly solid before the deposition of new material. This also causes a break in the cementation, which may cause the formation of a bedding surface. An essential number of the bedding surfaces showing a change in the material, are no doubt formed in a similar manner. Should, however, no bedding surface arise but the earlier deposited material be firmly united with the later deposited, the formation of a lamination is very pro bable. It is obvious that the drying of a layer should be a common cause of the formation of a bedding surface.

Laminations and probably bedding planes may also be due to an occasional formation by autigenous minerals. The layers of pyrite are examples of this and so are certain occurrences of glauconite. Whether the frequently very thin layers of haematite have also been formed in this way or by rhythmic precipitation or in both these ways the author can not at present determine in all the cases observed. It is quite obvious (see p. 22) that they are sometimes due to a secondary

Fig. 36. Worm trails, *Psammichnites gigas,* on the upper surface of a sandstone bed. Lower Cambrian. Brantevik. — 1/1. (Pl. 50.)

precipitation but the author considers it probable that in many cases they have arisen primarily during the sedimentation.

The occurrence of a bedding surface in itself tells us nothing of the depth at which the sandstone has been deposited. On the other hand the bedding surfaces often show tracks or markings, which reveal to us not only the conditons at the formation of the rock but also the causes of the development of the bedding surface. These circumstances have already been mentioned above.

If the bedding surfaces in a sandstone are near each other, the rock is thin-bedded or slaty. If the lamination planes are near each other, it is fine-laminated. The reason why one sandstone is thick-bedded and another thin-bedded, one fine-laminated and another unlaminated is that the conditions for the formation of a bedding surface or a lamination have been present more or less frequently. These conditions have already been discussed. There is a certain relation between the thickness of the beds and the character of the sandstone, as is distinctly seen on studying these rocks.

As a rule the pure sandstones are more thick-bedded than the clayey or muddy ones. In the same manner the coarse sandstones are usually more thick-bedded than the fine-grained. To a certain degree these facts overlap, as the coarse sandstones are mostly pure, while the impure sandstones are as a rule fine-grained.

Fine-grained sandstones developed into thick beds are remarkably even-

Fig. 37. Parallel stratification. Sandstone bed with thin parallel layers of pure white silt and dark argillaceous matter. Rhaetic. Margreteberg, Höganäs. — $^1/_1$. (Pl. 236.)

grained. As a rule they have plane bedding surfaces and sometimes show a fine lamination. They are formed in tranquil water with an even supply of already sorted material. Occurring in a sandstone series with coarser rocks or with uneven bedding surfaces, they have arisen during a period of subsidence and consequently in relatively deep water.

In connection with the formation of the stratification the thickness of the strata will also be touched upon. In the first place it is dependent on the supply of sediments and the duration of the sedimentation. But there is a third factor of no small importance: — the extent of the negative sedimentation. It is not all the primarily deposited material but what remains of it that forms a bed. The author has already had the opportunity of illustrating in several details how the negative sedimentation interferes with the formation of the sedimentary rocks, especially with regard to the formation of conglomerates. Examples of this are perpetually found in the sandstones.

Consequently on estimating the extent of the sedimentation it is not sufficient only to measure the thickness of the layers. Due regard must be paid to the negative sedimentation and also to the crowding of the material especially

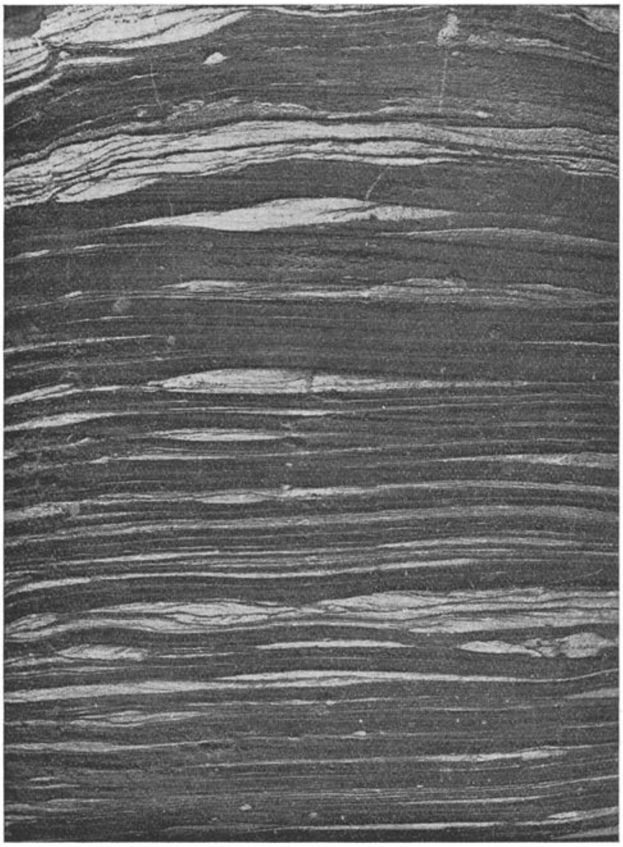

Fig. 38. Lenticular stratification. White layers arenaceous, dark argillaceous. Rhætic. Drilling core. Klappe. 182,9 m. — 1/1. (Pl. 440.)

when the fossil sediments are concerned. In the sandstones, however, this is relatively slight.

The nature of the stratification.

In the Swedish sandstones the stratification is mostly parallel to the bedding planes but cross-bedding is by no means rare. As a third form of stratification may be counted the form arising during irregular sedimentation. In the following this is termed lenticular stratification (bedding or lamination).

The cross-bedding often shows a number of parallel planes interstratified with the oblique ones. Such a stratification can be formed in deltas as well as in drift-sand. The material may be extremely even-grained. This is for inst. the case in the Liassic sandstone at Hjelmshult. The cross-bedding found in several of the Keuper sandstones at for inst. Ottarp is of a different character. Marked variations in the size of the grains and an irregular dip of the bedding planes are characteristic of these layers deposited in running water.

In the parallel-bedded rocks the bedding surfaces and the laminations are practically parallel. Slight divergences due to unevennesses in the substratum or to irregularities in the sedimentation are common.

Fig. 39. Lenticular stratification. Arenaceous and argillaceous layers. Drilling core. Rhaetic. Viken, 262,7 m. — 1/1. (Pl. 432.)

On following a bed in a horizontal direction it will be found that it changes in thickness more or less rapidly. Not infrequently local variations in the thickness of the bed are found. If these become very marked, the parallel bedding (lamination) passes into lenticular bedding (lamination).

The lenticular bedding is particularly well developed in the Rhætic sandstones in NW Scania but it is also present in the Lower Cambrian series of strata, for inst. in its upper part at Hardeberga. In some vertical sections the Rhætic beds are seen traversed by sinuous laminæ interwoven into a net-work, which separates small lenticles of sandstone. The laminæ are often dark and muddy, clayey or bituminous, while the lenticles consist of relatively pure sand. The bedding surfaces are irregular and show the same substance as the laminæ.

The origin of the lenticular bedding stands in connection with irregularities in the sedimentation. It occurs in muddy sandstones deposited in shallow water, in several cases probably in estuaries or lagoonal regions.

The primary dip of the bedding surfaces.

In the parallel-bedded rocks the beds have, during the sedimentation, been approximately parallel to the surface on which they have been deposited. Thus their position has in most cases been practically horizontal. This is also the case in rocks with lenticular bedding, if the irregularities of the lamination are

Fig. 40. Cross-bedding. Coarse sandstone. Lower Cambrian. Brantevik, 8.

left out of consideration and attention only paid to the directions in which the lenticles are most extended.

As mentioned above, layers parallel to each other are sometimes found in the cross-bedded sandstones. They have no doubt primarily had a fairly horizontal position or a slight dip in the same direction as the steeper laminations. The latter incline in the same direction in which the sand has been transported, i. e. to leeward.

The disturbances which the series of strata have undergone may, to a certain degree at least, be inferred from the position of the layers. Only seldom are the sedimentary layers found undisturbed but the disturbances in the Paleozoic and Mesozoic series of strata in southern Sweden are remarkably small, apart from the numerous faults.

It is often valuable to be able to determine which is the hanging wall and which the footwall surface of a bed's bedding surfaces. This is the case in series of strata where the layers can have been overturned or where the rock is not found in outcrops. It is known of old from experience that concavo-convex shells are, in most cases, buried with their concave side down. Besides that there are many examples of rounded or cylindrical fossils with an eccentric

Fig. 41. False cross-lamination. Thin red colored bands with infiltrated ferruginous matters. Lower Cambrian sandstone. Brantevik, 3.

centre of gravity being embedded with this next to the lower bedding surface. In the sandstones the author has found still another means of making the above mentioned determination.

If the sandstones contain small, light shells of closed forms they usually occupy a non-orientated position in the beds. Sometimes it is found that sand has trickled into the shells without filling them up. On examining these shells the sand will be found accumulated on one and the same side of all the shells. This must have been the lowest one, that facing on the lower bedding surface.

The upper part of the shell is filled up by calcite or other secondarily precipitated matter, usually the one forming the cement in the rock.

An excellent example of the possibility to determine the upper resp. lower surface of a bed from the said circumstances is found in the Lower Cambrian sandstone with *Obolella Mobergi* (see fig. 42). As another equally illustrating example we may mention the Tertiary blocks in Scania. The small gastropod shells occurring in these rocks can also make this determination possible. Sometimes no sand is contained in the interior spirals and the one containing only a smaller portion shows this placed to the lower side of the layer. As a rule this phenomenon can be observed in a number of fossils in the same thin section, on which account requisite control of the correctness of the determination is readily procured.

The above-mentioned fossil »water-level» may also be used to show the primary

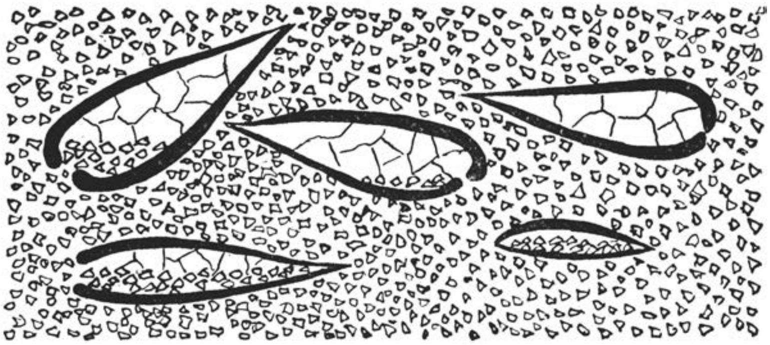

Fig. 42. *Obolella Mobergi* WALC. as geological levelling instrument. The upper surface of the enclosed sand was at the time of cementation parallel to the sea-level. Lower Cambrian sandstone. Hardeberga.

dip of the beds, i. e. the divergence of the bedding planes from the horizontal plane during the formation of the beds. But in the rocks, in which the author has had the opportunity of observing the phenomenon there is only slight or no divergence between the bedding planes and the surface of the sand deposits present in the fossils.

The relation between sandstones and other sediments in a series of strata.

Just as clay beds are common in the sandstone series are the sandstone beds no uncommon phenomena in sediments rich in clay. In such cases there is often a marked contrast between the two rocks. Thus the sandstone beds enclosed in clayey layers are not infrequently free from clay and the purest sandstones sometimes contain layers of sand-free clay. In fact, from the point of view of formation this is more natural than an occurrence of highly argillaceous sandstone in layers of clay and sandy clay between sandstone beds. In a basin where a pure sand is deposited the motion of the water is so strong that no deposition of the mud present in the water is possible. If the motion for some reason or other stops or diminishes, the transport of the coarser material also comes to an end. The deposition of this material ceases and the finer mud present in the water is deposited instead. On the pure sand a layer of clay is deposited, which in its turn may be covered by pure sand when the motion in the water again becomes sufficiently strong to allow of the transportation of sand-grains and to prevent the particles of clay from sinking to the bottom.

The formation of a sandstone bed in layers of clay is effected in a similar manner. An occasional increase in the transporting power of the water prevents the deposition of clay at the same time as it effects a supply and deposition of sand. Are the conditions of deposition otherwise unchanged, a sandstone bed in a series of clay ought to consist of relatively pure sand.

A pure sandstone passing into a clayey one and a pure clay rock passing into a sandy clay rock generally indicates a change in the local conditions of sedimentation (a change in the *milieu conditions*). The sediments, consisting of a mixed coarser and finer material such as sand and clay, can only be formed in relatively shut off regions with a supply of this material and only slight possibility of its sorting. A depression of the region may result in a more open connection with the sea so that waves and currents can perform the sorting. The formation of the arenaceous-clayey rocks then ceases and a formation of purer sediments of sand and clay begins.

As a rule the rocks with a well sorted material are formed in such a milieu that sorting has been possible. This is always the case in the coarser sediments, the sandstones. A pure clay on the other hand can very well be deposited in a smaller closed basin also, where no sorting occurs. But this implies the previous sorting of the material so that only the clayey matter reaches the basin.

On estimating the relation of the sandstones to the clayey sediments it is necessary to take the forming conditions mentioned above into consideration. If for inst. a series of pure sandstone is superposed by a series of clayey sediments, the occurrence of the fine material (the clayey substance) may not simply be interpreted as evidence of a deposition in deeper water, caused by a depression of land. A closer study of the rock will very likely show us that the occurrence of the finer material can be due to an elevation of land with subsequent shallowing and shutting off of the region of deposition.

The author has previously (1927) had the opportunity of discussing the occurrence of the sandstones in relation to the conglomerates. Attention may here only be drawn to the fact that most conglomerates occur in the sandstones, and that these are seldom entirely devoid of conglomerates.

In the limestone series pure sandstones are uncommon just as relatively pure limestones are seldom present in the sandstone series. Transitions between limestone and sandstone, on the contrary are very common. Beds of sandy limestone occur in the calcareous sandstones and they can pass into slightly arenaceous limestone. Examples of such a variation of rocks are also found in series with relatively pure sandstone, as for inst. in the Lower Cambrian sandstone at Hardeberga. Analogously we sometimes find, in the limestone series, beds containing sand, possibly passing into sandy limestone or calcareous sandstone. Examples of this occur *inter alia* in the Silurian series of strata. In these cases also the increase in content of sand may have been parallel to a decrease in the content of clayey material.

The occurrence of sandstone together with oolitic limestone is of special interest. The Gothlandish series of strata shows examples of this and later on the author will give an account of them.

The coal-beds in the Swedish Rhaetic-Liassic strata sometimes occur enclosed between sandstones, sometimes in clayey sediment. The sorting of the material in the overlying and underlying rock can be more or less complete.

An *interstratification* between sandstone and shales is often found but seldom so regularly developed as between calcareous and clayey sediments. This shows that the factors regulating increase or decrease in the deposition of sand seldom occur as rhythmically as those regulating the deposition of lime.

The Formation of the Sandstones.

The deposition of the sand.

After the following account of the Swedish sandstones a summary will be given on the observations made on their formation. In this connection more general problems concerning the sedimentation will also be discussed. The short survey already given here is only intended as an orientation.

With regard to their place of formation the sandstones are either marine or continental. To the former the author also counts the littoral ones, i. e. those formed between the ebb and flow level.

The marine sandstones are chiefly formed in the shore region. The material has been transported by waves, tidal or bottom currents, irrespective of the fact that it has eventually first been transported by running water or by wind.

During the transport the material has undergone sorting according to the size of the grains. At the same time it has become more or less worn as is seen from the form of the grains.

The origin of the material and the direction of its transportation may sometimes be concluded from its character. Grains of minerals, the parent rock of which can be ascertained, are in this respect of great value.

The content of fossils or certain autigenic minerals in a sandstone give us good guidance in judging the conditions of formation. The same is true of the rock's general development, stratification, size of grains, etc., and of its occurrence in relation to other sediments.

The continental sandstones are partly lacustrine and exhibit several qualities which remind us of the marine ones. The fluvial are of another character.

Among the continental sandstones we also find the glacial and the aeolian with their specific qualities and those consisting of slightly sorted residual substances.

The forming conditions of the continental sandstones are practically judged according to the same principles as the marine ones. In most cases the occurrence and character of the material reveal to us the conditions under which the sedimentation has taken place.

The diagenesis of the sandstones.

After the deposition of the sediments a series of processes begins in them, which we sum up under the term diagenesis. In the different sedimentary rocks the diagenetic processes vary somewhat. A recrystallization is specially conspicuous in several limestones, in the clayey sediments the decrease in volume is one of the most pronounced changes, and in the sandstones the formation of cement is no doubt the most noticeable result of the diagenesis. Traces of the three said processes can, however, be found in most sediments. To this there is added a drying and possibly a leaching (removal of salt) in all sub-aquatic sediments and partly in the others also.

The compressing, which the material in the sandstones has undergone after the deposition, is to a large extent dependent on its character. If the deposit consists of pure sand, the decrease in volume is minimal. This is also the case, if the sand-grains are embedded in hard, crystalline calcite. With increased content of mud the shrinkage becomes greater.

Pure sand can also show a certain decrease in volume, and this becomes more noticeable, the more the sand is exposed to pressure before cementation. If cementation takes place at the time of deposition, the grains will be considerably less closely situated than if the cementation has occurred first after the covering of the sand by a series of younger sediments.

In the sandstones the grains are sometimes found scattered and separated by large pores. Only a slight amount of cement prevents the mass from falling in. In such cases we may conclude that, during the deposition, the sand-grains have been embedded in a matrix, in most cases carbonate of calcium. As the latter has been partly dissolved, the grains have become almost free.

A recrystallization in the sandstones is far from uncommon but as may be understood it is confined to the cement or the matrix. Traces of it are most frequently found in the calcite of the sandstones. To the recrystallization we may also count the metasomatic processes.

Calcite cement is sometimes replaced by silica, and in some sandstones calcite has changed into siderite. There may also be good reasons for counting dolomitization among the diagenetic processes. The formation of limonite after for inst. siderite, on the contrary, is a result of weathering.

The *cementation* of the sandstones may be effected exclusively by recrystallization of the material deposited together with the sand-grains. On the other hand the cementation may also be effected by secondarily added material.

In the pure sandstones the cementation is mostly due to deposition of the cement from water solution and in the muddy ones partly to recrystallization of the matrix, partly to newly added substance. The development of the cement in different cases has already been illustrated (p. 17 seq.) The changes in the fossils enclosed in the sand also belong to the diagenetic processes in the sandstones. The fossilification varies to a certain degree with the diagenesis.

The Metamorphism of the Sandstones.

The metamorphism of the sandstones may be regional as well as contact metamorphism and weathering.

On the regional metamorphism the clastic character disappears or weakens. The recrystallization can be more or less complete. The formation of new minerals is dependent on the primary character of the sandstone. Pure quartzites are formed from the pure quartz sandstones, phyllites and mica-schists of different composition from the calcareous and clayey ones. In Sweden thick series of more or less regional-metamorphic sandstones occur especially in the mountain formation and quarzite-sparagmite region of northern Sweden.

The contact-metamorphic sandstones can show a distinct recrystallization. As a rule, however, this is mainly confined to the cement. In the pure quartz sandstones there is often no change to be noticed at the contact with the diabases, which here and there are found traversing them.

The weathering of the sandstones consists partly in a hydratization of certain minerals, especially the ferruginous, partly in a leaching and dissolution. In both cases the weathering is mainly noticeable on the cement and the matrix. The pure sandstones are most resistant against weathering. This deserves special attention seen from a practical point of view. Most resistant are the pure quartz sandstones, after them the pure calcareous sandstones. Even an inconsiderable content of clay in the latter often prevents us from using it as building material. A noticeable content of iron has the same influence, unless it occurs in the form of haematite. The red haematitic sandstones have often the same resistance against weathering as pure sandstones.

Some Selected Sandstones, their Petrographical Character, Stratigraphical Occurrence and Formation.

The Lower Cambrian Sandstone in Scania.

The Lower Cambrian sandstone is exposed in many places in Scania. It is, however, nowhere possible to follow it throughout its thickness from foot wall to hanging wall. In places where the series of strata is easiest of access it is also traversed by a number of faults, which in their turn make the investigation of the series of strata more difficult. But the intensive quarrying of sandstone at Hardeberga will in course of time permit a detailed observation of the variations of the rock in this place. Broadly speaking there is a great conformity in the formation of the series of strata in the different occurrences in Scania, and therefore we may hope that the Hardeberga profile will facilitate the stratigraphical investigation of other equivalent sandstone series in Scania.

In an account of the rocks in the Lower Cambrian sandstone series it is practically advisable to group them primarily in three stratigraphical classes. These are from the top downwards:

c. The upper and middle parts of the sandstone series, with tracks and fossils, phosphorite and glauconite, cement of quartz or calcite.

b. Hardeberga sandstone (in a restricted sense).

a. Arkose with or without conglomerates.

The bulk of the rocks belongs to the first-mentioned group, the lesser part to the arkose.

The arkoses at the base of the Lower Cambrian sandstone.

Everywhere in Scania the Lower Cambrian sandstone rests directly on Archaean gneisses or gneissic granites. The boundary between the crystalline rock and its clastic covering is as a rule sharp, but sometimes a fairly insensible grading from the one kind of rock into the other can be found. The occurrence of the arkose is best elucidated by the cuttings at Gislöv, Forsemölla and Rekarekroken.

The Cambrian basal strata at Gislöv.

In a few small quarries 1,5 km SW of the village of Gislöv a good opportunity is given at present of studying the basal strata of the Lower Cambrian sandstone as well as their Archaean substratum.

The granite-gneiss is relatively fresh in its lowest accessible part. It consists of medium-grained and medium-acid hornblende-gneiss with unaltered potassic feldspar but with partly chloritized hornblende. Secondarily formed ferric oxide gives the rock a darker reddish colour than it would otherwise have had. The rock is quite compact and solid and shows no traces of the disintegration occurring in overlying parts.

The top part of the granite-gneiss presents quite a different appearance. This rock is brighter in colour, with an uneven splintery fracture and a more porous structure. The chloritized hornblende lies distributed in spots in the same manner as in the fresher rock, and the fragments of the crumbling feldspar crystals remain in their original position. However broken up by weathering the rock may have been, the material has not been rearranged.

The bright colour in the top part of the granite-gneiss is partly due to kaolinization of feldspar. This is not as advanced as might be concluded from a superficial examination, but the potassic feldspar may instead be characterized as remarkably fresh. Still the grains have a dull surface and are powdered as it were with kaolin dust. Haematite, that gives the underlying parts a darker reddish colour, is absent and there is instead an abundance of secondarily formed quartz. The rock is in reality strongly silicified. For this reason it is also relatively solid. Besides that, it is traversed by thin quartz veins, showing us the jointing planes of the gneiss.

The Arkose. The top part of the granite-gneiss has been so altered that the material has easily been broken up and rearranged by the waves on the shore of the transgressing sea. It would be hard to determine where to draw the line between weathered gneiss and shifted gneissic gravel, if a sorting of the material had not taken place in connection with the rearrangment.

The loose chlorite and kaolin dust has been washed away from the suspended weathering gravel, and the grains of feldspar have lost their dull coating of kaolin. Therefore the arkose differs already by its red colour from the upper part of the granite-gneiss.

Owing to the suspension the sorting has also influenced the coarser material. Immediately above the gneiss the arkose is fine-grained, the majority of the grains having a diameter of 0,2 to 0,6 mm. The size of the grains increases slightly upwards, and some outthinning layers of coarser gravel are found. Not until about 1 m above the gneiss does the arkose pass into an arkose-conglomerate, with pebbles frequently attaining up to 12 mm. in size. The conglomerate is about $^1/_2$ m thick. The overlying bed is not visible in the above-mentioned sections but can be observed in the immediate vicinity. It consists of pure white quartz sandstone.

We thus find at Gislöv as in so many other localities that the »basal conglomerate» does not form the base of the series of strata but occurs instead enclosed in more fine-grained sediments belonging to this same series. How this state of things has come about the author has already had the opportunity of discussing [1]. The conditions at Gislöv indicate a new solution.

In the arkose as well as in the conglomerate the grains are only slightly rounded or quite angular. Thus the weathering gravel has undergone only slight wear. A stronger or more lasting washing would have caused the grains of feldspar to split or to be wholly crumbled at the same time as the quartz grains would have been rounded and enriched. Had this process continued for a sufficient space of time, the result would have been an arkose of slight thickness resting on a more abraded substratum (less altered than the one exposed at Gislöv) and covered by a quartz conglomerate. This is the type of basal deposits to be found in several places.

At Gislöv the abrasion has been slighter. The loose weathering gravel has only been exposed to a suspension of short duration and, as mentioned above, the finer material, that did not immediately sink to the bottom, has then been carried away. By the motion the coarser material was carried up to the surface of the sand, while the smaller grains were accumulated next to the bottom. This sorting is quite natural. We obtain it directly on shaking a mixture of sand and coarser gravel, and we obtain the same result on exposing the sand-gravel mixture to a sufficiently strong and lasting wash.

If the above-mentioned sorting and bedding is a normal phenomenon, we may ask ourselves why it is not always to be found. As is known, the basal conglomerate sometimes lies directly on the gneiss (or on the rock, which forms the substratum of the series). The reason is that the negative sedimentation there has been stronger than at Gislöv. The water has been able to carry away all the loose matter with the exception of the larger pebbles forming the conglomerate. Where the water has had this power it has also abraded the substratum more strongly, so that the conglomerate rests on a more compact (less altered) substratum than is the case at Gislöv. A typical example of this is the conglomerate at Råbäck at the foot of Kinnekulle [2].

In connection with the above discussed stratification it should be mentioned that beds of pure sandstone are also to be found between the conglomerate and the underlying arkose. In this case the formation has, to begin with, taken place in the same manner as at Gislöv. The conglomerate has rested immediately on the arkose. The formation of conglomerate (the sorting and wearing) continued till the waves lacked power to move the blocks. The cause of the decrease in power is in most cases a continued depression of land. Gradually the conglomerate became covered by finer sediment, principally sand. If the transgression proceeded normally and no other disturbing factors supervened, the series of strata became as we find at Gislöv, namely: —

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[1] HADDING 1927, p. 49.

[2] HADDING 1927, p. 55.

Sandstone
Conglomerate
Arkose
Gneiss

But if a regression occurred after the deposition of sand on the conglomerate, the process that had taken place at the formation of the conglomerate could be repeated. The pebbles in the conglomerate could be brought up entirely or partly above the sand. The aspect of the series of strata differed acc. to the depth of the wave-action on the substratum. Two cases are exemplified here (sand is thought to cover the conglomerate again): —

Sandstone	Sandstone
Conglomerate	Conglomerate
Sandstone	Sandstone
Arkose	Conglomerate
Gneiss	Arkose
	Gneiss

The formation will be further illustrated in the summary of the observations on the arkoses.

The weathering of the sub-Cambrian land-surface. At the time of Cambrian transgression the ground was covered by weathering gravel. The thickness of this covering has of course varied from one place to another partly owing to different depth of weathering action in different places and partly to the shifting of the weathering products, undoubtedly effected in some places by aeolian, fluvial or other continental transportation previous to the transgression.

At Gislöv we find no indication of a transportation of the weathering gravel before the Cambrian transgression.

The rearrangement during the transgression took place without marked transport of the coarser material. No part of the material enriched under the conglomerate pebbles has remained in suspension a sufficient length of time to be carried away. The coarsest part of the weathering gravel, that has covered the ground in a place with such a stratification as at Gislöv, then remains in the form of arkose and arkose conglomerate, while the finer weathering products (sand, silt and clayey mineral) have been carried away. We may therefore conclude that the weathering gravel has been thicker than the arkose and the conglomerate together. Consequently the cover of weathering gravel broken up at Gislöv has been more than 1,5 m. thick.

How great a part of the decomposition products were carried away cannot be directly determined. If the upper part of the granite gneiss were not silicified, all the chlorite (the altered hornblende) and nearly half the feldspar and quartz would show on washing (suspension) a smaller size of grain than the arkose. More than 50 % of this still undisturbed part of the rock decay would thus have been carried away by the waves if attacked by them in the same manner as the overlying strata.

The upper part of the weathering gravel has been more crumbled and altered than the basal part. We may take it for granted that in the upper parts the feldspar has been practically quite loose, and that the quartz aggregates have been so disintegrated that very little has been left of the material acted upon by the waves. From this follows that the arkose and the conglomerate cannot occupy 50 % of the rearranged decomposition products but only a considerably smaller part, probably 10—20 % at most. We then also arrive at the conclusion that the sub-Cambrian landsurface of SE Scania has been covered by a layer of weathering gravel, that no doubt exceeded 5 m and probably attained to at least 10 m in thickness.

The weathered material being preserved to such a large extent, partly *in situ*, it reveals to us something about the nature of the alteration and the conditions existing before the Cambrian transgression. The abundance of relatively fresh feldspar in the arkose could be interpreted as evidence of a relatively slight chemical weathering, i. e. of a formation in an arid climate. As shown above, however, the weathering must have been rather strong and to all appearances mainly chemical. Right down in the still undisturbed parts of the granite-gneiss the hornblende is quite chloritized and the feldspar to no small extent kaolinized. We must therefore without hesitation set down the possibility of the Cambrian sea having transgressed here over an arid region as being out of question [1].

Whether the weathering has taken place in a nival or a temperate climate can hardly be determined, the former as well as the latter sometimes showing a rather strong chemical weathering, a fact which has often been called attention to, especially of later years. That the region has not been of a pronounced humid type we may conclude from the fact that the weathering products have to a large extent remained in an undisturbed position.

The circulation of water in the rock decay cannot have been strong enough to carry away the fine-grained weathering products, but it has resulted in the disappearance to a large extent of the iron content by leaching. We see this best in the undisturbed top parts of the granite-gneiss. Lime and alkalis have of course also been removed together with the iron, and some silica has no doubt also gone into solution. It could be expected that the latter had to a certain extent been secondarily deposited in the thick layer of decomposition products, cementing and impregnating them or forming nodules (concretions and secretions) of the type we are acquainted with from other weathered rocks. These solid formations rich in silica ought, if present in the weathered material, to have been included as pebbles in the conglomerate. Such occur in several basal conglomerates (HADDING 1927, p. 57, 106). Still, they have not been found at

[1] If the weathering gravel had existed in an arid region, we should no doubt also have found traces of æolian action, for example in the form of »Dreikanters» in the conglomerate, or by æolian action well rounded grains in the arkose.

Gislöv, a fact which, on the other hand, does not exclude a deposition of silica taking place previous to the transgression. It must, however, have been limited to the lower, still undisturbed parts of the weathered gneiss. The silicification shown by this may just as soon have taken place in connection with the cementation of the arkose.

The formation of the arkose at Gislöv: The Lower-Cambrian arkose at Gislöv is formed at the transgression of the Cambrian sea by the washing and sorting of the weathering products covering the sub-Cambrian land surface. All the fine-grained material of less than 0,1 mm diameter has been washed away at the same time as the larger grains (pebbles) in the remaining gravel have been transported to the surface and thus formed a conglomerate on top of the arkose.

The material of the arkose is derived from the underlying granite-gneiss, the upper part of which is so strongly weathered that it may be called unwashed weathering gravel. On the formation of the arkose the washing was not sufficiently strong to effect a wear of all the loose weathering material. The lower parts were protected by the coarser material remaining at the weathering place.

The nature of the decomposition products indicates that the weathering occurred in a semi-arid, probably temperate or nival zone.

The Cambrian basal beds at Forsemölla.

Besides those at Gislöv the Cambrian basal beds are exposed in several places in SE Scania. They are easiest of access in the brook cutting at Forsemölla, about 2 km. SE of Rörum. The beds have been observed by Angelin already before 1862 [1] and are also mentioned by Holst (1892, p. 12) in his description to the geological map-sheet »Simrishamn».

The arkose rests directly on strongly weathered, fairly acid and fine-grained gneiss. The contact between the two rocks is quite distinct.

The arkose is, especially in the lower part, very rich in feldspar. This is red and relatively fresh. The rock is well cemented and quite solid. The size of the grains is smaller and more uniform than at Gislöv, and there is no conglomerate at Forsemölla. This is no doubt due to the weathering gravel being derived from a more fine-grained and more crumbled rock.

The thickness of the arkose may be estimated at 9 m. In the upper part it is poor in feldspar. It is covered by white sandstone of normal »Hardeberga-type».

The arkose at Forsemölla is formed in the same manner as at Gislöv. The difference in the nature of the rock and its stratigraphical development and occurrence is due to a different material (decomposition products from different kinds of rocks).

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[1] Angelin 1877 (1862) p. 13.

The Cambrian basal beds at Rekarekroken in NW Scania.

At Svanshall, immediately NW of the fishing-village of Rekarekroken in NW Scania, the Cambrian basal beds and their foot-wall, the gneiss, are found exposed. The distance from this locality to the two already described, Gislöv and Forsemölla, is about 120 km.

The basal beds at Rekarekroken, differing widely in their petrographical character from those at Gislöv and Forsemölla, deserve like them a brief account. As seen from the following the Cambrian basal beds at Rekarekroken are formed in a region with pre-Cambrian bed-rock of a relatively fine-grained, strongly weathered gneiss, the decomposition products of which have been only slightly washed. The basal beds at Gislöv may, contrary to these, be considered typical of a region with a bed-rock of gneiss, that is coarser, and more acted upon by the waves.

The gneiss at Rekarekroken. Some metres below the sandstone the gneiss is perfectly fresh, without any traces of either pre-Cambrian or younger weathering. The rock is of medium acidity with more or less distinct parallel structure. The main minerals are quartz, microcline and hornblende. The size of the grains varies somewhat but on the whole the rock is very fine-grained. The colour is reddish grey.

The uppermost metre of the gneiss is strongly altered by weathering. The quartz grains lie almost detached in the loose weathering products of hornblende and feldspar. Haematitic dust gives a deep red colour to the lower parts of the weathering zone. In the upper part of the gneiss the red colour disappears entirely and is replaced by rusty brown and greyish green. The rock consists in this part of quartz and decolourized, strongly weathered microcline, which lie embedded in weathering dust coloured by chlorite and limonite.

The uppermost part of the gneiss differs only slightly from the lowest bed of the sandstone. The content of minerals and the colour are equal. In fact, only a schistosity of the weathered gneiss shows where the boundary between rearranged and undisturbed material is to be found.

The sandstone-arkose. The basal bed in the Cambrian series of strata at Rekarekroken is a greyish green, in some places rust-coloured sandstone or arkose. The feldspar is hardly seen macroscopically.

In the second lowest bed the arkose-nature of the sandstone is more distinct. In some parts at the base of this bed the author has found an abundance of relatively fresh, pale red microcline. This bed is also rich in finer weathering products, which give the rock a greenish grey colour.

Certain parts of the said bed are relatively coarse-grained (scattered grains with a diameter of 3—5 mm). The bulk, however, is fine-grained (diameter of grain $< 0{,}5$ mm).

The third bed, as well as those following, differs only slightly from the two lowest. The rock is a relatively fine-grained arkose with only slightly noticeable feldspar. All through it is rich in powdery, greenish grey weathering products. Coarser parts, also out-thinning conglomerates are found in several places, and sometimes the beds show a distinct cross-bedding.

The 19th bed is almost wholly developed as a conglomerate, the thickest (11—13 cm) and most extended in the series of strata observed by the author. The pebbles attain a size of up to 15 mm, but the bulk of the rock is fine-grained and contains, as in the other beds, an abundance of compact greenish grey weathering products.

About two metres above the base of the sandstone series the greenish grey colour disappears and the rock becomes white. Still, feldspar is to be found in small, white, strongly kaolinized grains as far down as in the lowest white beds. The following beds are hard, quartzitic and almost entirely free from feldspar.

Thus only the rock in the two lowest metres of the series of strata may be termed arkose. The content of feldspar is, however, easily overlooked, as the mineral only occurs in small, strongly weathered grains, which often merge into loose (earthy) weathering products.

The formation of the arkose at Rekarekroken. As already mentioned the Cambrian basal beds at Rekarekroken have been formed under somewhat different conditions from the corresponding beds at Gislöv. This is partly owing to a different size of grains in the weathering gravel (coarse at Gislöv, fine at Rekarekroken), but other factors must also have helped to create the differences at hand.

At Gislöv the granitic weathering gravel has been stirred up and the finer material held in suspension by the waves. It has then been thoroughly sorted: the silt carried away and the sand-grains separated from the pebbles, which during the washing have been brought up above the sand and formed a conglomerate bed.

At Rekarekroken the shifting of the weathering gravel has taken place without any stronger sorting of the material. The silt has not been washed away but is included in great abundance in nearly all the arkose beds. Nor have all the larger grains been enriched into a conglomerate bed, but lie mostly dispersed in the sandstone.

Characteristic of the arkose at Rekarekroken is also its occurrence in thin beds, seldom more than 10 cm thick.

We may conclude that the Cambrian basal beds at Gislöv have been formed on an open shore, where the waves of the transgressing sea could freely participate in rearranging the weathering products. From the comparison between the rocks at Gislöv and at Rekarekroken we may infer that the arkose in the latter place could not be formed on an open shore.

In several places impure sandstones and arkoses of the same type as at Rekarekroken are found in series of strata deposited in smaller, closed basins, for inst. in lakes or lagoons. Such rocks are found in the Keuper of Scania, in the Visingsö series as well as in the Norrlandish Cambro-Silurian series of strata (for example in the Wemdal quartzite).

The continuity between the arkose and the overlying, normally developed Lower Cambrian sandstone beds at Rekarekroken is quite evident. They form a series of strata without any disconformity. Therefore the arkose as well as the younger beds may be marine.

We may sum up the results of our investigation on the formation of the rock thus: The arkose at Rekarekroken was formed during the oldest Cambrian transgression in lagoon-like or otherwise protected part of the shore.

Rekarekroken is situated in the SE part of the horst Kullen. This is constructed mainly of acid, gneissic rocks but also contains an abundance of basic, garnet-rich amphibolic rocks. The content of garnet in recent sand deposited within the region is remarkably great, and therefore special attention may be called to the fact that no garnets have been found in the Cambrian sandstones from the same region. As to the arkose this is easily accounted for: the material of this rock has not undergone any transportation to speak of, and garnet-bearing rocks are absent in the immediate vicinity of Rekarekroken.

The sandstones, on the contrary, are composed of grains, that have probably been transported a shorter or longer distance while being sorted and acted upon. The absence of garnet also in these rocks can hardly be due to any other cause than that the garnet-rich rocks do not lie bare on the Cambrian shore. This may support our opinion that the basic rocks (metamorphic diabase) originate from post-Cambrian time.

The quartzitic, fossil-free Lower Cambrian sandstone (»The Hardeberga sandstone»).

In most places in Scania where the Lower Cambrian sandstone is exposed its pre-Cambrian substratum is not visible nor its arkosic basal layers. As a rule the oldest observed parts of the series of strata consist of a white, hard quartzitic sandstone, called »Hardeberga sandstone» after its most known occurrence.

The Hardeberga sandstone occurs typically developed at Simrishamn, Brantevik, Jerrestad, Gislöv, Forsemölla, Kivik a. o. places in SE Scania, at Hardeberga, Röstånga and other places in central Scania, and at Rekarekroken and Torekow in NW Scania.

North of Scania typical Hardeberga sandstone occurs in the neighbourhood of Kalmar. To what extent the occurrences of Lower Cambrian sandstones situated further north contain rocks corresponding not only in their petrographical character but also in their stratigraphical position with the Hardeberga sandstone of Scania, is at present uncertain. The main part of these rocks, however, is of a different character.

The petrographical character of the Hardeberga sandstone.

The Hardeberga sandstone is a pure, white quartzitic sandstone. Besides quartz only small quantities of other minerals occur among the grains. Of them feldspar (microcline) is most common. Glauconite is absent.

The size of the grains is varying. In a sample from Hardeberga it was determined to 0,1—2,0 mm, in a sample from Jerrestad to 0.05—0.5 mm.

The grains are as a rule well rounded. By secondary growth, however, they obtain an angular appearance.

The cement consists of quartz. As a rule it is present in such abundance that the pores between the grains are completely filled up by it. As mentioned above it occurs as a secondary growth of the quartz grains.

The Hardeberga sandstone contains no fossils or tracks. Foreign inclusions (clayey flakes, pyrite nodules, etc.) are exceedingly rare. Phosphorite has no more been observed in the rock than glauconite. (These minerals occur, on the contrary, fairly abundantly in the younger beds of the same series of strata).

The Hardeberga sandstone is developed in distinct beds, usually several decimetres thick. The different beds are often separated by thin layers of soft yellow or green shale.

Sometimes the bed surfaces show ripple marks. This is for inst. the case at Hardeberga. The wave-length is there 60 cm. The direction of the ridges E-W. The marks are unsymmetrical with their lee-side (steep) to the north. (About ripple marks in the overlying sandstone, see p. 95).

The formation of the Hardeberga sandstone.

At Gislöv, Forsemölla and Rekarekroken one can follow the transition from arkose to Hardeberga sandstone in the basal part of the Lower Cambrian series of strata. The change consists in the material being not only sorted but also strongly worn. The Hardeberga sandstone is deposited when the transgression has progressed so far that the first suspended weathering products have finally settled down in a region and the succeeding deposition of better sorted, more worn and possibly farther carried material has commenced.

The purity of the Hardeberga sandstone and the marked roundness of its grains shows us that the deposition has occurred first when the material has been acted upon for a longer time and in a region with such a strong current in the water that silt or grains under a certain size have not been deposited in larger quantities.

During the wear, resulting in the rounding of the quartz grains, the weathered grains of feldspar have crumbled and been washed away together with the rests of fine silt. The few and small grains of microcline present in the sandstone give us no idea of the feldspar content in the primary material.

The clayey layers between the sandstone beds were no doubt deposited during periods with only slower currents in the water. It is, however, not possible to infer from the kind of rock the cause of the alternation between »still-water-periods» and periods with moving water. Various possible causes have been discussed elsewhere (p. 87 a. o.).

The paleogeographical significance of the Hardeberga sandstone.

The possible conclusions to be drawn from the petrographical character of the sandstone and its occurrence regarding its forming conditions may be shortly summed up thus: The Hardeberga sandstone is formed at slight depth but mainly below the littoral zone. The uniformity of the bedding and the grains shows that the current conditions have not been subjected to the strong changes characteristic of many open shore regions.

The large distribution of the rock, its uniform development and bedding are essentially explained, if we presume that the sub-Cambrian land surface, over which the transgression took place, was a strongly denuded, relatively flat peneplain.

The Cambrian sea was at least apparently free from organic life during the formation of the Hardeberga sandstone. Neither in the sandstone beds nor in the clay layers between them are traces of fossils to be found. The absence of both organic remains and calcite is also remarkable on comparison with the overlying sandstone beds.

The different occurrences of Hardeberga sandstone well deserve to be mentioned, partly because the rock shows certain variations, partly because the deposition has not been quite simultaneous in all places. A detailed analysis of these circumstances would, however, be too extensive to be included in this work.

In an account on the Hardeberga sandstone it should also be mentioned that fluorite is often found filling fissures in it (especially at Hardeberga and Brantevik). Galena veins have also been observed but mainly in the younger strata.

The middle and upper part of the Lower Cambrian sandstone.

In Scania the above described Hardeberga sandstone grades without break into the sandstones described in the following. The series of strata shows no disconformities. A change occurs, however, and on that account each rock is here treated separately.

While the Hardeberga sandstone is a pure quartz sandstone with neither fossils, tracks, glauconite or phosphorite, the overlying part of the series of strata is composed of calcareous sandstones alternating with quartz sandstones. The beds are sometimes phosphorite- or glauconite-bearing, many of them are rich in tracks and some are fossiliferous (Olenellus beds).

Certain types are easily distinguished and will be further illustrated in the following. As it is not possible to determine whether they are typical to certain stratigraphical horizons or whether they are local forms of development deposited in different places at different times according to the change of outward circumstances, they may however be mentioned here in uninterrupted succession.

The development of the middle and upper parts of the Lower Cambrian sandstone is fairly similar in Scania and in the neighbourhood of Kalmarsund. In Vestergötland, where they rest directly on the Archaean, they are partly otherwise developed. The scattered occurrences of sandstone known from the Mälar region, Östergötland, Nerke etc. should no doubt be grouped with the same part of the series of strata. Their formation is frequently rather peculiar, and we shall also illustrate some of them.

The middle and upper part of the Lower Cambrian sandstone in Scania.

The middle and upper parts of the Lower Cambrian sandstone are exposed in a number of places in Scania. We shall not give an account of all of them here, but only illustrate the stratification in a couple of localities (Hardeberga and Simrishamn-Brantevik) and subsequently discuss the different rocks and their occurrence.

The series of strata at Hardeberga.

The completest and easiest accessible series of strata in the Lower Cambrian is to be found at Hardeberga. In the large quarries worked there, only the very oldest strata are absent: the basal conglomerates and the arkose.

The beds only show a slight dip, but they are traversed by a number of faults in such a manner that the bulk of the series of strata becomes accessible in a small region.

As illustration of the stratification some chosen parts of the series of strata are given below.

In the lower part of the series immediately above the white quartzitic Hardeberga sandstone we find the following stratification (section 1): —

Gray sandstone with white winding worm trails (at the top of the section)	260	cm.
Sandstone, greenish gray, in the upper part with vertical tracks, in the lower part with fine but irregular bedding	31	»
Gray sandstone with vertical tracks	12	»
Sandstone, gray in the upper part, white in the lower	23	»
» gray and white, rich in tracks	19	»
» at the top white, at the base gray, rich in tracks	25	»
Gray sandstone, with fine but irregular bedding. The rock full of vertical and winding tracks, as a rule with a white cylindrical nucleus and darker wall. Thickness of the beds	21 7 25 17 13 20 17 13	» » » » » » » »

White sandstone, with dark, vertical and horizontal tracks and ripple marks. *Diplocraterion sandstone*	18 cm.
	21 »
White sandstone, partly rather coarse and granular, with out-thinning clayey layers and scattered gray or greenish gray vertical tracks. *Diplocraterion sandstone*	17 »
	49 »
	24 »
	78 »
	93 »
	51 »
White sandstone, the upper part slightly argillaceous, green	60 »
White or slightly green sandstone with out-thinning clay layers and scattered clay slabs. In certain beds is the sandstone rather coarse-grained and granular	37 »
	30 »
	27 »
	28 »
	25 »
Green, hard shale, here and there replaced by white sandstone	3—4 »
White sandstone, coarse, with slight cross-bedding	14 »
Green, hard shale	4 »
White, granular sandstone	12 »
	9 »
	25 »
Green, hard shale	3 »
White, granular sandstone, with indistinct clay layers, rounded clay slabs and here and there traces of cross-bedding	22 »
	7 »
	15 »
	10 »
	54 »
	29 »
	42 »
Hard, green shale	5 »
White, granular sandstone, with small clay slabs..............................	13 »
Hard, green shale	1—3 »
White, granular, rather coarse sandstone, with occasional green slabs of clay.	57 »
Out-thinning, white, granular sandstone in thin green layers of clay. Below this large *ripple marks*	0—6 »
White, granular sandstone, with out-thinning clayey layers. *Syringomorpha sandstone.* Beds as a rule 20—40 cm thick. (The bottom of the section)	250 »

In a somewhat younger part of the series of strata the following stratification has been observed (section 2, about 3 m thick):

7 Light gray crystalline sandstone, with calcite cement and matrix. In the upper part a thin layer of *phosphorite nodules.*
6 White siliceous sandstone, with some cement of calcite.
5, 4 Blackish gray arenaceous shale.
3 Gray calcareous sandstone, with glauconite and pyrite.
2 Light gray, somewhat calcareous quartz sandstone, with dark winding worm trails.
1 Light gray, somewhat calcareous sandstone, without trails (at the bottom of the section).

In the upper part of the sandstone series, the *Kjerulfizone*, TROEDSSON (1917, 619—622) has measured the following section (section 3):

1 a	Highly calcareous crystalline sandstone, on weathering loose, sandy, greenish. In the middle part a layer of *phosphorite* nodules. In the lower part *Hyolithus De Geeri* HOLM..............	60 cm.
1 b	Calcareous crystalline sandstone, here and there with worm trails and with an out-thinning *conglomerate* containing phosphorite nodules and large quartz grains	15—25 »
1 c	Light gray, on weathering green calcareous crystalline sandstone, rich in pyrite..	50 »
2	Gray sandstone, with worm trails in the upper and lower part and in the middle part pyrite in the form of grains and flat lenses	45 »
3	Light gray, quartzitic, pyrite-bearing sandstone, with curved trails and dark, thin layers.................	30 »
4	Gray, on weathering green, shaly sandstone, rich in winding trails (*Scolithus errans*). Bed surfaces uneven, frequently covered by scales of mica	300 »
5	Light gray, quartzitic sandstone, with pyrite and occasional worm trails	50 »
6	Thin-bedded, fissile, quartzitic sandstone, with scattered coarse worm trails	25 »
7	Light gray, quartzitic sandstone, with scattered worm trails ...	20 »
8	Gray sandstone, with *Scolithus errans* (like stratum 4)	50 »
9	Gray, pyrite-bearing sandstone, with *Scolithus errans* (more sparingly) and occasional phosphorite nodules (at the bottom of the section)	150 »

The upper part of the series at Hardeberga shows the following stratification (section 4):

Alum shale of Middle Cambrian age (Paradoxides beds)	
Gray sandstone with worm trails	15 cm.
Dark shaly sandstone	2 »
Calcareous sandstone, in the upper part gray, spathic, in the lower part dark and rich in fragments of fossils (»fragment limestone», with *Holmia Kjerulfi* a. o.).	61 »
Black fragment limestone	3 »
White sandstone, in the upper part hard calcareous sandstone with phosphorite nodules, in the middle part loose, sandy, in the lower part harder calcareous quartz sandstone	100 »

The above section was measured on the recent exposure of the strata (1916). A year later the series of strata was measured by TROEDSSON (1917, 614), who found that several of the beds had been divided by weathering of the rock. Also in other respects the series of strata appears somewhat different in the two measurements, owing to these not being made in the same place, and the strata showing a certain change in a horizontal direction.

The petrographical character of the Lower Cambrian sandstones at Hardeberga. A summary.

In the above sections the following types of sandstone occur: —

A. Pure sandstones:

1. Quartz sandstone: — a. Without secondary growth of the grains.
   b. With secondary growth of the grains = crystalline sandstone; with or without interstitial calcite.
2. Calcareous sandstone: — a. With fine-crystalline calcite as cement.
   b. With coarse-crystalline calcite = spathic sandstone.

B. Sandstone with one or several kinds of mineral inclusions: —

1. Clayey or muddy sandstone.
2. Pyrite-bearing sandstone.
3. Phosphorite-bearing sandstone.
4. Glauconitic sandstone.

C. Sandstones characterized by an abundance of tracks or burrows: —

1. Sandstone with winding trails.
2. Sandstone with straight, vertical tracks or burrows.

D. Sandstone with an abundance of fossil fragments: — arenaceous fragment limestone.

The different types grade into each other in such a manner that for example a sandstone with winding trails can contain an abundance of clayey substance and pyrite also and be developed as a normal quartz sandstone or as a crystalline sandstone with or without calcite.

A number of different combinations are then possible, many of which have also been observed. Not infrequently several of the types are observed in one and the same bed (for inst. spathic sandstone, phosphorite sandstone, normal calcareous sandstone with or without pyrite, crystalline sandstone with interstitial

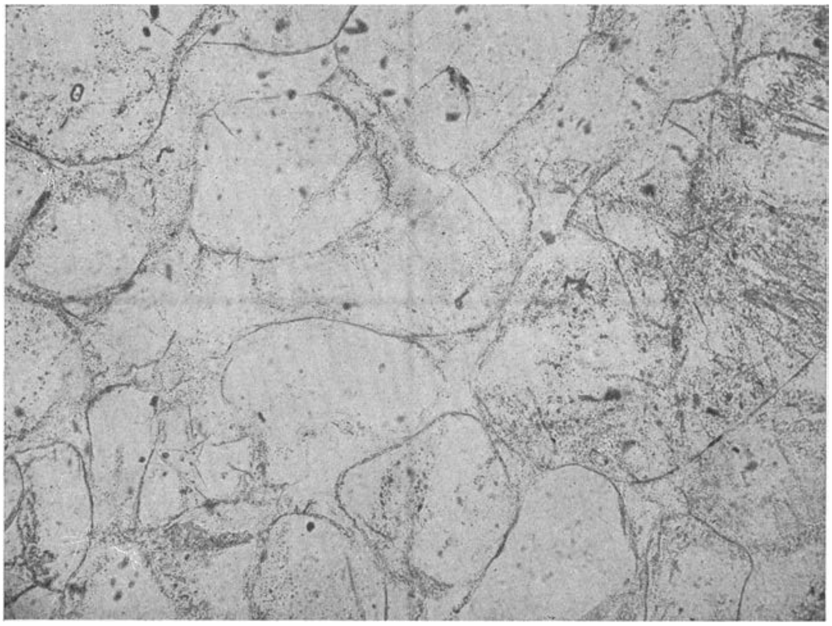

Fig. 43. Quartzitic sandstone. Cementation by enlargment of the quartz grains. Lower Cambrian. Hardeberga. 60 ×. (Pr. 610. Pr. 342.)

calcite). In field work it is therefore hardly possible and often absurd to distinguish the different types. On the other hand a sample of rock may give us a false idea of the nature of a bed or series of strata, as it only shows one of the possibly numerous types occurring in the bed or the sandstone series.

It would be of small use to describe here all the different combinations observed. We shall only give a short account of the pure types and examine some of the more interesting facts, for inst. the occurrence of the calcite in the crystalline sandstones, the spathic sandstones, the occurrence and paleogeographical significance of the autigenous minerals (pyrite, glauconite and phosphorite) and the character of the tracks.

Quartz sandstone. Most of the beds in the middle and upper parts of the Lower Cambrian series consist of quartz sandstone, i. e. a sandstone in which quartz occurs as cement. In a great number of these beds calcite is also found, often in large quantities and then always interstitially as crystallized, last formed cement.

Common quartz sandstone, with SiO_2 cement but without secondary growth of the quartz grains, has not been observed in a pure form but only as rocks rich in clay or mud. These sandstones often have an abundance of winding trails.

Crystalline sandstone without calcite is not present in larger quantities in this part of the series of strata. Where it occurs it is petrographically like the Hardeberga sandstone. As a rule inclusions (glauconite etc.) and trails are absent.

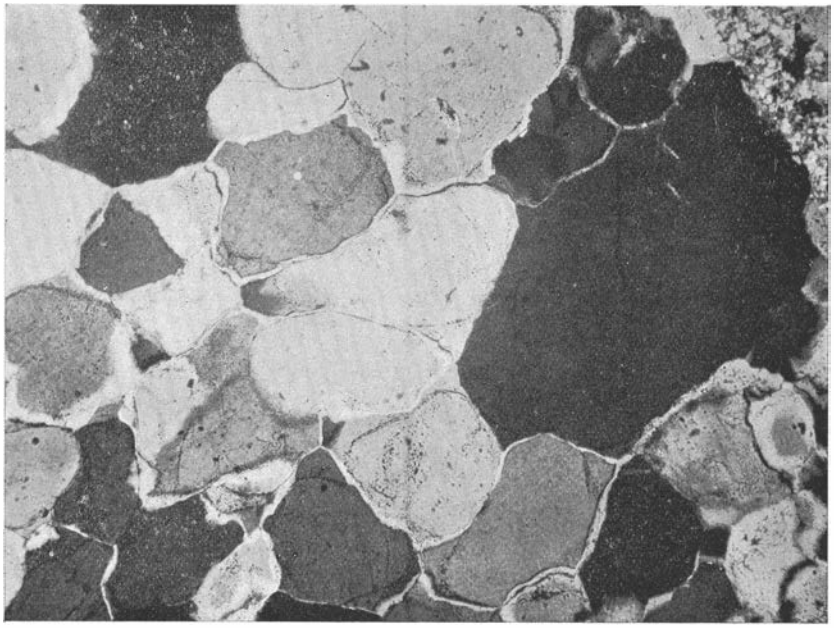

Fig. 44. Quartzitic sandstone. Prep. = fig. 43. 50 ×. Nic. +. (Pl. 343.)

Crystalline sandstone with calcite is perhaps the most typical form of sandstone in the part in question of the series of strata. The secondary growth of the quartz grains varies greatly. A strong growth is found in pure forms having a quartzitic appearance and greatly reminding of the Hardeberga sandstone. As a matter of course the calcite content in these must be small, the pores for the most part being filled with the secondarily formed quartz. Lime-poor, quartzitic crystalline sandstone often grades into lime-free as well as into more calcareous. Like the pure crystalline sandstone the one with interstitial calcite is as a rule free from glauconite and other mineral inclusions. Out-thinning layers of clayey substance occur in several beds.

In certain beds the lime-poor crystalline sandstone contains vertical tracks with clayey or muddy walls. We may regard this sandstone (also in its locally lime-free development) as the actual and almost sole bearer of the vertical, U-formed tracks of *Diplocraterion*-type. These tracks often occur in such numbers that they give the rock a characteristic appearance. (See below).

Lime-rich crystalline sandstone, i. e. a sandstone with a minor secondary growth of the quartz grains and with more abundantly occurring calcite cement, forming the bulk of the white or light gray rocks in the series of strata in question.

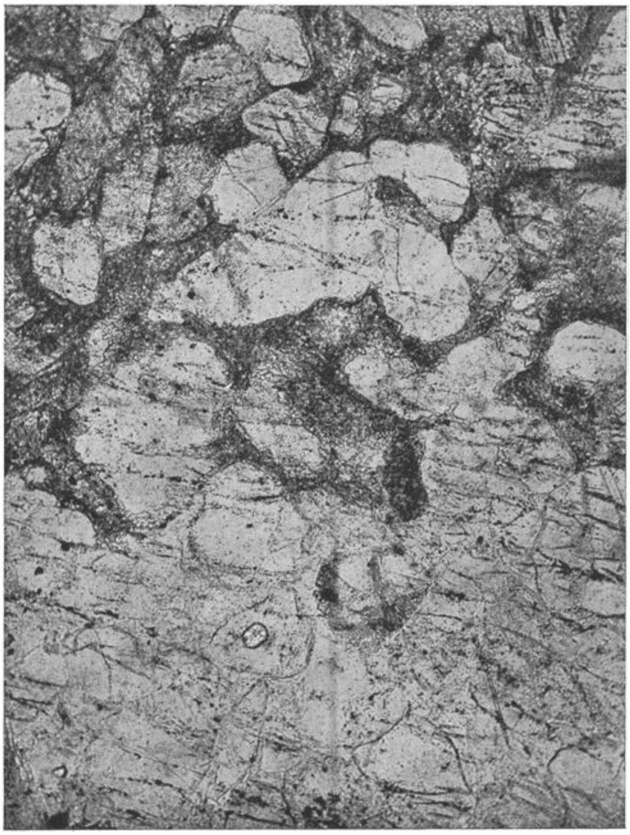

Fig. 45. Sandstone bed partly with calcareous cement (upper part), partly with siliceous cement (lower part). Lower Cambrian. Hardeberga. 60 ×. (Pr. 2646. Pl. 337.)

The sandstone has no quartzitic but a more granular appearance. Contrary to the usual calcareous sandstone it remains quite solid, also on weathering.

The calcite is formed into distinct crystals, often of such a size that a crystal fills several adjacent pores.

The lime-richer crystalline sandstone contains, contrary to that poor in lime, no tracks of Diplocraterion-type. But not infrequently it is pyrite-bearing and can also contain phosphorite.

The lime-rich crystalline sandstone grades in certain beds into calcareous sandstone (without SiO_2-cement).

The calcareous sandstone occurs in the series of strata far more sparingly than crystalline sandstone with interstitial calcite. It is conspicuous either by the calcite (the cement) having developed into crystals with reflecting cleavage planes or by crumbling into loose sand on weathering.

The calcareous sandstone is often rich in pyrite and not infrequently phosphorite-bearing. Sometime it is muddy and also shows winding worm trails.

The content of lime in the rock can in certain beds exceed the content of sand. The sandstone has then graded into arenaceous limestone. There is some-

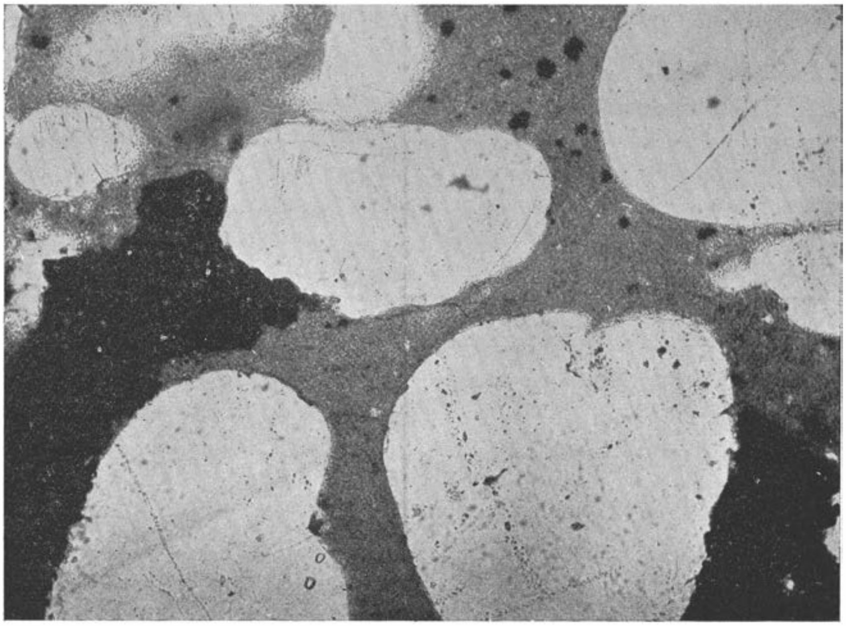

Fig. 46. Calcareous sandstone. Well rounded quartz grains cemented by fine-crystalline calcite. Darkest parts = pyrite. »Rispebjer sandstone». Lower Cambrian. Hardeberga. 60 ×. (Pr. 511. Pl. 339.)

times such an abundance of fossil fragments in this that the rock may be designated a »fragment limestone».

The content of clay and mud in the Lower Cambrian sandstones varies greatly. As a rule, however, we find that all the beds in certain parts of the series of strata consist of pure, white sandstone, while all the beds in another part are characterized by a high content of clay or mud.

The clayey substance occurs mainly between the sandstone beds in the form of a green, rather soft shale without distinct lamination. Similar clayey substance is found scattered in extremely thin, out-thinning, often slightly inclined laminae in the sandstone beds. The quantity of clay is so small in these layers that the rock does not, as a rule, split after them.

The clayey substance also occurs around the vertical tracks. In this case it is most likely an infiltration zone around the tracks, wider at the top, less conspicuous at the base and limited to the wall of the cylindrical tube.

Clayey substance also occurs in several beds in the form of irregular or disc-shaped slabs of clay, a few millimeters thick and with a diameter of 1—5 cm. In their petrographical character these small clay flakes are perfectly uniform with the shale between the sandstone beds. Their rounded form shows that they have been exposed to wear or disintegration and their isolated position in pure sandstones that they must have been transported and deposited as consolidated, relatively solid slabs. Therefore we must interpret these clay flakes as fragments of the layers of clay interbedded with the sandstones. As mentioned above, these layers have been deposited during periods with tranquil water. The water after such a period having begun to move again and the deposit of clay having been replaced by a deposit of coarser material (sand), part of the deposited clayey substance has been detached and carried away or possibly been embedded in the deposited sand. The latter has occurred especially when consolidated parts of the clay have been torn away. They cannot have been transported any greater distance. Even a washing of short duration and a slight dislodgment have been sufficient to give them a rounded form.

If the suspended clayey material has been loose (earthy), it can only have been deposited in the sand in the form of very thin, only slightly extended, scattered layers of clayey dust. The out-thinning clayey laminae mentioned above are no doubt formed in this manner.

The black, dust-like substance occurring abundantly in the dark sandstone beds can hardly be designated as a clayey substance. It contains an abundance of relatively easily weathered iron mineral, mainly *pyrite-dust,* and often muscovite in even macroscopically visible scales. Thus the substance may appropriately be designated a pyrite- and muscovite-rich mud.

Contrary to the above-mentioned clayey substance this mud does not occur accumulated between the sandstone beds and only exceptionally as isolated laminae or occasional flakes. It occurs instead as matrix in fine, uneven laminae, with very small interstices (usually 0,5—3 mm.).

The muddy layers are often truncated by the worm trails, that traverse the rock in excessive quantities in all directions.

The muddy sandstones have been deposited in more tranquil water than that in which the pure sandstones have been formed. A mixture of mud and coarser material, such as exhibited by the sections, implies *a formation in secluded or lagoon-like basins.* The innumerable worm trails, the thin beds, the irregular lamination, the pyrite-rich mud and the angular quartz grains tally well with this interpretation.

Pyrite-bearing sandstones occur in several places in the series of strata. They are of two different kinds, partly white or light gray with macroscopically visible yellow pyrite crystals, partly dark gray with black pyrite dust.. The latter form is the above described mud-bearing sandstone.

As a rule the white, pyrite-bearing sandstone is calcareous, often thick-bedded, sometimes phosphorite- or glauconite-bearing. The pyrite occurs in these beds accumulated in some horizons or in scattered, spherically limited portions of the rock. The crystals are usually less than 1 mm in diameter. Petrographically this pyrite has not the same significance as the dust-like one in the dark muddy sandstones. The pyrite crystals are no doubt secondarily formed.

Phosphorite-bearing sandstone is found in many places in the Lower Cambrian series of strata. It occurs as a crystalline sandstone with calcite or as calcareous

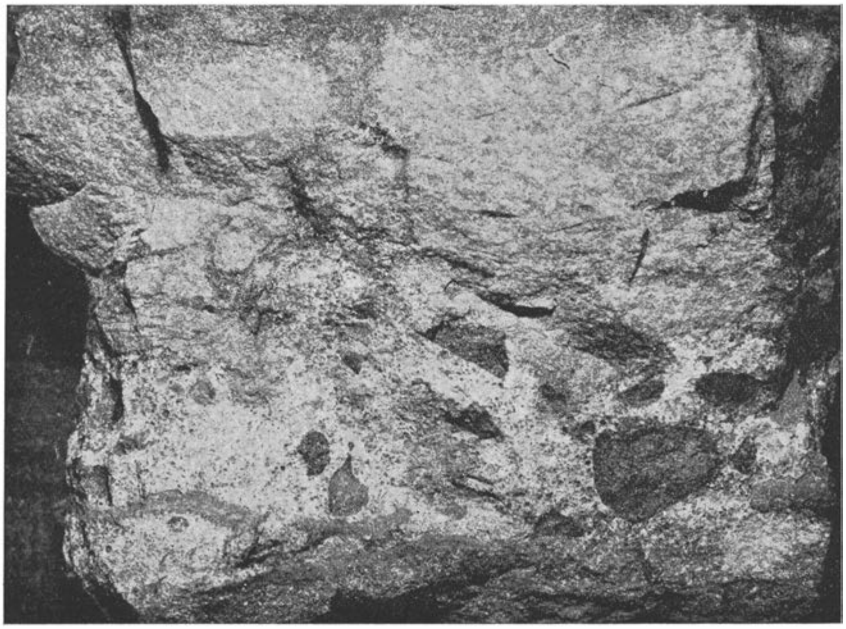

Fig. 47. Sandstone containing phosphorite nodules. Lower Cambrian. Hardeberga. — 1/1. (Pl. 269.)

sandstone, but never as a lime-free, quartzitic sandstone nor as a track-rich and muddy rock.

The occurrence of the phosphorite in the sandstones is not everywhere uniform. In certain beds it is no doubt secondarily present. It then lies embedded in a layer of coarse sand. The pebbles are rounded and contain as a rule sand grains of a completely different size (usually much finer) than those found in the phosphorite-bearing bed.

In other beds the phosphorite nodules are less distinctly demarcated. They have an uneven surface and a fairly angular form. The grains of sand enclosed in the nodules are uniform with those present in the phosphorite-bearing rock. We have no occasion to suppose a secondary occurrence here. In these cases the phosporite has, in all probability, been formed at the same time and in the same place as the phosphorite-bearing bed.

Glauconite-bearing sandstone occurs only sparingly in the said sections at Hardeberga. Only exceptionally has this rock been observed in other parts of the same series of strata and then with but a small content of glauconite. The fact is the more remarkable, as glauconite is a very prominent component in the Lower Cambrian sandstone of other Scanian regions, for inst. at Simrishamn, Brantevik and Torekow.

The glauconite sandstone at Hardeberga is a quartz sandstone, a lime-rich crystalline sandstone or calcareous sandstone, mostly of a light gray colour. It is usually thick-bedded and without traces of lamination. Sometimes it is pyrite-bearing. The grains of glauconite are light green. Their size is about 0,25 mm in a sandstone with quartz grains 0,1 mm in diameter. In the glauconite bed occurring in the above-mentioned series of strata, section 2, the glauconite grains are not rounded but are of varying form. They are squeezed in between the sand grains and seem to have shaped themselves in some degree after the space between these grains in a manner indicating that they were soft at the time of deposition. The chalcedony cement abundantly present in the rock has also impregnated at least part of the glauconite grains. In this and other beds the glauconite occurs primarily. The author has not observed it as secondary deposit at Hardeberga except possibly in the Syringomorpha sandstone (see p. 95). In other occurrences of Lower Cambrian sandstone an essential part of the glauconite-richer rocks may, on the other hand, contain glauconite as secondary deposit.

The tracks in the Lower Cambrian sandstone at Hardeberga are of two different kinds: — winding or arched trails and straight or U-formed, vertical burrows.

The winding or arched trails occur partly on the bedding planes, partly in the interior of the beds. In the latter case they can have a horizontal, vertical or (as a rule) more irregular course, often from one bedding plane to another.

The winding trails are more or less compressed cylinders. Their diameter varies from 3 to 6 mm. The trails consist of a thin dark »wall» and a lighter nucleus. In dark sandstones the lighter trail nucleus contrasts with the dark surroundings. In the white or light gray ones the dark cylinder wall contrasts with the rock. Hence one is apt to consider the trails dark in light sandstones and light in dark ones.

The trails are not all quite the same type. As shown elsewhere they are no doubt derived from different kinds of animals.

In certain cases the cylinders are well developed. The cylinder wall may then have been regularly developed and relatively solid. In other cases the trails only consist of semicylinders. The cylinder wall has then been differently developed on each side. The large, arched, dark trails in the light, relatively pure sandstones are often of this type. One and the same trail may also be differently developed in its different parts for inst. with one-sided development of the wall in one part and normal development in another.

The trails traversing the dark, mud-bearing sandstones in excessive numbers, have a more indistinct construction. They truncate the dark mud laminae and make the bedding look still more irregular than it really is.

The occurrence of the different trails in certain types of rock and the conclusions we can draw concerning the conditions under which the trail-bearing rock were formed, are discussed elsewhere in this work (p. 41 seq.).

A winding trail of peculiar type should be mentioned in this connection, though it does not, as the above-mentioned ones' impart a special character to the rock. This trail occurs on mud-coated bedding planes. It forms even curves,

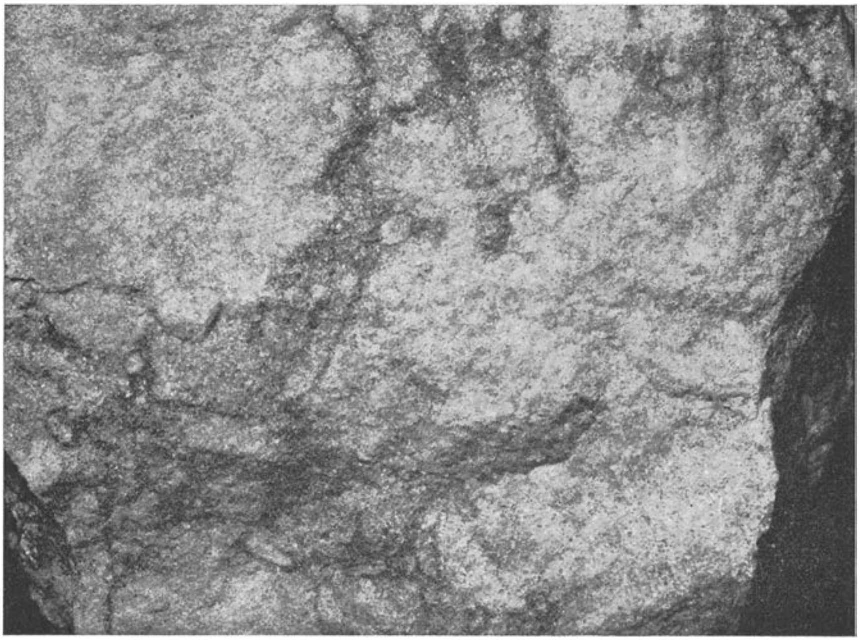

Fig. 48. Diplocraterion sandstone. Horizontal section. Lower Cambrian. Hardeberga. — $^1/_1$. (Pl. 257.)

all of which have about the same width and bend alternately from one side to the other (fig. 34, p. 56). In the only case in which this trail has been observed at Hardeberga the mud-coated bedding plane shows indistinct ripple marks and the trails follow the troughs. Two trails running in the same trough may intersect in the middle line of the trough. They then form a chain like a series of eights piled on each other $\begin{pmatrix}8\\8\\8\end{pmatrix}$. These regularly curved trails occur in a bed with U-formed vertical burrows (*Diplocraterion*). Whether the same animal that formed the latter formed the 8-trail also has not been determined with certainty. These phenomena will be further discussed elsewhere.

Sandstone with vertical tracks, or to put it more exactly, with straight burrows at right angles to the bedding planes, is always relatively pure, white or light gray. The burrows are green from clayey substance or black from mud. In vertical sections the sandstone beds are thus divided by green or black lines about 5 mm broad.

In horizontal sections the vertical tracks are found not to be single but in pairs connected by a thin layer of clay or mud. Vertical sections through two connected tubes resemble clay or mud ribbons about 3 cm broad, traversing the beds vertically. Here and there in these ribbons a series of even, downward convex curves connecting the tubes (= outer edges of the ribbon) is to be seen. The tracks are described more in detail elsewhere. They are interpreted as formed by worms and are termed *Diplocraterion*.

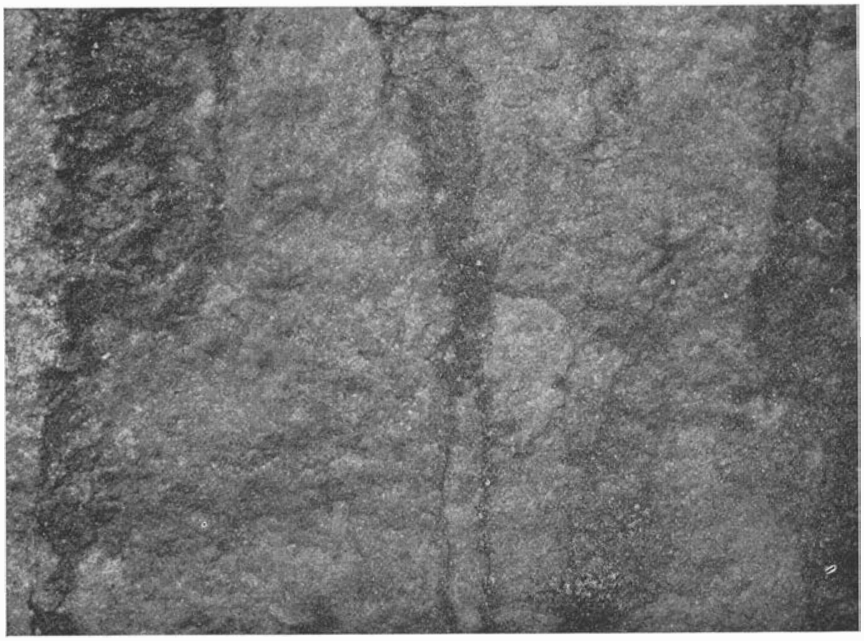

Fig. 49. Diplocraterion sandstone. Vertical section. Lower Cambrian. Hardeberga. $^1/_1$. (Pl. 259.)

The Diplocraterion beds are deposited in moving water without any deposition of clay or other fine material. What is present of such a material in the tracks must either have trickled down along the burrows after the formation of the sand bed or have been caught by the track-building animals and conveyed to the tube wall by them.

Neither glauconite nor phosphorite have been observed in the Diplocraterion sandstones.

Another type of vertical tracks, the single but often very closely clustered tubes of *Scolithus linearis*, has not been observed in the series of strata at Hardeberga.

In the Lower Cambrian *fossiliferous sandstone* only occurs in its very youngest part. Trilobites, brachiopods and *Hyolithes* are accumulated in great numbers in certain beds. These beds are always rich in calcite, sometimes even so highly calcareous that the rock should be better termed arenaceous limestone than calcareous sandstone. On account of the shells being mostly fragmentary certain parts of the rock have also been termed fragment limestone.

The highly fossiliferous calcareous sandstone and the fragment limestone are often pyrite-rich. Phosphorite also occurs in certain beds. These contain consi-

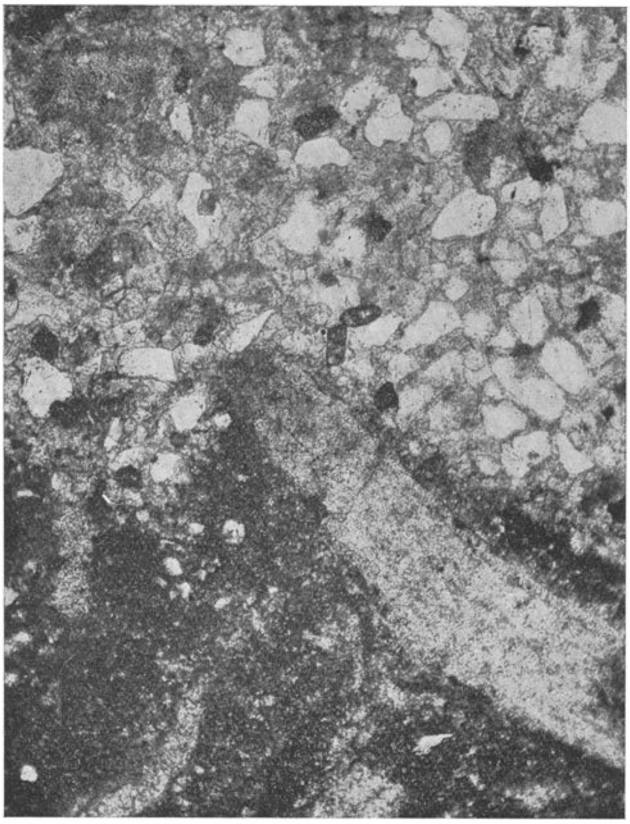

Fig. 50. Calcareous sandstone resting on »fragment limestone». Lower Cambrian. Hardeberga. 60 ×. (Pr. 2782. Pl. 348.)

derably coarser sand grains than the rest of the rock and have been formed during a period of increased current- or washing wave-action. The phosphorite nodules are well rounded. Their content of exclusively finer sand grains shows that they were formed where fine-grained sediments were deposited. Their occurrence together with the fragments of fossils and the coarse sand grains is secondary. As the nodules, fragments of shells are also secondarily enriched in certain beds, fragment limestone beds.

Fossils also occur in fine-grained, somewhat muddy forms of the sandstone. Especially on weathering of the rock are the moulds of the shells very distinct.

In such a rock of rusty or dark green colour the fossils (the Olenellus fauna) were found by Moberg 1891.

The fossiliferous beds of the Lower Cambrian sandstone have not all been similarly formed. The fine-grained, muddy beds are deposited in relatively still water, the coarse, conglomerate-like, phosphorite-bearing in relatively moving water and the other beds under the same conditions as the bulk of the underlying series of strata.

The muddy as well as the coarse-grained fossiliferous beds may be formed

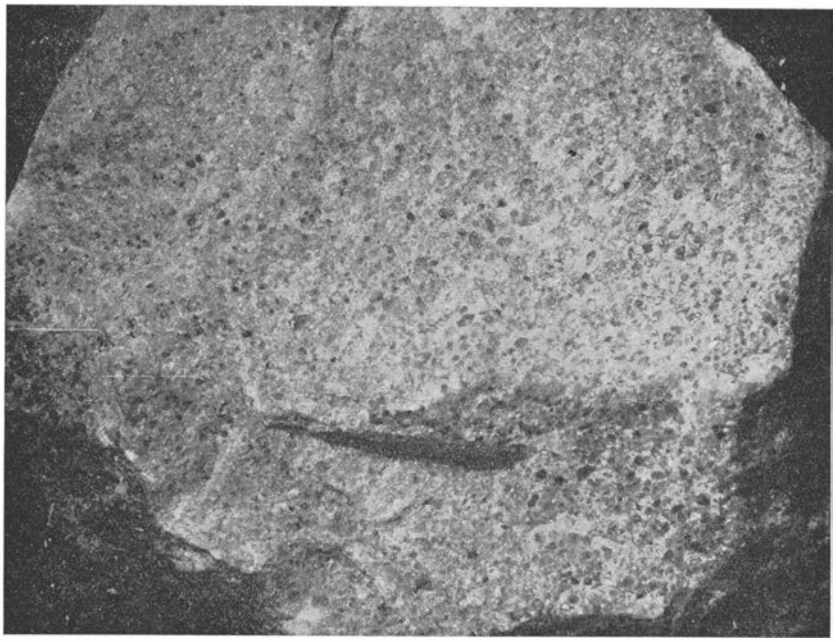

Fig. 51. Granular (non-quartzitic) siliceous sandstone. Syringomorpha sandstone. Lower Cambrian. Hardeberga. $^1/_1$. (Pl. 260.)

during a shallowing of the water by elevation of land. Still, the latter must have been formed on an open shore or on freely situated bars, while the former were formed in more secluded, possibly lagoon-like basins.

The fossiliferous beds (with fragments of trilobites, *Hyolithes* and brachiopods) therefore mark a deposition in shallow water, sometimes in connection with a slight elevation of land.

Besides the tracks and the fragments of shells a fossil of more uncertain nature occurs at Hardeberga. It has been described as *Syringomorpha* (*Cordaites*) *Nilssoni* Torell. Its structure and occurrence will be illustrated elsewhere. It is not present in such abundance that it characterizes the rock but it seems to be confined to a sandstone of certain type, which for that reason is appropriately termed *Syringomorpha sandstone.*

The Syringomorpha sandstone is a white or light gray quartz sandstone with a more granular than quartzitic fracture. The rock is fine-grained (diameter of grain 0,2 mm) but contains occasional thin layers of coarser sand (diameter of grain 2 mm).

In certain beds of the Syringomorpha sandstone glauconite is present as small green grains (diameter about 0,5 mm). The grains are rounded and distinctly defined. They have been fully developed and quite hard before being embedded in the sand, and consequently it is not excluded that they occur as secondary deposits. (Cf. The glauconite in other beds. P. 91).

The occurrence of ripple marks in the series of strata at Hardeberga is not confined to certain types of rock. The oldest observed ripple marks are in the lower part of the series of strata i. e. in the white quartzitic »Hardeberga sandstone» (see p. 78). They are large and unsymmetrical. In the middle part of the series of strata ripple marks are observed in three different horizons. Two of them are indicated in section 1, the third is situated about 1,5 m below the basal bed of this section.

The lowest of the three ripple mark horizons occurs in a white sandstone of medium coarseness. There is no layer of clay or mud at the ripple-marked surface but a slight coating of hydrated ferric oxide. The rock does not cleave with special readiness along the ripple-marked surface. The marks are shallow, about 10 mm wide grooves divided by sharp crests. Sometimes they are double.

The middle ripple mark horizon lies in a well marked bedding plane. Green clay and in the troughs lenses of sandstone occur in the ripple-marked bed. Below and above the bedding plane the rock consists of a middle-coarse, white sandstone with out-thinning clay ribbons. The wave-length of the ripple marks is about 45 cm; the direction of the ridges N 37°E.

The upper ripple mark horizon lies in the Diplocraterion sandstone. Also in this case the rock is a white or light gray sandstone with no content of clay or mud to speak of. The ripple-marked surface is covered by a firm black layer of mud, in its present condition less than 1 mm thick. On the bedding surface and especially in the troughs the above described, regularly winding trails are found (see p. 91). The wave-length is about 9 cm. The ripples are very shallow, almost obliterated.

The Lower Cambrian series of strata at Simrishamn and Brantevik.

In SE Scania there is no continuous section through the Lower Cambrian strata. On account of the petrographical development of the strata changing from one place to another it is not possible to reconstruct, to any greater certainty, the series of strata from the several small profiles. The possibilities of doing this are also reduced by the numerous faults traversing the region (see fig. 52).

To a certain degree, however, we are able to estimate the age-relations between the strata of one section and those of another, so as to get an idea of the kinds of rock that may be considered typical of the different parts of the series of strata. In the following a short account will be given of those parts of the series which are exposed in the neighbourhood of Simrishamn and Brantevik.

On the Lower Cambrian arkose and the basal conglomerates in SE Scania follows a white or slightly red, quartzitic »Hardeberga sandstone». These rocks have already been illustrated above (p. 70, 74, 77, seq.). On this part of the series of strata follow the beds corresponding to the middle and upper parts of the series at Hardeberga.

In these beds the rock varies greatly and is partly otherwise developed than at Hardeberga.

The lower strata consist of a white or light gray, even- and fairly fine-grained sandstone, in certain beds almost quartzitic. It is relatively pure and contains neither tracks nor fossils, neither glauconite nor phosphorite.

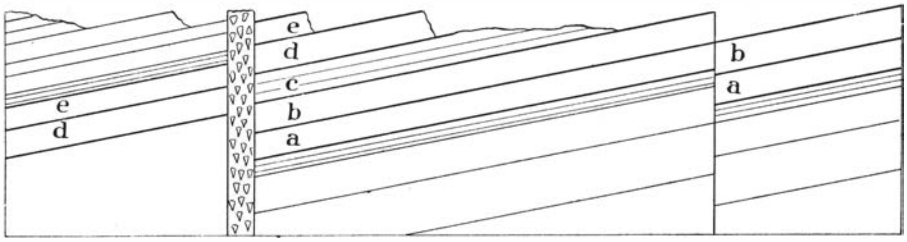

Fig. 52. Diagram of the Lower Cambrian strata at Brantevik. Only the superficial part of the series is exposed.

In the upper part of this white sandstone an abundance of large ripple marks occurs in some places. This is for inst. the case at Jerrestad where the ripple marks are present in a great number of successive beds. The wave-length was measured at about 60 cm. The direction of the ridges is S 70° W, S 80° E, and S 30° W on three successive wave-levels.

The rock with the ripple marks is light gray and rather coarse. It contains pyrite nodules with a diameter of $^1/_2$—3 cm and clay-flakes up to 15 cm in size.

At Jerrestad a gray or on weathering white sandstone rich in *Diplocraterion parallellum* follows above this sandstone. The tracks are often strongly weathered but the openings are only slightly enlarged.

The Diplocraterion-bearing beds are the youngest ones at Jerrestad. From the nature of the rock as well as from the size and form of the burrows we may conclude that the exposed part of the Lower Cambrian sandstone at Jerrestad is the same as we find in the lower part of the series of strata at Brantevik. In the following we shall give a somewhat more detailed account of this series, as it is the most complete we have in SE Scania. Together with the Hardeberga sandstone it gives us a good idea of the varying development of the Lower Cambrian strata in South Sweden.

The section at Brantevik, published here, is not complete. In many places the beds are traversed by faults. The result of these has sometimes been a duplication of the series of strata, sometimes a concealment of some of the beds (see fig. 52).

The Brantevik section.

13 Black silicified limestone, fragment limestone and alum slate (= Paradoxides beds).
Light gray limestone (fragment limestone) and shales with *Olenellus Kjerulfi*.
— — — Fault. Gap. — — —
12 f Phosphorite, bed of connected nodules (see fig. 13)[1].
12 e Sandstone, coarse, gray (113 cm).
12 d Phosphorite-bearing bed with large nodules.
12 c Glauconitic shale with phosphorite nodules (11 cm).
12 b Glauconitic sandstone with phosphorite and worm trails (*Scolithus errans*) 38 cm.
10 a Glauconitic shale with worm trails (*Psammichnites gigas* ?).
9 h Quartz sandstone, black, with glauconite.
9 g Glauconitic sandstone, slightly calcareous, spotted, with worm tracks.
9 f Glauconitic shale.
9 e—c Glauconitic sandstone, highly calcareous.
9 b Phosphorite conglomerate.
9 a Glauconitic sandstone with small nodules of phosphorite.
— — — Fault-breccia. Gap. — — —
— — — White sandstone, fine-grained, with ripple marks and »rain impressions». Thick beds. About 6 m.
8 c White sandstone, coarse, cross-bedded; beds about 0,5 m thick. Large ripple marks. About 2,5 m.
8 b White sandstone, thin-bedded, fine-grained with occasional coarser layers (also conglomerates). 0,9 m.
8 a Yellowish white sandstone, fine-grained with fine worm tracks and »rain impressions». Ripple marks.
7 b White sandstone with *Syringomorpha*.
7 a White sandstone with *Psammichnites gigas*.
— — — (Interruption in the series at the south harbour) — — —
6 d Glauconitic sandstone, dark, with worm tracks (*Scolithus errans*?).
6 c—b Gray sandstone, fine-bedded, rich in mica, somewhat glauconitic, graywacke-like.
6 a Conglomerate with phosphorite nodules and large sandstone pebbles.
— — — White sandstone.
5 b Gray sandstone with »rain impressions».
5 a Sandstone with *Diplocraterion*, reef-forming.

[1] The layers 12 f—12 d are also exposed at the localities 11 and 10 (termed 11 f—11 b and 10 f—10 b).

4 f Dark sandstone with light worm tracks (*Scolithus errans*).
4 e—a White sandstone with *Diplocraterion* (in several beds).
3 Gray sandstone with cross-lamination.
2 White sandstone with *Diplocraterion.*
1 White sandstone, fairly coarse.
— — — (The north harbour).

In the series of strata at Brantevik and its neighbourhood we can distinguish the following larger or stratigraphically important sections:

Middle Cambrian: Black limestone (partly fragment limestone) and alum slate.
Lower Cambrian: The Kjerulfi zone. Light gray limestone and shales.
The Torelli zone. Calcareous sandstones rich in glauconite and phosphorite. The upper glauconite zone. About 3 m.
The Psammichnites zone. White or gray quartz sandstones with winding worm trails. About 15 m.
The »graywacke zone» (see also p. 102). Argillaceous sandstones, phosphorite- and glauconite-bearing sandstones. The lower glauconite zone. About 2 m.
The Diplocraterion zone. White and gray quartz sandstones. About 6 m.
White and gray partly calcareous sandstones (Scolithus linearis zone?)
The quartzite zone. Quartzitic sandstone. Hardeberga sandstone.
The arkose zone. Arkose and arkose-like sandstone. About 4 m.

The series of strata may be about 50 m thick, half of which belongs to the strata under the Diplocraterion zone.

The lowest part of the series of strata is best exposed at Gislöv, about 5 km WSW of Brantevik. The sandstones lying immediately below the Diplocraterion zone are nowhere exposed to such an extent that it has been possible to measure their thickness, nor is their connection with the lower quartzitic or arkose-like sandstone quite obvious. At Brantevik this sandstone is fairly coarse and distinctly clastic. Generally it is purely white but includes also layers and flakes of clay. In the exposed parts of this sandstone no traces of organisms have been observed at Brantevik but it is not impossible that it contains here as in other places in Scania (Röstånga, Rekarekroken) beds with *Scolithus linearis.* Among the shingles of the shore, fragments of a *Scolithus linearis*-sandstone are found, which may possibly be derived from the strata of the place but the author considers that they may just as well have come from afar, for they occur only very sparingly, and the rock is the one typical to the neighbourhood of Kalmarsund, a form that has hitherto not been seen outcropping in Scania.

The Diplocraterion sandstone is well exposed at the north harbour of Brantevik and along the shore south of this. The rock is a pure white or slightly coloured (gray or yellow) quartz sandstone developed into distinct beds of varying thickness.

Under the microscope the Diplocraterion sandstone shows a secondary growth of the quartz grains. Felspar and mica occur in small quantities, but clay, mud and glauconite are absent. The quartz grains are well rounded. Their medium size is 0,15 mm.

The Diplocraterion tubes vary somewhat in size. They are not very deep and do not traverse the beds. The core of the tubes or cylinders is muddy and looser than the surrounding rock. This is also true of the part connecting the

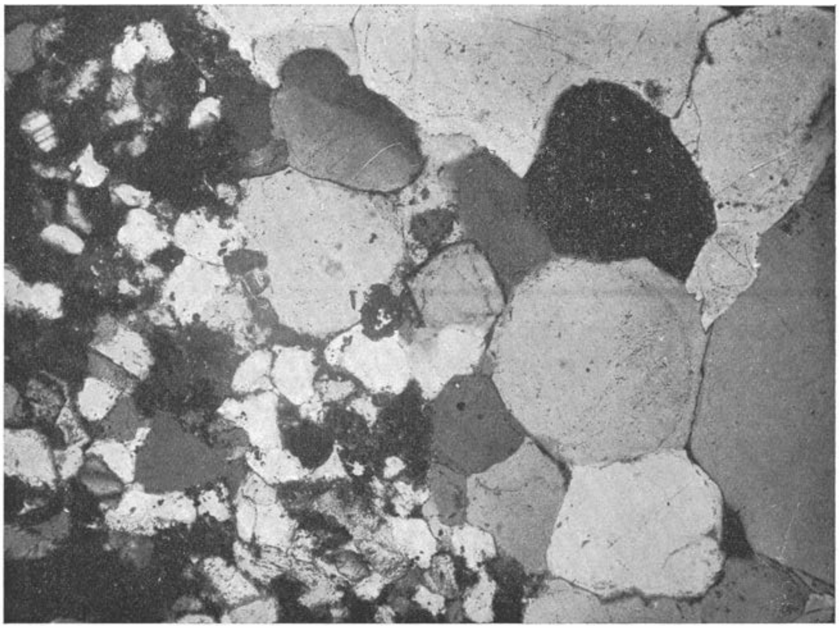

Fig. 53. Conglomerate with pebbles of sandstone and phosphorite. To the right some part of the matrix: — siliceous sandstone with enlarged quartz grains. To the left pebbles of fine-grained sandstone. Lower Cambrian. Brantevik, 6. 50 ×. Nic. +. (Pr. 2849. Pl. 362.)

two limbs of the U-shaped burrow. On the exposed, weathered bedding surfaces of the Diplocraterion beds dumb-bell shaped slits are therefore to be seen.

The beds in the Diplocraterion zone that do not contain *Diplocraterion*, differ also in petrographical respects from those described above. Some of the beds are dark, mud-bearing and rich in light, winding worm trails (*Scolithus errans*), other beds have no trails. The latter are often distinctly cross-bedded, sometimes quartzitic but otherwise not essentially unlike the Diplocraterion beds. In the upper part of the zone fine-grained sandstones occur, with their bedding surfaces torn or broken up into grooves, as it were, that are separated by sharp-crested, indented, low ridges. The same phenomenon in quite similar sandstone occurs in still more magnificent development in the Psammichnites zone (see below).

The conglomerate forming the base of the lower glauconite zone or the graywacke zone is built up of phosphorite pebbles and still more of sandstone pebbles (figg. 53 and 54). The latter have a diameter of up to 30 cm. They are distinctly rounded, irregular and often flat. They consist of a fine-grained white or gray sandstone with occasional small grains of glauconite.

In comparison with the sandstone pebbles the phosphorite pebbles are insignificant regarding both their size and the part of the rock they form. They

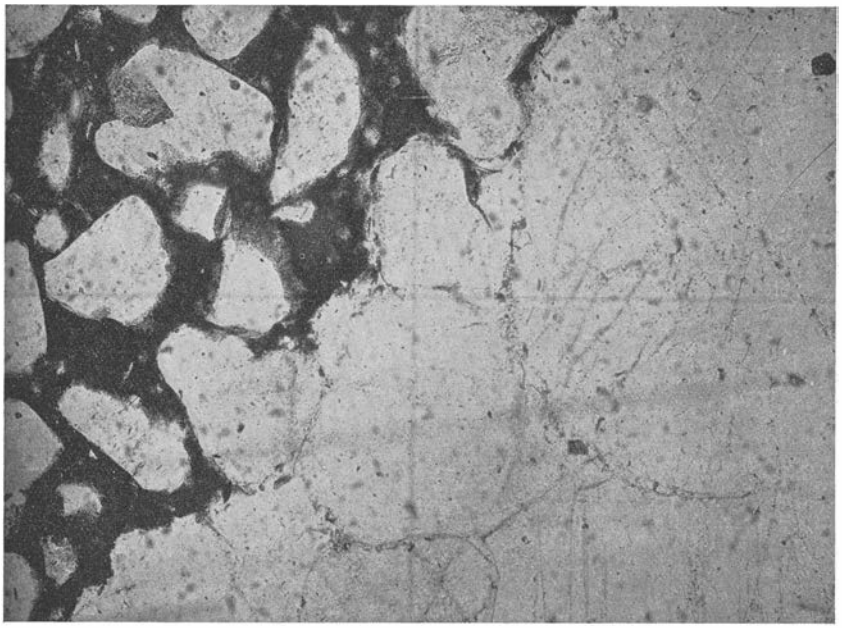

Fig. 54. Phosphorite nodules (allochthonous phosphorite), to the left, in coarse-grained siliceous sandstone. From the same conglomerate as fig. 53. 60 ×. (Pr. 2850. Pl. 365.)

consist of black, sand-rich nodules or thin cakes, always distinctly rounded and well defined from the surrounding rock material.

The matrix of the conglomerate is a coarse, gray sand, fairly rich in glauconite grains. The quartz grains are well rounded, the glauconite on the contrary has a diffuse demarcation or is pressed in between the quartz grains. The cement is siliceous.

Glauconite does not only occur interspersed among the filling material but also as a thin, easily overlooked coating on some of the sandstone pebbles.

The conglomerate no doubt indicates an occasional elevation of the sea-bottom. The stronger action of waves and currents during this elevation has caused a disintegration of the beds already deposited, not only the soft ones but also those already consolidated. We can infer from the coating of the pebbles that the formation of glauconite was going on at the time of the deposition of the conglomerate. It may also be inferred that the phosphorite was formed before or during the negative sedimentation. None of the phosphorite pebbles contain quartz grains of a size characteristic to the matrix of the conglomerate.

The conglomerate is superposed by beds of gray, argillaceous, micaceous sandstone or of arenaceous shale, sometimes somewhat graywacke-like, sometimes phyllite-like. The adjoining specified profile (fig. 55) shows the occurrence of the rock between the conglomerate and the glauconitic sandstone.

Immediately above the conglomerate there follows a slightly calcareous quartz sandstone (6 b) with a fairly considerable content of glauconite (fig. 55). The quartz grains are angular and mostly 0,06 mm in diameter. The glauconite occurs in irregular grains, squeezed in between the sand grains. Their size varies from 0,02 to 0,15 mm.

The dark, almost black colour and the fine lamination of the rock originates from the pyrite-rich mud occurring accumulated in thin layers or lamellae (fig. 56).

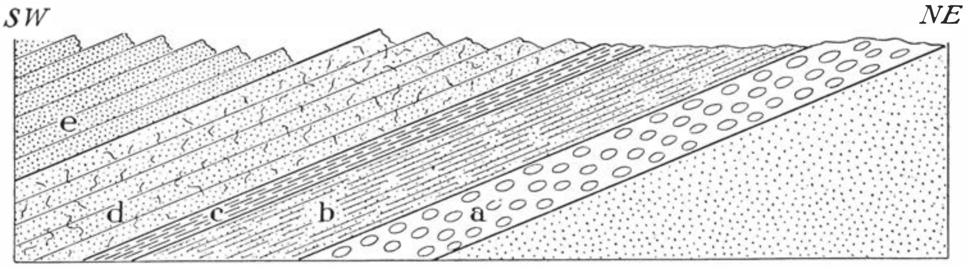

Fig. 55. The layers at loc. 6, Brantevik. a. Conglomerate, intraformational, with pebbles of sandstone and phosphorite (see figg. 52 and 53), 20 cm; b. Laminated dark sandstone, micaceous and glauconitic, 25 cm; c. Dark arenaceous shale (»graywacke»), 7 cm; d. Gray sandstone with winding worm trails and ripple mark, 41 cm; e. Dark glauconitic sandstone, 38 cm.

Where these layers are rich in mica the rock readily cleaves. The mica as well as the dark mud also occur interspersed in the rock between the dark layers. The graywacke-like shale in the middle of the profile differs from the surrounding rock only by its greater content of mud and the more uniform distribution of the same. Least muddy is the sandstone with ripple marks and worm tracks.

The furrows of the ripple mark are shallow and the wave-length short, about 10 cm. Interference ripples are common.

The worm trails are cylindrical and winding, 1—4 mm broad. They occur both on the bedding surfaces and traversing the beds.

The above-described, gray, shaly or fine-bedded strata at Brantevik show such a petrographical resemblance to the strata forming the lowest part of the profile in the harbour of Simrishamn that one might be inclined to parallel them. Here as in other cases, however, the point is not to jump at conclusions. Certainly, we only know of one »graywacke zone» at Brantevik and one at Simrishamn but the series of strata is in none of these places so complete that we can say that similarly developed strata do not occur in other horizons also. The fact that the »graywacke zone» at the harbour of Simrishamn is directly superposed by a bed of a *Hyolithes*-bearing sandstone goes against the above-mentioned paralleling. It seems to the author as if the strata at the harbour of Simrishamn were situated immediately below the glauconite-rich *Olenellus Torelli* beds. Therefore, if that be so, we have an upper »graywacke zone» underlying the upper glauconite zone and a lower »graywacke zone» underlying the lower glauconite zone [1].

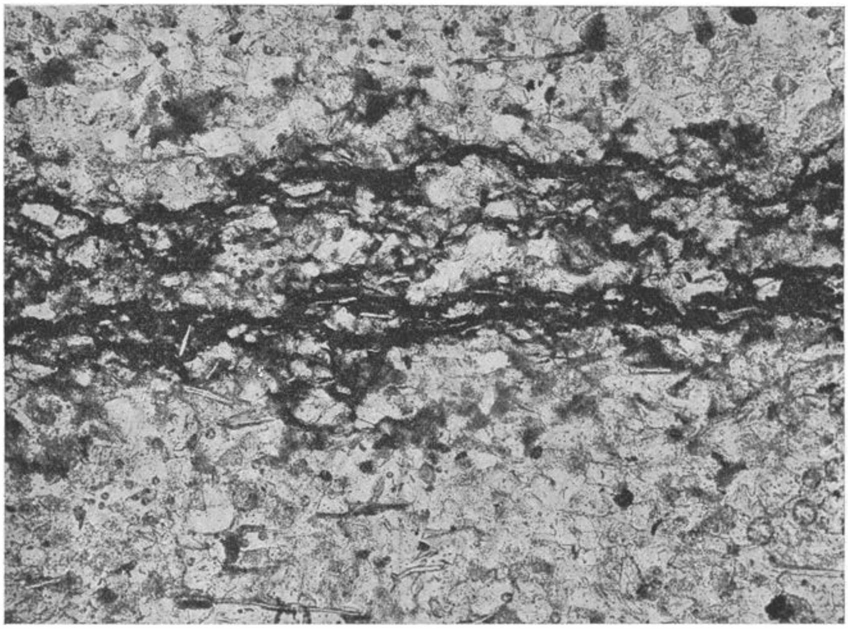

Fig. 56. Dark laminated sandstone with glauconite, pyrite and muscovite. Lower Cambrian. Brantevik, 6 b. 60 ×. (Pr. 2793. Pl. 358.)

The glauconite sandstone (6 e) overlying the »graywacke sandstone» at Brantevik is a dark greenish gray, almost black quartz sandstone, fairly rich in pyritic dust. The weathering crust is rust-coloured. The rock is indistinctly stratified

[1] Though the author has no opportunity here to enter on a discussion on the stratigraphical and tectonic problems, he will nevertheless draw attention to the fact that the upper and lower glauconite and graywacke zones may very well be considered to be only apparently separated. The Psammichnites beds may be regarded as horst-like interposed, truncating an otherwise unbroken series of strata. Such an interpretation compels us to locate the whole Psammichnites zone below the Diplocraterion zone which, considering the conditions at Hardeberga, may seem very desirable but implies considerably larger dislocations than are otherwise found in the series of strata. The large fault-breccia between the Torelli beds and the Psammichnites zone may possibly indicate such a stronger vertical movement but the author has not been able to find anything corresponding at the lower (north) limit of the Psammichnites beds.

and cleaves along uneven, nodose surfaces. The majority of the quartz grains are 0,03—0,06 mm in diameter but occasional grains attain a size of 0,5 mm. The small grains are angular, the larger somewhat rounded.

The glauconite occurs partly as small irregularly formed grains interposed between the quartz grains, partly as rounded grains with a diameter of up to 0,7 mm. Their colour is relatively dark grass-green.

No fossils have been found in the glauconitic sandstone. Winding, cylindrical worm trails, 3 mm wide, are on the other hand rather abundantly present. They are lighter than the surrounding rock.

The beds overlapping the above-mentioned glauconitic sandstone are not exposed at Brantevik. In the glauconitic sandstone a number of fissures filled by calcite are found. In one of them zinc-blende occurs in centimetre-sized crystals.

The strata following immediately on the glauconitic sandstone in the dip direction consist of white, thick-bedded sandstones. The coarse, winding trails termed *Psammichnites gigas* Torell, occur in a couple of the lower beds. The rock is a pure quartz sandstone, with secondary growth of the quartz grains. These are somewhat rounded, mostly 0,1—0,2 mm large.

The Psammichnites trails are to be found on the bedding surfaces. Sometimes they are present in such abundance that they almost cover these. The trails are 3 cm broad and about 1,5 cm high, with a convex upper and a flat lower surface. Along the upper side they often show a dorsal ridge and an irregular transverse sectioning (see fig. 36, p. 58). A detailed account of the character of the tracks will be given elsewhere.

At Brantevik the Psammichnites beds are accessible in the southernmost part of the north harbour. They are superposed by a thick series of white or light gray, on weathering slightly yellow sandstones that may be grouped together with the said ones into a zone, the Psammichnites zone.

Immediately above the beds with Psammichnites follows the sandstone with *Syringomorpha* (fig. 57). The rock is a fine-grained, granular, almost pure quartz sandstone formed into thick beds. The fossil present in the rock, *Syringomorpha Nilssoni* Torell, is very abundant in some parts. Its form is shown in the fig. 57. The cylinders, that are somewhat flattened against each other, have a gray, muddy wall and a white nucleus perfectly conformable to the surrounding rock.

In a petrographical respect the sandstone beds nearest in age differ only slightly from the above-mentioned ones with Psammichnites and Syringomorpha. Thus the rock is often a fine-grained, thick-bedded and relatively pure quartz sandstone. Coarser strata (fig. 58) and even real conglomerates occur here and there. They have well rounded pebbles of quartz, but never contain phosphorite or glauconite, contrary to the younger conglomerates occurring in the Torelli zone.

In certain beds the lamination is indistinctly parallel, in others it is a cross-lamination. (See fig. 40, p. 62.) The bedding is always distinct.

The bedding surfaces show as a rule tracks or marks of some kind or other. Worm trails, ripple marks, »rain impressions», and mud-cracks may be specially mentioned.

The worm trails are narrow, cylindrical and visible only on the bedding surface. They contain the same material as the rest of the rock.

The ripple marks are large and distinct. In one bed the wave-length is 145 cm, the double amplitude 15 cm and the direction of the ridges N 55° W. In another upper bed the corresponding figures were 65 cm, 5 cm, N 80° W, and

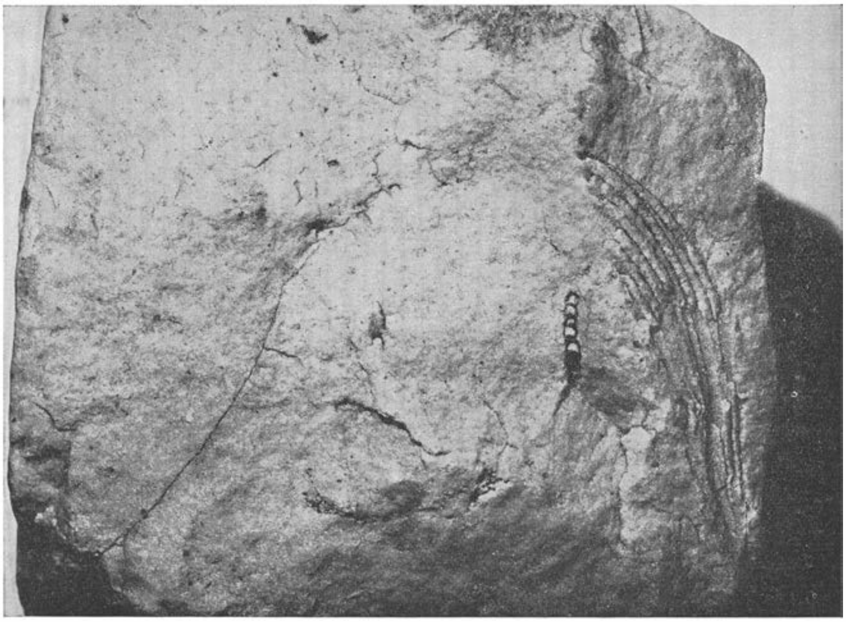

Fig. 57. Syringomorpha sandstone. To the right *Syringomorpha Nilssoni* in longitudinal and transverse section. Lower Cambrian. Brantevik. — $^1/_1$. (Pl. 431.)

in a third bed 112 cm, 10 cm, N 78° E. Besides the normally formed ripples, which are all symmetrical, interference ripples occur, even in the same bed as the uncomplicated marks.

Almost as common as the worm trails and the ripple marks are the markings the author has termed *»rain impressions»* which occur on the upper surface of several beds. They consist of irregular grooves with a diameter of 2—10 mm and a depth of 2—8 mm. So closely do they lie that they completely cover the bedding surface. The edges between the grooves are sharp and uneven. On certain bedding surfaces the marks are smaller, on others larger.

The markings have here been termed »rain impressions» on account of their great resemblance to the marks occurring in moist sand, if this is exposed to a heavy fall of rain. On the bedding surfaces »rill-markings» are found, perfectly resembling those occurring together with the rain impressions in the sand on a shore, that was moist before the rain fell. The »rain impressions» are obliterated along the »rill markings» that follow the »valleys» on the somewhat uneven bedding surfaces and run together in a certain direction. Larger shallow depressions without »rain impressions» are also found. Rain-water has probably accumulated in them and has then gradually sunk into the sand. But before that the water has obliterated the»rain impressions» or prevented their formation.

Even though it is not possible at present to give decided evidence that the said marks are really formed by the fall of rain drops on moist sand, the author

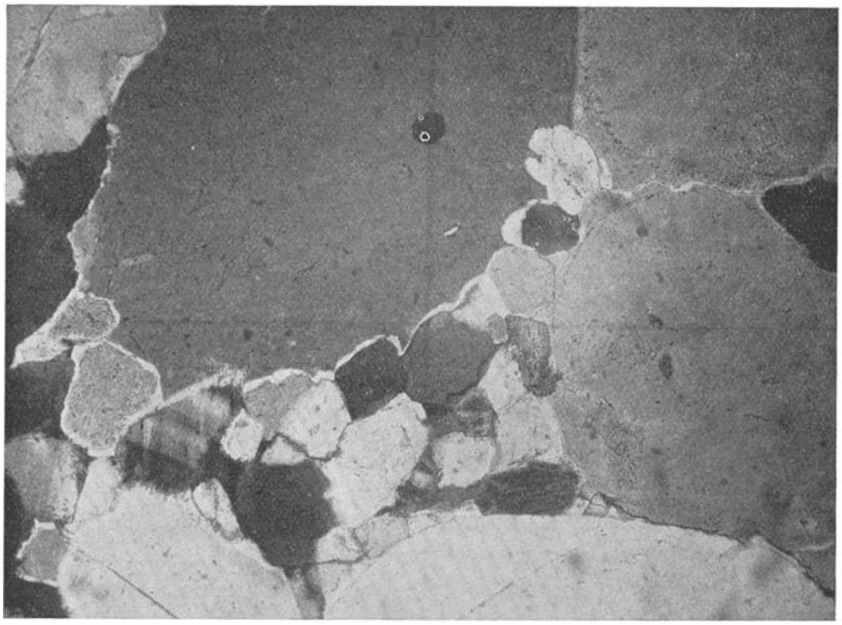

Fig. 58. Coarse-grained sandstone with a fine-grained matrix. Lower Cambrian. Brantevik, 8. 50 ×. Nic. +. (Pr. 2869. Pl. 361.)

does not deem this improbable. The difficulty is to find a plausible explanation of how the rain impressions could be preserved. Marks formed on a shore are immediately destroyed if a wave surges over them. They also disappear if the sand dries. Possibly the thin clay-beds, which we find between the sandstone beds containing »rain impressions», have helped to preserve the marks. Mud cracks in these clayey strata show that they have been drained periodically. If the sand has been covered by a thin, moist layer of clay during the formation of the rain impressions, the clay has after desiccation or beginning desiccation been able to prevent the obliteration of the rain impressions on continued sedimentation.

The mud cracks are of the same type as in the Mickwitzia sandstone at Lugnås. The sand filling up the cracks may have been cemented together with the material in the underlying as well as the overlying bed. On the upper surface of a sandstone bed a branched or reticular track may therefore be found, forming a cast of mud cracks. Sometimes these »tracks» are formed only on the highest parts of the uneven bedding surface, on »hills» or »ridges», which shows that the desiccation of the layer of clay and the formation of mud cracks have not been of such long duration that the lower parts of the clay bed (the »valleys» and the depressions in the bedding surface) have also cracked.

As is shown by the above related facts, the middle and upper parts of the Psammichnites zone have been deposited in shallow water. Periodically the deposited sediments have been above the water surface.

The fact that the rock, in spite of this distinct littoral character, is for the most part fine-grained may be due to deficient supply of coarser material. The layers of clay or mud between the beds are obviously deposited in lagoon-like minor basins, formed during periods when the sea has subsided.

The basal beds of the Torelli zone are not exposed at Brantevik. But we may suppose that these strata are of the same type at Brantevik and at Simrishamn, as the series of strata is for the rest similar in the two places. Besides, they lie only 5 km apart.

On the gray, muscovite-rich, shaly sandstone in the bottom of *the harbour of Simrishamn* there rests a light gray, almost white sandstone with numerous Hyolithes fragments. We may regard this *Hyolithes sandstone* as the basal bed of the Torelli zone. A darker gray sandstone comes on the top of this sandstone.

At *Simrislund*, the following series of strata is found (south of Horshäll):

Glauconitic sandstone, thin-bedded, green	— —
White, porous sandstone, with ripple mark	8 cm.
Glauconitic sandstone, dark green, irregularly bedded	70 »
Gray sandstone, partly quartzitic, with »rain impressions» and ripple mark	59 »
Gray sandstone, with small U-shaped tracks	52 »

This series of strata corresponds well to that recorded by Moberg (1892,3) from *Björkelunda* (N of Horshäll):

Glauconitic sandstone, thin-bedded, green, here and there replaced by calcareous sandstone.
Glauconitic sandstone, brownish green.
Quartz conglomerate.
Light gray sandstone.

The upper strata of the profiles mentioned contain *Olenellus Torelli*. Hence the upper part of these series of strata may be supposed to correspond to the lower part of the strata in the said profile at Brantevik (p. 97 and 98), that is grouped with the Torelli zone (9 a—12 f). The rocks in the three said profiles will be examined in the following, in doing which, however, we shall mainly dwell on the strata at Brantevik.

The gray sandstone forming the lower part of the profile at Simrislund (S of Horshäll) is fine-grained and formed into distinct, fairly thin beds (10—20 cm). On the bedding surfaces we sometimes find an abundance of small holes which turn out to be paired. They are the openings of a small form of *Arenicolites*, with the U-shaped track 6—10 mm broad and 5—25 mm deep.

The overlying, likewise gray sandstone is also mostly fine-grained, but coarser beds are to be found. The ripple marks (in the lower bed) have a wave-length of about 9 cm. The ridges are sharp. They run N 20° E.

The »rain impressions» (in the second lowest bed) are of the same type as those from Brantevik described above (p. 104).

The quartz conglomerate at Björkelunda (N of Horshäll) mentioned by Moberg, has well rounded quartz pebbles with a diameter of 3—8 mm. The conglomerate is glauconitic and forms the base of the glauconitic sandstone.

The lower parts of the glauconitic sandstone contain here and there coarse worm tracks but no fossils. Some of the beds are less glauconitic. In some places the upper thin-bedded glauconitic sandstone contains abundant fragments of fossils. The white sandstone bed embedded in the glauconitic strata at Simrislund, exhibits large ripple marks with sharp crests on its upper surface. The wave-length is about 80 cm. The direction of the ridges N 60° E. The rock is fairly coarse and only slightly cemented.

At Brantevik the accessible Torelli beds are highly glauconitic. Sandstone rich in glauconite is interstratified with sandy glauconitic shales. Phosphorite is also abundantly present in this series of strata, partly in the form of small scattered nodules, partly as complete beds of large nodules.

The basal bed in the glauconitic sandstone (= stratum 9 a in the profile p. 97) is light greenish gray. The content of glauconite is smaller than in the younger beds. The quartz grains are well rounded. They show secondary growth but the rock is nevertheless porous and relatively loose. It also contains a coarse-crystalline calcitic cement. The majority of the quartz grains are 0,2—0,6 mm in diameter. The glauconite grains are diffuse, often squeezed in between the sand grains, more infrequently rounded. The phosphorite grains are to a large extent only about 1 mm in size but nodules with a diameter of 1—2 cm are also to be found. The phosphorite contains abundant small grains of quartz, about 0,07 mm in diameter.

The phosphorite conglomerate (stratum 9 b) occurs in the upper part of a 6 cm thick sandstone bed rich in glauconite in its lower part (2 cm), free from glauconite in its middle part (2 cm) and in its upper, phosphoritic part, glauconitic. The glauconite occurs no doubt as a primary deposit. It occurs as matrix between the quartz grains and as impregnation in fissures in the quartz and calcite grains. Small reddish brown grains of iron oxide (haematite) occur in the glauconite-free part. They may be regarded as substitutes for the glauconite. The sandstone consists of well rounded grains, 0,1—1 mm large, in a coarse-crystalline calcitic cement.

The phosphorite nodules are rounded but are irregular in form. Their diameter seldom exceeds 3 cm. The nodules are black or greenish black in colour. They contain quartz grains in varying quantity. The enclosed grains are mostly 0,1—0,3 mm large. In some nodules an abundance of glauconite is present, in others this mineral is absent. Not infrequently the phosphorite nodules show shining cleavage surfaces, owing to interposed, coarse-crystalline calcite. This is studded with quartz grains and phosphoritic substance and may therefore be regarded as a kind of cement. It is often divided into rounded united grains, with uniform orientation (simultaneous extinction between crossed nicols).

The glauconitic sandstone (stratum 9 c—e) immediately above the phosphorite conglomerate is highly glauconitic. The rock disintegrates along the glauconitic thin strata. Calcite occurs as in the above-mentioned beds in the form of a coarse-crystalline cement. Large gray mud-cakes are found immediately above the phosphoritic conglomerate.

Under the microscope the rock turns out to consist of angular or slightly rounded quartz grains from 0,06—0,15 mm in diameter. The calcite occupies such a volume of the rock that the quartz grains do not everywhere come into contact. The glauconite grains sometimes enclose the quartz grains or are squeezed in between them, sometimes they are enclosed in the calcite crystals. In the latter case the glauconite has often a very irregular form. Not infrequently is it bound to the planes of cleavage. In this form the glauconite is the youngest mineral in the rock. In the same rock, however, round grains of glauconite also occur enclosed in the calcite and obviously older than this.

Towards the overlying bed, the glauconitic shale (9 f), the sandstone becomes more coarse-grained but otherwise retains the same character regarding its content of calcite and glauconite. The quartz grains are here well rounded and mostly 0,3—0,6 mm in size.

The black, glauconitic quartz sandstone (stratum 9 h) is very even-grained. The quartz grains are angular, about 0,1 mm large. Interposed between the grains a black, compact substance is sparingly found. The glauconite occurs in the form of rounded grains and as filling material. It is of varying colour and shows pigmentation of different strength in different grains. No doubt, it is a secondary deposit.

The glauconitic shale, stratum 10 a, above the quartz sandstone shows large winding trails, resembling *Psammichnites gigas* but without distinct dorsal ridge. Narrower worm trails are also present in the same stratum. The rock is fine-grained, with grains seldom exceeding 0,1 mm, mostly about 0,05 mm, in diameter. Glauconite occurs in abundance, sometimes with a number of grains united. Phosphorite is sparingly present in small nodules containing quartz and glauconite grains of the same type as those in the surrounding rock.

The glauconitic sandstone overlying the Psammichnites shale, stratum b in the profiles 10, 11 and 12, is traversed by winding worm trails. The rock consists of irregularly mixed, lighter and darker portions. It contains phosphorite nodules.

The overlying glauconitic shale, stratum c in the profiles 10—12, is loose, disintegrating. Here the phosphorite occurs in scattered nodules.

The phosphorite-bearing bed, stratum 12 d, forms a layer 6—8 cm thick, in a heterogeneous bed of sandstone and fragment limestone. The phosphorite nodules are arenaceous or sand-free, small or large, the latter often united into large cakes.

They are very irregular in form but are as a rule rounded though full of grooves.

The matrix consists partly of a highly glauconitic quartz sand with calcareous cement, partly of fragment limestone. It contains a large quantity of pyrite in scattered small crystals and accumulated into small nodules.

In the fragment limestone the author has observed fragments of trilobites and brachiopods. The stratum no doubt belongs to the Torelli zone.

The development of the phosphorite shows that the bulk of it at least, is a primary deposit. The content of phosphorite is fairly large in the underlying glauconitic shale and increases rapidly in connection with the deposition of the shell fragments, or rather immediately before their deposition. When the deposition of calcium carbonate ceases and that of sand begins, the formation of phosphorite decreases and soon stops.

The sandstone, stratum 12 e, overlying the above-mentioned phosphorite conglomerate and underlying another, is a gray, quartzitic sandstone poor in glauconite. The quartz grains are well rounded, about 0,5—1 mm in size. They show a very distinct secondary growth. A fairly abundant, dark substance and a small amount of calcite is interspersed between the quartz grains (fig. 59).

The upper phosphoritic stratum (12 f) consists, like the above-mentioned one, of large nodules, to a large extent grown together and forming a phosphoritic bed (fig. 13, p. 31). The phosphorite contains an abundance of sand grains of the same size as those in the underlying and surrounding sandstone. In this case the phoshorite is no doubt a primary deposit.

Beyond the fault traversing the above described series of strata a black siliceous rock, black fragment limestone and alum shales belonging to the Paradoxides beds, are met with. The Kjerulfi zone, i. e. the upper part of the Lower Cambrian, is thus not accessible here. It has, however, been observed between Brantevik and Gislövshammar. The rock consists of light gray limestone and shales.

The above-mentioned siliceous rock belonging to the Paradoxides beds occurs in a 10 cm thick bed. On the upper surface of this bed cylindrical, somewhat curved worm tracks 0,5—1 cm broad are to be seen. The rock contains an abundance of glauconite and pyrite as well as phosphorite, the latter in irregular nodules, 0,5—3 cm in diameter. The pyrite is unevenly distributed all over the bed, mostly as diffusely defined nodules but also as small scattered crystals. The accumulation of the mineral is most abundant in the lower part of the bed, where it occupies in spots the greater part of the rock. The bulk of the rock consists for the rest of quartz. This mineral, however, is not formed here into more or less rounded grains as in the sandstones. The material does not show a clastic but a crystalline structure, not unlike that found in for inst. jasper. The quartz is no doubt for the most part autochthonous. Chalcedony is wholly absent.

The grains of glauconite are 0,07—1,5 mm in size. They are partly rounded, partly ragged at the edges. In the latter case the quartz forms intrusions in the glauconite. These intrusions have often a distinct crystalline demarcation but

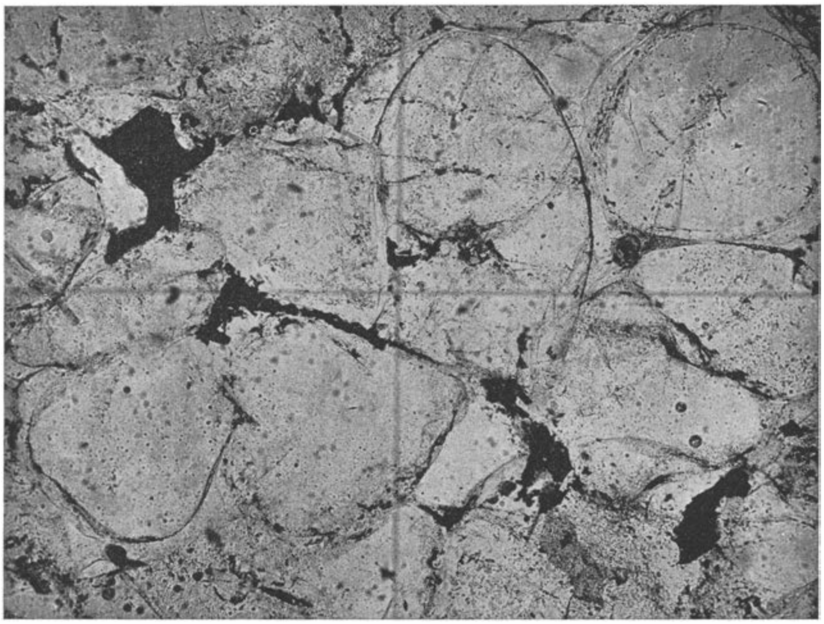

Fig. 59. Dark sandstone with secondarily enlarged quartz grains. Lower Cambrian. Brantevik. 60 ×. (Pr. 2860. Pl. 360.)

the form is not that of the quartz crystal, nor has the substance in the crystals a crystallographically uniform orientation. Thus the quartz occurs here as pseudomorphosis after another mineral, judging from the crystal form, calcite. Pseudomorphoses of the same kind have also been observed in the interior of glauconite grains [1].

The glauconite grains often contain pyrite. The rounded grains are not infrequently split or cracked in the same manner as the glauconite grains in certain limestones. On the whole the glauconite shows a development usually found in limestones but never in sandstones. According to the opinion of the author the quartzitic bed has been formed from a limestone bed by the complete replacement of calcite by quartz. The phosphorite, glauconite and pyrite have

[1] Only observed in rock slices, and the inclusion may thus be a seeming one.

all of them been included in the primary rock, the limestone. On the whole this has been of the same character as the limestone beds occurring in the same series of strata. It is hardly possible to determine how the change has taken place and what has caused it. But we can see that no rearrangement of the material has taken place in connection with the dissolution of the calcite. This has possibly been caused by water rich in carbon dioxide and humic acid and also containing dissolved silica. It is also possible that sulphuric acid formed by decomposition of pyrite has helped change the calcite. The crystals of gypsum found in the rock indicate this, but they may be recent formations.

The petrographical character of the Lower Cambrian sandstones in southeastern Scania. A summary.

A classification of the Lower Cambrian sandstones in southeastern Scania according to their petrographical character results in approximately the same scheme as that on Hardeberga (p. 83). The author does not deem it necessary to reillustrate all these types. It may instead be appropriate to give a summary of the new contributions to the interpretation of the sandstones' formation gained by examination of the series of strata at Brantevik, Simrislund, Simrishamn, and other places in SE Scania.

The Hardeberga profile is completed by the said series of strata in the following particulars: —

1. the character and petrographical significance of the tracks and trails is more evident at Brantevik than at Hardeberga;

2. evidences of the littoral character of Lower Cambrian strata are more abundant and distinct at Brantevik than elsewhere in Scania;

3. glauconite and phosphorite are more abundantly present at Brantevik than in other localities of Lower Cambrian sandstone, and their occurrence and formation can nowhere be better studied than at that place.

In the following we shall give a short illustration of these three points, especially with regard to the possibility of inferring the forming conditions of the rocks from their character.

The sand in which *the tracks and trails* have been formed has been of two different kinds: — partly pure quartz, partly muddy and more or less rich in organic matter. Hence it follows, as we have already introductorily called attention to, that track- or trail-forming animals have not occurred under the same conditions in the different sediments.

The Diplocraterion beds, present in great numbers at Brantevik, are almost sterile, and there is no doubt that the tube-building organisms have sought their food outside the sand. The burrows having for a longer time served as the abodes of the animals, these most likely have not sought their food elsewhere but have in the same manner as *Sabellaria* (see Richter 1920 and 1927) subsisted on plankton. If this has been the case, the Diplocraterion beds may no doubt have been formed in shallow water with continuous supply (by shore currents) of planktonic material. The nature of the rock and especially the absence of clay and mud, also indicates a formation in water with such strong motion that finer detritus could not be deposited in it.

The winding worm trails occur in muddy as well as mud-free sandstones. We have no occasion to suspect that they have ever been formed in greater deeps but find on the contrary several examples of such trails in beds that have been exposed to occasional drying up. The trails do not occur in the Diplocraterion beds, nor in the coarse or cross-bedded sandstones. These facts indicate that the trail-forming animals have not existed in more moving water. Their presence in the mud-free sand has probably been occasional and limited to the superficial stratum, that has probably in most cases been covered by a thin layer of mud. The bulk of the winding trails is found in muddy, indistinctly bedded, often very heterogeneous sandstones, probably formed in basins periodically lagoon-like or enclosed by bars below the sea-level. It is however remarkable that rocks rich in trails are often highly glauconitic.

The ripple marks and *the conglomerates* in certain beds show that these have been formed in shallow water. *Mud cracks, clay flakes* and *»rain impressions»* give direct evidence that the sediments already deposited have been temporarily elevated above the sea-level. All these formations and marks are found in the white or gray sandstones poor in mud, never in the muddy or glauconitic ones. This indicates that the pure sandstones are more distinct littoral formations than the other rocks in the series. The nature of the *cross-bedded* sandstones is not directly evident from their structure but their occurrence together with conglomerate beds and beds with ripple marks shows that they have been formed near a shore. Nevertheless some of them may be of eolian formation, as they contain in themselves no traces of a subaquatic formation.

Glauconite occurs abundantly in two parts of the Lower Cambrian series at Brantevik. Its occurrence is equal in both places. The glauconite grains lie mostly squeezed in between the quartz grains or, if the glauconite occurs in particularly large quantities, enclosing them. In most cases the glauconite has either been formed simultaneously with the deposition of the sand or has been embedded in it in the form of soft, gelatinous grains. Only exceptionally have already solidified glauconite grains been enclosed in the sand. In the latter case it may be a question of secondarily occurring glauconite grains, in other cases, i. e. as a rule, the glauconite of the sandstone is no doubt a primary deposit.

The transition from the pure sandstones to the glauconitic strata comes about either in such a manner that the percentage of glauconite gradually increases from bed to bed or so that muddy (»graywacke-like») strata are deposited between the glauconitic beds and the sandstone. In both cases we may suppose that the formation of glauconite has begun after a subsidence of land. That the depression has not been great is, however, evident from the fact that the glauconitic strata not infrequently contain worm tracks, which, as mentioned above, may have been formed at a slight depth.

The phosphorite occurs in the profile of Brantevik partly as scattered nodules in the sandstone beds, partly accumulated into beds of nodules grown together. The former type is found in the glauconite-rich as well as in the pure or glauconite-poor sandstones. The later type (true phosphorite beds) only occurs together with glauconite- or mud-bearing sandstones.

Where the phosphorite forms beds of connected nodules it is, mainly at least, formed in the place where it is found. It then also contains an abundance of grains of the same size, form and kind as the surrounding rock. The upper beds at Brantevik (12 d and f) are such typical primary deposits of phosphorite.

We may, presume that primarily deposited nodules of phosphorite must not necessarily have grown together. They ought of course also to be apt to occur scattered in a rock. The phosphorite in the glauconitic shale with *Psammichnites* (stratum 10 a) is of this type. The nodules are small and scattered but contain an abundance of quartz grains and also some glauconite of the same kind as that found in the surrounding rock. On the other hand, no constituents foreign to this are enclosed in the phosphorite nodules.

In several beds the phosphorite is no doubt secondarily deposited. The nodules are then often of varying nature and include material of a different kind from that constituting the surrounding rock. A typical phosphoritic occurrence of this kind is the phosphorite-bearing glauconitic sandstone, stratum 9 a, at Brantevik. The sandstone consists of well rounded quartz grains, usually from 0,2 to 0,5 mm but often 1,0 mm in diameter. The phosphorite in this rock contains no quartz grains of this size but only much smaller ones, from 0,05 to 0,07 mm in diameter.

The beds in which the phosphorite occurs secondarily deposited have a coarser and more worn material than the strata of primary occurrence. The former have been deposited in relatively moving water, the latter in more tranquil. The fine-grained material included in the secondarily occurring phosphoritic nodules shows that they have been formed under the same conditions as those of primary occurrence. From these facts we may venture to infer that the phosphorite has been formed outside the littoral zone proper, and that its occurrence in the coarser sandstones and conglomerates is a result of transport or rearrangement of the material, probably in connection with elevation of land.

The series of strata at Brantevik clearly shows us that the formation of a rock at greater or lesser depths cannot be inferred only from the presence of phosphorite in it. It must necessarily first be etablished whether the phosphorite is a primary or secondary deposit.

The Lower Cambrian Sandstone in the Neighbourhood of Kalmarsund.

The Lower Cambrian sandstone beds are only slightly exposed on Kalmarsund though they are widely spread there. It has not been possible to entirely establish the succession of strata in any outcrops but mainly by studying the occurrence of the erratic boulders and pebbles. Hence it follows that the series of strata can only be roughly outlined. In spite of this, it is included here in the chosen series of rock on account of its exhibiting certain interesting characters, absent or less developed in other regions with Lower Cambrian sandstone.

According to Holst (1892) the series of strata on Kalmarsund is as follows:

Gray sandstones and green, glauconitic ones, in the upper part with phosphorite.

White sandstone with granular structure; in this also shaly and calcareous sandstone-beds.

Diplocraterion sandstone, upper, with large Diplocraterion form (6—7 cm between the limbs).

Greenish gray, clayey sandstone, traversed by winding tracks (»crowstone»).

Diplocraterion sandstone, lower, with small Diplocraterion form (2 cm between the limbs).

Scolithus linearis sandstone, possibly enclosed in the following rock.

Red-striped sandstone.

Conglomerate and arkose.

The red-striped Kalmarsund sandstone rests on or is interbedded with the basal conglomerate [1]. The sandstone is of a somewhat varying character, sometimes quartzitic, sometimes more granular, often coarse but not infrequently fine-grained. Characteristic to the different forms of development is a very distinct red colour. This is not evenly distributed in the rock, it occurs in more or less thin, bed-like portions or laminæ. These can be less than 1 mm thick. Sometimes they are separated by likewise thin, white layers. They may be extended or out-thinning.

The red substance originates from secondary pigmentation. This fact is most clearly seen when the rock shows a primary lamination caused by alternation of coarser-grained and fine-grained layers. The red laminæ often cross the primary and real bedding.

According to Holst (1892, 5) a double system of stripes may occur and the rock therefore be apparently double-bedded. One of these systems is that formed by the pigmentation. According to Hedström (1906, 85) the rock has generally a nice cross-bedding. In this case also the red, secondary infiltration »beds» are referred to. Where the rock shows primary lamination this is as a rule parallel to the bedding planes.

The red pigment consists of haematite.

On the conglomerate see Hadding 1927, p. 50.

The Scolithus linearis sandstone is petrographically very like the red-striped sandstone. It may in fact often be regarded as only a special form of this, as it is of the same coarseness and can be and probably most frequently is red-

[1] Acc. to Holst 1892 and Hedström 1906.

striped. The only difference is that the Scolithus sandstone is traversed by innumerable, straight, vertical cylinders.

The Scolithus cylinders are (probably worm-) built tubes filled up with sand. They are often strongly red-coloured, even where they traverse white portions of the sandstone, and they can be white or very slightly coloured, even where they traverse strongly red-coloured beds. This shows on the one hand that the cylinder wall has not been permeable to the pigment matter nor the solution from which it was deposited, on the other hand that the pigmentation has taken place after the formation of the Scolithus cylinders.

The cylinders in the said Scolithus sandstone are of one and the same type. *Scolithus linearis* is also known from elsewhere, partly with the same development as on Kalmarsund, partly in other forms. Everywhere these »tracks» occur in (primarily) pure marine sandstone, formed at a relatively slight depth.

Diplocraterion sandstone occurs in two different horizons and with two different forms of *Diplocraterion* on Kalmarsund. Probably the beds with the smaller form occur under the »crow stone» and those with the larger form over it.

The rock is of the same type as the Scanian Diplocraterion sandstone: a relatively pure, white or light gray sandstone.

The greenish gray sandstone, the »crow stone», with winding trails of the *Scolithus errans* type, is less pure. Besides a considerable percentage of clay it also contains small flakes of muscovite. Like the corresponding Scanian rock it is readily weathered.

The white sandstone beds occurring above the »crow stone», show in many respects good correspondence with the beds in Scania, for inst. at Hardeberga, overlying the gray Scolithus errans sandstone. Calcareous sandstone and arenaceous shales characterize this part of the series of strata. In the Kalmarsund region a fairly loose, white sandstone with a granular, sugar-like fracture is probably the commonest rock in this part of the series.

The gray and green sandstones, forming the upper part of the Lower Cambrian series of strata on Kalmarsund are fossiliferous and rich in glauconite in certain beds. As a peculiarity it should be mentioned that no trilobite-bearing rocks have been found but very well brachiopod-bearing ones.

One of these youngest sandstones is known under the term the *Discinella Holsti sandstone.* The rock is a light gray, almost white, crystallized sandstone, in which the secondary growth of the grains is usually so slight that the rock is more granular than quartzitic in appearance. In the samples examined the rock is calcareous. In one of them the calcite was developed into sand-studded crystals from 3 to 4 mm large, the cleavage planes of which are distinctly to be seen on splitting the rock. The small brachiopod after which the rock is termed, is so insignificant that it is easily overlooked. As a rule its shell is preserved.

The Discinella Holsti sandstone is somewhat glauconitic. The glauconite is present in small round grains.

A peculiar development of the Lower Cambrian sandstone is found at *Mörbylånga* in Öland. According to Holst (1892) the following series of strata has been found there.

Gray sandstone, light at the top, darker and containing *Diplocraterion* (the large form) in the lower part	2,4 m.
Black, bituminous sandstone	0,4 »
Black and white, marbled sandstone	0,4 »
Sandstone with glauconite and thin argillaceous layers	2,2 »

The Diplocraterion-bearing bed may possibly serve as the index stratum on fitting the above-mentioned section into the Lower Cambrian series of strata. It undoubtedly belongs to the youngest part of this series.

The black bituminous sandstone is of special interest. The content of bitumen in an analysed sample was close upon 4 %. The percentage of $Al_2\ O_3$ was much the same. The grains of quartz are angular and completely embedded in the black clayey-bituminous matter. On being deprived of its content of bitumen by heat the rock becomes purely white. It also becomes loose and crumbles readily but retains sometimes a certain solidity owing to the grains being partly cemented by quartz.

In one sample glauconite has been found in the black sandstone. It occurs in the form of small round grains. Whether it is present in more than one bed is not known. It may be regarded as certain that it is not to be found as a primary deposit.

The origin of the bitumen present in the rock, is not known to us. Nor do we know how it was added to the same. Judging from the nature of the rock, a secondary infiltration might be considered possible. Sometimes, however, the bituminous matter occurs in thin layers alternating with bitumen-free ones or to put it more exactly, it may, perhaps, occur in the same manner as the clayey substance in the varved clays: abundantly in the upper part of the stratum but gradually more sparingly towards its lower surface. The lamination of the bitumen is parallel to the bedding planes and the rock cleaves (though not completely) after this lamination. It is hardly possible to interpret this lamination as the result of a secondary rhythmic precipitation. The bituminous mud was probably deposited together with the sand.

The black, bituminous sandstone at Mörbylånga belongs to the youngest part of the Lower Cambrian. It might possibly be considered prognostic of the thick, highly bituminous deposits forming an essential part of the Middle Cambrian. This, however, is not the case. The Middle Cambrian of Öland is namely remarkably poor in bitumen. It consists mainly of bitumen-free sandstones. In Scania, on the contrary, alum shale and bituminous limestones are found already at the base of the Middle Cambrian but no correspondence to the bituminous Mörbylånga sandstone is to be seen in the upper part of the Lower Cambrian [1].

The bituminous sandstone at Mörbylånga is a purely local formation. Its formation implies partly a marine basin into which quartz sand and grains of glauconite have been washed in, partly a locally well developed organic life, from which the content of bitumen derived its origin. Whether this organic material has been formed at the place of deposition or has been transported there together with the clayey mud can only be decided when we have been able to determine its primary character and formation. The absence of »worm trails», however, as well as the fairly uniform bedding and the fine-grained, rather thick beds seem to the author to make a deposition beyond the shallow shore zone probable. At any rate, we have no occasion to suppose that an elevation of land has occurred during the formation of the bituminous sandstone, nor can this have taken place in a lagoon-like basin, as it may have done in the case of the dark, highly pyritic muddy sandstone full of winding worm trails which has been described from Hardeberga (p. 88).

It was stated above as probable that the content of bitumen in the Mörbylånga sandstone in question was primary, and in support of this opinion the occurrence of the organic substance as distinct layers in some beds was mentioned. However, the dark, organic substance may also occur irregularly in the rock. Its fracture faces are then speckled or marbled in appearance. We find the same in the Lower Cambrian sandstone at Munka Tågarp in SE Scania.

Undoubtedly, such a distribution of the organic substance speaks most for a secondary infiltration on account of the transmissibility of the different portions according to their greater or smaller cementation or porosity. The difficulty of interpretation caused by these different manners of occurrence of the organic substance disappears on considering that this substance occurs in such a form that a secondary removal of it in the different beds is not only imaginable but also quite natural [2].

A comparison between the Lower Cambrian sandstones on Kalmarsund and in Scania becomes of special interest as we are able to parallel the different parts of the one region with those of the other.

We may take for granted that the »crow stone» and its substratum, the Diplocraterion sandstone, correspond to the Scanian dark, muddy sandstone, with the winding worm trails, and to the series of Diplocraterion-bearing white sandstones underlying it.

Correspondent to the red-striped Kalmarsund sandstone, with *Scolithus linearis*

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[1] The bituminous sandstone at Munka Tågarp in Scania belongs to the lower or middle part of Lower Cambrian.

[2] Of course, it may also be imagined that »the bitumen stratification» is secondary and originates from the absorption of more bitumen by more porous layers than by less porous. No difference at all could, however, be ascertained in the size of the grains or their qualities in the highly bituminous and the bitumen-free layers.

sandstone embedded in it, are the beds underlying the Diplocraterion sandstone at for inst. Hardeberga. That they do not correspond to the whole of this thick series may be understood, if we think of the greater thickness and more varying character of the Scanian series of strata. It seems most probable to the author that the said lower part of the Kalmarsund series corresponds only to those parts of the series overlying the quartzitic Hardeberga sandstone.

This correlation being correct implies that the Cambrian transgression has begun earlier in Scania than in the neighbourhood of Kalmarsund. The Middle and Upper Cambrian series of strata also speak for this in so far as it is deposited in shallower water in the neighbourhood of Kalmarsund than in Scania.

To parallel broadly the youngest Lower Cambrian strata at Kalmarsund with the Scanian is not very difficult. It could also have been done more in detail, had the former been more exposed. The fact that trilobites are absent or, at any rate, have not yet been found in the Kalmarsund rocks makes of course the correlation more difficult.

In Scania there is an abrupt transition from the Lower Cambrian (the Olenellus beds) to the Middle Cambrian (the Paradoxides beds). The sandstones forming the top bed of the Lower Cambrian, are directly superposed by alum shale which forms the basal bed of the Middle Cambrian (see section 4, p. 83).

In Öland the boundary is more indistinct. The lowest part of the Middle Cambrian (the Oelandicus beds) is developed as a glauconite-bearing sandstone, petrographically not differing much from the glauconite-bearing sandstone in its foot-wall, the Olenellus beds.

The Lower Cambrian Sandstone in Vestergötland.

The Lower Cambrian sandstone series is well developed in Vestergötland. It is also accessible in many outcrops. The great interest always shown by the geologists of Sweden with regard to the Cambro-Silurian of Vestergötland, has also been bestowed upon the sandstone and has resulted in several works. These, however, are more illustrative of the stratigraphical and paleontological than of the petrographical conditions.

Both from a petrographical and a stratigraphical point of view it is suitable to divide the Lower Cambrian series of strata in Vestergötland into two or three parts. We may then proceed from the proposals made by Wallin (1868, 18) and Holm (1901, 6).

Vestergötland.		Scania
Acc. to Wallin	Acc. to Holm	Acc. to Moberg (1911, 22)
Fucoid sandstone. Eophyton » Conglomerate.	Lingulid sandstone. Mickwitzia » with Conglomerate.	Zone with Olenellus (Holmia) Kjerulfi. Zone with Olenellus (Schmidtiellus) Torelli.

The conglomerate, and the arkose replacing or occurring together with it, will be treated separately in the following, being from a petrographical point of view connected with certain special problems.

The Mickwitzia sandstone and the Lingulid sandstone represent two partly different petrographical types of sandstone. They cannot directly be grouped with the sandstone described from Scania and the neighbourhood of Kalmarsund.

It is not very difficult to estimate the age of the sandstones of Vestergötland in relation to those of Scania. In Vestergötland there is no equivalent to the oldest part of the Scanian series of strata. The basal conglomerate at Kinnekulle contains an abundance of *Torellella laevigata* (see HADDING 1926, 56), a fossil typical to the Mickwitzia sandstone, which MOBERG (1911 a, 23) correlated with the *Schmidtiellus Torelli* zone. However, the presence of *Torellella lævigata* in Scania has not been proved to a certainty [1].

If MOBERG's correlation is correct, the basal beds in Vestergötland correspond to the middle part of the sandstone series overlying the quartzitic Hardeberga sandstone at Hardeberga. The presence of *Diplocraterion* in the lower strata at Lugnås forms a further basis for this interpretation, the same form of Diplocraterion being found in the said part of the series of strata at Hardeberga (see p. 81).

The Cambrian basal beds at Lugnås.

At Lugnås there are abundant opportunities of studying the Cambrian basal beds and their immediate substratum. The conditions are especially favourable from the point of view that the contact is accessible in a number of quarries, in which attempts have been made to gain access to the pre-Cambrian rock intact by post-Cambrian denudation. This rock consists of gneiss, strongly weathered and rich in kaolin. It has a secondarily formed calcite cement that makes it fairly solid. The rock, however, is easily worked and has been quarried for millstones of old. Where the rock has lain exposed to the influence of atmospheric agencies it has lost its practical value. The calcite has been dissolved and the kaolin washed away, so that the rock has become porous and loose. In order to get the best possible stone one has therefore gone down through the sandstone where this rests on the gneiss and protects it. As a result we have got the best possible sections for the study of the basal bed of the sandstone and its foot-wall.

The millstone gneiss and the arkose.

The sub-Cambrian rock at Lugnås consists of a red, middle-coarse gneiss with biotite in varying] quantity and on that account of varying schistosity. In its

[1] In Bornholm, SE of Scania, *Torellella lævigata* has been found in the »green shales» forming an equivalent to the zone whith *Schmidtiellus Torelli* in Scania. (See further GRÖNWALL 1916, 58).

upper weathered part the gneiss is lighter, as a rule slightly pink, due to the decolourization of the biotite and the kaolinization of the felspar.

The weathered gneiss, the millstone gneiss, is somewhat porous but the pores have as a rule been filled up with quartz and calcite, more infrequently with limonite, for the most part changed into hæmatite. The quartz cement forms

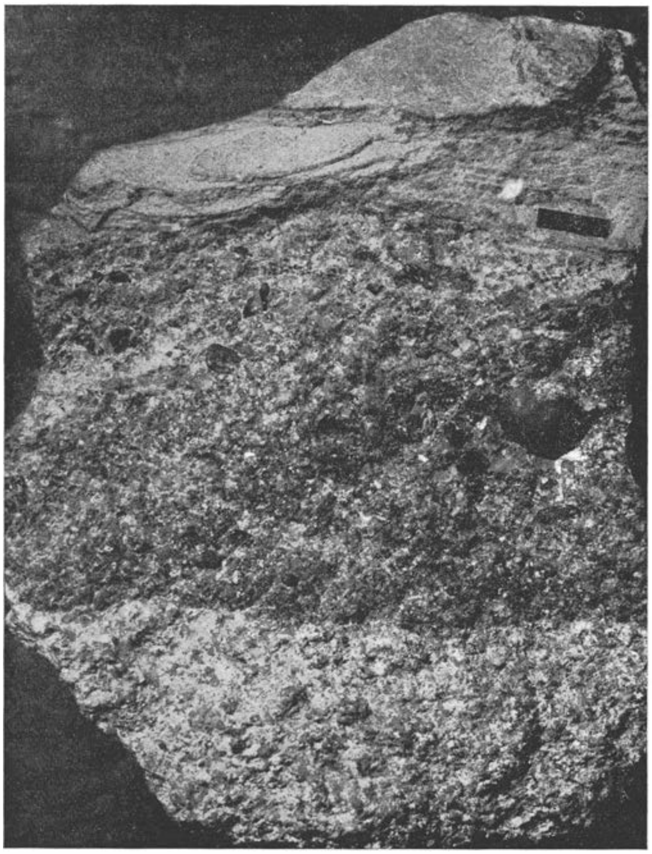

Fig. 60. Lower Cambrian basal layers at Lugnås: Above the altered gneiss we see the basal arkose and the overlying fine-grained sandstone. — $^{1}/_{1}$. (Pl. 233.)

a secondary growth of the quartz grains. The calcite cement is distinctly crystalline.

No plagioclase has been observed in the arkose and the occasional grains present in the millstone gneiss are strongly altered. Probably the plagioclase at Lugnås, as at Kinnekulle [1], has for the most part been replaced by calcite.

In places where the weathered gneiss is not impregnated and cemented by calcite but by iron oxide this substance (the iron oxide) is also found in the

[1] Högbom 1924, p. 75.

overlying arkose, though in a much smaller quantity and only in scattered grains. The calcite is of later formation than the iron oxide.

The contact between the gneiss and the arkose is sharp or at any rate quite distinct. The rock, however, does not cleave along this surface but the millstone gneiss and the arkose generally form a continuous bed. What makes the boundary specially distinct is the rich admixture of kaolin in the gneiss. This is white-powdered and dull while the arkose is gray and has the lustre of fresh rock.

The occurence of the arkose. The beds resting directly on the denudation surface are not everywhere alike. They vary particularly in the size of the grains. In quarries situated close to each other the author has observed somewhat different series of strata.

In one section the conglomerate rests directly on the gneiss, in another it lies enclosed in the sandstone, about 10 cm above the gneiss, and in a third one it is wholly absent.

As seen in the sections the basal beds sometimes enclose a conglomerate. This is mostly felspar-bearing, even if the quartz pebbles for obvious reasons dominate. The author has already given an account of this conglomerate [1] and will therefore here only call attention to the fact that not infrequently does it contain wind-etched pebbles (»Dreikanters»). The majority of the pebbles, however, are rounded and without eolian polish.

The lowest sandstone bed is as a rule arkose-like, but with no specially high percentage of felspar. (In comparison with the content of felspar in the arkose at Gislöv it is only slight.) Where the conglomerate is absent, a fine-grained, felspar-free sandstone can rest directly on the gneiss. The arkose (with the conglomerate) is generally not more than 0,5 m. thick. It is covered by fine-grained, laminated, sandstone.

The petrographical character of the arkose. The arkose consists of partly well rounded, partly more angular grains of quartz, of usually less rounded fragments of felspar, and of small interspersed lumps of kaolin. The presence of the latter indicates a silicification in the weathering gravel previous to the transgression and washing [2].

The cement in the arkose consists mainly of calcite but a cement of quartz has also been observed in smaller quantities. It occurs as secondary growth of the quartz grains, as a rule only as a thin crust around the grains [3]. The calcite on the other hand occurs as relatively large crystals, the reflecting cleavage planes of which are also macroscopically visible.

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[1] HADDING 1927, p. 52.

[2] Silicification of certain parts in a weathering gravel has been found in several places. Cf. HADDING 1927, p. 57.

[3] This crust of secondarily formed quartz is probably identical with that shown by HÖGBOM on the pebbles of the conglomerate at Kinnekulle. See HÖGBOM 1924, p. 76.

The stratification in the arkose is as a rule indistinct, unless it appears in a layer of (conglomerate-) pebbles. Sometimes out-thinning layers rich in kaolin or hæmatite are also found and are specially conspicuous on the weathering of the rock.

The formation of the arkose. The arkose has been formed at the Cambrian transgression by wear and rearrangement of the weathering gravel covering the sub-Cambrian land surface. In connection with the rearrangement a transportation of material has taken place. This has not only been a carrying away of

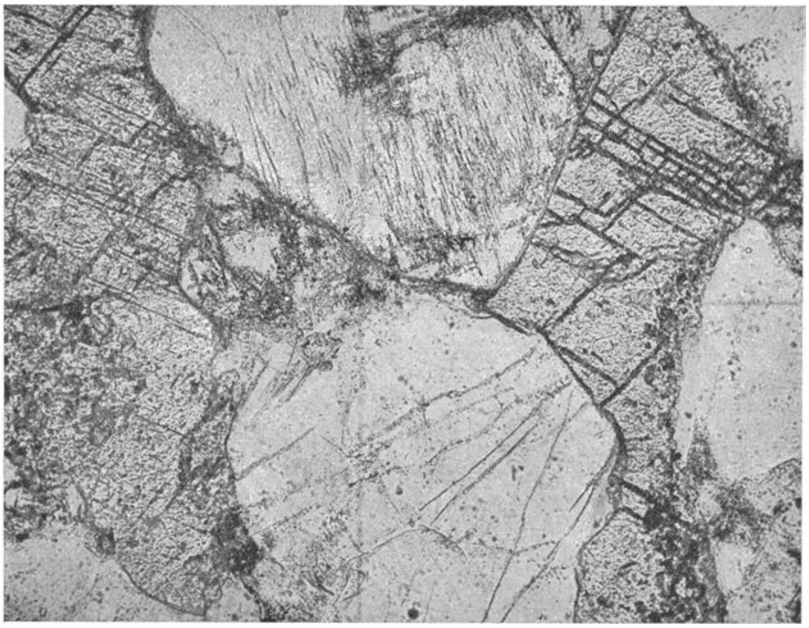

Fig. 61. Arkose cemented by coarse-crystalline calcite. Lower Cambrian basal layer. Lugnås. 60 ×. (Pr. 602. Pl. 352.)

the finer mud and the smaller grains but also a shifting of the coarser material. This may be inferred partly from the fact that the loose grains as well as the rock surface have been exposed to strong wear, and partly from the presence in the arkose of elements not to be found in the direct substratum. As an example of the latter circumstance we may mention that well rounded grains of a dark, smoky quartz are abundantly present in the arkose together with the colourless or white forming the bulk of the rock. In the foot-wall, the millstone gneiss, only the latter type of quartz is found.

A weathering gravel, that has been rearranged without any transportation worth mentioning shows no or only slight wear of the hard mineral grains. An example of this has already been given in the account of the arkose at Gislöv (see p. 71). But in the Lugnås arkose the material is distinctly worn. Some of the quartz grains are so well rounded that they must have been worn during transport by wind. The presence of the wind-etched pebbles gives further evidence that an eolian transport has taken place. Only part of the material, however, may be regarded as eolian. Transport and wear have also been effected by waves and currents. That this has also been considerable is less evident from the small grains than from the strong wear of the pebbles without wind-polish.

The weathering of the sub-Cambrian land surface.

If the arkose material has been exposed to strong wear, the surface on which it rests must also have been strongly worn. Consequently there must have been a considerable denudation, but not so deep that the fresh gneiss has been laid bare [1]. We may assume that the cause of this is partly that the weathering zone has been very deep, and partly that the lower part of the weathering gravel has been secondarily cemented. This opinion (of strong denudation) is also supported by the fact that the denuded surface is often washed clean of all the weathering gravel (arkose and conglomerate material). In the supposition of a relatively thick weathering cover we have a natural answer to the question, whence the material of the thick sandstone beds has come.

If we presume that the sub-Cambrian land surface has been covered by a thick layer of weathering products, we must also try to find an explanation of the fact that they have not left more traces in the form of conglomerate and arkose beds. That the felspar could disappear to such an extent is quite natural, considering that it is strongly weathered in the millstone gneiss also and has been so in a still higher degree in overlying strata, so that, owing to the strong wear of the material, it has crumbled and been carried away.

The reason why the conglomerate has never attained a greater thickness in spite of being formed from a thick weathering gravel is to be found in the fact that this weathering gravel has only contained a slight amount of larger quartz grains or more coherent solid aggregates. The millstone gneiss is so fine and even-grained that it would be difficult for us to find any material for conglomerate pebbles in it, if it appeared as a loose weathering gravel.

It was mentioned that the denudation at Lugnås has been arrested as early as in the weathering zone, and that this has partly been due to a cementation of the weathering gravel. We have evidence of such a cementation having occurred before the Cambrian transgression. Cement of limonite occurs commonly in the millstone gneiss. In the arkose it is present only in the form of loose grains detached by the denudation. A cement of quartz has also been deposited before the transgression. It is this cement only that has prevented the gneiss pebbles in the conglomerate as well as the lumps of kaolin in the arkose from disintegrating during the wear.

[1] Högbom has discussed the conditions at Kinnekulle and then also expressed the idea that the upper part of the gneiss might have been weathered after the deposition of the arkose. On the same occasion he shows the improbability of this idea. (See Högbom 1924, p. 75).

The cementation in the weathering gravel was effected by the deposition of silica or ferric hydroxide from water solution. Consequently the weathering of the felspar and the biotite has also been due to the cooperation of water. Nothing in the rocks at Lugnås indicates that an arid climate should have prevailed in this place at the time preceding the Cambrian transgression. The slight thickness of the arkose and the absence of grains of felspar in the sandstones indicate that the chemical weathering has been so strong that most of the potassic felspar also has decomposed to kaolin and other weathering products.

The Lugnås arkose compared with the arkose at Kinnekulle.

On the western side of Kinnekulle the Lower Cambrian basal beds and their sub-stratum, the gneiss, are exposed on the Vener shore. The conditions differ somewhat from those at Lugnås. The sub-Cambrian bed-rock is less uniform. The weathering is hardly as conspicuous as at Lugnås and the arkose (as well as the conglomerate) is still less developed than at the latter place. A possible explanation of this is that the weathering in the Kinnekulle region has only been slight and that the sub-Cambrian land surface has been relatively fresh and free from weathering gravel at the time of the transgression. But the author deems it more reasonable to presume the same strong weathering in this region as at Lugnås. A stronger denudation may have laid bare fresher rock at the same time as the weathering products have also crumbled still more and been carried away by a more lasting and intensive washing. The pebbles in the conglomerate are well rounded but never exhibit any wind-polish. Possibly a later wear by water action has caused this polish to vanish. The pebbles of clayey material also present in the conglomerate have not been present among the blocks when these were polished but must have been washed in at a later period. (Cf. Högbom 1924 and Hadding 1927).

The Mickwitzia sandstone in Vestergötland.

The arkose and conglomerate beds described above are superposed by a sandstone series about 34 m thick. The lowest 10 m consist of a hard white or light gray rock. The rock is termed Mickwitzia sandstone after the index fossil, the brachiopod *Mickwitzia monilifera* Linrs. It has also been called Eophyton sandstone after trails, *Eophyton*, occurring in it.

The Mickwitzia sandstone is fine-grained and laminated. The quartz grains are angular and have a diameter of 0,02—0,10 mm. Somewhat larger grains are also found in certain layers and occasional quartz pebbles with a diameter of up to 20 mm.

Some beds consist of fairly pure quartz sandstone with layers of ferric oxide, others are more impure, argillaceous and often rich in ferric oxide or ferric hydroxide (see analyses p. 125). The beds are only one or two centimetres thick.

The lamination in them is emphasized by the thin red layers of ferric oxide, often succeeding each other with interspaces of only 1 mm.

Analyses of Mickwitzia sandstone from Lugnås (by Sv. PALMQVIST).
a) Yellow sandstone, b) Red laminated sandstone.

	a	b
SiO_2	90,09	72,09
Fe_2O_3	3,57	11,72
Al_2O_3	2,09	2,53
$CaCO_3$	......	12,00
K_2O / Na_2O	3,63	......
H_2O	1,36	1,30
	100,74	99,64

The sandstone beds are often separated by shale layers. Fragments of these are also embedded in the sandstone beds. The shales are greenish gray and of the same type as those before mentioned from approximately the same horizon at Hardeberga. In the Mickwitzia sandstone they are (especially at the bedding surfaces) rich in small scales of muscovite. Where the layers follow close on each other, the rock may rightly be termed sandstone shale. A still finer shaly cleavage is seen in the rock when there is an abundant admixture of clayey substance in the sand. This arenaceous shale or laminated argillaceous sandstone cleaves in millimetre-thick flakes. The colour is gray. Limonite often imparts a brownish yellow colour to the bedding surfaces. Flakes of muscovite are abundantly present and give the rock a lustre sometimes resembling that of the phyllites.

On the upper surface of the clay layers various tracks and trails are found. These have been closely studied and described by TORELL (1867 and 1870), by LINNARSSON (1869 and 1871) and, above all, by NATHORST (1874, 1881 and 1886). A great number of these trails (*Eophyton*) have been formed by floating objects dragging on the clayey mud. Other »tracks» (*Cruziana*) are probably trails left by animals crawling and others again are imprints of medusae a. o. Mud cracks occur in abundance.

Ripple marks are common.

The bedding in the Mickwitzia sandstone is not always uniform. The sandstone beds are often found thinning out or varying in thickness from place to place.

The Mickwitzia sandstone is not glauconitic or only slightly so, nor does it contain phosphorite. The cement often consists throughout of quartz. Haematitic dust is a common admixture. It occurs not only in thin layers but also more lumpily enriched. The rock then becomes spotty. More seldom it is evenly distributed in a bed.

Muscovite often occurs in the sandstone beds. The mineral is for inst. to be found in the red-striped, laminated sandstone at Lugnås in flakes with a diameter of 0,5 mm. The sand grains in the same bed have a diameter of 0,03—0,06 mm. The glauconite grains are rounded and 0,06 mm large.

The Mickwitzia sandstone is no doubt a littoral deposit. The ripple-marks, the out-thinning beds, the trails and imprints show that the deposition has taken

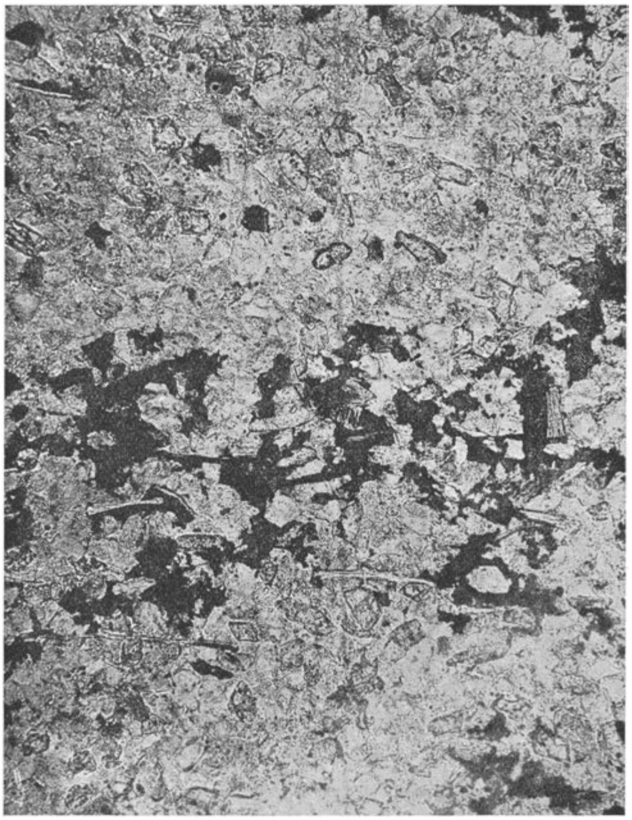

Fig. 62. Mickwitzia sandstone, thin-bedded, containing abundant hæmatite and muscovite. Lugnås. 60 ×. (Pr. 2567. Pl. 378.)

place in shallow water. The moulds and casts of the medusae and the mud cracks show that the beds have periodically been above the sea-level, for inst. at ebb with unusually low water level.

The trails and tracks in the Cambrian sandstones will be treated elsewhere in one connection. It may, however, be appropriate here to give a brief illustration of the different types to be found in the Mickwitzia sandstone, especially as they appear on almost every lower bedding-surface of the sandstone-beds. They are more characteristic in the Mickwitzia sandstone than in any other Swedish rock.

The tracks have been mainly formed in the upper surface of a layer of clay and are found as moulds in the lower surface of the overlying sandstone bed. On the upper surface of the sandstone beds some uncomplicated, cylindrical tracks have only exceptionally been observed; these may be interpreted as worm trails of the same type as has been found in most rocks rich in sand.

The »tracks» formed on the clay or in the Mickwitzia sandstone are of four (or five) different kinds (mentioned also on p. 41):

1 Tracks formed by objects resting on the clay or pressed into it (*imprints*).
2 Trails and tracks formed by animals moving across the layer of clay (crawling tracks).
3 Trails formed by a floating object dragging on the layer of clay.
4 Burrows built by animals.
5 Marks formed by desiccation (mud cracks).

Tracks of the first-mentioned type formed by objects resting on or possibly sunk down into the clay give a better idea of the shape of the track-forming body than the other types of tracks. In this case the tracks found in the lower surface of a sandstone bed are a (positive) cast of the (negative) mould in the clay. As examples of tracks of this type the medusae described in detail by NATHORST (1881) may be mentioned (see fig. 20).

Tracks and trails of the second type formed by animals moving across the layer of clay, are already more difficult to determine as to their origin. The uncomplicated worm trails occurring on the upper surface of a layer, may also, be found on the lower side and in the interior of the rock. Another track of more peculiar development has been described as *Cruziana* and interpreted as tracks of medusæ (NATHORST 1881, 34) or tracks of trilobites (NATHORST 1894, 136). The correctness of this interpretation will not be discussed here [1]. At any rate, the tracks may be formed by animals moving across the clayey mud (see fig. 21).

Tracks of the third type were formed by objects trailing on the mud while being transported in the water by waves or currents. Characteristic of these tracks is a longitudinal striation. A transversal striation is excluded. The tracks described as *Eophyton* are of this type (see fig. 22). The trails often intersect but are never ramified. As a rule their breadth is greater than their depth.

As a fourth type of tracks we might consider the burrows or tubes built by animals. Of this type the Mickwitzia sandstone contains, besides the above-mentioned cylindrical worm tubes, also the U-shaped *Diplocraterion* burrows.

»Tracks» of the fifth type formed by desiccation and cracking of the clay [2],

---

[1] Trilobites have never been found in the Mickwitzia sandstone in Vestergötland.

[2] The desiccation cracks can only be formed if the clayey mud dries up. That a periodical drainage has really taken place is proved to a certainty by the clay also exhibiting rain impressions, pointed out already by LINNARSSON (1869, 37). The casts of the medusae also imply an occasional drainage (acc. to NATHORST, 1881, 34 a. o.).

would not have been mentioned together with the preceding types, had not their character been somewhat disguised so that they could be mistaken for tracks of for inst. the first type. As a rule there is no difficulty in recognizing mud cracks or casts of such but if the system of cracks has been only slightly developed or partly effaced on account of increased content of water in the clay, isolated parts of the crack system may be preserved in such a form that the identification of their character becomes more difficult. So is often the case with the Mickwitzia sandstone.

The track-like mud cracks are irregularly ramified. From a broader trunk finer branches may proceed. They may be fairly straight, often bent at a sharp angle (knee-shaped). Sometimes they also show arched portions. They have neither longitudinal nor transversal striation, and are often more deep than wide. The walls stand, in the deeper tracks at least, at right angles to the bedding surfaces.

The varying thickness of the layer of clay has been the cause of the different width and depth of the cracks. A similar effect has been brought about by a stronger or slighter desiccation as well as by a stronger or slighter expansion of the clay previous to the sand filling the cracks.

The cracks have earlier been described as imprints of plants (*Archaeorrhiza* Torell 1869 a. o., see fig. 32). They may appear on a bedding surface together with tracks of different types.

The Lingulid sandstone in Vestergötland.

At Kinnekulle the Mickwitzia sandstone grades imperceptibly into the Lingulid sandstone (Holm 1901, 10). In other places, however, a conglomerate interstratifies the two series of sandstone. This is for inst. the case at Lugnås (Linnarsson 1871, 4).

Petrographically the Lingulid sandstone differs widely from the Mickwitzia sandstone. It lacks the latter's red hæmatitic dust and the fine banding caused by this, it also lacks the shaly layers and the abundance of mica and consequently also the pronounced stratification into thin beds and laminæ.

The Lingulid sandstone is a relatively pure, white or slightly yellow quartz sandstone developed into beds usually several decimetres thick [1]. Characteristic of the rock is a granular appearance and great porosity, both due to an incomplete cementation. The cement of quartz is however sufficient to make the rock pretty solid.

The lingulid sandstone is even- and fine-grained. Of the samples examined the most coarse-grained showed quartz grains with a diameter of 0,07—0,15 mm,

[1] In a quarry on Kinnekulle the beds in the Lingulid sandstone are of the following thickness (acc. to Holm 1901, 11): — 1,0 m, 0,27 m, 0,32 m, 0,80 m, and 0,47 m. The last-mentioned forms the basal bed in the quarry.

the most fine-grained grains with a diameter of 0,05—0,10 mm. The grains are angular.

As a rule the content of clay in the Lingulid sandstone is so low that it is not even observable under the microscope. The following two analyses (published by HOLM 1901, 12) are made on samples of the typical Lingulid sandstone.

Analyses of Lingulid sandstone from Vestergötland.

a. Yellow sandstone from Kinnekulle.

b. Gray sandstone from Kinnekulle.

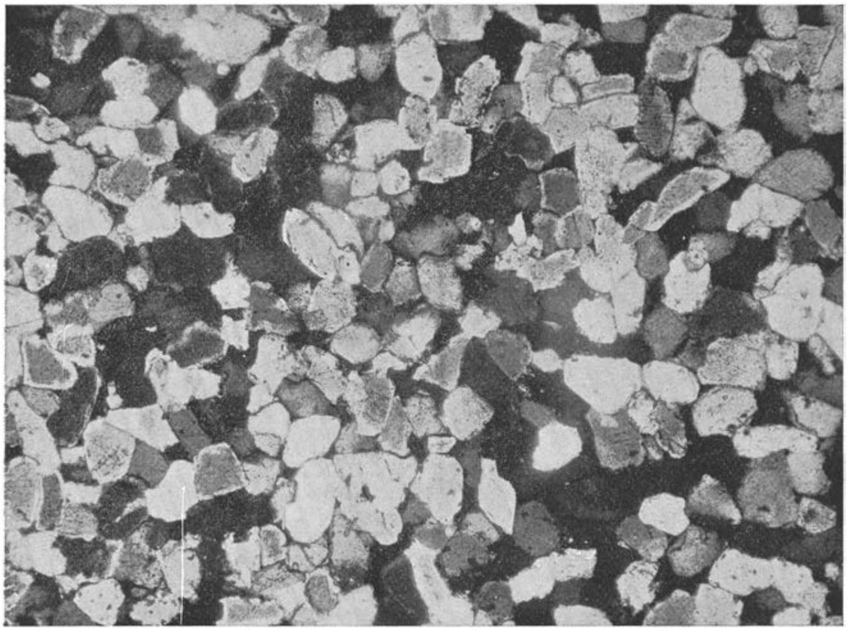

Fig. 63. Lingulid sandstone. Lower Cambrian. Lugnås. 50 ×. Nic. +. (Pr. 613. Pl. 354.)

	a	b
SiO_2	97,7	96,6
Al_2O_3	1,3	2,1
Fe_2O_3	0,1	0,1
CaO	0,2	0,4
MgO	0,1	0,1
Alkalis, etc.	0,6	0,7
	100,0	100,0

As shown by the analyses the Lingulid sandstone is not only remarkably free from clayey substance, the content of calcium and iron is also minimal. In certain beds, on the other hand, pyrite is found either in form of small crystals or as concretions with a diameter of up to a few centimetres. On the weathering of the scattered small crystals rust-coloured spots arise, while on the weathering of the larger nodules a more wide-spread brown-colouring of the sandstone bed takes place (Holm 1901).

The uppermost part of the Lingulid sandstone is as a rule particularly rich in pyrite. It is present in the rock as cement. At Motorp this top layer is found broken up and worn into a conglomerate with small pebbles of sandstone cemented by pyrite (Holm 1901).

Glauconite occurs only sparingly in the Lingulid sandstone but this mineral seems to be present in the majority of the beds. As a rule it is not macroscopically visible, partly because it never colours the rock, partly because it only occurs in very small grains (diameter $< 0{,}2$ mm). The grains are irregular in form and not perceptibly rounded. Probably they occur as primary deposit.

Fossils are only very sparingly found in the Lingulid sandstone. In fact, only one form is known, a small brachiopod (*Lingula? favosa* Linrs).[1] It occurs as moulds and is only known from a couple of places (Kinnekulle and Djupadalen).[2]

Tracks and trails resembling those in the Mickwitzia sandstone are absent in the Lingulid sandstone. But cylindrical worm tubes are found, especially in the basal part of the sandstone. At Gösäter on Kinnekulle thin, straight, vertical tubes have also been observed. The author has only seen them in one sample from this locality. The tracks are possibly a form of *Scolithus linearis* with unusually slender cylinders (1,5 mm in diameter).

In one of the uppermost beds, immediately below the alum shale a bed is found which differs from the Lingulid sandstone (Holm 1901, 12). This bed is namely highly calcareous. The content of calcium carbonate is sometimes uniformly spread in the bed, sometimes localized in larger or smaller spots. It occurs in the form of crystals and aggregates of calcite. In spite of being closely studded with quartz grains they have lustrous cleavage planes.

On weathering the calcareous sandstone becomes loose and usually brown-coloured. If the calcite is only present in occasional crystals or small aggregates, the sandstone obtains, on weathering, brown spots with loosely cemented grains of sand. Such a sandstone is termed *leopard sandstone.*[3]

The formation of the Lower Cambrian sandstones in Vestergötland.

The Lower Cambrian series of strata in Vestergötland is marine throughout and formed in shallow water. The basal parts of the series, the conglomerate and the Mickwitzia sandstone, are littoral sediments.

The wind-worn stones in the basal conglomerate show that the material of this rock has been exposed to a super-aquatic action. On the other hand, the

[1] *Lingula? favosa* Linrs = *Obolella (Glyptias) favosa* Walc. (see Walcott 1912, 600).

[2] In a sandstone uncommonly rich in glauconite and acc. to label in the Geological Museum at Lund collected by Torell at Carlsfors, an abundance of moulds is present.

[3] A similar spotty sandstone is the result, if the rock contains pyrite that passes into limonite. The author has also observed spots of red haematite, probably formed secondarily after pyrite.

fossils in the same conglomerate (*Torellella*) show the marine character of the rock.

The Mickwitzia sandstone is a marine formation developed on a very flat shore where no stronger tidal or wave currents have prevented the deposition of the fine sand and the layers of silt building up the series of strata.

The mud cracks, the rain impression, and some of the tracks show that an exposure to the atmosphere has sometimes taken place, probably at low tide (especially strong ebb).

The content of haematite in the Mickwitzia sandstone, primarily deposited as limonitic mud, is quite natural in regard to the rather considerable content of iron in the source of the material, the gneiss. How the precipitation has occurred may be inferred from the occurrence of the haematite. This forms a thin crust or coat on the quartz grains, and the limonite has no doubt been precipitated as coating on the same grains. The same formation is common in recent sediments. The cause of the precipitation and of the formation of the fine, uniform banding in several of the beds is less clear. Possibly the precipitation has taken place in connection with an oxidation caused by exposure to the atmosphere. Had the precipitation taken place during periodically recurrent drying up, the fine, uniform haematitic banding in several of the beds would be explained.

The Lingulid sandstone has not been formed under the same conditions as the Mickwitzia sandstone. It has been deposited at a greater distance from the shore in deeper but more mobile water. This may be inferred from the fact that the rock has become purer (the percentage of clay and iron has sunk to a minimum), and that the trails, mud cracks, etc. are not found in this part of the series of strata.

The deposition of sand has nevertheless taken place in relatively tranquil water. The beds are uniform and the size of the grains remarkably constant. The slight content of glauconite almost always present indicates a formation at a greater distance from the shore than that of the Mickwitzia sandstone.

Towards the end of the formation of the Lingulid sandstone an elevation of land with accompanying shallowing has taken place. Layers richer in pyrite are deposited together with a calcareous bed. A conglomerate has even been formed though only a local one.

With the Lingulid sandstone the deposition of sandy material ceases for a long space of time in Vestergötland as well as in large parts of South-Sweden. Clayey shales and limestones dominate entirely in the series of strata succeeding the Lower Cambrian sandstone. Irrespective of Öland in South-Sweden no traces of littoral depositions with sandstones or coarser rocks from Middle Cambrian or Younger Cambrian time have been found hitherto. Certainly, the elevations of land occurring during this time have caused the formation of conglomerates but they have been formed exclusively at the cost of the new sediments.

The Lower Cambrian Sandstone in Östergötland and Nerke.

The Lower Cambrian sandstone is only slightly exposed in Östergötland. Certainly, some newly discovered occurrences have been added of later years to those known of old but a more complete part of the series of strata is nowhere accessible. It was therefore of great interest to improve our knowledge of these strata by the observations made at a drilling in Stavlösa. According to a survey made by WESTERGÅRD (1928, 201) the series of strata we now have reason to consider typical for the Lower Cambrian of Östergötland is as follows: —

Glauconite-bearing sandstone	about	2	m.
Quartz sandstone, pure, fine-grained	»	10	»
Sandstone and shale, interbedded	»	2	»
Quartzitic sandstone	»	10	»
with a 0,5—0,7 m thick layer of grayish blue plastic clay			
Conglomerate			

The basal conglomerate is only known in erratic boulders. The pebbles consist mainly of quartz. In boulders of a conglomerate-like sandstone *Mickwitzia monilifera* has been observed (by J. G. ANDERSSON).

According to ROSÉN (1922, 38) the bed of plastic clay is at Vågforsen embedded in a grayish blue calcareous sandstone. This shows *Cruziana* tracks.

The quartzitic sandstone is known partly from a section at the Stacka kvarn (Stacka mill) and partly from Vågforsen in Stångån.

The upper, pure quartz sandstone is known from a couple of other places besides from the drill section. The rock is light gray or slightly yellow. In colour as well as petrographical character it is very like the Lingulid sandstone in Vestergötland.

In *Nerke* the sandstone is widely spread in the Örebro field, but it is only exposed in a few small sections. At Holmstorp it has been found by boring that the sandstone series is 26 m thick and rests directly on the gneiss.

On the whole the beds of sandstone are of the same petrographical character in Nerke as in Vestergötland. The upper beds consist of typical Lingulid sandstone (*Lingula*, however, not found). In the lower strata fragments of *Mickwitzia monilifera* (HOLM 1902, 58) have been found. [1] The clayey beds mentioned from the drill cutting at Holmstorp probably also belong to this lower part of the series of sandstone.

A fairly great variation in the character of the rock is shown by a section in the Cambrian sandstone (about 17 m thick) at the Klara mine in the neighbourhood of Vintrosa. According to KULLING (1925, 345) the series of strata here would be: —

[1] *Torellella laevigata* is also present in this sandstone (as in Vestergötland), according to what GAVELIN's (1909, 11) investigation of erratic blocks has shown.

Fine-grained white sandstone, greenish at the top, gray at the bottom .... 11—12 m

Dark greenish gray shale, with *Torellella laevigata* and worm trails, interbedded with

Light green shales, with *Medusina costata*

Light green shale-conglomerate (position uncertain)

Coarse-grained, white calcareous sandstone, with occasional pebbles. Contains *Torellella laevigata*

Archaean

The strata are easily correlated with those of Vestergötland. The essential difference between the series of strata in the two regions is that the Mickwitzia sandstone of Vestergötland is partly replaced in Nerke by more fine-grained and clayey rocks.

Ripple-marks, mud-cracks and clay slabs occur in the Lower Cambrian sandstone of Nerke as well as in that of Vestergötland. The formation of the rocks has no doubt been similar in both places.

Scattered Occurrences of Lower Cambrian Sandstone Dykes.

In many places on the western shore of Lake Vener sandstone dykes occur in the fissured gneiss. They have been observed on small islets S of Åmål and on the eastern side of Vermlandsnäs and further in the vicinity of Karlstad (Gavelin 1909, Sundelin 1919, Johansson 1920 a, 23 and 1920 b, 21).

The dykes and veins are nowhere broader than 12 cm and in most cases they are only from 1 to 4 cm in breadth.

The rock seems everywhere fairly uniform. It is a greenish gray or yellowish gray, often calcareous sandstone, partly greywacke-like.

Gavelin's detailed account of the rock in the sandstone dykes on Rävkulteholmen (the R. islet) may be cited here, as it undoubtedly gives us a good idea not only of the rock in these dykes but also of the others (Gavelin 1909, 6).

»In both dykes the rock is a greenish gray, distinctly clastic, highly calcitic sandstone, consisting of well sorted and mostly well rounded grains mainly of quartz and some microcline and sparse scales of mica embedded in a cement of calcite, in which pyrite is also present in the form of small grains and round concretions from a few mm to about 1 cm in diameter. As a rule the grains of quartz and feldspar are from 0,1 to 0,6 mm, mostly from 0,2 to 0,5 mm, in diameter. As has often been found in sandstones, they sometimes show a thin marginal zone of new substance, grown on to the original grain.

In the sandstone small, round, black pebbles (from 1 to a couple of mm in diameter), probably consisting of phosphorite, occur sometimes together with a number of inclusions of another kind. Thus small pebbles of dark sandstone differing microscopically from the surrounding rock only by a dark brown, clayey cement replacing the calcite in the latter, and pebbles and fragments of green shales are found. The said inclusions are obviously closely related to the principal rock and can hardly be considered essentially older than this. — In addition the sandstone contains pebbles (up to 2—3 cm in diameter) of quartz and quartzite and angular fragments of the rocks of the immediate neighbourhood (diorite, granite and pegmatite). The last-mentioned are strongly weathered, especially the diorite; in certain fragments this consists mostly of epidote, calcite a. o. secondary products.»

In the sandstone dykes on Rävkulteholmen *Mickwitzia monilifera* Linrs. and *Torellella laevigata* Linrs. have been found (determined by J. G. Andersson).

The sandstone dykes on the western shore of Lake Vener are situated at a distance of 50—100 km from Halleberg and 50—60 km from Kinnekulle, the nearest occurrences of a preserved Cambro-Silurian series of strata. The dykes do not only bear evidence of the wide distribution this series of strata once had but also of the even denudation surface on which it was deposited.

Sandstone dykes also occur on the shore of Lake Vener W of Halleberg, and there a still more convincing picture of the flatness of the sub-Cambrian denudation surface is obtained (Munthe 1915, 623).

On the islands of Östergötland Lower Cambrian sandstone has been found in dykes filling up NE fissures in the Archaean (Gavelin 1904, 63, Asklund 1921, 669). The rock is grayish or greenish yellow and distinctly clastic. The grains are sometimes well rounded, in other cases more angular. The larger grains are from 0,5—0,8 mm in diameter; the smaller from 0,1—0,2 mm. A secondary growth has sometimes been observed in the grains. As filling matter a brownish black pigment is present (Gavelin l. c.). The dykes are from 0,5 to 15 cm wide. No fossils have been found in them, nor was such a finding to be expected as they are probably of the same age as the lower or middle part of the Kalmarsund sandstone.

In Åland sandstone dykes have long been known (see Tanner, 1911). Here also they have a NE or, more correctly, a NNE direction. Their width is in most cases only a few centimeters but in one of them it increases in one place to nearly 60 cm. The rock is somewhat varying, sometimes a gray, fine-grained and even-grained sandstone, sometimes a coarser one almost conglomerate-like. In some places the grains are angular, in others well rounded. Bedding can be quite distinct or wholly absent. In one of the dykes a small brachiopod (*Kutorgina* or *Acrotreta* acc. to Wiman) has been found. In boulders of a similar rock from Åland a sample of *Discinella* (*Mobergella*) *Holsti* has been found.

The Lower Cambrian sandstone dykes in Bornholm (Denmark).

Lower Cambrian sandstone dykes occur in many places in Bornholm, the majority in granite but some of them also in diabase. The dykes are described by Ussing (1899) and Grönwall (1916). They are mentioned here partly because very likely dykes of this type are to be expected in Scania also, partly because the author has had the opportunity of examining the rocks in these dykes. The material for this investigation has been collected by Grönwall and kindly placed at the disposal of the author.

The rock in the veins is somewhat varying. Practically three different types can be distinguished.

The first type is a sandstone with angular grains and an abundant admixture of fragments of felspar. The rock is formed by cementation of a weathering gravel with a slight content of finer detritus. The Aakirkeby dyke, the Prästebo dyke and one of the Gräsholm dykes are of this type.

The other two types, occurring at Listed, are characterized by a purer quartz sand sometimes with rounded grains and a more abundant content of fine material forming the matrix between the grains.

In the commonest of these two types an abundance of larger, well rounded grains ($0{,}5$—2 mm) mixed with smaller and more angular ones ($0{,}05$—$0{,}5$ mm in diameter) are found.

In the third type the larger grains are absent. The rock thus consists of small, angular or slightly rounded grains of quartz embedded in an abundance of filling material. Felspar is not present in any amount to speak of.

In all the dykes the cement consists of quartz, frequently occurring as secondary growth of the quartz grains.

The colour of the sandstone varies with that of the filling material. In the majority of the dykes the colour is gray, grayish green or light grayish brown. The dyke at Aakirkeby is grayish red and the dyke at Prästebo reddish brown; in both there is a high percentage of microcline.

The sandstone shows no distinct bedding. In a section 2 m high through one of the Listed dykes we find the same size of grains throughout but a certain variation in the content of mud (the content of filling material). The upper part of the dyke is a purer quartzitic sandstone, its lower part is fairly rich in dark matrix.

The sandstone dykes are formed as sand-fillings of fissures in the granite. Ussing pronounced the opinion that these fissures (»earthquake fissures») have been formed when the granite was already covered by loose sand, which has immediately slid down and filled the fissures. It is of course also possible that the fissures have been formed before the sand was deposited on the granite in which they occur. In the one case as well as in the other adjoining dykes will show the same rock.

Two facts, the content of clay in the dykes and the repeated formation of fissures, seem to the author to indicate that the fissures or at any rate several of them have been filled up by sand being washed in and not by the sliding down of the already deposited sand.

If the material had slid down, its character ought to be the same as in the lowest part of the sandstone series to which the dykes belong. That this is the Lower Cambrian series of strata is not altogether certain but it is most plausible. [1] In a couple of the dykes we also find a rock corresponding very well with the lowest part of the Nexö sandstone (the oldest Lower Cambrian sandstone). So it is in the case of the sandstone at Aakirkeby and in the Prästebo dyke.

The material in the dykes rich in mud (clay) is partly deposited under other conditions than the normal basal beds of the sandstone. Sand and fine mud have been deposited simultaneously in the fissures but not otherwise on the granitic rock-surface in Bornholm. This implies that narrow splits with relatively still water have existed when the rock was washed clean of weathering gravel and the Cambrian deposition started. The fissures were then filled up by muddy sand. Similar sand was possibly also deposited periodically on the surface of the granite but that was further acted upon and sorted by waves and currents and possibly had to give place to coarser material. What had lodged in the fissures, on the contrary, could remain unchanged.

That the fissures containing sandstone dykes have not always been formed after the deposition of the sand is also evident from the fact that one and the same dyke sometimes contains material of more than one kind. In these cases the dyke must have been formed at two different epochs. In one of the dykes at Listed we find firstly fine-grained, muddy sandstone, which has formed the original dyke, secondly pure, coarse-grained sandstone formed in younger fissure in the cemented, first deposited sand. It is quite possible that the younger coarse part of the dyke ows its origin to deposited sand sliding down into a fissure formed after the deposition of sand but it is very improbable that the older, more muddy part has been formed in this manner.

The Lower Cambrian Series of Strata in North-Western Dalecarlia.

The Cambro-Silurian series of strata in the region of Lake Siljan contains no Cambrian rocks. Its basal beds belong to the Lower Ordovician. The petrographical and faunistic qualities of this series of strata, however, are so like those found in the series farther S and SE that the correlation is not difficult to carry out.

In north-western Dalecarlia, on Lake Guttu, Skärvagen, etc. in the parish of Idre we find a series of strata of a quite different kind. The bulk of the rocks consists of sandstones and quartzites free from or poor in fossils. Even after Middle Cambrian fossils (*Agnostus parvifrons* and *Paradoxides*) have been found

[1] A formation before the Cambrian transgression is not excluded.

(Törnebohm 1882, 280) in an alum shale with stinkstone nodules, that occurs in the series, has it not been possible to exactly follow up the correlation with the normally developed Cambro-Silurian series.

The discoveries of Lower Cambrian fossils (*Torellella lævigata* and *Olenellus*) in the sandstone underlying the alum slate confirmed the fact that also the lower part of the series of strata was Cambrian (Schiötz 1892, Schmalensee 1892, Holm 1893, 148; Hedström 1896, 68). Törnebohm (1882) regarded the strata lying over the alum shale as younger but after the theory of overthrust had asserted

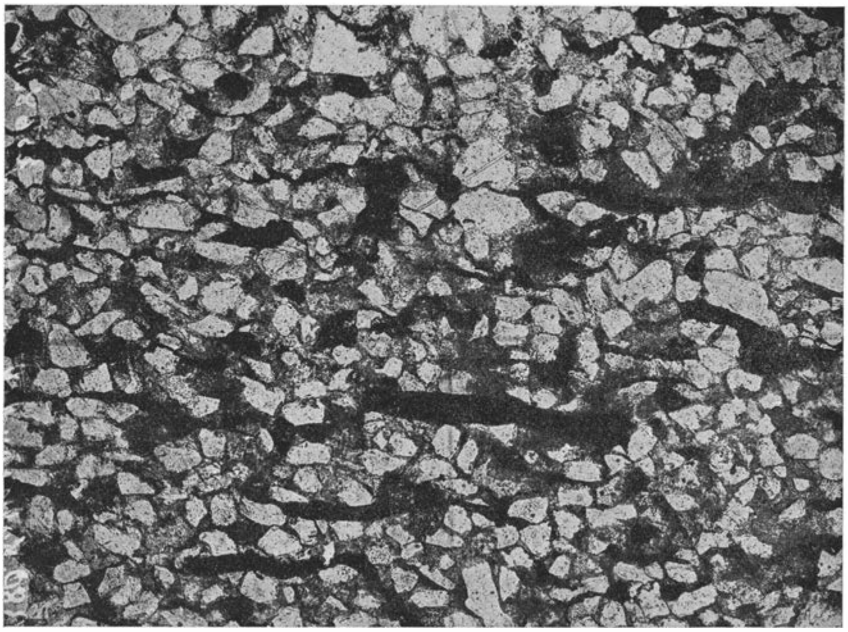

Fig. 64. Calcareous sandstone containing phosphorite. Lower Cambrian, Knallarna, Dalecarlia. 60 ×. (Pr. 2568. Pl. 380.)

itself, they were grouped with the supposed pre-Cambrian sparagmites. Their position over the alum shale was explained as secondary. We have no occasion to stick to this latter interpretation any longer and a general renunciation of it has also begun.

The distribution of the Lower Cambrian strata in NW Dalecarlia is seen from a map made by Tegengren (Frödin 1920, 18). According to the fairly unanimous statements of Törnebohm, Hedström and Tegengren the series of strata is as follows: —

White or gray quartzite, resembling the Wemdal quartzite	10—20 m
Black or dark gray shale with stinkstone nodules; in this fragments of *Agnostus parvifrons* and *Paradoxides*	10 »
White or gray (yellowish, bluish or blackish gray) sandstone, quartzitic or calcareous; in this *Torellella lævigata* and *Olenellus*, about	13 »

The sandstone series lying under the shale is no doubt Lower Cambrian. Whether a detailed investigation in the field will give more guidance for the correlation of the beds with the corresponding ones in other regions is uncertain and hardly probable.

The fossiliferous beds are calcareous and phosphoritic. In examined samples of it (collected by SCHMALENSEE 1900) the percentage of calcite was so high that the rock should be termed arenaceous limestone. The grains of quartz are from 0.03—0.1 mm large. Only the largest show traces of wear. The rock is dark gray and has an even grit. In certain parts the calcite is fine-crystalline or dense, in other parts coarse-crystalline. The rock contains an abundance of black, lustrous chitin shells of *Lingula*.

According to HOLM (1893, 148) *Torellella lævigata* occurs in phosphoritic conglomerate in the calcareous sandstone. The shells have been filled by phosphorite and then rolled and worn.

With regard to the Cambrian strata in north-western Dalecarlia we may infer that they are marine and deposited under such conditions that the material has been strictly sorted after the size of the grains. The formation has occurred in an open but shallow basin.

The Lower Cambrian sandstone in Norrland.

We may infer from a number of scattered observations that the Lower Cambrian strata are well developed in the North of Sweden also. But the character of the strata and the variations occurring both in vertical and horizontal directions are very little known. The reason of our want of knowledge concerning these strata rests largely in the fact that fossils have only been found sparingly and therefore it has not been possible to determine their age. In the mountain region the strata are also highly metamorphosed and their succession disturbed.

In some places it has been possible to determine the Middle Cambrian and Upper Cambrian beds as fossiliferous alum shales. The sediments lying immediately below these shales may be regarded as Lower Cambrian. At occasional places fossils of the *Olenellus* stage have been found in them. (At Kyrkberget and at Tallträsk, both places situated on Stor-Uman, *Olenellus Kjerulfi* has been found — see MÖRTSELL 1890 and HOLM 1890.)

The Olenellus-bearing rock is a greenish gray shale. The Lower Cambrian series of strata is however also built up of other rocks. From the Hiberget on Lake Skikki LIDÉN (1911, 10) mentions a yellowish white quartzite resting on the Archaean and probably covered by a dull gray shale.

Towards the north the series of strata becomes richer in arenaceous sediments. SVENONIUS (1892, 36) states the following series of strata from Norrbottens län (Östra Ramanvare): —

Dark, strongly pressed shale (»Raman shale»)	90 m
Black shale with conglomerate of phosphorite and quartzitic sandstone	> 30 »

Greenish gray shale with *Hyolithes*	15 m
Scolithus sandstone	> 50 »

Archaean.

The Lower Cambrian Hyolithes series can be followed all through Norrbotten. At some places the arenaceous rocks seem wholly dominant, at others the shales occupy a large part of the series of strata. Here and there basal conglomerates have also been observed. We shall only dwell on one of the points of observation here: the point we choose is Luopahta on Torneträsk.

The Lower Cambrian series of strata on Torneträsk has been measured by MOBERG (1908). The series of strata in a couple of the profiles is given below.

Profile I at the NE corner of Luopahta: —

19	Kakirite.	
18	Shale, in the upper part black, in the lower gray	86.40 m
17	Sandstone, greenish gray, calcareous, with *Scolithus errans*	0.65 »
16	Green shale	0.30 »
15	Reddish brown shale	5.16 »
14	Greenish gray shale	1.34 »
13	Bluish gray sandstone, calcareous and phosphorite-bearing	1.55 »
12	Green shale with layers of sandstone	1.72 »
11	Light gray sandstone, fine-grained, almost quartzitic	2.16 »
10	Gray or greenish gray sandstone, yellow-dotted, fine-grained	0.55 »
9	Gray sandstone with brown spots (»leopard sandstone»)	0.75 »
8	Green shaly sandstone	2.10 »
7	Gray shale (phyllite-like) with lenses of sandstone	11.67 »
6	Greenish gray and white sandstone (arkose), partly conglomeratic but rich in fine-grained material	4.56 »
5	White sandstone, coarse-grained	1.52 »
4	White sandstone, fine-grained, almost quartzitic	0.68 »
3	Greenish sandstone (arkose), white-spotted, fine-grained	0.85 »
2	Gray sandstone, fine-grained	0.21 »
1	Conglomerate, coarse	0.30 »

Archaean.

Profile II, a few hundred metres W of profile I.

25	Kakirite.	
24	Black shale (Middle Cambrian?)	72.0 m
23	Gray shale, slightly calcareous, with the youngest *Olenellus* fauna. In the upper part dark fragment limestone	1.72 »
22	Green shale (weathered, red)	15.48 »
21	Shaly sandstone	0.16 »

20	Dark limestone with grains of quartz	0.54 m
19	Dark gray sandstone, quartzitic, blue-quartz-like	5.42 »
18	Yellowish gray sandstone, shaly, with winding trails. Rich in clay galls	6.20 »
17	Grayish yellow sandstone, with clay galls	0.69 »
16	Yellowish gray sandstone, brown-spotted	0.49 »
15	Yellowish gray sandstone, brown-dotted, with clay galls	15.03 »
14	Green sandstone, shaly, with layers of clay	0.95 »
13	Yellowish gray sandstone, with grains of phosphorite and clay galls	11.58 »
12	Green sandstone, with thin layers of clay and thicker beds of gray calcareous sandstone	8.30 »
11	Grayish green shale, the upper part sandy	1.50 »
10	Red shale, with *Platysolenites* and *Hyolithes*	16.00 »
9	Green shale, arenaceous, with *Monocraterion*	1.15 »
8	Green sandstone, fine-grained, glauconite-bearing	1.67 »
7	Green shale, with thin sandstone beds	1.00 »
6	Green sandstone, shaly	0.60 »
5	Grayish yellow sandstone, brown-dotted	4.00 »
4	Gray sandstone, with brown spots (»leopard sandstone»)	0.85 »
3	Grayish green sandstone, brown-dotted or brown-spotted	0.50 »
2	Green sandstone, thin-bedded	1.90 »
1	Gray shale, hard, with gray lenses (concretionary) of limestone.	

The fossils found in profile II, stratum 23 are *Arionellus primævus* Brögger, *Ellipsocephalus Nordenskiöldi* Linrs. and *Obolus* sp. They belong to the zone with *Olenellus* (*Holmia*) *Kjerulfi*, i. e. the youngest part of the Lower Cambrian. Already on account of the occurrence of these fossils one may venture the statement that the underlying part of the series of strata belongs to the older parts of the Lower Cambrian. This is confirmed by the findings of *Platysolenites antiquissimus* Eichw. and *Hyolithes* sp. in stratum 10. The *Monocraterion* formation and the *Scolithus errans* trails may also be regarded as typical of the Lower Cambrian, even though such formations are also found in other strata.

As Moberg points out, the series of rock reminds us in certain parts of the Lower Cambrian strata in Scania. Phosphorite has been observed in several beds, and ripple marks as well as trails are common on the bedding surfaces. On the whole, however, the Lapland series contains more clayey sediments than the corresponding series in Scania (or Vestergötland).

Part of the rocks collected by Moberg, have been examined by the author. An account of some of the observations made will be given here.

As a rule the sandstones consist of coarser rounded grains, 0.3—0.5 mm in diameter, and smaller angular ones. The cement is mostly quartz, sometimes (for inst. in profile II, stratum 19) occurring as secondary growth of the quartz grains.

Calcitic cement is found in some of the beds and also locally in the quartz sandstone. Thus the white spots in the green quartz sandstone, stratum 3 in profile I, have an abundant cement of calcite.

The clayey substance frequently occurs in the sandstones, in some beds even abundantly. This for inst. is the case in the partly conglomerate-like arkose, stratum 6 in profile I. The mixture of coarse and fine material shown in this part of the series of strata, indicates a formation differing from that of the other beds. It has probably been deposited during an occasional elevation of the sedimentary

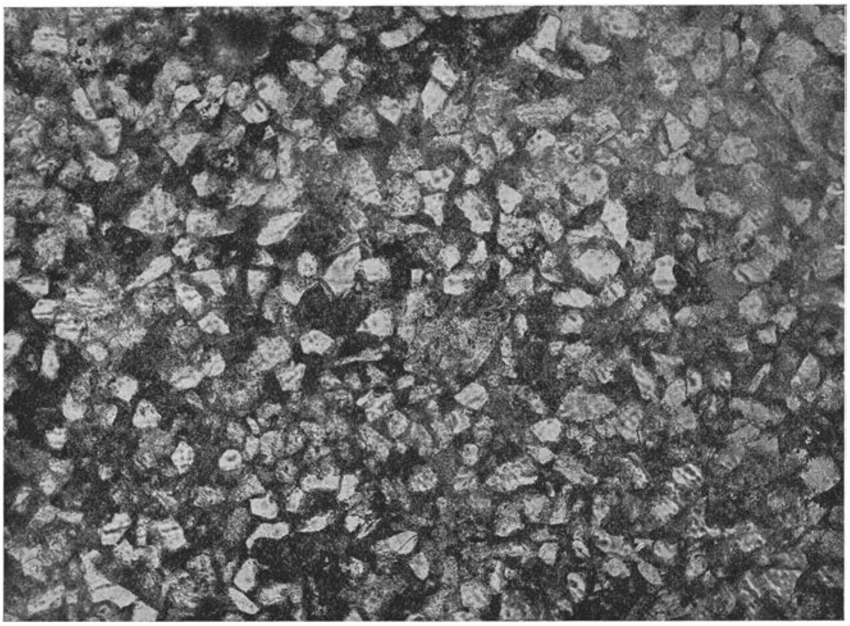

Fig. 65. Fine-grained sandstone with quartz cement. Lower Cambrian. Pessinenjokk Luopahta, Lapland. 60 ×. (Pr. 904. Pl. 381.)

region and in a closed basin. The underlying coarse sandstone speaks for the same elevation but it has been deposited while the finer material could still be washed away to a deeper and more tranquil region.

Clay galls are frequently present in the sandstones. We recognize their rounded form and wide-spread position from the Lower Cambrian sandstones of Hardeberga (see p. 88). No doubt the mode of formation is the same in Lapland as in Scania.

The shales interstratifying the sandstone beds are of the same type as those at Hardeberga. The stratification is often indistinct and the cleavage irregular. The shales are frequently so rich in small grains of quartz that they deserve to be termed clayey sandstones rather than shales.

The presence of *glauconite* in certain sandstone beds is of interest. This mineral seldom occurs in rounded grains, but is mostly found in small diffuse lumps or as matrix between the quartz grains, just as in certain Lower Cambrian sandstones in Scania. In none of the beds has it been observed in larger quantities. Of the strata examined no. 8 in profile II had the highest content of glauconite.

Phosphorite is frequently present in the series of strata at Luopahta. This mineral always occurs in irregularly formed rounded nodules, varying in size from a couple of millimetres to a couple of centimetres. In the samples exa-

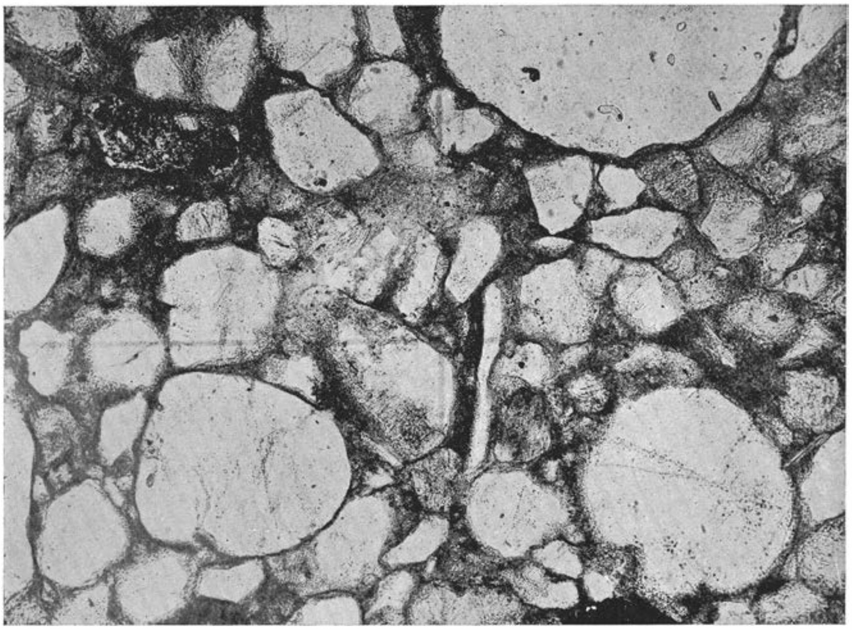

Fig. 66. Coarse-grained quartz sandstone. Lower Cambrian basal layer. Pessinenjokk, Luopahta, Lapland. 60 ×. (Pr. 906. Pl. 382.)

mined by the author they were not accumulated in such quantities as to form a real conglomerate.

It is possible to get a fairly good idea of *the origin* of the series of strata at Luopahta. Owing to the presence of a marine fauna, glauconite and phosphorite we know that the strata, mostly at least, must be marine. The ripple-marks and the trails show that the deposition has taken place in shallow water. The variations in the character of the rocks indicate changes in the local conditions of formation. The deposition has sometimes taken place in more moving water (coarse, pure sandstones), sometimes in more tranquil water (shales and fine-grained sandstones). At certain epochs the place of deposition has probably been wholly secluded from the sea, as is indicated by the impure sediments containing a mixture of coarse and fine material.

On comparing the Lower Cambrian strata at Luopahta and at Hardeberga, the one locality in the extreme north of Sweden, the other in the extreme south, we may perhaps venture to infer that the strata at Luopahta are deposited in shallower or less open water than those at Hardeberga. We may also infer that the formation of the series of strata in Scania has in all probability begun earlier than in Lapland.

The Sandstones of the Visingsö Series.

The Visingsö series lies as an isolated pile of sediments surrounded by the Cambro-Silurian fields of Vestergötland, Östergötland and Nerke but without coming so much in contact with these as to allow a certain determination of its position in relation to them. Certainly Seth Rosén believed himself capable of showing that the Cambrian basal conglomerate in the northwestern part of Östergötland contains pebbles of the rocks of the Visingsö series, but as pebbles of similar rocks occur in almost all basal conglomerates, it seems to the author that the statement, however probable, cannot simply be considered as a conclusive evidence of the pre-Cambrian age of the Visingsö series. No doubt further investigations will throw more light on the question. At the same time it would be desirable to subject the Visingsö series to a systematical investigation also. By giving the following account of some types of sandstone belonging to the series the author has by no means wished to forestall such an investigation. Here the question can only be one of illustrating certain types of rock characteristic to the series.

The sandstones on the Gera brook, N of Grenna.

Along the Gera brook, N of Grenna, the basal beds of the Visingsö series are visible in a few small sections. Whether they are separated by faults the author cannot tell, it is, however, not improbable. Consequently we do not know the size of the series of strata, of which the visible strata are probably only fragments, nor can we say that the series of strata, as it appears from the dip conditions, is the original one. We must, however, desist from this discussion here.

The rocks outcropping on the Gera brook form, apparently at least, the following series of strata: —

Dark gray shale with limestone nodules.
Red and green sandstone, with conglomerates.
Green sandstone.
Red shale interstratified with green and red sandstone.
Yellow sandstone.
Archaean.

The yellow sandstone has an arkosic, partly conglomeratic basal bed. Fragments of felspar occur a little way up in the yellow sandstone and in the overlying strata also. For the most part, however, the yellow sandstone is free from or poor in felspar.

It consists of more or less rounded grains of quartz, 0.1—1.0 mm in diameter. The majority of the grains are 0.3—0.4 mm in size.

Contrary to a number of other sandstones in the Visingsö series this sandstone is devoid of matrix in the form of muddy or clayey matter. On the other hand, the grains of quartz are to a large extent covered by a coating of yellow iron hydroxide. The rock is sometimes yellower, sometimes whiter in colour, dependent on the quantity of iron. In the upper part of the sandstone red portions also occur.

The cement in the yellow sandstone consists of silica. It is but sparingly present and only at the points of contact of the grains. On this account the sandstone is porous.

The sandstone is developed into beds of varying thickness. These are relatively even in the size of the grains, colour and solidity. As a rule they show no finer stratification.

The yellow sandstone on the brook of Gera is a rock built up of fine quartz sand washed clean and worn. Its purity and the rounding of the grains indicate either a subaquatic formation in a moving water or a subaerial formation. The even bedding indicates more decidedly a formation in a water basin and excludes the possibility of a fluvial or aeolian formation.

(White veins of quartz are often found in the yellow sandstone. They have an irregular course and are formed secondarily by infiltration along fissures.)

Red shale interstratified with thin beds of red or green sandstone follows immediately above the yellow sandstone. The shale is thin-bedded and cleaves readily. It is fairly rich in small scales of mica and not harder than it can be scratched with a fingernail.

The sandstones interstratified with the shale are fairly loose, often argillaceous and varying in colour (different shades of red and green). The beds sometimes thin out rapidly. Here and there small flakes of clay are interspersed in them.

Fairly hard beds of *green sandstone* overlie the red shale and sandstone beds. The rock is argillaceous and contains an abundance of small scales of mica in certain strata. Winding trails are to be observed on the bedding surfaces. Some of the beds are fine-laminated.

The grains vary in size from a couple of millimetres to the finest dust. As a rule the larger grains ($>$ 0.5 mm) are well rounded, the smaller on the contrary angular. Grains of feldspar occur in no small quantity.

The cement consists of silica. It is abundantly present, and in spite of its considerable content of clayey matter the rock is well consolidated. On account of the abundance of mica in certain beds, however, it cleaves readily.

The conglomerate-bearing sandstones overlying the green sandstone are, like this, impure (argillaceous). As a rule the cementation is slight. In colour they are shot with red and green.

In these sandstones out-thinning conglomerate beds occur and are, with one exception, relatively insignificant. Boulders of the older sandstones of the series are also to be seen among the pebbles.

The sandstones are thin-bedded, especially in the upper part of the section. There they are also laminated with dark gray or grayish green, thin, highly argillaceous layers in a slightly grayish red or light grayish green sandstone. The stratification is irregular, the dark clayey layers enclose thin lenses of sandstone.

The gray or greenish gray shale in the upper part of the series of strata on the Gera brook, forms a natural continuation of the fine-bedded, highly argillaceous sandstone, if the sedimentation has tended towards a steady decrease in the coarse material carried out to the place of deposition. The sand-grains disappear and the clayey matter dominates entirely. Carbonate of calcium is added, partly as a usually inconsiderable content of calcite in the shale and partly as small calcareous nodules.

In certain respects *the origin* of the series of strata on the Gera brook is easily inferred from the character of the rocks, in other respects it is more obscure.

The yellow sandstone must have been deposited during a strong washing-away of the fine (argillaceous) weathering products, the overlying sandstones during a less strong. Consequently the capacity of the water to carry away material from the place of deposition has decreased during the deposition. The capacity of transporting material to the place of deposition on the other hand has not diminished in the same degree. Coarse material (sand) also occurs after the deposition of clayey mud has begun in the region. Periodically the transportation to the place of deposition has increased so much that conglomerate has also been formed but without simultaneous removal of the finer material. But at last the capacity of transport decreases gradually so that only fine clayey mud is carried to the place of deposition.

An eolian formation is out of question and so is a purely fluviatile or glacial. A subaquatic is the only one possible for the greater part of the series of strata. We can imagine the following progress of formation.

In a stream a settling basin has been formed for inst. by faults. At first this basin has been shallow so that only relatively coarse grains (sand) have been impeded in their further transport. Then it has gradually become deeper (for inst. by new faults). This has resulted in a deposition of still finer material. During poor supply more argillaceous material and during rich supply a mixture of sand and clayey matter were deposited. The occurrence of the conglomerates shows that the deposition in this place has happened in the immediate vicinity of the edge of the basin (the shore). The more and more increasing content of clayey matter in the upper part of the series of strata shows that sand has no longer been carried out to the place of deposition. This fact can be due either to a deepening and widening of the basin of deposition, to the formation of a new settling basin in which the coarser material has been caught or possibly to a decrease in the transporting capacity of the water.

The earlier described mud-cake conglomerates [1] in the upper part of the Visingsö series show that *no* deepening of the basin has occurred towards the end of the sedimentation period. The mud-cake conglomerates and the mud-cracks in the shale give certain evidence of a periodical drying up of the strata. They have been deposited in a (by the sedimentation?) silted water.

Consequently the decrease of coarser material must have been due to a deficient supply of this kind of material. Where the cause of this is to be looked for can hardly be decided. However (judging from the deposited sediments) it may not be more arid conditions and a consecutive decrease in the transporting capacity of the streams. It seems more probable to the author that changes in the level of land, possibly in connection with land movement during the Cambrian transgression, have caused changes in the drainage regions of the water-courses, which have influenced the sedimentation.

Sandstones of the Visingsö series in the neighbourhood of Jönköping and in Visingsö.

The rocks described above from the Gera brook are also found in other occurrences of the Visingsö series. In some places the lower strata, the yellow sandstone, are principally found, in others only the upper, the red and green sandstones and the shale. All these occurrences will not be described here but the character and occurrence of the rocks in two places, viz. in the neighbourhood of Jönköping and the SE shore of Visingsö, will be shortly mentioned.

At Huskvarna the sandstone rests directly on the Archæan. The rock is here an even-grained, yellow quartz sandstone of the same character as that described from the Gera brook. At Jönköping the same rock appears, as also farther to the NW at Trånghalla. In the latter place the outcropping sandstone is 3,5 m. thick, at Jönköping it has been drilled to a depth of 58,3 m without reaching the bottom. [2]

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[1] HADDING 1927, 60.

[2] MUNTHE 1907, 89. Acc. to the driller's log the series of strata was of the following character: —

Hard, white sandstone	....	2,4 m
Loose, » »	....	7,9 »
Loose, red »	....	7,2 »
Hard, » »	....	6,0 »
White »	....	12,0 »
Red »	....	10,5 »
Yellow »	....	0,6 »
Red »	....	3,0 »
Hard, white »	....	5,1 »
Loose, » »	....	3,6 »

In the most southerly part of Visingsö, on the eastern side of the island, the rocks of the Visingsö series are better exposed than anywhere else. Over a long distance a cliff runs along the shore.

At the southern point of the island the rock consists of yellow sandstone. Judging from the easterly dip this is the oldest outcropping rock in the section. [1] Along the shore to the north-east younger strata are found: — red sandstone and arenaceous shale, yellow- and red-striped sandstone, green shale and green, coarse sandstone, sometimes in a handsome interstratification. The weathering surfaces of the sandstone are often red, and the green shale includes red layers. The youngest beds, gray shale with calcareous nodules, are found in the middle part of the island.

The rocks are altogether of the same character as on the Gera brook. This uniform development is the more remarkable as the rocks are of such a kind that strong local variations in their forming conditions might be expected. As mentioned above there may be reason to regard them as formed in a closed basin with a varying supply of sediments and varying currents. The even bedding and lamination imply not only an even surface of deposition but also a relatively constant depth and an equivalent transporting capacity over wide areas of the water in which the deposition took place.

It is astonishing that no cross-bedding is found in the sandstone of the Visingsö series. It might have been expected that the formation would have taken place as delta-like fillings in the deposition basin, and that the rocks for that reason would not have shown such a pronounced parallel bedding as is now the case. The author has observed a distinct cross-bedding in one case only, viz. at Lemunda NW of Motala, in the lower, yellow sandstone. [2]

The Gävle and the Mälar Sandstone.

At the Lake Mälar and in the neighbourhood of Gävle as well as in a few other places in the northern part of the Baltic region sandstone probably of Cambrian age is found. There is, however, no direct evidence or certain landmarks (neither paleontological nor stratigraphical) of the correctness of the said age. Opinions on this have also varied: sometimes the sandstones have been interpreted as Devonian strata, sometimes as Algonkian, and even the Ordovician has been regarded as the time of formation (Törnebohm 1877, 420). However, the establishment of Lower Ordovician and fossiliferous Cambrian blocks (Lower Cambrian with *Hyolithes* also) together with the sandstone blocks makes it possible to determine the age to a certain extent. From the occurrence of the blocks we may infer that the Gävle sandstone (and then probably the other sandstones)

[1] A smaller occurrence of yellow sandstone on the western side of the island shows undoubtedly still older strata.

[2] A false cross-bedding caused by infiltration of hydrated iron oxide is fairly common.

is formed at an earlier date than the fossiliferous Olenellus sandstone. Consequently a Lower Cambrian age is very probable.

The Gävle sandstone occurs *in situ* at Gävle and at some places in the vicinity. Besides that, it is very abundantly present in erratic blocks in a somewhat wider region.

The rock varies somewhat in character. (Wiman 1892, 67; Blomberg 1895, 36; Törnebohm 1877, 412). Sometimes the sandstone is purely quartzitic with a glassy, lustrous fracture surface. More frequently, however, it is distinctly clastic and fairly loose. The size of the grains varies. Fine-grained as well as coarse-grained and not infrequently conglomeratic forms are found. Real conglomerates with pebbles 5—10 cm in size also occur, though not in larger quantities or in beds of greater thickness.

Fine-grained sediments, shales, are interspersed in the sandstone, also together with the conglomerates.

As a rule the colour is reddish brown in lighter or darker shades. But yellow and gray sandstones also exist. The latter forms contain an abundance of small grains of kaolin.

The rock is generally a lime-free quartz sandstone but calcareous forms have also been found in erratic blocks. The grains of quartz are more or less distinctly rounded. Felspar, in angular grains, occurs in varying quantity.

The pebbles in the conglomerates are sometimes distinctly wind-polished. Besides Archæan blocks (mostly quartzite and quartz) pebbles of sandstone are also found.

Ripple marks are very common. They occur (acc. to Wiman) with the ridges in different directions. Sometimes they are separated by sandstone beds only a couple of centimetres thick.

Of secondary formations in the sandstone should be mentioned white quartz veins and bitumen. The latter occurs partly as matrix in the coarser sandstones and the conglomerates, partly in fissures and at bedding joints.

The Gävle sandstone differs by its high content of hæmatitic dust from the marine, Lower Cambrian sandstones. Nor does it as these contain tracks, glauconite or phosphorite. On the other hand it has many characteristics in common with continental sandstones: strong variations in coarseness and colour and often a high content of iron. The wind-polished blocks, the conglomerates and the ripple marks show that the deposition has occurred in shallow water, and that the material has partly been subjected to eolian wear.

Consequently there is reason to suppose that the Gävle sandstone has been formed in a shallow water, probably a lake basin.

The Mälar sandstone is accessible *in situ* at a few places on the Södra Björkfjärden in Lake Mälar (Törnebohm 1862, 16; Tamm 1915, 266; Asklund 1924, 307). In the same region it is abundantly present in erratic blocks.

The rock is a red or yellow quartz sandstone of varying solidity. The rock varies from fine sandstone to coarse conglomerate. The succession of strata cannot be directly observed but according to Törnbohm (1862) it may be as follows:

Grayish yellow, conglomeratic sandstone (in the Midsommar Island)
Yellow, fine-grained sandstone (in the Midsommar Island)
Brownish red sandstone (in Ekerön)
Conglomerate (in the Pingst Island)

The conglomerate consists of pebbles of granite and quartzite up to the size of a head. The cement is silica. The cementation is so strong that the pebbles cleave rather than loosen from the matrix (Törnebohm).

The brownish red sandstone is hard, quartzitic. Coarser beds alternate with more fine-grained. The rock includes several conglomerates (Tamm 1915, 273).

The yellow sandstone is somewhat looser than the red. It is also more fine-grained except in the upper part where it grades into a grayish yellow, conglomeratic sandstone. Sometimes thin strata of red clay occur between the sandstone beds.

Ripple marks occur in different directions in the sandstone. Indefinable tracks have also been observed in loose blocks of the sandstone (Törnebohm 1862, 19).

The most recent investigation of the series of strata in *Ekerön* has been made by Asklund (1924, 307), who also gives a detailed account of the occurrence, character and supposed formation of the rocks. According to Asklund the series of strata is as follows:

Red- and yellow-striped sandstone with small out-thinning conglomerate beds. In the conglomerates pebbles of quartz and red quartzitic sandstone and more sparingly porphyry and felspar.

Red- and yellowish white, fine-grained sandstone with numerous embedded strata of coarse sandstone and conglomerate. In the conglomerates pebbles of quartz, felspar and quartzitic sandstone, here and there also pebbles of porphyry and flat lenses of red clay-stone.

Conglomerate with embedded sandy or clayey strata. Pebbles, up to the size of a head, of granite, pegmatite, quartz, mylonite, red quartzitic sandstone and grayish green clay-stone.

Asklund regards the strong mechanical and slight chemical weathering of the material as evidence of the rock's continental formation and arid character.

The age of the sandstone cannot be inferred from its character and occurrence. Like the Gävle sandstone, however, it may be supposed to be older than the Olenellus sandstone.

The Mälar sandstone and the Gävle sandstone show such conformity in development that they may be supposed to have been formed under similar conditions, in relatively small continental basins or possibly on a shallow sea-shore.

The Middle and Upper Cambrian Sandstones.

Sandstones are not found dominating in the same manner in the Middle and Upper as in the Lower Cambrian. Irrespective of the Norrlandish regions, with sandstone facies throughout, we may say that limestones and above all alum shales petrographically characterize Sweden's Middle and Upper Cambrian. In the »normally» developed series of strata in South Sweden as well as in the similarly developed ones of Middle and North Sweden only relatively insignificant Middle Cambrian and very few Upper Cambrian sandstones are found. There is no occasion to dwell on any of these with the exception of those of Öland.

The Middle Cambrian sandstones of Öland.

The Lower Cambrian sandstone on Kalmarsund does not pass directly into a Middle Cambrian. It is instead superposed by a series of light grayish green shales. Here and there these are somewhat sandy. Frequently they contain large concretionary nodules of limestone. In the latter a fairly abundant fauna, consisting especially of trilobites and hyolithes, has been found. The shale is termed *Oelandicus shale* after *Paradoxides Oelandicus* Sjögr.

The Oelandicus shale is superposed by a sandstone about 10 m thick, called *Tessini sandstone* after the index fossil *Paradoxides Tessini* Brongn.

The Tessini sandstone is everywhere developed as a relatively thin-bedded, sometimes almost shaly, fine-grained sandstone. It is never a pure quartz sandstone. Frequently it is rich in calcite, and passes sometimes into a sandy limestone.

The content of clay varies. In certain parts of the series of strata it is hardly noticeable, in others it increases so that the rock passes into a shale of the same character as the Oelandicus shale.

What is immediately observed on examination of the Tessini sandstone is its high content of glauconite. Phosphorite, on the contrary, has not been seen in it.

The quartz grains in the samples examined have been relatively even in size, from 0,01—0,06 mm in diameter. They are not perceptibly rounded.

The calcitic cement is usually crystalline and not infrequently develops into large crystals, in each of which a number of quartz grains are enclosed.

The glauconite occurs in the form of dark bluish-green grains from 0,03 to 0,08 mm in size. The grains are not distinctly rounded. Their outline is often diffuse. Sometimes they lie embedded between the quartz grains in a manner which shows that they are primary deposits.

The Tessini sandstone cleaves readily in thin layers. Not infrequently do the bedding surfaces show tracks of different kinds, some of them resembling the trails in the Mickwitzia sandstone of Vestergötland.

In the Tessini zone in Öland a number of fossil forms have been found: trilobites, hyolithes, and brachiopods. Besides the index fossil *Conocoryphe exsulans* Linrs and *Acrothele granulata* Linrs should also be mentioned.

The occurence of a conglomerate, the conglomerate with *Acrothele granulata*, at the base of the Tessini sandstone is of great interest for the interpretation of the rock's forming conditions.[1]

In the lower part of the Tessini sandstone a fragment limestone usually called *exsulans limestone* occurs at some places. It is dark and arenaceous.

The upper part of the Tessini sandstone can be developed as a conglomerate formed from denuded parts of the sandstone series. This conglomerate can also merge into the so-called *exporrecta conglomerate*, which as a rule forms the only preserved remains of the rocks of the Forchhammeri zone (= the upper part of Middle Cambrian) (HADDING 1927, 78 seq.).

The formation of the ölandish Tessini sandstone has taken place in tranquil water admitting the deposition of the fine-grained material and the formation of the even, thin beds. The conglomerates lying over and under the sandstone have been formed by occasional stronger currents, which have broken up already formed strata that, after the wear and rounding of the fragments, have formed part of the conglomerates. The sandstone has probably been formed in somewhat deeper water than these coarser sediments. That it has not been formed in a more secluded basin is evident from the fact that the rock is often remarkably free from finer detritus. On the whole it shows a well sorted material. Its content of glauconite also indicates a formation in open water.

Though we cannot discuss the paleogeographical problems here, we find it appropriate in connection with the account of the Tessini sandstone and its boundary-strata to call attention to the fact that traces of the same conglomerates as the above-mentioned ölandish are found in Scania as well as in Vestergötland and Norrland. The forming conditions of the Middle Cambrian sediments have consequently been influenced throughout by earth movements.

The Arenaceous Sediments of the Sparagmite Formation.

Under the term »the sparagmite formation» a thick series of rocks, occurring in the central part of Scandinavia are grouped together. In Sweden the bulk of the formation is found in Härjedalen and Jämtland.

The rocks in the sparagmite formation vary somewhat. Coarse conglomerates as well as fine-grained sandstones, argillaceous and highly calcareous sediments as well as pure quartz rocks are found there. Arkoses are very abundant but felspar-free rocks are also present.

The age of the sparagmitic series has been much discussed. It has been interpreted as pre-Cambrian (Algonkian), Eocambrian, Cambrian, and Ordovician. Each new investigation in the sparagmitic regions has thrown more light on the problem of age also, and we may perhaps not be entitled to expect that the present opinion on it will last. According to this the sparagmitic formation is either (or partly) late pre-Cambrian or a »local» development of the Cambro-Silurian. The sparag-

[1] HADDING 1927, 72.

mites of one region are not necessarily of the same age as those of another. The estimation of their age is made more difficult partly by the absence of fossils in the rocks and partly by variations in horizontal direction according to the local, varying forming conditions. Only by a further study of the relations of the sparagmites to other rocks, the age of which we are able to determine, can we obtain a better knowledge of their time of formation.

It is quite out of question in this work to give a comprehensive illustration of the sparagmite formation or a detailed analysis of its rocks [1]. An account of some of the more typical forms of the rocks will be given here, and in this connection the forming conditions will be shortly discussed.

The division of the sparagmite series into a lower section, with a certain type of rocks, and a younger section, with at least partly another type, is, I think, not unjustifiable but no doubt difficult to maintain on all points. The stratigraphical division into the two said groups is undoubtedly of some importance but it is also liable to cause errors, if it cannot be based on a certain correlation between the strata of one region and those of another. After these remarks, however, I cannot abstain from giving (according to Törnebohm and Högbom) a résumé of the rocks in the two groups, before passing on to a more detailed investigation of some selected sections in the sparagmite formation.

The upper section of the sparagmite formation.

Thickness (acc. to Törnebohm 1896, 53) about 800 m.

Types of rock:	Sparagmites Sparagmitic sandstones Quartzites	light, often reddish, form the bulk of the section.
	Gray sparagmite, in the lower part of the section.	
	Conglomerates.	
	Limestone Shale	relatively unimportant; especially at the base of the section.

The lower section of the sparagmite formation.

Thickness (acc. to Törnebohm 1896, 53) about 100 m.

Types of rock:	Shale.	
	Limestone Calcareous sandstone	Hede limestone, acc. to Högbom about 75 m thick.
	Quartzite, not infrequently »blue-quartz»-like.	
	Sparagmite, gray, often dark.	
	Conglomerate.	

[1] The author hopes to be able to continue his investigations in detail in the sparagmitic region and then also to give a more comprehensive picture of the general as well as the special sediment-petrographical and paleogeographical problems.

The *Sparagmites* are coarse or middle-coarse felspathic sandstones (arkoses) of a more or less distinctly crystalline (quartzitic) structure. The content of felspar is often very high, especially in the coarser sparagmites and in the conglomerates. The bulk of the felspar consists of microcline but plagioclase is also present. As a rule the felspar is remarkably fresh.

As is evident from the above scheme the upper sparagmitic section according to Törnebohm is characterized by red sparagmites and the lower by gray ones.

The *quartzites* are often fine-grained or dense, sometimes chert-like. The

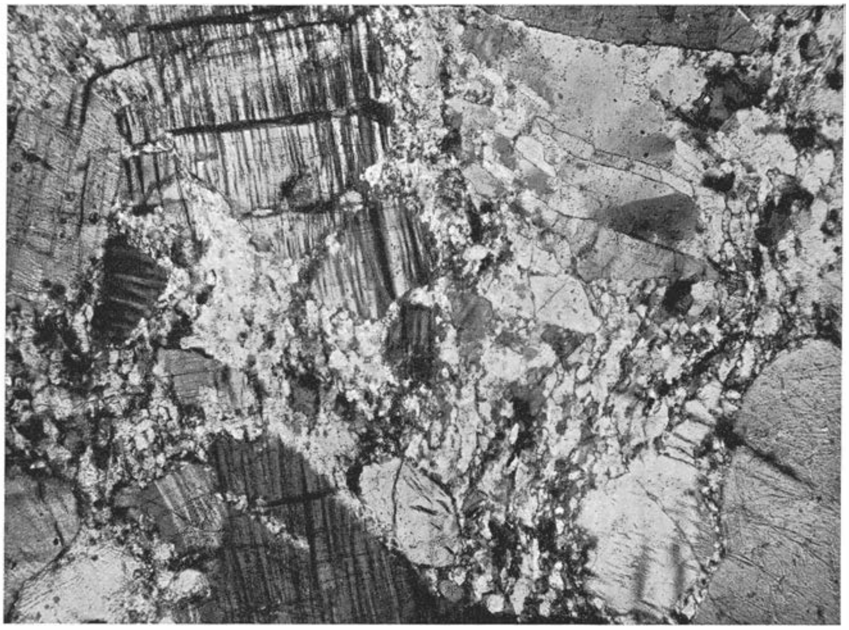


Fig. 67. Sparagmite, coarse-grained, occurring in quartzite. Lågvålen, Härjedalen. (Pr. 544. Pl. 411.) — 50 ×. Nic. +.

dark forms resemble in a high degree the so-called *blue-quartz*, which is Ordovician and mainly occurs accumulated in certain regions, for inst. the Ovik mountains (see p. 174).

The *Hede limestone* is a dark gray limestone or calcareous sandstone, often dolomitic. In the above scheme it forms the bulk of the lower sparagmitic section.

The profiles described and discussed in the following are chosen so that they give an idea of the different types of rock and, as far as possible, of their mutual position also. The author has been especially anxious to find the contact relations or the transitions between the different types.

Of the profiles one is derived from the western part of the sparagmitic region (Fjällnäs, Bolagen) and three from its eastern part (Hede, Rånddalen and Sörvallen).

The section of Fjällnäs-Storvigeln. *(The Bolagen Section).*

During a short stay at Fjällnäs the author made a couple of days' excursion across Lågvålen down to Lake Bolagen and up on Storvigeln. The series of strata then observed was not investigated in detail but still deserves to be recorded.

Amphibolitic slate.
Quartzitic slate } NE of Lake Malmagen, close to Fjällnäs.
Mica-schist }
(Gap. The series of strata hidden below Lake Malmagen).
Mica-schist.
Gray quartzite.
Soft, gray mica-schist.
»Eyed-gneiss», beds in
Quartzite, thin-bedded or slaty.
Black shale.
Quartzite.
Porphyry.

Before passing on to an investigation of the arenaceous rocks of the section a few words should be said on eventual dislocations in the series of strata.

Owing to the strata being inaccessible for a fairly long distance, the gap present in the upper part of the section is of no great significance for our conception of the general character of the strata. The strata above and below the gap are of the same type and there is no occasion to presume any greater variations in the hidden part of the series of strata.

In the upper part of Lågvålen the state of things is somewhat different. In well marked beds an »eyed-gneiss» occurs here in the series of strata. According to Törnebohm (1896, the map) this rock indicates the bottom of a large overthrust, to which the rocks above the beds of »gneiss» also belong. Under such circumstances the upper part of the series of strata would not be primarily connected with the lower part. In the author's opinion, however, there is no occasion at all to see such a disturbance in the profile.

The »eyed-gneiss» is no Archaean rock pressed up on younger (sedimentary) rocks. Certainly it is, like other rocks in the series, highly metamorphosed by pressure but it occurs as an inclusion in a series, in which nothing indicates a disturbance of the original succession of strata. The presence of two lower thin beds of »eyed-gneiss» in the quartzitic series renders it impossible to interpret the »eyed-gneiss» here as the bottom of an overthrust.

We shall not discuss the formation of the »eyed-gneiss» here [1], we can only

[1] The beds of »eyed-gneiss» on Lågvålen occur in such a manner that they cannot have been pressed into the series of strata in solid form. It may be impossible to doubt that the large eyes or crystals of felspar are formed secondarily during the metamorphism.

establish that it does not indicate the boundary between a lower, younger series of strata and an older, overthrusted. The series of strata is unbroken and, regardless of the metamorphism and tilting of the strata, undisturbed.

The quarzites, occurring in the series of strata, are somewhat varying in character. In certain parts of the series or in certain beds they are pure quartz rocks, in other parts they are more or less mixed up with argillaceous matter. On the other hand the slates are not infrequently rich in grains

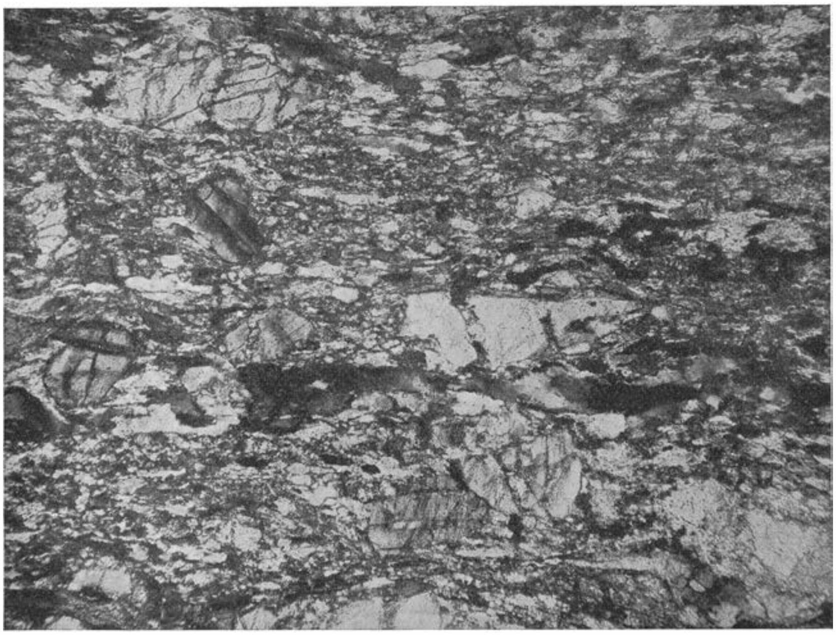


Fig. 68. Quartzite, fine-grained, felspar-bearing. Lågvålen, Härjedalen. (Pr. 538. Pl. 408.) — 50 ×. Nic. +.

of quartz. Slate layers in the series of quartzite and beds of quartzite in the series of slate are also common.

Relatively well preserved felspar crystals sometimes contain interspersed fragments of the parent rock, thus showing that the crystals are secondary formations.

If the felspar is thus a perfectly secondary formation, we have no occasion to consider it a matter of course that the »eyed-gneiss» is a metamorphic igneous rock. It may just as well be a para-gneiss. In fact, its occurence as well as its character indicates this. The »eyed-gneiss» forms extended beds in the series. Their stratigraphical occurrence differs in no way from that of other rocks. The primary mass in the »eyed-gneiss» is perfectly conformable to certain slates in the same series. Quartz and sericitic mica form the bulk, and to this garnet and epidote (pistazite) are sometimes added.

To what extent the above points of view on the »eyed-gneiss» in Lågvålen may also be applied to the same in other regions, the author, not having had the opportunity of studying them, cannot decide. Very probably, however, the term »eyed-gneiss» comprises rocks of different origin.

The undermost quartzite resting on the porphyry is partly white or light gray, partly darker gray and »blue-quartz»-like. Immediately below the black shale it forms thick beds with indistinct lamination. No change at all is shown towards the porphyry contact. The rock is fine-grained and poor in or free from felspar throughout.

The black shale is only slightly outcropping. It is embedded in the quartzite. The rock is rich in quartz and also slightly calcareous. On account of a strong pressure its stratification is indistinct.

The quartzite above the black shale is thin-bedded and often shaly. The latter is especially the case in the less pure forms. Light mica or chlorite are abundantly present and felspar is seldom absent.

The mica is a colourless, slightly green, seldom slightly brownish, sericite-like phlogopite developed into scaly aggregates that enclose the other mineral grains. In cases where it is abundantly present the cleavage surfaces have a fatty or phyllite-like silky lustre. The mineral in the samples examined has been optically uniaxial or has had a very acute axial angle. In cleavage laminae it shows a hardly noticeable double refraction ($\gamma - \beta = 0{,}002$). In sections at right angles to the cleavage direction the double refraction has been determined to $0{,}045$. Optical character negative.

In the purer (mica-poor or mica-free) quartzites the quartz crystals are more isometrically developed. Single larger crystals lie scattered in the more fine-grained bulk. All of them have a very irregular, indented outline.

In the mica- and felspar-bearing quartzites the quartz occurs in small stalks or thin lenses often from only 1 to 2 mm in diameter. The felspar, microcline as well as plagioclase, occurs in somewhat larger crystals, often with a thin trimming of quartz. The felspar crystals are generally distinctly pressed, curved or broken.

The felspathic quartzites in this series of strata differ generally both macroscopically and microscopically from the real sparagmites. In the latter the felspar occurs as a primary constituent in the weathering gravel of which the clastic rock has been built up. In the felspathic quartzites described above the felspar is wholly or at any rate essentially a product of the metamorphism. On that account the grains or crystals of felspar occur as lenses or eyes in the metamorphic quartzites and mica-schists but in the sparagmites as in other arkoses as scattered grains.

Where the micaceous quartzites acquire an increased content of felspar, this occurs in larger and larger aggregates. There are all the transitions from pure quartzites over micaceous quarzites, mica- and felspar-bearing quartzites, micaceous quartzites with felspar eyes to the typical eyed gneisses. The only difference between the latter and the quarzitic slates with small crystals and lenses of felspar is in the size of the grains.

The formation of the rocks in the series of strata at Fjällnäs may without difficulty be interpreted from their character. In spite of the metamorphism they

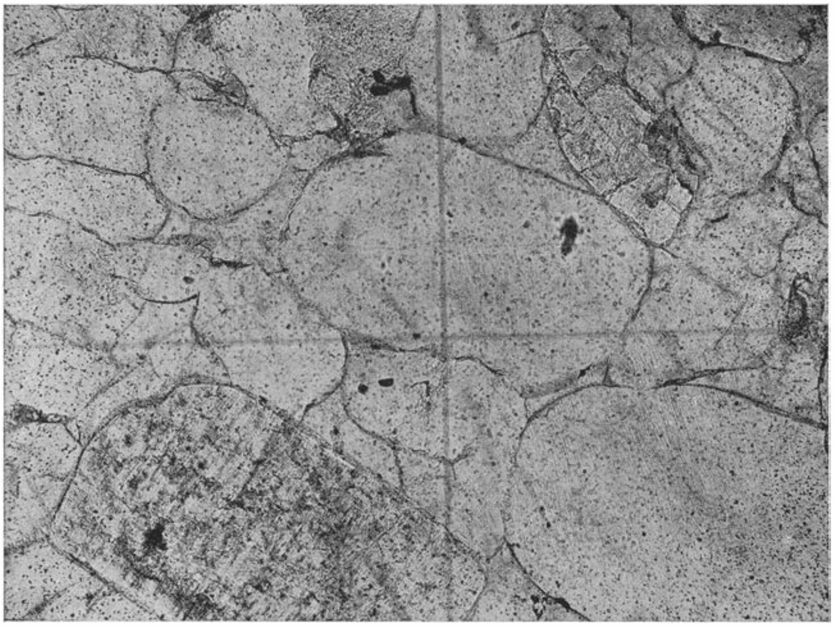


Fig. 69. Sparagmite with distinctly clastic structure. Quartz grains secondarily enlarged. Långå, Härjedalen. (Pr. 557. Pl. 384.) — 60 ×.

Fig. 70. Quartzite. Långå, Härjedalen. (Pr. 556. Pl. 406.) — 60 ×.

have undergone and the perfectly crystalline character they now show, their clastic origin is not to be doubted. The crushing and recrystallization that has taken place in the sandstones has been so thorough that we are not able to decide with certainty how coarse-grained they have been. From the alternation of pure quartz beds and argillaceous beds, however, we may conclude that pure sandstones have alternated with argillaceous sandstones and arenaceous shales and that the sandstones have dominated in the lower part of the series of strata and the shales in its upper part.

It may be specially emphasized that no (metamorphic) conglomerates have been observed in the series of strata. Probably the quartzites have also been formed from relatively fine-grained sandstones, in which conglomerates could not be expected. The material in the sandstones has been well sorted. The absence of felspar indicates a stronger chemical weathering than in the sparagmites. The sorting and the even stratification of the material is more indicative of a marine than a continental formation.

The Sections at Hede and Rånddalen.

Sections at Hede.

No cutting throughout the whole series of sparagmite at Hede exists but a comparison of the observations made at different points gives us a fairly good idea of the succession of strata or at any rate of the types of rock in the region.

From Knätten, S of Hede, the following section is quoted (Högbom 1889, 19 and Schiötz 1890, 57):

Gray sparagmite with red grains of feldspar (Högbom red sparagmite).

Shaly, dark gray limestone
Gray conglomerate } several interstratified beds, thickness about 2 m.

Grayish green sparagmite (Schöitz quartzite).

Red sparagmite.

Green, sandstone-like shale or gray quartzite and Hede limestone (Högbom).

Granite.

Judging from the general dip of the strata in the Hede region the section quoted above ought to contain older layers than the sections from the region N and E of Hede mentioned in the following. However, great disturbances in the position of the strata are found and no certain conclusions can on that account be drawn concerning the mutual age of the separated sections.

The occurrence of the granite indicates that this should be the lowest part of the series of strata. According to Högbom it is connected with the overlying gray sparagmite by a weathering breccia[1].

The profile is also interesting because it shows conglomerate interstratified with limestone. Högbom groups this with the Hede limestone, which has its place in

[1] Acc. to Schiötz the granite is younger than the sparagmite and injected into this.

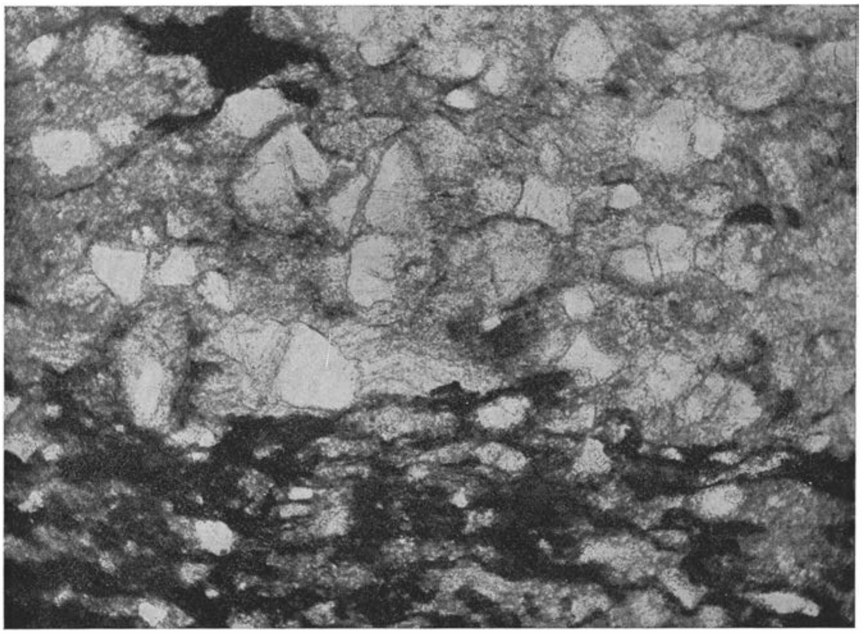


Fig. 71. »Hede limestone». Black argillaceous and gray arenaceous bands. Hede, Härjedalen. (Pr. 762. Pl. 385.) — 60 ×.

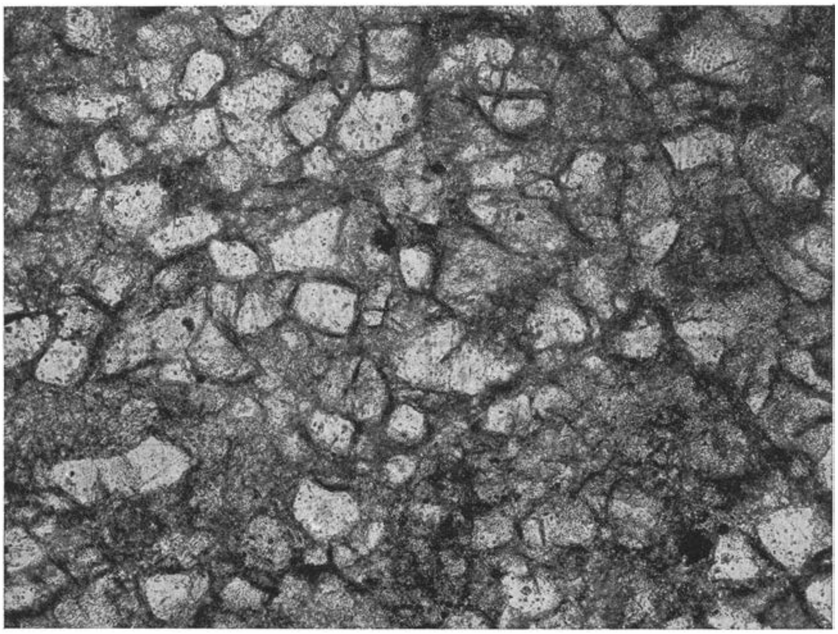


Fig. 72. Calcareous sandstone, gray, occuring together with the dark »Hede limestone». Hede, Härjedalen. (Pr. 579. Pl. 386.) — 60 ×.

the lower, usually gray sparagmite. According to Schiötz the fact that the limestone at Knätten is only from 1 to 2 m thick, while N of Hede it attains a thickness of about 75 m, can only be interpreted so that the deposition has taken place in a basin, the edge of which has lain where the limestone thins out.

At many places we find the arenaceous strata, sparagmites or quartzites, locally replaced by (out-thinning) calcareous, more or less coarse-grained rocks. This is also the case at *Ulvberget* E of Hede. As an example of the character and occurrence of the rocks a section noted down by the author from Ulvberget's south-easterly offset may be communicated here.

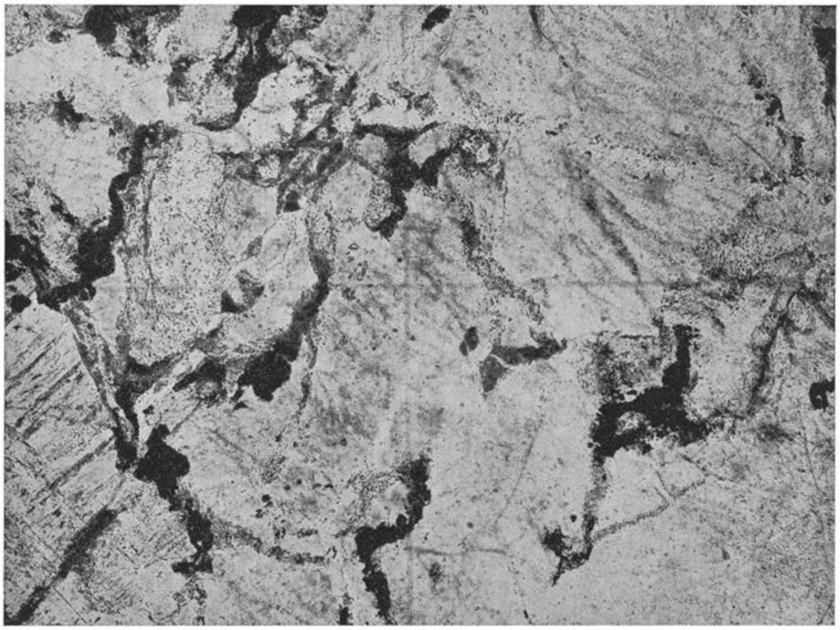


Fig. 73. Quartzite, dark, »blue-quartz». Ulvberget, Hede. (Pr. 718. Pl. 404.) — 60 ×.

Pink, quartzitic sandstone.
Gray, coarse sparagmite, calcareous, with white grains of felspar.
Conglomerate, dark gray, with white grains of felspar.
Black, dense, calcareous shale (shaly Hede limestone).
Dark gray, middle-coarse sparagmite, non-calcareous, »blue-quartz»-like.
Light gray calcareous sandstone, quartzitic.
Dark gray quartzite, calcareous, »blue-quartz» (fig. 73).
Greenish gray, fine-grained quartzite, non-calcareous.
Greenish gray calcareous sandstone, quartzitic.
Light gray, quartzitic sandstone, non-calcareous.
Greenish-gray, fine-grained, calcareous sandstone.
Light greenish gray fine-grained calcareous sandstone.

Light gray fine-grained, calcareous sandstone.

The thickness of the series is about 30 m.

A section somewhat W of that described above shows in broad outline the following series of strata: —

Red sparagmite.
Gray sparagmite.
Black, calcareous sandstone (Hede limestone).
Black, calcareous shale with beds of greenish-gray, calcareous sparagmite.
Greenish-gray, breccia-like sparagmite, calcareous.
Black, calcareous sandstone (Hede limestone } in several interstratified beds.
Greenish-gray, coarse sparagmite, calcareous }

The strata are partly strongly pressed and their dip varies a little, on account of which disturbances in the succession of strata are not excluded.

Before passing on to an account of the rocks a section through a similar series of strata at Rånddalen will also be communicated.

The section at Lillråndan in Rånddalen.

The series of strata divided by several faults and situated at Lillråndan, W of Rånddalen, consists, to all appearances at least, of an *upper part* with red and gray sparagmite, partly fine-grained and partly coarse, conglomeratic, a *middle part* with limestone, calcareous sandstone and gray sparagmite, and a *lower part* with gray sparagmite.

As a rule the upper and lower parts show indistinct stratification but in the middle part this is very marked. In the different parts, divided by faults, a number of sections were measured by the author, one of which (section II) may be given here (with approximate measurements): —

Coarse, gray limestone	—
Fine-grained, gray limestone	0,3 m
Gray limestone and calcareous sandstone, interstratified	4,0 »
Gray limestone, upper part shaly, lower part thick-bedded	3,0 »
Banded, gray and black limestone	0,3 »
Gray, calcareous sandstone, weathered rusty brown	1,0 »
Light gray, quartzitic sandstone	0,5 »
Banded, gray and black limestone	0,2 »
Black, partly shaly limestone, with a bed of gray calcareous sandstone	7,0 »
Limestone and calcareous sandstone (in the bottom of the river)	7,0 »
Black and gray shale and limestone	8,0 »
Gray, calcareous sandstone	2,5 »
Gray, shaly limestone	2,0 »
Gray, calcareous sandstone in alternating hard and loose beds	10,5 »
	46,3 m

The section shows the typical series of strata in the Hede limestone and together with the already communicated section from Ulvberget at Hede it gives a good idea of the character of this rock.

The rocks in the series of strata at Hede and Rånddalen.

The rocks occurring in the above sections at Hede and Rånddalen may be divided into the following type groups: —

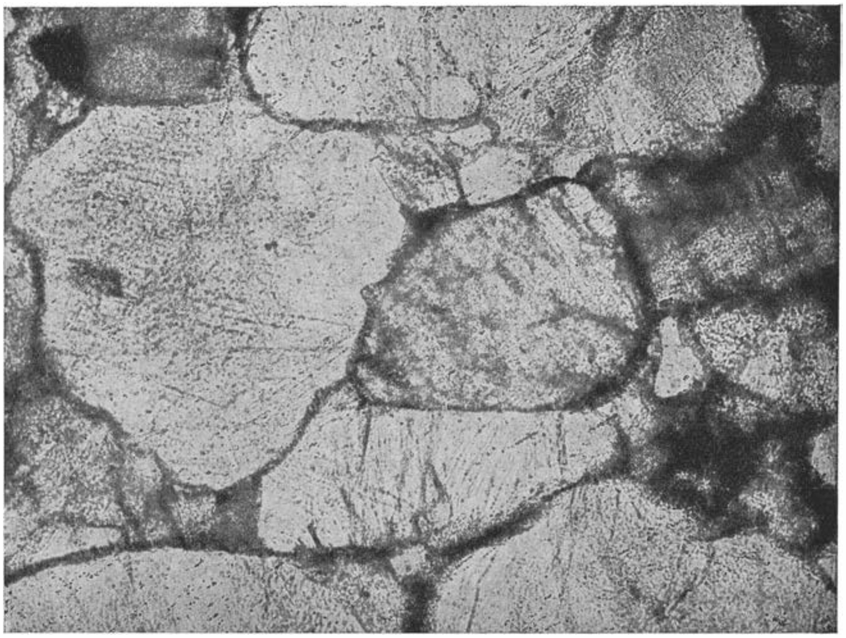


Fig. 74. Sparagmite, gray. Lillråndan (V a), Rånddalen, Härjedalen. (Pr. 569. Pl. 389.) — 60 ×.

Sparagmites: — conglomerates.
red sparagmites.
gray sparagmites.

Quartzites.

Calcareous sandstones.

Limestones.

It may however be directly emphasized that the different groups are not distinctly separated from each other. The sparagmites, especially the gray ones, are often calcareous, and so are the quartzites. The calcareous sandstones are sometimes quartzitic and the limestones always arenaceous. In the following account, however, the said grouping may be used.

The sparagmite conglomerates are most abundantly present in the upper (red) sparagmite. The author has made a special study of them at Ulvberget, Husåberget and Säterberget at Hede. The rocks show a well sorted and worn (rounded) material. They are formed of clean-washed, highly felspathic gravel. (See further HADDING 1927, 66).

A rock of an entirely different type but still soonest to be counted as a residual conglomerate occurs in the upper part of the series of strata SE of Ulvberget. It may be characterized as a *breccia* if only seen in samples, or, if greater importance is attached to its relation to other rocks in the same series

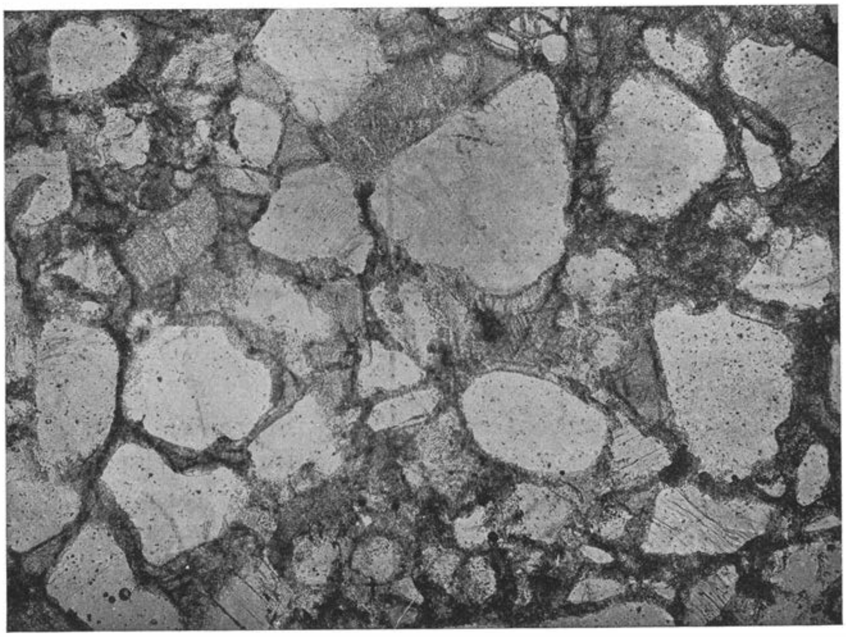


Fig. 75. Calcareous sandstone. Lillråndan, Rånddalen, Härjedalen. (Pr. 570. Pl. 391.) — 60 ×.

of strata, as a calcareous, *impure sparagmite* with interspersed larger grains of felspar. No doubt it is identical with rock from the same place mentioned by HÖGBOM under the term »rotten granite». In reality it is only a coarser form of the coarse, gray, calcareous sparagmite.

The red sparagmites are fairly varying in colour, size of grains and structure (clastic or crystalline). In certain beds this rock is pink, sandstone-like and resembles a common form of the Dala sandstone. This is the case in the upper part of Ulvberget. In other beds it is more quartzitic. On the whole the rock is built up of a well sorted material, with distinctly rounded grains of quartz.

The red sparagmite may be interbedded with the gray, as is evident from the series at Lillråndan (the upper part of this series has been examined for the author by MATS WEIBULL Junior).

A not uncommon form in the red sparagmite is a gray, quartzitic sparagmite with scattered red grains of felspar. Acc. to SCHIÖTZ this occurs at the section of Knätten (see p. 158). The author has observed it in the red sparagmite on Säterberget and at Lillråndan.

The gray sparagmites may be light gray, almost white, or darker, even almost black. As a rule they are middle-coarse or fine-grained. Not infrequently do they contain clayey substance and sometimes they are also calcareous. The material is often less well sorted and less rounded than in the red sparagmites. A decrease in the content of felspar causes a transition into gray quartzites. If the content of lime increases at the same time, they pass into Hede limestone.

The quartzites in the Hede and Rånddalen fields are somewhat different from those mentioned from the Bolagen-section. They are considerably more coarse-grained and usually darker and less pure than the latter. Their colour is often grayish green or dark gray. In the latter case the rock becomes »blue-quartz»-like. Thin-bedded, parallel-bedded, fine-grained forms of the »Bolagen type» have not been observed either at Hede or Rånddalen.

The calcareous sandstones, which may be regarded as the more sandy parts of the Hede limestone, are fine-grained, light gray or greenish gray (fig. 72). Not infrequently they are quartzitic in appearance. Sometimes they pass into calcareous, light quartzites. More frequently, however, they are found in connection with the limestone (see below).

The limestone in the sections described above forms the specific *Hede limestone.* It is gray, sometimes almost black and often rich in white veins of calcite. It is never a pure limestone but rather a highly calcareous, clayey rock. The content of sand can be fairly great and is always worthy of consideration. The rock is fine-grained, never as coarse-grained as the light, calcareous rocks of the same series.

The limestones like sparagmites and sandstones are detritus rocks but they are built up of finer material than these. They have been deposited under different conditions. The currents in the basin of deposition have been weaker during the formation of the limestones than of the other rocks.

The handsome *banding* present in certain beds of the Hede limestone is of special interest. Lighter gray bands of arenaceous limestone alternate with darker gray, more argillaceous (fig. 71). A dark band shows a limit equally sharp towards underlying as towards overlying light bands. The quartz grains are somewhat larger in the bands rich in calcite than in those rich in clay. No sorting of the material within the bands, with for inst. coarser grains in the lower part, is noticeable.

The connection between the more calcareous and the more quartz-rich rocks will be shown in detail in three small sections from *Rånddalen.*

A general transition from gray sparagmite to shaly limestone is found in the following section (the author's diaries No. I_{3g} fig. 76):

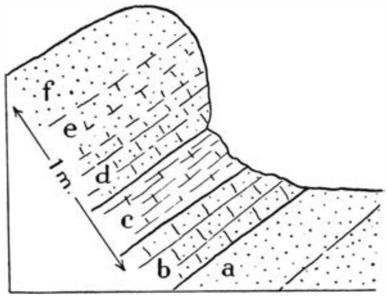
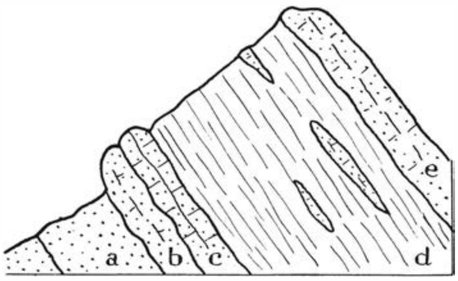


Fig. 76. Section from Rånddalen.

f Light gray sparagmite.
e Light gray sparagmite, calcareous.
d Gray, hard, thick-bedded, arenaceous limestone.
c Dark gray, shaly, impure limestone.
b Gray, hard, thick-bedded, arenaceous limestone.
a Light gray sparagmite.

In another section (IV r, fig. 77) a lime-free shale occurs together with the calcareous rocks in the following manner:



Fid. 77. Section from Rånddalen.

e Quartzitic sparagmite, gray, highly calcareous.
d Gray, lime-free or lime-poor shale with lenses of light gray, fine-grained, calcareous sandstone.
c Sparagmite, gray, calcareous.
b Sparagmite, gray, somewhat calcareous.
a Calcareous sandstone.

A section with calcareous sandstone and sparagmite in black Hede limestone had the following appearance (section II d, fig. 78):

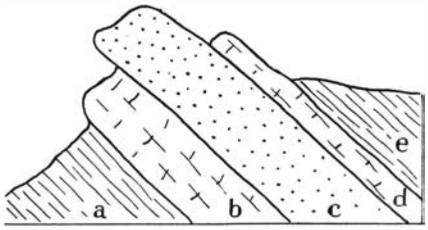


Fig. 78. Section from Rånddalen.

e Shaly, black limestone.
d Light gray, calcareous sandstone.
c Gray sparagmite.
b Light gray, calcareous sandstone.
a Shaly, black limestone.

The three profiles are drawn to about the same scale.

The formation of the rocks in the above-described series of strata at Hede and Rånddalen must have been practically uniform, their nature and occurrence being almost equal in the two places. From this great conformity we may also venture to conclude that the series of strata are formed simultaneously.

The greatest interest is connected with the *light arenaceous limestone* and its different coarse forms. Nowhere among the normal marine sediments is a rock of this type found. In all its forms it is a product of a period with strong deposition of lime. There is occasion to expect limestones of different kinds from the same period. The material building up the rock together with the carbonate of calcium is, in a higher degree than this, a result of the local conditions.

A higher or lower content of mud, sand, fossils, etc. helps us to judge the forming conditions of a rock. The mode of formation is also evident from its occurrence, bedding and stratification, the extent of the strata and the character of the surrounding rocks.

Judging the light, relatively mud-free limestone, containing an abundance of fairly coarse, angular grains of quartz (sometimes also of felspar), from these points of view or from those possible here, we may immediately infer that the rock is formed in water where 1) a deposition of lime has taken place, 2) detritus has been washed out, and 3) the movement of the water has prevented a deposition of finer detritus (clayey mud), without preventing the deposition of lime.

We may infer from the thinning out of the light limestone beds or their varying thickness, from the never distinct and mostly quite absent lamination and from the strong variation in vertical as well as horizontal directions in the series of strata that the deposition has taken place in small basins or rather in enclosed bays, though not so closed as to prevent the sorting of the material.

Of course, the fine mud that has been carried away has been deposited in some other place. We may presume that this mud has been deposited in more tranquil water. The banding or stratification shown by the more muddy rocks speaks for the correctness of our interpretation.

When the coarse, unstratified, mud-free rocks are over- or underlain by rocks rich in mud, it shows us that the local conditions in a place have changed from one time to another. Probably, however, changes in the depth of the water have been of less importance than changes in the currents and in the supply of material.

The coarsest rocks contain angular fragments of quartz and felspar of such a size that they cannot have been transported any longer distance by running water. These rocks also contain a larger amount of fine detritus, the presence of which also decidedly contradicts a deposition in running water. To interpret the rock as outcropping portions of granite or breccias in these (Högbom) seems to the author impossible, owing both to its manner of occurrence in the series of strata and its relation to other less coarse sediments of the same type and in the same series of strata. Still less may the rock be interpreted as granite injected in the series of strata (Schiötz). The author has called attention elsewhere (1927, 71) to the fact that the formation of this rock as well as certain others in the sparagmite formation is naturally explained by the presumption that a nival climate has prevailed during the deposition of the detritus, and that ice-rafting has also taken place in the region of sedimentation.

The lime-free sparagmites, quartzites and shales occurring together with the calcareous rocks are formed during periods without deposition of lime but otherwise with the same changes in the forming conditions as those mentioned above.

The red sparagmites, and the rocks connected with them are built up of a well rounded and sorted material. The formation has taken place under conditions not allowing of a deposition of lime or during a period when such a deposition has been less strong than at the formation of the strata mentioned above.

There is no occasion to suppose the wear of the grains in the red sparagmites to be eolian and the deposit to be a desert-formation. The red colour in certain of these rocks is not caused by intermingled lateritic or other red constituents colouring the sand, but is instead derived from the red grains of felspar. The fresher these grains are the brighter is the red colour. Where the grains are somewhat kaolinized, which is often the case, the colour is paler red. The fact that it has been possible at all for the felspar to be preserved to the extent it has, cannot be considered as evidence of an arid and desert-like formation [1]. The gray and black shales present in the series of strata as well as the sandstones mentioned above speak against such a formation.

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[1] The Cambrian sandstones have often basal strata in which the felspar is as fresh as in the sparagmites.

Sections from the sparagmite region at Sörvallen.

At Sörvallen, about 4 km SW of Rånddalen, the quartzite-sparagmite series is found developed in a sandstone free from lime, often quartzitic or sparagmitic and interstratified with gray, arenaceous shales.

As a rule the strata are distinctly bedded and there is often also a parallel lamination in the beds. The adjoining drawing of a section about 2 m thick shows a typical development of the series of strata (fig. 79).

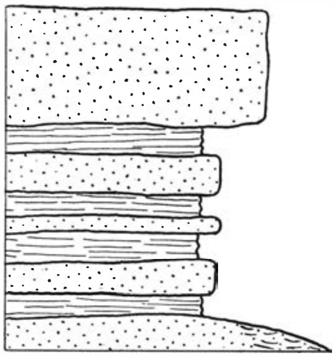

Fig. 79. Beds of grayish green, fine-grained, somewhat quartzitic sandstone interstratified by hard, arenaceous shale. Outcrop about midway between Rånddalen and Sörvallen, E of the road.

E of Sörvallen (on the Hammerlands-brook) the following series of strata was noted down:

Red, fine-grained, sparagmitic sandstone.
Red, sparagmitic conglomerate.
Bluish gray, quartzitic sandstone.
Gray quartzitic sandstone, with red grains of felspar (in beds about 1,5 m thick).
Fine-grained, reddish gray, quartzitic sandstone (beds about 1 m thick).
Gray, arenaceous shale, about 1 m.
Gray calcareous sandstone, about 1 m.
Gray, arenaceous shale, 1,5 m.
Gray, sparagmitic sandstone (weathered, with distinct parallel lamination).
Red sparagmitic sandstone, partly conglomeratic.
Red sparagmitic sandstone, alternating coarse- and fine-grained strata.
Gray sandstone.
Gray, arenaceous shale interstratified with
Gray sandstone.

The strata have a dip of 10—25°. The series is more than 200 m thick.

The rocks are more clastic in structure than is otherwise often the case in the sparagmitic region. They are more argillaceous than those described above, are generally free from lime like the quartzitic strata at Bolagen but are more coarse-grained than these. They differ from the upper sparagmitic, lime-free strata at Hede and Rånddalen by a more pronounced bedding and by a less well sorted or more fine-grained material.

With regard to the *mode of formation* we can infer from the rocks that they are formed in relatively tranquil water, in a continental basin of a not too inconsiderable size, or on a not quite open shore. Neither wind-polish on the boulders nor a strongly oxidized detritus material can be found here, no more than in the regions mentioned above, as a support to the opinion that the strata were formed in a desert region. The shales as well as the impure (argillaceous) sandstones show that chemical weathering has by no means been absent.

The types of rock of the quartzite-sparagmite series: A summary.

The three regions described above show as many primary types of the series of strata in the quartzite-sparagmite formation. It might perhaps still be possible to find one that differs from these. The author has not touched upon the relation of the Orthoceras limestone, the Vemdal quartzite or the Dala sandstone to the quartzite-sparagmite series. To what extent these should be counted to the same series cannot be discussed here, as it would carry us beyond the limits of this work. The author has treated the Vemdal quartzite as a special sandstone series regardless of its eventual connection with the quartzite-sparagmite formation. Like the Almesåkra series the Dala sandstone is to a large extent built up of rocks of more continental character and above all with a more oxidized material. Nowhere in the normal Cambrian nor in the quartzite-sparagmite series are rocks of this type found. Fully aware of the fact that the local conditions may cause great changes in the character of the deposited sediments the author is nevertheless of the opinion that the characteristics of the Dala sandstone have developed during a different and earlier period than those found in for inst. the sparagmites. Consequently the author considers the Dala sandstone to be a pre-sparagmitic and pre-Cambrian deposit. On that account it has not been treated of in this work.

The three chosen series of types from the quartzite-sparagmite formation, of which the author has previously given a short description, may be characterized as follows:

The Bolagen series — the quartzite and mica-schist series: fine-grained sediments, frequently very pure and almost dense quartzites.

The Hede-Rånddalen series — the sparagmite- and Hede limestone series: quartzitic, highly felspathic, usually rather coarse rocks (typical sparagmites) together with limestones rich in quartz and calcareous and arenaceous dark shales.

The Sörvallen series — the sandstone and shale series: quartzitic or sparagmitic, often argillaceous sandstones and gray shales free from lime.

In all these series the formation is subaquatic. The Bolagen series has been formed in the most open water, the upper part of the Hede-Rånddalen series in the most moving water (possibly as delta).

The sparagmites proper, quartzitic rocks with a high content of comparatively fresh felspar, occupy a more marked position in only one of the said type-series. The presence of fresh felspar in larger quantities than are usually found in sandstones has given rise to the interpretation of these rocks as desert formations. In many places in the marine Lower Cambrian sandstones felspar is found

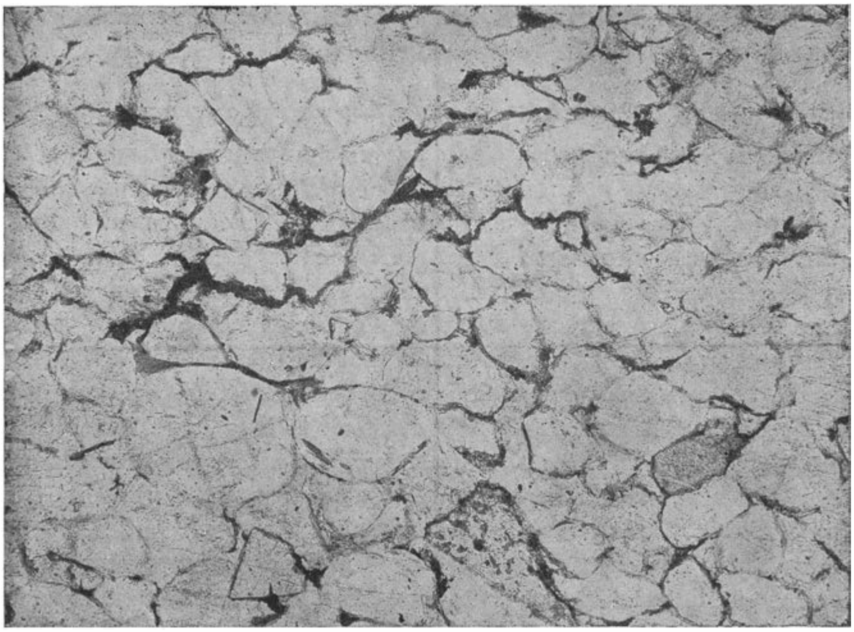

Fig. 80. Vemdal quartzite, dark, »blue-quartz». Klövsjö.
(Pr. 713. Pl. 401.) — 60 ×.

as fresh as in the sparagmites. The greater part of the quartzite-sparagmite formation also consists of sediments formed by no inconsiderable chemical weathering. Even if this has not been as strong as in the present temperate zones, it has at any rate been stronger than in the arid regions. The author presumes that the formation has taken place in a nival (polar) climate. No purely glacial sediments are found in the series of strata described but certain of the rock-types indicate that the ice might have contributed to the sedimentation as a factor of transportation (p. 167). Regarding the wear, sorting, stratification and polymixed nature of the material some of the coarse-grained sparagmites are of the same character as certain Pleistocene deposits. The banding in the dark quartz- and clay-mixed Hede limestone shows that a rhythmic sedimentation has also taken place, just as on the formation of the varved clay.

As the author emphasized introductively he does not at present consider himself able to give a universal exposition of the quartzite-sparagmite formation or its rocks, nor does he think there is room for it in this publication. He hopes, however, by the type-series quoted and the short discussion of the character and the forming conditions of the rocks to have given a certain orientating picture of the formation and some of the problems connected with it. But we must leave it to future, regionally made detailed investigations to throw further light on the nature, stratigraphy and forming conditions of the sparagmite and other rocks belonging to the same series.

The Vemdal Quartzite.

Under the term »Vemdal quartzite» is comprised a series of quartzitic rocks occurring along the eastern border of the sparagmite formation. Their area of distribution extends from northern Dalecarlia through Härjedalen into the South of Jämtland. In some places the Vemdal quartzite is found resting concordantly on Ordovician strata (Ortoceras-limestone). Its relation to the quartzite-sparagmite series entitles us to suppose that the Vemdal quartzite is formed simultaneously with parts of this series (see Frödin 1920 and there reviewed older works).

In the two sections from the Vemdal quartzite at Klövsjö, published by the author in the preceding part of this work (Hadding 1927, 91) the following types of quartzite are mentioned besides the conglomerates:

White quartzite.
Light gray quartzite.
Pink, breccia-like quartzite.
Red, fine-grained quartzite.
Greenish gray and yellowish gray quartzite.
Dark quartzite.
Blue-quartz.

Colour as well as size of grains vary greatly. However, the rock is always quartzitic and as a rule strongly influenced by pressure. The bedding is distinct but no lamination has been observed by the author, and the absence of this has also been called attention to by Högbom (1920, 56).

The adjoining figg. 80—82 illustrate the microscopical characteristics of the rock.

The Ordovician Arenaceous Sediments in Central Jämtland.

In some places in central Jämtland the Ordovician strata show a development coinciding in many respects with that found in corresponding strata in Scania. Phyllograptus shale and Dicellograptus shale, Orthoceras limestone and Chasmops limestone are well developed in the Storsjö region and so is the Brachiopod shale (the

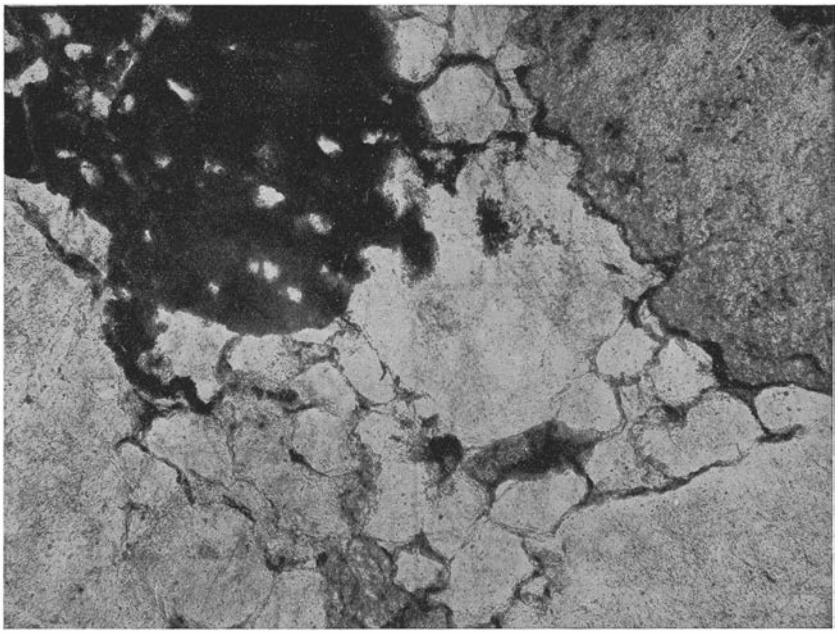

Fig. 81. Vemdal quartzite with fragments of sedimentary rocks (calcareous and argillaceous). Klövsjö. (Pr. 715. Pl. 402.) — 60 ×.

Fig. 82. Vemdal quartzite, white. Klövsjö. (Pr. 766. Pl. 399.) -- 50 ×. Nic. +.

Dalmanites shale) somewhat N of the same region. Arenaceous embeddings, increasing in thickness towards the peripheral parts of the region, can be traced here and there. One finds without difficulty, transitions from the normal sediments, the fossiliferous limestones and shales, to more local arenaceous forms of development, quartzites of different types such as Sunne quartzite, Kyrkås quartzite, Ströms quartzite, Vemdal quartzite, »Blue-quartz», a. o. We shall not dwell on all these quartzites here but only follow a series in its varying facies. The author has chosen a series of sections through the Orthoceras limestone investigated

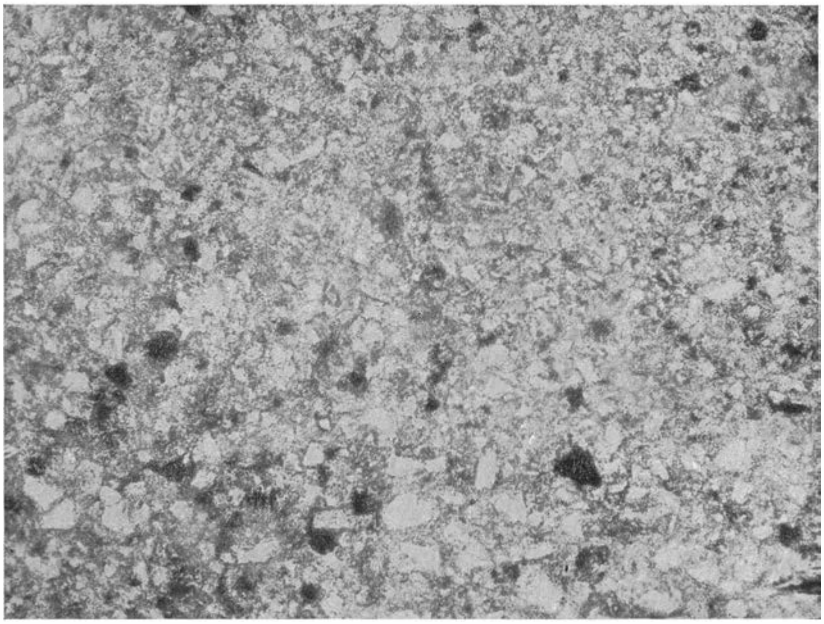

Fig. 83. Calcareous sandstone, fine-grained, bituminous. Hallen, Jämtland. (Pr. 2366. Pl. 393.) — 60 ×.

by him in 1919 and the shale and sandstone deposits equivalent to this and situated along the distance Brunflo—Andersön—Hallen—Västerfjället.

At *Brunflo,* 15 km SE of Östersund and at the eastern border of the Cambro-Silurian field in Jämtland the Orthoceras limestone has a pronounced limestone facies. The rock consists of a dense gray or dark brownish red limestone in well developed beds, mostly from 5 to 15 cm thick.

In *Frösön,* near Östersund, Orthoceras limestone is also found but of a somewhat different petrographical character than that at Brunflo. The rock is gray, often thin-bedded and fairly argillaceous.

In *Andersön,* about 20 km WNW of Brunflo, the Orthoceras limestone is partly replaced by dark graptolite-bearing shales. In these shales more calcareous parts are present, partly as thin, out-thinning beds and partly as concretionary nodules. Extremely fine sand-grains, specially distinct in certain layers, are also found in the shales. In this place the Orthoceras limestone is dark gray, almost black. The content of sand is hardly noticeable under the microscope.

In *Utöarna,* about 30 km WNW of Brunflo, the Orthoceras limestone is developed approximately as in Andersön, i. e. with dark beds of limestone and partly replaced by black shales. Macroscopically the series of strata show no marked difference. Under the microscope, however, it is found that the strata in Utöarna contain an abundance of sand-grains. Occasional thin sandstone beds also occur in the shale. The rock in these is a black, bituminous, calcareous sandstone with no small content of clay. The grains of quartz are angular, mostly from 0.06 to 0.4 mm in size. In the black shales the grains of quartz are smaller, from 0.01 to 0.05 in diameter.

At *Hallen,* further west, about 40 km WNW of Brunflo, we still find some beds of Orthoceras limestone [1] of the same gray type as at the localities mentioned above. But here the limestone has made more room for the black shales interbedded with black sandstones. The latter are developed into thicker beds than in Utöarna. The rock is partly a fine-grained, bituminous, calcareous sandstone (grains 0.01—0.05 mm) and partly a coarser, less calcareous sandstone (grains about 0.4 mm). The grains are always angular. They consist mainly of quartz, but microcline is also found, though only sparingly.

The black shales at Hallen are always quartz-bearing and often rich in quartz. As in the sandstones the grains are angular. The greatest size measured is 0.5 mm.

W of Hallen no Orthoceras limestone is found but only the black shale and sandstone equivalent to it. On *Västerfjället,* 62 km W of Brunflo, a thick series of these rocks is met with, often interbedded with each other. The shale is richer in quartz than at Hallen; it may more frequently be called shaly sandstone than arenaceous shale.

In Västerfjället the sandstone beds are less argillaceous and bituminous than at Hallen. Certainly, the rock is still dark but has a higher lustre and a quartzitic appearance. This is the rock that is termed *blue-quartz.* The quartz grains are of varying size, in several beds from 0.5 to 1.0 mm in size and sometimes so large that the rock is conglomeratic. The grains show secondary growth. They are colourless in themselves, the characteristic dark colour being derived from the frequently very insignificant, black, bituminous filling material.

In certain places the black shales have been transformed by metamorphism into dark phyllitic shales. Sometimes the dark colour has been replaced by light rusty brown. The sandstones also show more or less distinct traces of metamorphism, katamorphism as well as new formation of minerals, especially mica.

The content of felspar is sometimes not inconsiderable in the blue-quartz.

[1] Somewhat E of Hallen.

The blue-quartz attains its greatest development in the Ovik mountains and their neighbourhood. It is of interest that graptolites, not precisely determined but no doubt belonging to the Dicellograptus shale [1], have also been found in these regions in shales embedded in blue-quartz.

A comparison between blue-quartz and other quartzites, partly at least of the same age, for inst. the Vemdal quartzite and the Ström quartzite, is of course of petrographical interest also [2]. They all represent a Middle Ordovician sandstone facies. This is also the case with the quartzites in the parishes of Föllinge and

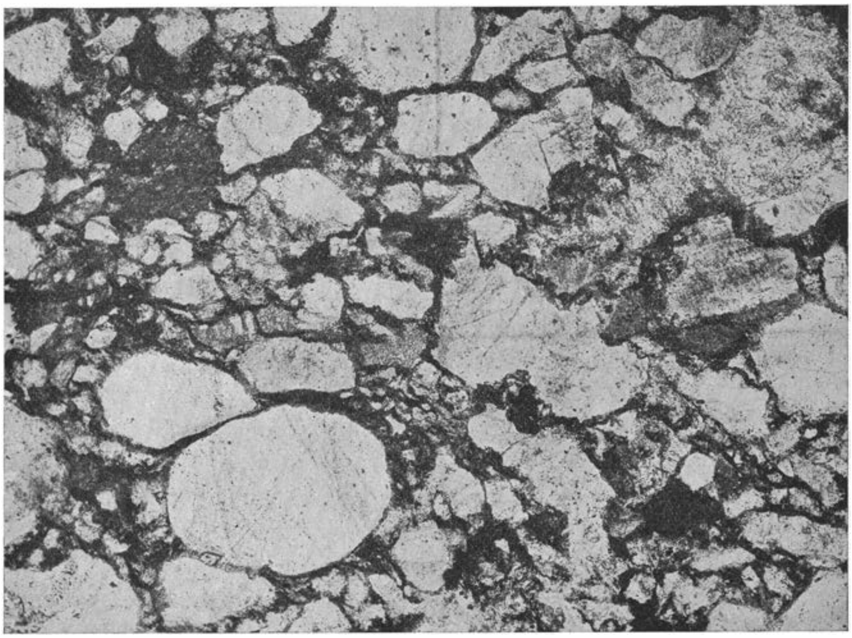

Fig. 84. Sandstone, bituminous. Överhallen, Jämtland. (Pr. 2368. Pl. 392.) — 60 ×.

Laxsjö (the Hotagen quartzite), which probably stand very near the blue-quartz in primary character and forming conditions. The essential difference between the dark quartzites (the blue-quartz, the Hotagen quartzite, a. o.) and the lighter (the bulk of the Vemdal quartzite, the Ström quartzite, and so on) seems to the author to be that the former have been formed in regions with a deposition of bituminous mud, while the latter have been formed in regions very poor in such matter. This absence of bitumen is also noticeable in the Orthoceras limestone and the shales, as far as these rocks occur together with the light quartzites.

As an example of the interstratification between the blue-quartz and shale the following detail of a section from Västerfjället, measured and published by Wiman (1896, 297), may be added in fig. 85.

[1] Found by von Schmalensee on Gräftån. See Wiman, 1893, 19.

[2] On the quartzites of Jemtland see Wiman 1896.

The formation of the here discussed series of strata rich in sandstone and quartzite is less obscure than the formation of the previously illustrated sparagmite-quartzite series. By the direct transition into an easterly, normally developed limestone and shale facies and above all by the sporadic findings of fossils, some fixed points for judging the formation of the rocks are obtained. There cannot, I think, be any doubt of their marine character nor their formation in shallow water in the immediate vicinity of the shore. The regular stratification and the frequently great content of highly bituminous mud show that no strong currents have prevailed at the place of deposition. Neither do the grains show traces of wear. On the whole, the material is less acted upon than in for inst. the Lower Cambrian sandstones of Scania.

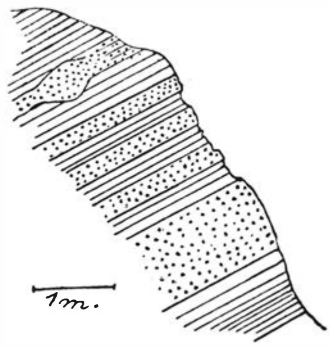

Fig. 85. Section from the crevice above Hövallen, Västerfjället, Jämtland. Interstratified blue-quartz and shale. (WIMAN 1896, fig. 26).

The blue-quartz and the sandstones comparable to it are formed in gulfs or bays on the shore of the Ordovocian sea. They are built up of a detritus formed by chemical as well as mechanical weathering. The material has not been exposed to eolian transportation and probably only to inconsiderable fluviatile or marine. Nevertheless, it has been well sorted, so that the coarser grains have remained farthest west, while the finest have been carried eastward. From this we may also infer that the material is derived from land to the west.

The content of bitumen shows that organic life has been developed in those parts of the sea where the deposition took place. The trilobite and brachiopod fauna of the corresponding deposits with normal marine facies is, however, absent in the quartzitic series. Certainly, the local conditions have not been favourable for the development of this fauna. No doubt the higher percentage of sand has been less important than other factors (the temperature of the water, its salinity, etc.).

From a common point of view the thick, subaquatic, to a large extent no doubt marine series of sandstone, quartzite and sparagmite appear as a facies development of the Cambro-Silurian (and acc. to the opinion of the author principally of the Ordovician), to which there is no correspondence in South Sweden. The sandstone series occurring there are of a different character. The rise of the facies mentioned here does not only imply a detritus-yielding region but also certain special qualities in this, which have not been traced in the regions farther south. The author has already spoken in favour of the opinion that in central and northern Scandinavia we have had a nival climate during the time when the sparagmites were formed. The abundant supply of detritus material to the sea and to the continental basins implies a destruction of the land surface on a large scale, and there is occasion to suppose that this destruction is ultimately due to the folding movements starting at this very time [1] and gradually giving rise to the Caledonian mountain-range.

The Loftarstone at Lockne in Jämtland.

At Lake Lockne, 20 km SSE of Östersund, the eastern border of the Cambro-Silurian region is situated. Here the series of strata shows *inter alia* normally developed, fossiliferous, gray Orthoceras limestone, Chasmops limestone and

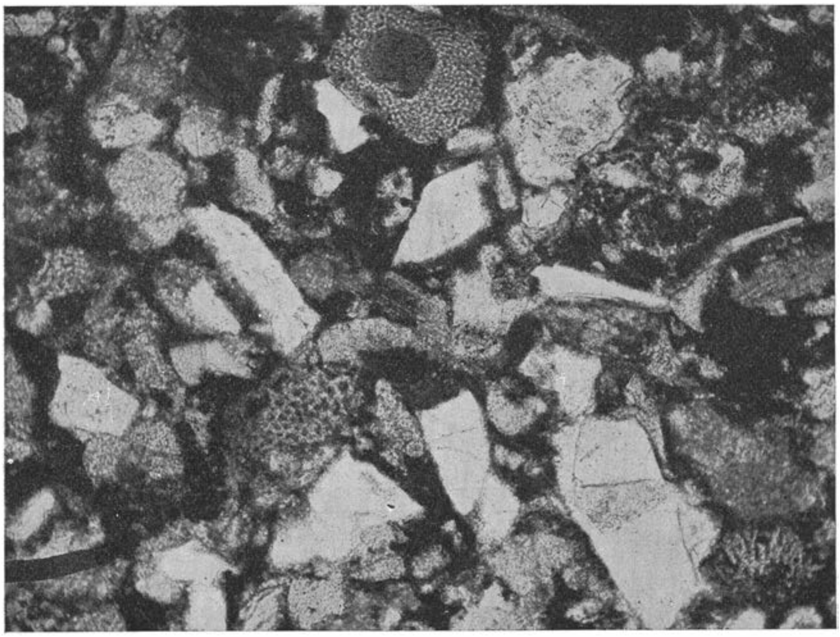

Fig. 86. Loftarstone. Fragments of fossils, shales, limestones and granite. Tandsbyn, Jämtland. (Pr. 691. Pl. 395.) — 60 ×.

Chasmops shale with a rich fauna (HADDING 1927, 97). The rocks are marine and formed under the same conditions as the corresponding and petrograpically similar strata at other places in Sweden.

For two reasons, however, the series of strata at Lockne is of special interest. We find on the one hand that the basal bed is of varying age in different parts of the region and on the other hand that the series includes sedimentary rocks of a peculiar type, namely the *loftarstone* and the conglomerates connected with it.

[1] The author is specially thinking of the strong disturbances occurring in the Lockne field during the time when the Orthoceras limestone was formed. In this case the dating is certain and the disturbances are no doubt a phenomenon connected with the folding process to the west (see the following and HADDING 1927, 94).

Where the series of strata is most complete we find between the Orthoceras limestone and the Archæan (the granite) partly Lower Didymograptus shale with several species of graptolites (*Tetragraptus*, *Phyllograptus*, *Didymograptus* and *Clonograptus*; see WIMAN 1900, 137) and partly Cambrian alum shale underlying this (belonging to the Olenus and Paradoxides stages). In other places the Orthoceras limestone rests with a basal conglomerate directly on the granite. This stratification might be interpreted as indicative of a subsidence of land and a continuous transgression during the time of deposition. However, the mode in which the different series of strata occur in relation to each other as well as the tectonic conditions show that no depression but on the contrary an elevation of land has taken place. Still, this has not been uniform all over the region

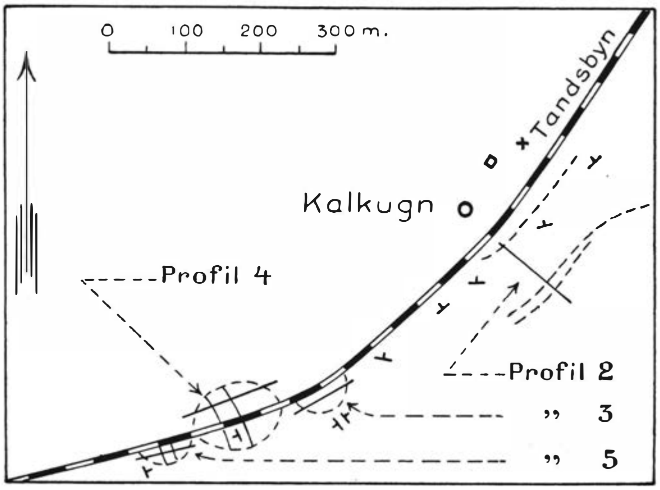

Fig. 87. Sketch of the region SW of the railway station of Tandsbyn, with sections (profiles) marked out (see figg. 88—91).

but has occurred along certain lines and has been strongest in the middle part of the region.

By this elevation the deposited sediments have been broken down and new, younger ones built up on the denuded bedrock. The basal conglomerate contains pebbles of the rocks of the broken-down series of strata (alum shale, Didymograptus shale, Orthoceras limestone; HADDING 1927, 93).

Certainly, the elevation of the sea-bottom in different parts of the region has not happened all at once by a few great dislocations. It has taken place in several stages; on one occasion it has been most marked along one line, on another along a different. During the tectonic movements the elevated sediments have, partly without previous disintegration, been submerged again below the surface of the sea and formed the basis of the continued sedimentation. In the opinion of the author the beds of Orthoceras limestone with very pronounced mud cracks bear witness to such an occasional drying.

The tectonic disturbances in the Lockne field during the Middle Ordovician are also evident from the rocks mentioned above, the conglomerates and the Loftarstone, which lie embedded in the series of strata. The intraformational conglomerates rest on the granite cropping up through the series of strata (Hadding 1927, 97). That the granite occurs as horsts, formed at the time of sedimentation,

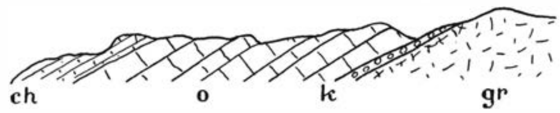

Fig. 88. Section 2. The Orthoceras limestone conglomerate (k) rests on the granite (gr) and is covered by Orthoceras limestone (o) and Chasmops limestone (ch).

Fig. 89. Section 3. Anticlinal in Loftarstone (l) on Loftarstone conglomerate (lk). At the top of the series nodular limestone.

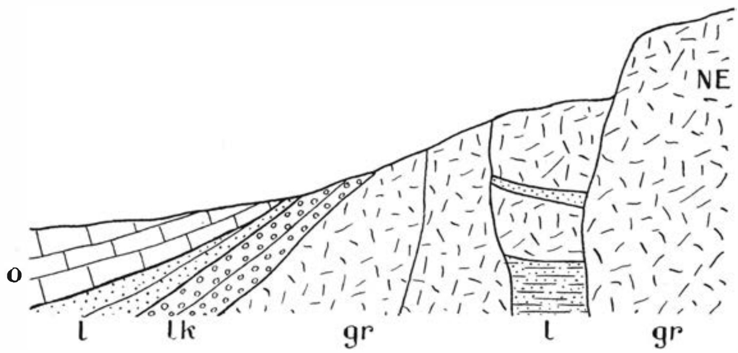

Fig. 90. Section 4. Granite horst, partly breccia-like, with faults and inclusions of fine-grained, stratified Loftarstone (washed-in material). The series of strata to the west in the section consists of Loftarstone resting on Loftarstone conglomerate and covered by limestone.

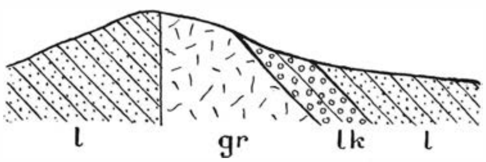

Fig. 91. Section 5. Granite horst with Loftarstone and Loftarstone conglomerate. A fault at the highest part of the section.

is easily seen from the fault lines traversing it, from the steep sides with fresh (unweathered) rock and from the sediments' mode of occurrence at the contact (fig. 90). Besides that, faults are also to be found in the sedimentary series of strata, as shown by Högbom (1886) and Wiman (1900), and as is also evident from the section sketched here, fig. 91.

The Loftarstone proper is a highly calcareous sandstone or arenaceous limestone, usually dark gray, almost black, though sometimes lighter gray. On weathering it assumes a light grayish brown tint. It occurs in thinner or thicker beds, sometimes unstratified, sometimes with a fine stratification, specially pronounced on the weathering of the rock.

Under the microscope the rock proves to consist of angular grains of quartz and felspar together with chloritic scales derived from the granite. A great deal of the material, however, consists of dark calcareous mud with fragments of shales, limestones and fossils from the disintegrated (or suspended) sediments (fig. 86). The bulk of the mud is derived from unconsolidated Orthoceras limestone. Secondary aggregates of calcite are sometimes abundantly present.

The variations shown by the rock are partly due to the varying quantity of granitic material and partly to the character of the sediments, that have been shifted and form an essential part of the rock. Consequently we cannot expect that a Loftarstone formed at one place and at a certain time will be exactly like one formed at another place or at another time, even though the mode of formation has been the same. However, the variations are not great.

As a rule the Loftarstone rests on a conglomerate, the Loftarstone conglomerate (Hadding 1927, 95), which may of course quite reasonably be regarded as the coarser, first deposited part of the Loftarstone. The adjoining sections (figg. 89 and 90) illustrate the occurrence of the rocks.

As is evident from what is said above, the Loftarstone is a marine, clastic rock formed essentially by disintegration of sedimentary rocks under formation. The rock forms an anomaly in an otherwise normal series of strata. The disturbance in the sedimentation has been caused by tectonic movements, which have thus led directly to the formation of the rock.

The fact that the Loftarstone is covered by a normally developed limestone (Chasmops limestone) shows that the sedimentary conditions have been »normal» and the same both after and before its formation. Thus the Loftarstone indicates a geological period of disturbance of only short duration [1].

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[1] If we shake a heterogeneous, unconsolidated material, it will to a certain degree be sorted acc. to the size, form and specific gravity of the grains. The same will be the case, if the mass is kept in motion in another way. The question can now be put: — might not strong earthquakes in some way be registered by a similar sorting in material of suitable nature. On standing before certain beds of the Orthoceras limestone in the Lockne region one can hardly abstain from these reflections. Parts of a series of Orthoceras limestone beds may be normally developed, with a regular, dense structure, while other parts of the same beds may consist of limestone nodules in a highly argillaceous matrix. No doubt the consolidation of many limestones takes place concretionarily from a number of centres. This often becomes noticeable on the weathering of the beds, when lumps of purer limestone are found enclosed in more clayey parts, but without decided difference between the former and the surrounding parts of the rock. Now, if an incompletely consolidated limestone of this type is shaken, the limestone nodules formed will be more markedly isolated in the still uncemented mass. In this, again, a sorting takes place in such a manner that the foliate substance is laid parallel to the surface of the nodules. The rock obtains a conglomeratic appearance. In the rocks of this type occurring at Lockne the author is inclined to see a registration of strong earth-quakes during the time of consolidation.

The Lower Ordovician Sandstone in Östergötland.

In several places in Sweden one finds on the boundary between the Cambrian and the Ordovician a gap in the series of strata and not infrequently a conglomerate, the Obolus conglomerate, which shows that the earlier deposited sediments have been partly broken down during this period. The cause of the negative sedimentation and the formation of conglomerate is no doubt an elevation of land. One could almost have expected to find coarse sediments, together with

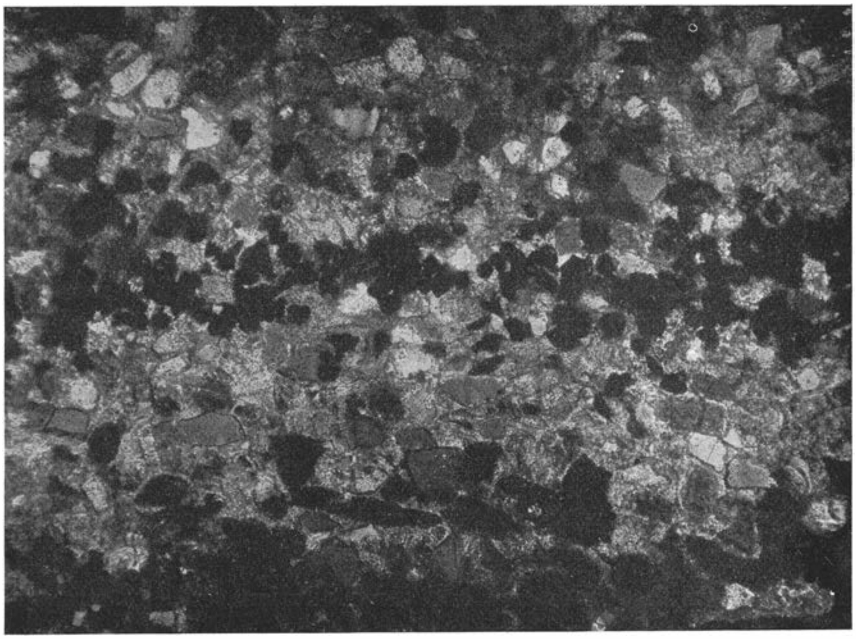

Fig. 92. Calcareous sandstone with pyritic laminae. Lower Ordovician (Dictyograptus shale). Storberg, Östergötland. (Pr. 627. Pl. 288.) — 50 ×. Nic. +.

the conglomerate, particularly sandstones. Hitherto, however, we have only found these coarser sediments in one region, Östergötland. The reason why they are not present in other regions, for inst. in Öland where the Obolus conglomerate is well developed[1], is no doubt that no sand-yielding region has existed in the vicinity.

According to WESTERGÅRD (1928, 196) the Lower Ordovician sandstone in Östergötland belongs to the lower part of the Dictyograptus shale. It is developed into beds of varying but always slight thickness. Farthest SE the sandstone-bearing horizon is only 1 m thick (Knivinge) and the sandstone beds thin and highly calcareous. Farther NW it attains a thickness of 2,1 m (Vestanå) decreasing westwards to 1,6 m (Storberg). According to ROSÉN (1916, 213) the sand-

[1] On the Obolus conglomerate in Dalecarlia see HADDING 1927.

stone is replaced farthest W by a conglomerate with pebbles of *inter alia* phosphorite, phosphatized stinkstone and the rocks of the Visingsö series.

The sandstone is calcareous, and can be replaced by an arenaceous limestone, sometimes with large crystals of calcite and a relatively small content of sand. The grains of quartz are angular. In samples from Knivinge they mostly measure from 0,06 to 0,09 mm in diameter, in samples from Storberg up to 0,5 mm. Small lumps of phosphorite ($<$ 0,1 mm) are fairly common, while typically developed grains of glauconite are very sparse. Judging from samples the author has had the opportunity of examining, they are somewhat less at Knivinge than at Storberg.

A fine lamination in the beds, sometimes very pronounced, originates from thin layers of bitumen. Pyrite also occurs in very small crystals enriched in similar layers (fig. 92). Certain lamination surfaces can be covered by graptolites (*Dictyograptus*).

Where the highly calcareous sandstone or arenaceous limestone has a high content of bitumen, it can closely resemble a fine-crystalline, black stinkstone. Otherwise the rock is lighter or darker gray or brownish gray.

Formation. The sandstone in the Dictyograptus shale is a marine shallow-water formation deposited during an oscillation of land, that has started in the youngest Cambrian with elevation of land and negative sedimentation. The sandstone has been deposited during the oldest Ordovician. As pointed out by Westergård its material is principally derived from the region N of the place of deposition.

Arenaceous Strata in the Middle and Upper Ordovician and in the Lower Silurian.[1]

In South Sweden the Ordovician and older Silurian series of strata is almost entirely built up of shales and limestones.

The arenaceous strata are mainly found in the upper part of the Ordovician and, in the South of Sweden, mostly in Vestergötland. The »Brachiopod shale» in this province is characterized by rough shales, sometimes with a fairly high content of sand.

Real sandstones of importance are met with in the Ordovician series of strata in Norrland. We have dwelt on these principally quartzitic forms and those connected with them above (for inst. the Vemdal quartzite and the »blue-quartz»). We shall only call attention here to one more sandstone horizon, namely that in the Lower Silurian of Jämtland. The fossil-rich *Pentamerus limestone* includes beds of black, impure calcareous sandstone (fig. 93), petrographically of the same type as those mentioned above, which occur in Utöarna and at Hallen. Downwards in the series of strata the Pentamerus limestone grades into a quartzite, sometimes »blue-quartz»-like. Together with the Penta-

[1] With the term Silurian the author refers to the upper part of the Cambro-Silurian, i. e. the Gothlandian of some authors (De Lapparent, Moberg a. o.)

merus limestones this »*quartzite with Phacops elliptifrons*» forms a petrographical series uniform with that found from the Orthoceras limestone to the »blue-quartz» but the development of the two series has not gone in the same direction, the one having developed so that the calcareous mud has been more and more mixed up with sand (the Orthoceras limestone at Hallen), while in the other the sand has been more and more replaced by clay and calcareous mud.

The calcareous sandstone in the Pentamerus limestone is uncommonly even-grained. In the beds examined the grains were 0,06—0,1 mm in size. They are

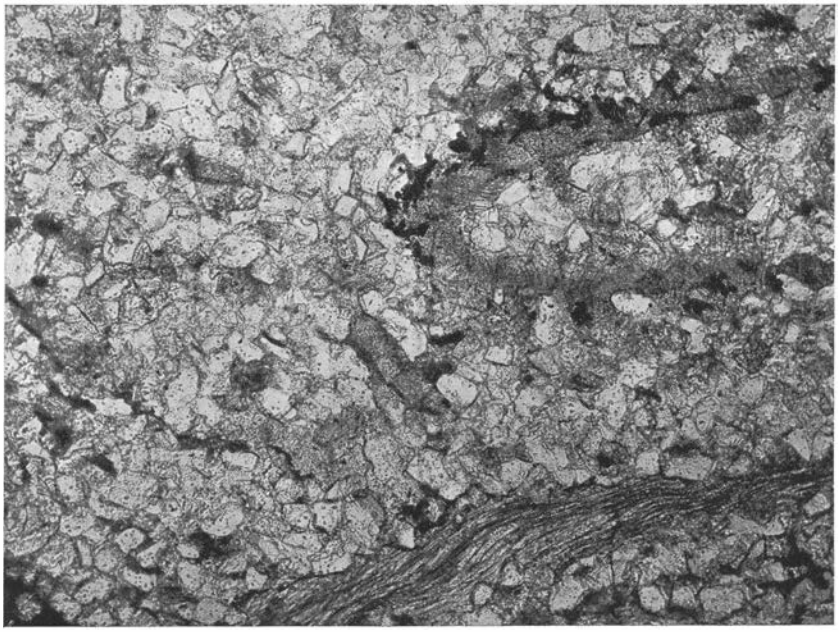

Fig. 93. Calcareous sandstone. Silurian (Pentamerus limestone). Norderön, Jämtland. (Pr. 753. Pl. 398.) — 60 ×.

not noticeably rounded. Essentially they consist of quartz but occasional grains of felspar are found in the rock.

No doubt the above-mentioned arenaceous facies in the series of strata otherwise rich in shale and limestone indicate periods with an increased capacity of transportation in the water in which the deposition has taken place. Certainly, we are not mistaken if we consider that the changed sedimentary conditions are due to an occasional elevation of land, resulting in a shallowing of the water at the place of deposition.

The Upper Silurian Sandstones.

In the Swedish Cambro-Silurian we find the series of strata in many places completed by thick sandstone series. A couple of these will be discussed in the following, namely the Scanian Öved-Klinta-Ramsåsa formation and the grindsandstone of Dalecarlia.

Sandstones also occur, enclosed in the Upper Silurian series of strata. Of these the Odarslöv shale in Scania and the sandstones of Gothland will be taken up for examination here.

The sandstones of Gothland.

In the Gothlandish series of strata, essentially built up of limestone and marl, sandstone occurs in two different horizons, viz. in the Slite group and in the Burgsvik series (see p. 188). The first-mentioned is relatively inconsiderable, the latter on the contrary rather thick. In both horizons the sandstone is found together with oolite.

The Slite sandstone occurs in a narrow zone with the direction NNE—SSW in the southernmost outcropping part of the Slite group. The strata are easy of access between Klinte and Klintehamn at for inst. the mill of Robbjer and at Klintebys. The series of strata is here: —

Marly limestone.

Oolite with ripple marks.

Calcareous sandstone or arenaceous limestone, about 3 m.

Marl-stone.

The sandstone is fine-grained and extremely even-grained in the different beds. In one bed the maximum size of the quartz grains was 0,05 mm, in another (uncommonly coarse) bed 0,15 mm. The grains are angular. Together with the quartz grains small brown and green scales of mica and chlorite are present, in certain beds so abundantly that they impart a slight lustre to the fracture surfaces. The rock also contains a no small percentage of clayey matter and grades downward into underlying marlstone.

In the Slite sandstone the calcareous cement is dense or fine-crystalline. It always occupies a large part of the rock and can also form the bulk of it (arenaceous limestone). The colour of the fresh rock is light gray, light bluish or greenish gray. On weathering it becomes grayish yellow.

The sandstone is poor in fossils, except in a few places where they are fairly abundant. Hede (1925, 19) mentions small ostracods, annelids (jaws), a few brachiopods (among others *Chonetes cingulatus* Lindstr. and *Atrypa cordata* Lindstr.), lamellibranchs, gastropods, etc., and three graptolites (*Monograptus Flemingi* Salt., *M. Dubius* Suess and *M. priodon* Bronn).

The Slite sandstone occurs in even beds, usually only one or a few centimetres thick but sometimes as much as 15 cm. The thickness of the sandstone series does not exceed 3 m (acc. to Hede 1925, 19). Towards the north it thins out.

On the upper surface of the sandstone there are irregular excavations, interpreted by Munthe (1915) as *corrosion grooves* arisen during an interruption in the sedimentation.

The *oolite* overlying the Slite sandstone is relatively coarse but not very thick (at Klintebys 0,25 m). The occurrence of large ripple marks in this rock (MUNTHE 1915, 430) is of special interest.

Petrographically the *Burgsvik sandstone* is very similar to the Slite sandstone described above. Like this the Burgsvik sandstone is an even- and fine-grained calcareous sandstone, light (bluish) gray and developed into beds of varying thickness. Both grade downwards into layers richer in clay and are covered by oolite.

In the samples of the Burgsvik sandstone examined the grains of quartz are angular or only slightly rounded. Their size seldom exceeds 0,2 mm and is mostly

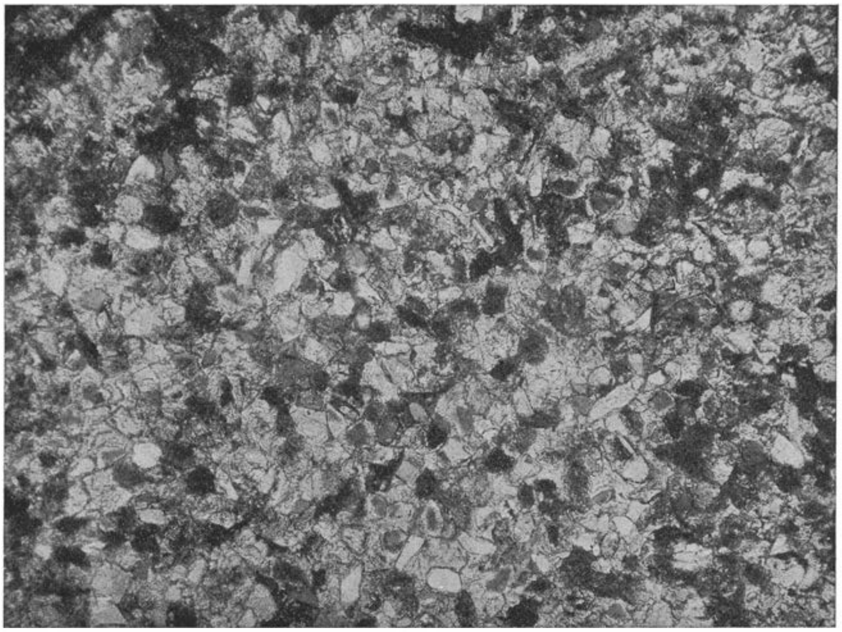

Fig. 94. Burgsvik sandstone. Upper Silurian. Burgsvik, Gothland. (Pr. 2554. Pl. 331.) — 50 ×. Nic. +.

0,05—0,1 mm. Grains of felspar of the same size are sparingly present. Scales of mica, muscovite as well as biotite, abound, especially in certain parts of the sandstone.

In certain beds the content of clay in the sandstone is slight, in others, on the contrary, so high that transitions to arenaceous marl and clay-stone are formed. The stronger argillaceous strata are often shaly.

The calcareous cement is always abundant. Sometimes the percentage of lime increases so that the rock is transformed into arenaceous limestone. The transitions from calcareous sandstone to oolitic limestone deserve special attention. In the normally developed calcareous sandstone harder portions, appearing as irregular lumps on the weathering of the rock, are not infrequently found.

These calcareous concretions contain about 40 per cent of lime, while the calcareous sandstone has only about 8 per cent (see MUNTHE 1921, 32).

Here and there the sandstone is rich in slabs of clay, sometimes rounded, sometimes angular. In both cases they are fragments of argillaceous strata cracked and hardened during drying.

The sandstone beds can attain a considerable thickness. In the neighbourhood of Fide the author observed a bed 1,5 m thick. This showed no lamination or banding at all. In other cases the thickness is slight, less than 1 cm. In the quarries at Burgsvik a thickness of 2—4 cm was measured on slabs 1,5 × 1,5 m in size. Several of the beds in the same quarry showed a fine lamination or banding with thin brownish red bands along which the rock did not cleave (possibly infiltration phenomenon).

On a sandstone bed at Burgsvik the author observed short-wavy but distinct ripple marks with ridges in the direction E—W.

The relation of sandstone to argillaceous marl and oolite is sometimes visible in an interbedding of these rocks. As types of such series of strata the following two profiles may be cited after MUNTHE (1921, 35): —

WSW of Burgsvik			*Grötlingboudd*		
Oolite	0,85	m	Highly fossiliferous sandstone	0,20	m
Argillaceous marl	0,08	»	Oolitic sandstone	0,05	»
Sandstone	0,31	»	Highly fossiliferous sandstone	0,05	»
Argillaceous marl	0,41	»	Oolitic sandstone	0,20	»
Sandstone	0,64	»	Slightly fossiliferous sandstone	0,10	»
Argillaceous marl	0,20	»	Oolite	0,15	»
Sandstone	0,78	»	Sandstone	0,10	»
Argillaceous marl	—		Oolite	0,08	»
Sandstone	—		Sandstone	0,30	»

According to a core-drilling at Burgsvik the thickness of the Burgsvik sandstone amounts to nearly 40 m. More than half of it, however, consists of shaly, argillaceous sandstone. Regardless of a couple of smaller embeddings and gaps in the core this shows the following series of strata (MUNTHE 1921, 22): —.

Hamra limestone	—	
Sandstone	1,05	m
Argillaceous, shaly sandstone	2,07	»
Oolite	0,38	»
Clay-stone	1,66	»
Oolite	1,96	»
Sandstone	0,35	»
Shaly sandstone	1,59	»
Sandstone	20,66	»
Shaly sandstone	22,70	»

Clay-stone	4,70 m
Eke-marl	—

The sandstone is found in a fairly large area. From the southern point of Gothland it can be followed with smaller interruptions about 50 km towards N and NNE in a zone of varying breadth.

In the lower and middle part the sandstone is poor in fossils, in the upper part it is highly fossiliferous. Lamellibranchs especially occur in great numbers (see HEDE 1921 and 1925).

Formation. Like the Slite sandstone and the oolite connected to it so are the Burgsvik sandstone and the Burgsvik oolite marine shallow-water deposits. In this case, the character of the fauna and the rock are very explicit. The ripple marks and trails give further support to this interpretation. From the angular or rounded clay-flakes enclosed in the sandstone we may infer that an occasional drying up has taken place at intervals.

The deposition of the sand is probably connected with temporary elevations of land and consecutive shallowing of the sedimentation region. Even if we have proceeded so far in our inferences, we are still unable to explain the formation of the sandstone. The arising of a shoal does not in itself cause a deposition of sand. There must be a sand-yielding region so near that the material can, by means of the transporting power of the water, be brought forward to a certain place, if a deposition of sand shall take place there.

Of course sandstones and other coarse sediments also arise exclusively by shallowing and consecutive stronger motion in the water, provided that the sediments already deposited contain some coarse material, which may be enriched by the washing away of the fine-grained bulk. But with regard to the Gothlandic sandstones this explanation will not hold good, as no notable quantity of sand is present in the series of rocks underlying the sandstones and no negative sedimentation has taken place in connection with the beginning deposition of arenaceous material.

Consequently we must look for a sand-yielding region. Certainly we make no mistake, if we locate this in those parts of the Baltic region that, during the time immediately before the formation of the Gothlandic sandstones have received coarser, more arenaceous sediments than Gothland then obtained.

The entire Gothlandic series of strata is formed in shallow water but the absence of coarser detritus than argillaceous mud indicates that the formation has not taken place in the immediate vicinity of a shore. The region that has delivered the argillaceous mud to the Gothlandic strata, has also supplied sand and coarser detritus, which have been deposited closer to the shore. Has this been situated in the Kalmar region, approximately where the Lower Cambrian shore was to be found, the arenaceous sediments have probably been deposited between Gothland and the present continent. On an elevation of land the shore-line has been displaced and the said deposits of sand have probably been partly shifted during transport to the east. The repeated sorting to which this arenaceous material has in this manner been subjected can also explain the remarkable even-grainedness of the Gothlandic sandstones.

Speaking of the formation of the sandstones, attention should also be called to the fact that the sandstone, like the rocks of Gothland in general, shows no traces of a strong oxidation, such as usually bear witness to a formation in very shallow water and a lasting or frequently repeated exposure to the atmospheric agencies. This indicates that the deposited material has not or only occasionally been above the sea level.

Occasionally the sandstone grades into oolite. The latter rock can be more or less rich in grains of sand. It may be specially emphasized that the nucleus of the oolites is frequently a grain of quartz but equally often and in certain beds almost exclusively a fragment of fossil. Like the sandstone the oolite is formed in shallow water.

The following scheme, mainly after HEDE (1921, 87), shows the stratigraphical position of the Gothlandic sandstones.

Gothland	England	Scania	The East Baltic	The Oslo region
13 Sundre limestone	Upper Ludlow Group (Downtonian)	Öved—Ramsåsa Strata 1—3	K	Stage 9
12 Hamra »				
11 Burgsvik *sandstone*				
10 Eke marl-stone	Lower Ludlow (Upper Salopian)	Colonus shale		
9 Hemse group				
8 Klinteberg limestone				
7 Mulde marl-stone				
6 Halla limestone				
5 Slite group with *sandstone*	Wenlock shales and limestone	Cyrtograptus shale	I	Stage 8
4 Tofta limestone				
3 Högklint limestone				
2 Upper Visby marl-stone				
1 Lower » »				

The Odarslöv shale in Scania.

As a rule the colonus shale[1] in Scania is developed as a light gray or bluish gray, muscovite-bearing shale. Not infrequently it is calcareous, marly, and includes beds of limestone. It generally contains small grains of quartz also and in certain places it grades into sandstones. The thickest of these sandstones is *the Odarslöv shale.*

In the quarries at Odarslöv, now mostly filled with water or caved in, the rock consists of a fine, even-grained sandstone, brownish or red-brownish gray in

[1] The zone with *Monograptus colonus* BARR. and *Cardiola interrupta* SOW.

colour. In one of the quarries a sandstone bed 1,8 m thick was measured. On weathering this disintegrates and breaks up into uneven plates, 2—4 cm thick. Occasional layers are thicker (the highest thickness observed 9 cm). Other portions are more shaly and break up into plates about 1 cm or less in thickness. These portions are more argillaceous and form the transition to the normal type of the colonus shale.

The sandstone is more or less calcareous. Most calcareous are the harder and least porous beds. Clay is never absent and is apparently evenly distributed

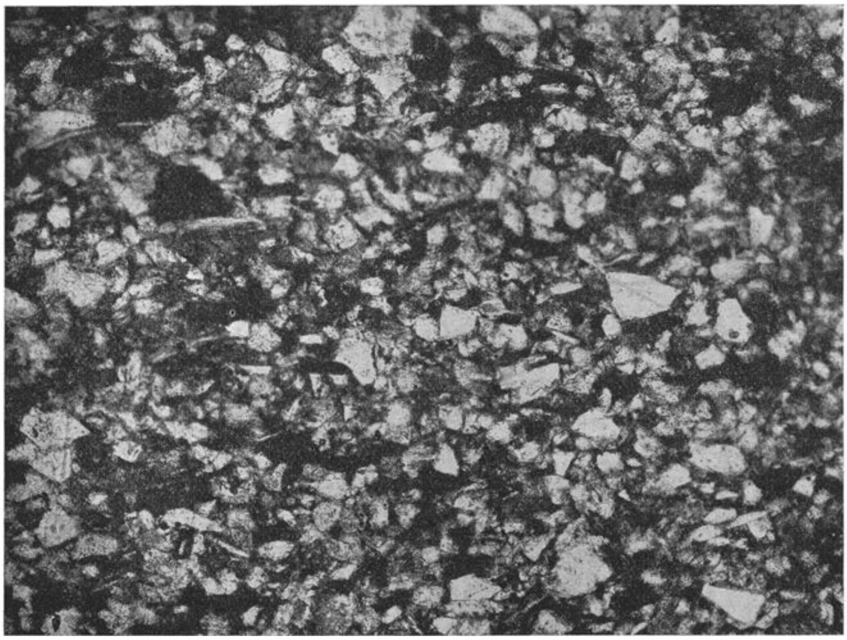

Fig. 95. Odarslöv shale. Argillaceous and calcareous, shaly sandstone. Odarslöv, Scania. (Pr. 2847. Pl. 329.) — 60 ×.

in the rock. Possibly, however, breaking up into thin layers by weathering may be resulting from an irregularity in the deposition of clay.

The sandstone contains light mica in small scales, as a rule only 0,2—0,5 mm in size. The mica scales always lie evenly distributed in the rock and do not make this cleavable parallel to the bedding surfaces. For the most part, however, the scales lie parallel to these surfaces, and for that reason the direction of the bedding planes can be immediately decided in a sample.

The grains of quartz vary in size from 0,001 to 0,3 mm. In certain beds grains with a size of 0,02 are found dominating, in others the majority of the grains are 0,07 mm in diameter, and at a third place the diameter is mainly 0,1 mm. The larger grains are often rounded, the smaller always angular.

The cement consists of calcite. Sometimes, however, the quartz grains show a somewhat rough surface owing to a slight secondary growth.

Here and there in the Odarslöv shale small slabs of clay occur. They are rounded and have consequently become somewhat worn or dissolved at the edges before being embedded in the sand. They are of the same nature as the above mentioned clay-slabs in the Burgsvik sandstone (p. 185).

The Odarslöv shale is extremely poor in fossils. As a rule traces of organic remains are only sparingly found in it. In a couple of places, however, strata rich in graptolites, with *Monograptus colonus* Barr., *M. bohemicus* Barr. and *M. dubius* Suess (see De Geer 1887, 20 and Moberg 1909, 6), have been found. The colonus shale as a whole has the reputation of being poor in fossils but here and there highly fossiliferous beds occur. This is for inst. the case with a limestone bed at Skarhult (Hede 1919), with the shale at Tolånga (Hede 1915) and with limestone and shale at Röddinge (Moberg and Törnquist 1908). Ostracods, lamellibranchs and brachiopods are especially abundant in this fauna. This is a typical shallow-water fauna, and on that account it is remarkable that, irrespective of the planktonitic graptolites, it is absent from the sandstone.

In the shaly, clay- and calcite-rich form of the Odarslöv sandstone the bedding surfaces are sometimes glossy like slickensides, in which case they also show track-like or wavy elevations.

Formation. The colonus shale is a typical shallow-water formation. The sedimentation has taken place in a region with an abundant supply of fine-grained detritus. The fauna is thoroughly marine.

The Odarslöv shale is the most coarse-grained of the different rocks of the colonus shale and is undoubtedly the one formed in the shallowest water. The clay-slabs in certain sandstone beds indicate a hardening and breaking up of the deposited clayey sandstone layers. The fine-grained material, the even stratification and absence of intraformational conglomerate and coarser sandstone beds shows that the deposition has not taken place next to an open shore or in water with strong currents.

The cause of the poorness in fossils of the Odarslöv shale (and the colonus shale) is not directly evident from the nature of the rocks. The water has been muddy and the supply of fine sand uninterrupted during the formation of the thick beds. Possibly this rich supply of sand and fine detritus has in itself had an unfavourable influence on the development of the fauna but the author finds it more probable that the deposition has taken place in partly closed basins with as a rule brackish water and only periodically entirely free connection with the sea.

The sandstones in the youngest Silurian of Scania.

The youngest Silurian strata in Scania, the Öved—Klinta—Ramsåsa formations, contain an abundance of sandstones just as the corresponding series of strata in England, the Upper Ludlow or Downtonian (see the scheme p. 188). The general stratigraphical occurrence of these sandstones in the three most important regions of distribution is evident from the following scheme principally made up by GRÖNWALL (1897, 233).

Klinta	Bjersjölagård—Öved	Ramsåsa
4 Red sandstone	Sandstone, mostly red	Red sandstone and shale.
3 Grayish blue shale	Grayish blue shale	Pink shale.
2 Sandstone, yellow and white	Sandstone, yellow and white	Shale?
1 Gray shale with limestone	Limestone and shale	Gray marly shale.

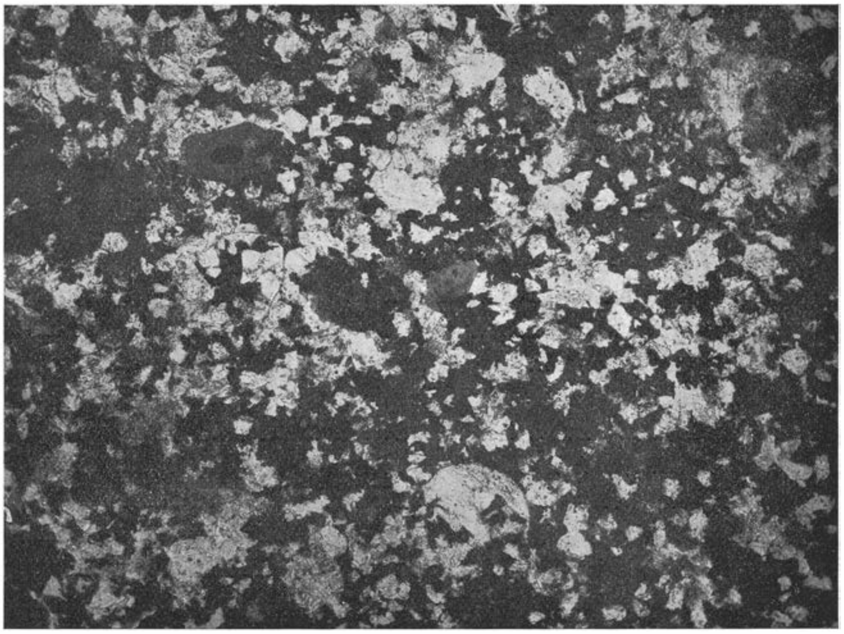

Fig. 96. Öved sandstone with quartz cement and abundant red hæmatite. Öved—Ramsåsa series (Downtonian). Öved, Scania. (Pr. 2816. Pl. 282.) — 60 ×.

As shown by the scheme there are two different types of sandstone, a white or yellow type included in the series of strata consisting of limestones and shales, and a red type which forms the youngest part of the series. All the zones are fossiliferous and the fossils are marine shallow-water forms throughout.

The white or slightly yellow sandstone is accessible at Klinta, at the Ringsjö shore and at Bjersjölagård. The rock is relatively loose. EICHSTÄDT (1888, 138) states its thickness to be 12 m at Klinta and 22,5 m at Bjersjölagård. No fossils have been found in the white sandstone at Klinta and at Bjersjölagård only a couple of species of *Grammysia* (according to TULLBERG 1882, 13 *Gr. cingulata* HIS. and *Gr. rotundata* SOW.).

The red sandstone forming the upper part of the series of strata is outcropping both at Klinta and at Öved and Ramsåsa. The colour is somewhat varying, more or less highly red, sometimes gray with red spots. The hardness varies also and so does the thickness of the beds. Some of the beds are suitable for building purposes, others are looser or more thin-bedded and of no practical value. Here and there between the sandstone beds layers of red clay occur. It has not been possible to measure the thickness of the sandstone series directly and the estimated values vary greatly. Thus Tullberg (1882, 12) states that the red sandstone at Klinta is 148 m thick, while Eichstädt states a thickness of only 27 m. No doubt the latter value is the more correct of the two. The sandstone at Öved is thicker. According to Tullberg the thickness amounts to 200 m. Eichstädt reduces this to a third or about 70 m.

The thickness at Ramsåsa is not known. Among the spread localities of the sandstone to be found in this region, one is interesting from the point of view that it enables us to study the occurrence of the sandstone in different developments and together with shale: at the large quarry at *Ramsåsa* the sandstone is exposed in a series about 15 m thick. The succession of strata is given here after Grönwall (1897, 221).

x	Shale, brown, nodular	25	cm
v	Sandstone, hard, dark	45	»
u	Shale and shaly sandstone	35	»
t	Sandstone, hard, dark, with *Beyrichia*	8	»
s	Sandstone, hard, shaly	18	»
r	Shale	112	»
	(Covered layers)	80	»
q	Shale, brown, with *Beyrichia* a. o.	10	»
p	Limestone, partly rich in fossils	7	»
o	Shale, gray and brown	30	»
n	Sandstone, shaly, and brown shale; in this *Beyrichia* a. o.	100	»
m	Sandstone, shaly, and brown shale; micaceous	15	»
l	Sandstone	15	»
k	Sandstone, shaly, interbedded with brown shale	42	»
j	Sandstone	7	»
i	Sandstone, shaly	15	»
h	Shale, brown	15	»
g	Sandstone, thick-bedded	50	»
f	Sandstone, shaly, with shale; in this a sandstone bed free from lime and rich in moulds of molluscs	150	»
e	Sandstone, thick-bedded	188	»
d	Sandstone, shaly, micaceous and with tracks	118	»
c	Sandstone, thick-bedded	68	»
b	Shale	33	»

a	Sandstone, thick-bedded, with shale	445 cm
	Shale, gray, highly micaceous	—

The series of strata exposed in the above section is principally built up of sandstone. Shale is mainly present as embedding between the sandstone beds. Limestone occurs in only one thin bed. At other places in the Ramsåsa field red limestones and shales occur in larger quantities.

The petrographical character of the sandstone varies somewhat in the different beds in one and the same section as well as in the one or the other locality. A few types will be illustrated in the following.

The building stone. The thick-bedded sandstone suitable for building purposes is a fine- and even-grained quartz sandstone with no or only a small content of calcite. As a rule the grains are somewhat rounded, 0,03—0,08 mm in diameter. Hæmatite occurs as cement and matrix in varying quantity and gives the sandstone a red colour, lighter or darker according to the content of hæmatite. The stratification is often distinct. Here and there a fine cross-bedding with material of somewhat varying coarseness is found. The rock is easy to work, even for finer ornaments, and very resistant to weathering.

Micaceous, red sandstone, often thin-bedded quartz sandstone, sometimes slightly calcareous, is a common type. Size of grains and content of hæmatite as in the thick-bedded form mentioned above. Moulds and tracks not uncommon.

Calcareous sandstone occurs in thin beds, usually fossiliferous, sometimes in a high degree. The mollusc beds at Klinta and Ramsåsa belong to this type of rock. A similar bed is to be found in the upper part of the series of strata at Helvetesgraven at Öved but here the rock is highly micaceous and so calcareous that it ought to be termed *arenaceous limestone.* Fragments of fossils are so numerous in this bed that it also deserves to be termed »fragment limestone».

As shown by the quoted Ramsåsa section, *argillaceous, red sandstone,* shaly or thin-bedded, occurs together with red shales in large parts of the series of strata. The content of mica varies. Ripple marks and tracks are not uncommon in this rock.

Two-coloured, white and red sandstones occur together with one-coloured, red ones. Fairly common are round white spots on a red ground. In this case the white sandstone is limited to spherical or disk-shaped portions in the red. The only difference between the white spheres and the red surroundings is that the former are devoid of hæmatitic matter. The same is found almost everywhere in red sandstones. Whether these white portions are »bleached» parts of an earlier wholly red sandstone or whether they are the last uncoloured remains of an originally white but afterwards by iron oxide coloured sandstone will not be discussed here [1]. An opportunity will be given to return to this question in connection with a general investigation of the colour of the sediments.

[1] Calcareous nodules in a white sand may have remained uncoloured when the surrounding sand was coloured by ferruginous matter.

The formation of the Downtonian sandstones in Scania has taken place in shallow water, partly in the littoral zone. Their marine character is confirmed by the marine fossils distributed in the greater part of the series of strata, sometimes accumulated in larger quantities.

The red sandstones completing the series of strata show that the forming conditions have to a certain degree undergone a change during the period of deposition. The material, with which the area of sedimentation was supplied during the youngest epoch of the Silurian time, was of a different character than the earlier deposited.

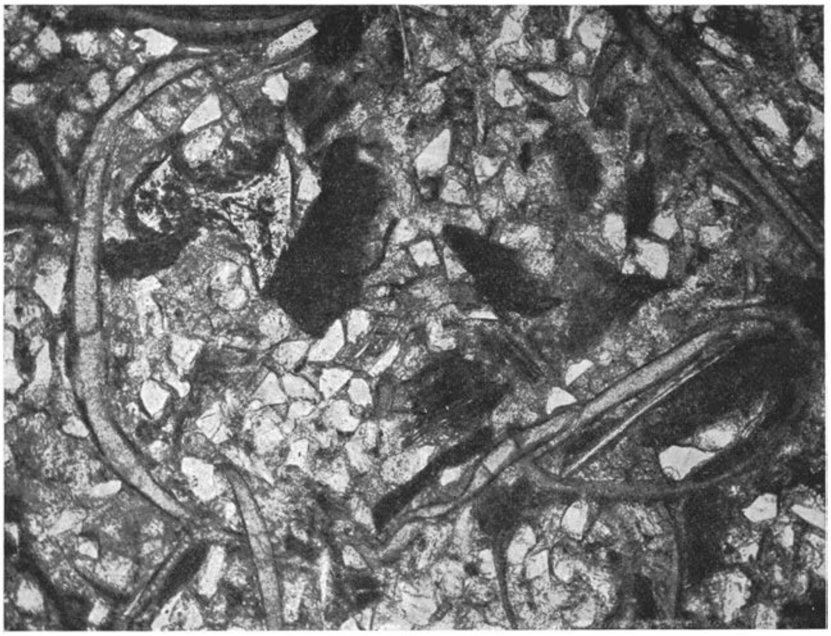

Fig. 97. Calcareous sandstone with shell fragments and hæmatite pigment. Öved-Ramsåsa series (Downtonian), Öved, Scania. (Pr. 2596. Pl. 280.) — 60 ×.

It indicates that the arid climate reigning during the oldest Devonian in the North of Europe has begun to be noticeable already at the end of the Silurian. In the South of Sweden the transition from Silurian to Devonian has been fairly imperceptible and at present it is uncertain whether the youngest strata of sandstone in the red sandstone series mentioned above should really be counted to the Silurian or whether they do not more likely belong to the oldest Devonian.

The grindsandstone in Dalecarlia.

Like the youngest Silurian strata in Scania those in Dalecarlia are developed as a red sandstone. In many places, especially in the neighbourhood of Orsa, they are quarried as grindsandstones, and on that account this sandstone series has of old been termed »the grindsandstone of Dalecarlia».

The rock shows a certain correspondence to the sandstones in the Öved-Ramsåsa series. It is developed as quartz sandstone or calcareous sandstone with varying content of hæmatite. As a rule the grains are of uniform size, 0,5—0,15 mm in diameter, angular or slightly rounded. The strata vary from thick-bedded to shaly.

Fossils are very sparingly present and only in the calcareous forms of sandstone. In the sandstone at Nederberga mentioned earlier (HADDING 1927, 28) the percentage of lime is in certain beds so high that the rock is transformed into arenaceous limestone. The fragments of shells in this rock are mostly strongly worn and rounded. At the same place, beds are also to be found built up of small, rounded, dense, red grains of limestone, 0.5—1.5 mm in diameter, which lie embedded together with small grains of quartz in a colourless, crystalline, calcitic mass. No doubt these lime-grains are formed by disintegration of an earlier deposited calcareous mud. The formation can have taken place in connection with the drying up and consolidation of the mud, i. e. in a similar manner as the formation of mud-cake conglomerates (see HADDING 1927, 63 and others).

Rounded clay-flakes, tracks and mud-cracks (see HADDING 1927, 20, fig. 4) show that the sandstone is a deposit in shallow water, partly formed in the littoral zone. It is of the same character as the red sandstones in the Öved-Ramsåsa series and is probably about the same age or rather somewhat older than the upper part of this series.

The Keuper Sandstones in Scania.

At a great number of places in the south-western half of Scania strongly coloured, often variegated clays, sandstones and conglomerates are found, which are now generally counted as Keuper sediments. The determination of their age is not based on the content of fossils, no such having hitherto been found in this series of strata, but instead on the series' connection with the carboniferous Rhætic strata of Scania. The transition from the latter to the Keuper proper is so imperceptible that it is often impossible to draw a definite line between them. This fact is distinctly seen in numerous sections (mostly drill cuttings) in the different coal districts. Though nothing in the character of the Keuper rocks contradicts a formation during for inst. the Paleozoic, they cannot, however, with their occurrence, have been formed during this era [1]. It is most correct to interpret these rocks and the Scanian carboniferous formations (Rhætic-Liassic) as a continuous series with transition from continental to lagoonal sediments and from these to normal marine deposits. Here, however, we may discuss the continental strata, the Keuper, separately.

In the following an account will be given of the occurrence of the sandstones in a few places, of their petrographical development and of their formation.

[1] Pebbles of Paleozoic rocks have been found in the Keuper conglomerates (see HADDING 1927, 102).

The Keuper sandstones at Bälteberga.

Nowhere in Scania are the Keuper strata so easy of access as at Bälteberga, 10 km NE of Landskrona. In the ravine in the northern part of the park there is a section 11—15 m high through a series of strata built up of sandstones, conglomerates and shales.

The position of the strata varies, in some places it is horizontal, in others

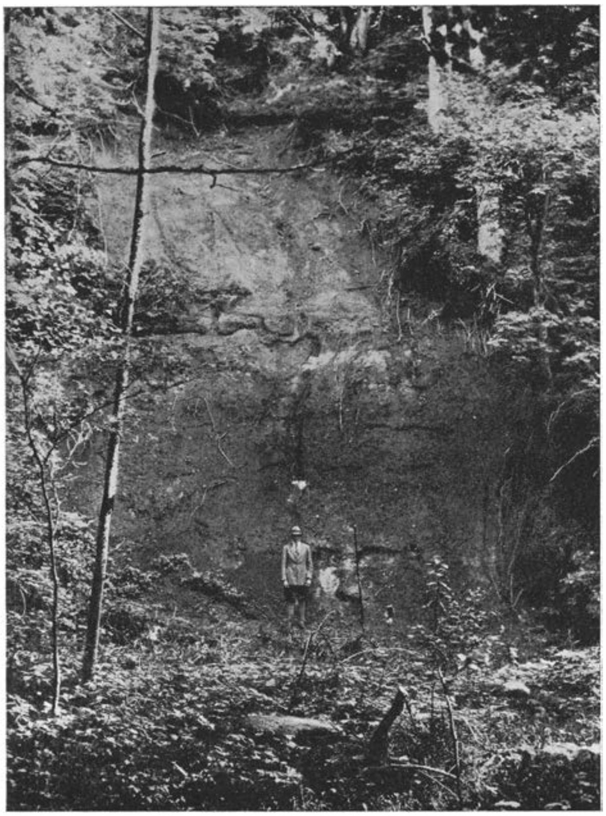

Fig. 98. Keuper sandstone and conglomerate. Bälteberga, Scania.

dipping. Possibly this is partly due to disturbances of the strata but partly it undoubtedly originates in primary conditions of stratification.

As the beds usually thin out to one or both sides, we find, if we follow the cutting along the brook, the series of strata fairly varying. At one place conglomerates are principally found (see fig. 99), at another there are hardly any conglomerates at all (see fig. 100). At one place the sandstone shows fine lamination, at another no distinct stratification.

Concerning the sandstone in the two sections reproduced here it should be noticed that it is often cross-bedded and sometimes shaly, when occurring between conglomerate beds but without distinct stratification, when occurring without any direct connection with coarser sediments.

The conglomerates occurring together with the sandstone are rich in well rounded pebbles, mostly from 1 to 5 cm in size but pebbles up to 20 cm in diameter are not uncommon. The cementation in the conglomerates is insufficient to make the rock solid. The pebbles loosen easily from the arenaceous matrix.

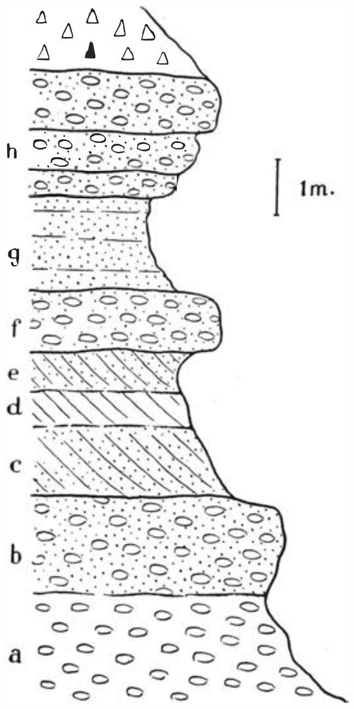

Fig. 99. *The Bälteberga section 1.*

h Conglomerate, coarse, red
g Sandstone, coarse, red
f Conglomerate, with distinct bedding, red
e Sandstone, loose, cross-bedded, red
d Sandstone, » » white
c Sandstone, » » red
b Conglomerate, coarse, red
a Conglomerate, coarse, white and red.

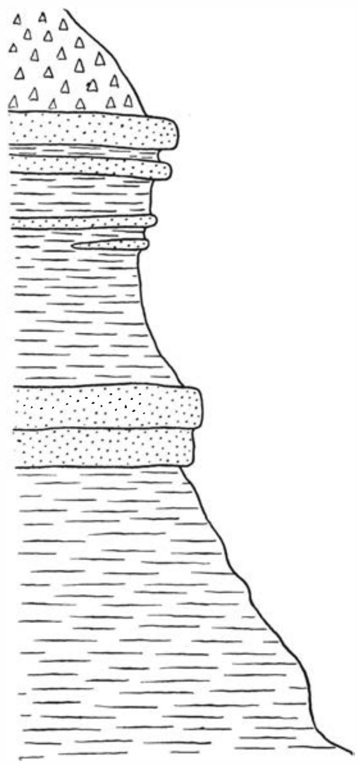

Fig. 100. *The Bälteberga section 2.*
The series of strata is wholly built up of sandstone, with harder and looser bed-like portions. Sometimes the hard beds terminate abruptly in a manner shown in the fig. 101.

The sandstone also is only slightly cemented. It can often be dug out with a spade. In other cases it is more solid, and here and there alternating hard and soft portions are found. In the sections the former are standing out and we have an impression of a distinct bedding (fig. 101). On closer scrutiny the phenomenon is found to be most intimately connected with the cementation. The harder portions run into the looser without interruption. The reason why some parts are harder than others is that the former contain more cement than the latter. As this additional cementation in the hard parts consists partly of hæmatite, these bed-like portions of the series of strata are red, while the looser parts are yellow or white. It should, however, immediately be emphasized that all red portions are not solid nor all yellow loose, sometimes examples of the contrary are also found, which show on the one hand that the hæmatite is not

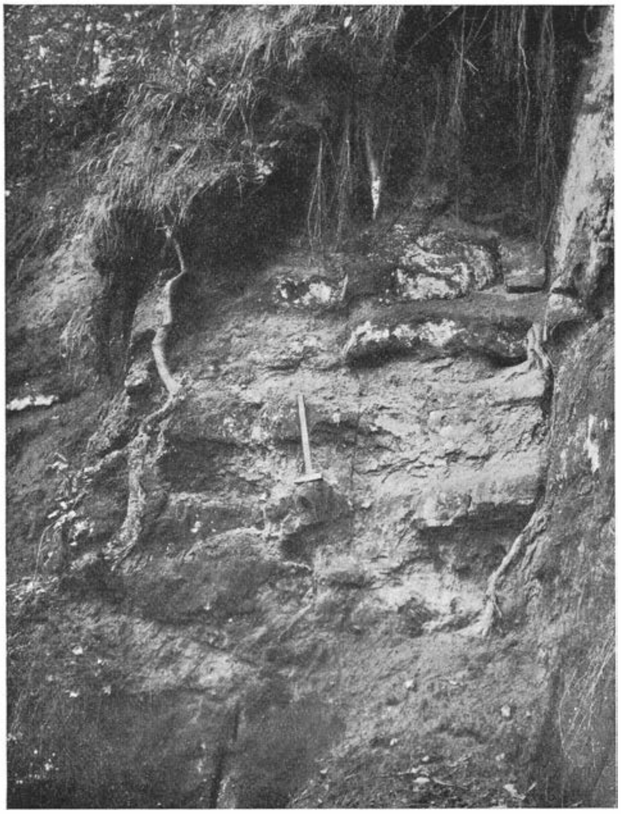

Fig. 101. Fine-grained, soft, yellow sandstone with hard, red beds. Keuper. Bälteberga, Scania.

always able to make the rock solid, and on the other hand that cement of some other kind (usually calcite) can also be present and give the rock a relatively good solidity.

The abrupt break in the bed-like portions is also distinctly visible in the Bälteberga section. That the break is not caused by faults is shown by its presence also where traces of such are not otherwise found in the series of strata.

As mentioned above the harder, bed-like portions are more cemented than their surroundings. If the cementation is not evenly divided in a horizontal direction, the solidity will vary. A layer appearing at one place as a hard bed may at another place consist of loose sand. The sudden transition may be due to different causes, either primary or secondary. It seems most probable to the author that the cementation has been more or less strong according to the sand's power of adsorption.

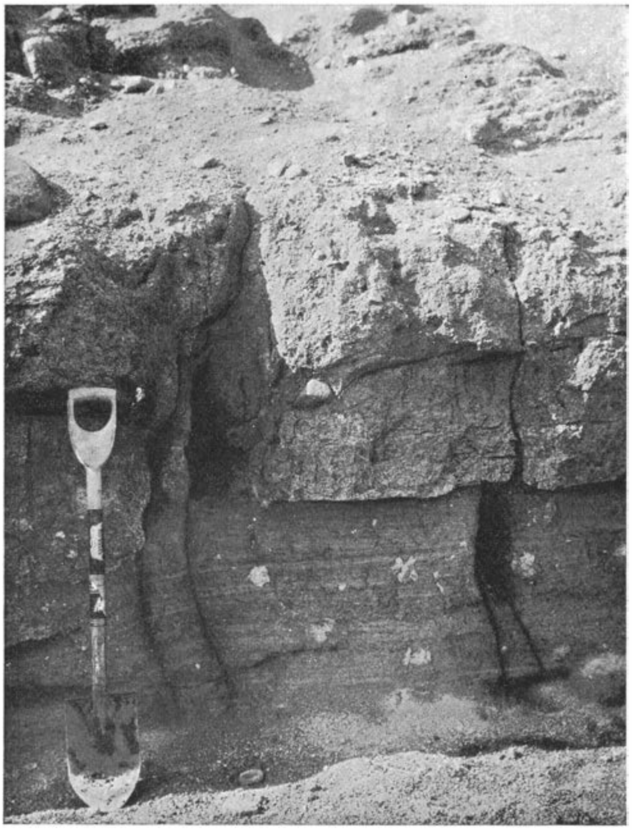

Fig. 102. Thick-bedded or unstratified, coarse-grained, partly conglomeratic sandstone resting on a more fine-grained and laminated one. Keuper. Ottarp, Scania.

The Keuper sandstone at Ottarp.

At Ottarp the Keuper beds are outcropping or easy of access in a number of places. Red clays and sandstones seem to be most common. In a cutting 350 m WSW of the church of Ottarp sandstone is found together with conglomerate. The rock is rust-coloured or brownish red. It is so loose that samples of it are smashed to pieces by a light stroke of the hammer.

In part of the section the stratification is the same as that found in fluviatile deposits. Lenses of coarse material, often conglomerate, lie embedded in fine-grained sandstone, which sometimes shows distinct cross-bedding. By the alternation of coarse and fine material the stratification is very pronounced.

In other parts of the section the material is of uniform size, middle-coarse sand. The stratification is indistinct and noticeable only in harder and looser, bed-like parts formed in the same manner as at Bälteberga — by a firmer cementation on certain levels. This form of development is mainly found in the upper part of the profile.

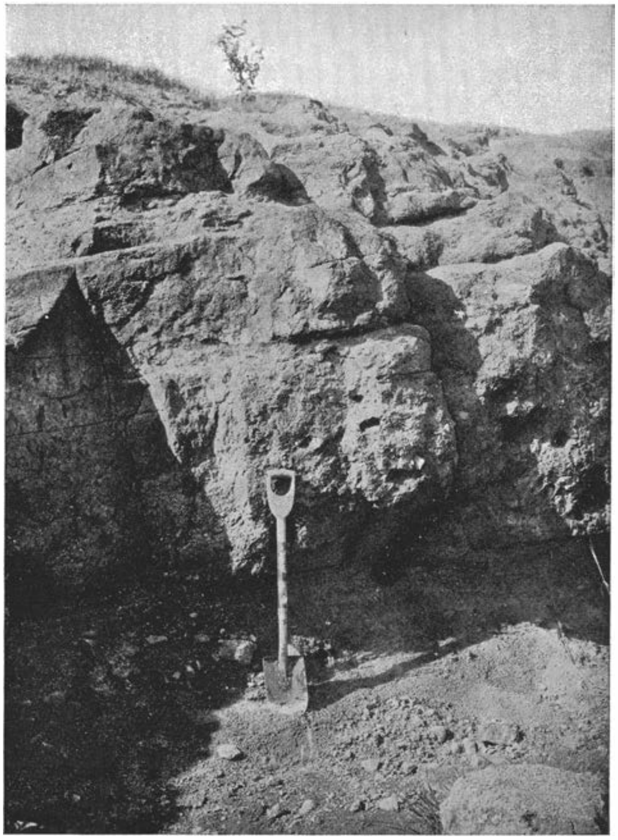

Fig. 103. Sandstone, partly conglomeratic. Keuper. Ottarp, Scania.

The Keuper sandstone at Kågeröd.

The Keuper beds in the neighbourhood of Kågeröd are of old well known. The Scanian Keuper was even called »the Kågeröd formation» before a definite opinion of the age was formed. As the strata are only slightly outcropping at present, no new observations are to be recorded from this place. The author refers to the earlier mentioned section (HADDING 1927, 102), measured by TULLBERG about 1880. As this shows, the sandstone occurs here between slightly yellow and slightly blue clay. The sandstone itself is green and bluish green.

The Keuper sandstones in the drill cutting at Klappe.

On the numerous deep drillings made in later years at different places in NW Scania the Keuper beds have frequently been found. The drilling cores or samples of them are kept at the Geological-Mineralogical Institute of Lund but unfortunately they are stored in such a manner at present that they are not accessible for an examination.

The drilling at Klappe, about 7 km SE of Höganäs, throws special light upon the uniform development of the Keuper beds. It was made in 1919 and to a depth of 517,81 m. More than half of this, or 271,05 m, was occupied by Keuper sediments, the remainder by Rhætic-Liassic and a few Quaternary beds (13 m).

A summary of the youngest part of the Keuper beds observed in the drill cutting will be given below. Similar beds occur in the lower part of the series of strata, on which account it is useless to go through it here also. The statements are based on the preliminary examinations of the cores made by the geologist Dr G. Ekström during the drilling.

The series of strata in the upper Keuper beds in the drill cutting at Klappe.

(at a depth of 246,76—327,11 m).

Clay, gray and red, flamy, somewhat arenaceous	5,34 m
Sandstone, white, middle-coarse, calcareous	2,40 »
Clay, reddish brown, gray-spotted	2,60 »
Arkose, grayish white	0,30 »
Clay, reddish brown, gray-flamy, partly calcareous and containing calcareous concretions	14,98 »
Sandstone, greenish gray, with felspar and brown lumps of clay	3,59 »
Conglomerate in arkose, pebbles 3—5 cm	0,38 »
Clay, reddish brown, arenaceous, with bluish gray lenses of sandstone	1,15 »
Arkose, bluish gray, with lenses of brown clay	5,32 »
Clay, reddish brown	0,20 »
Sandstone, grayish blue, with grains of felspar and lenses of clay	3,73 »
Clay, reddish brown	0,30 »
Sandstone, grayish blue, coarse, loose, with an edge of reddish brown clay	7,00 »
Clay, reddish brown, arenaceous, with lenses of grayish blue sandstone	1,65 »
Sandstone, middle-coarse, loose	0,71 »
Clay, reddish brown, arenaceous	2,73 »
Arkose, grayish blue, coarse and loose or fine-grained, calcareous and hard	11,56 »
Clay, reddish brown, gray-spotted, arenaceous	1,68 »
Arkose, loose at the top, with lenses of reddish brown clay, hard at the bottom, calcareous	2,75 »
Clay, reddish brown, gray-spotted, rich in gray, calcareous concretions (up to 26 cm in diameter)	3,41 »
Sandstone, bluish gray, middle-coarse	1,01 »
Sandstone, reddish brown, fine-grained, with calcareous concretions	1,92 »
Arkose, alternately bluish gray and reddish brown strata	2,04 »
Conglomerate, round pebbles in hard, calcite-cemented, bluish gray sandstone	0,14 »
Clay, reddish brown, arenaceous, with calcareous concretions	1,28 »
Sandstone, reddish brown, fine-grained, argillaceous	0,36 »
Sandstone, bluish gray, with calcareous concretions	1,82 »
	80.35 m

About 55 % of the series of strata consists of sandstone and arkose. The slight content of conglomerate (about 0,5 %) and the high content of clay show that the series of strata has been formed partly under other conditions than the series of strata at Bälteberga.

The petrographical development of the Keuper sandstones.

The Keuper sandstones show strong changes in the size of grains, colour and cementation. The content of minerals also varies. The said series of strata

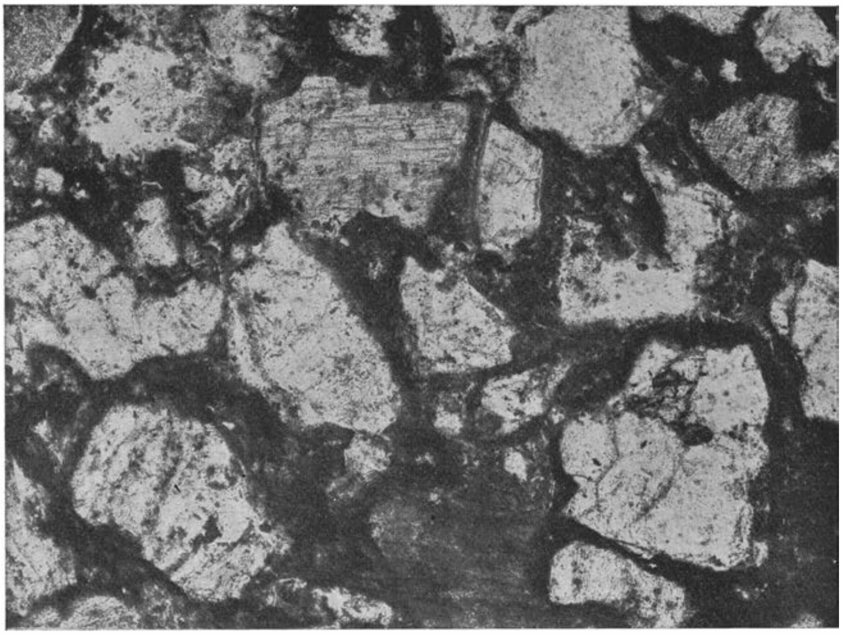

Fig. 104. Argillaceous and calcareous sandstone (arkose) with angular grains. Keuper. Hoby, Scania. (Pr. 665. Pl. 302.) — 60 ×.

contains arkoses as well as sandstones poorer in felspar. Instead of giving an account of all the observed combinations of variable qualities, we shall make the latter the object of our investigation. Grains (size, form and kind), matrix, colour and cement will be treated separately in the following.

The grains are usually sub-rounded. The more or less pronounced roundness can hardly be connected with the occurrence of certain other qualities. It may possibly appear as if the highly calcareous sandstones contain the best rounded grains. As a rule the grains of felspar are less well rounded than the quartz grains.

In most of the sandstones the diameter of the grains is about 1 mm. Transitions to the conglomerates on the one hand and to the arenaceous clays on the other hand are formed by increased or decreased size of grains. It is almost a matter of course that the argillaceous sandstones belong to the more fine-grained forms. Frequently, though not always, those rich in lime and iron also belong among them. The coarser forms sometimes show an abundant cement of calcite and a strong red colour.

The quartz grains dominate among the grains in the Keuper sandstones but the grains of felspar are always found and not infrequently in considerable quantities. In the samples examined, however, the ratio felspar : quartz has not exceeded 1:10.

The grains of felspar consist mainly of microcline but plagioclase has also

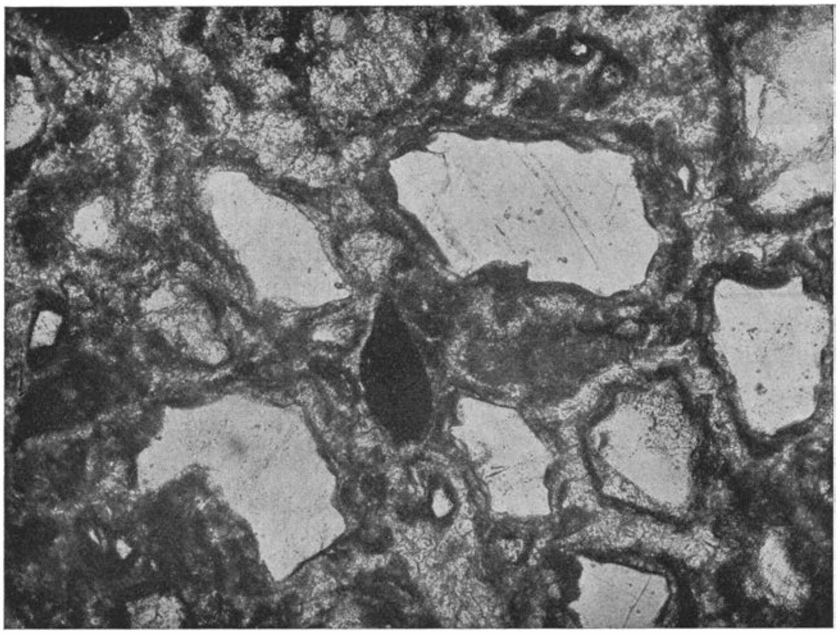

Fig. 105. Calcareous sandstone with angular grains. Red calcite matrix with zonal structure. Hæmatite abundant. Keuper. Hoby, Scania. (Pr. 2466. Pl. 301.) — 60 ×.

been observed. They are sometimes fresh but more frequently more or less kaolinized. In the gray sandstones the grains of kaolin are purely white, in the red, on the contrary, they are coloured by oxide of iron.

Of other grains observed in the Keuper sandstones grains of sandstone, fairly abundantly present in the sandstone at Nyhamn, may particularly be mentioned. The grains have a diameter of about 0,4 mm and are built up of quartz grains with a diameter of about 0,03 mm. In this case the grains of sandstone are probably derived from the Cambrian sandstone, which may be supposed to occur on the southern as well as the northern (at Rekarekroken) side of Kullen.

Grains of heavier mineral are very sparingly present, in which there is, perhaps, nothing astonishing, the detritus-delivering gneiss in this part of Scania being a rock poor in heavy minerals, save magnetite. Still, one might expect to find grains of garnet in for inst. the sandstone at Nyhamn, as the pre-Mesozoic bedrock in this region contains an abundance of garnet-bearing rocks. But this mineral seems to be absent in the Keuper sandstone as well as in the Cambrian sandstone from the same region (cf. p. 77).

The matrix consists of clayey substance and in certain cases probably of ferric and calcareous mud also. The clayey substance is partly the same as in the clay-beds: — a reddish brown or brownish red, arenaceous and sometimes calcareous mass. This gives the sandstone a red colour. In other cases the clayey substance is grayish blue and then, of course, the pigment of hæmatite is absent. Where the clayey substance occurs in the sandstones without connection with an abundant calcite cement the rock is loose and crumbles readily.

Lenses of clay are also found in the sandstone. They are rounded fragments of earlier deposited clay-beds. Besides these, out-thinning clay-layers are also present in the sandstones. These layers are no doubt primary deposits. They indicate occasional changes in the sedimentation, just as the sandstone lenses in the clay-beds.

Calcareous mud as matrix is no doubt primarily present in those cases where the sandstone is transformed into arenaceous limestone. The grains lie so scattered that they must, on deposition, have been separated by some substance simultaneously deposited (fig. 105). As no other substance than the calcite is present in any greater quantity, this must be considered to be the filling matter. It has, however, undergone a later recrystallization. In this case the matrix cannot be distinguished from the cement.

No doubt the hæmatite has also, in most cases perhaps, been deposited at the same time as the sand-grains, though it has first during the diagenesis obtained its present character. Like the calcite it is matrix and cement at the same time.

As is evident from the preceding *the cement* often consists of calcite or hæmatite. In the rust-coloured sandstones it consists of limonite, in the pure sandstones of quartz. The latter is probably far more common than a microscopic investigation shows, for it is not visible in the clayey or ferruginous sandstones. The good solidity sometimes noticeable in the lime-free, clayey sandstones is certainly due to the rock being cemented with quartz impregnating the clayey substance.

The calcite cement is sometimes fine-crystalline, sometimes developed into fairly large, macroscopically visible crystals. Thus at Nyhamn the sandstone shows about 1 cm^2 large, shining cleavage surfaces (fig. 106 and 107).

The calcite also occurs locally enriched partly in form of hard lenses or nodules in the sandstone, partly as secretions. The lenses and nodules are concretionary. They differ from the surrounding sandstone only by a higher percentage of calcite. Sometimes they give the rock a conglomeratic appearance (Hadding 1927, 100 and 162).

The colour of the sandstones is essentially dependent on the colour of the matrix. If the matrix is absent, the rock is white or, if fresh felspar is present, slightly red. Hæmatite or limonite in the matrix gives the rock a brownish red or rusty brown colour. The colouring effect of the argillaceous substance is due to its eventual content of iron. As shown by the series of strata at Klappe (p. 201), most argillaceous strata are reddish brown. Sometimes, however, a

Fig. 106. Calcareous sandstone, red, with coarse-crystalline calcite cement. Some reflecting cleavage planes of calcite crystals are to be seen in the fig. Keuper. Nyhamn, Scania. — $^1/_1$.

white, more frequently bluish gray or bluish green argillaceous substance, often mixed with small white grains of kaolin, is found in the sandstones. The green colour is occasionally fairly pronounced (Vallåkra).

The formation of the Keuper sandstones.

The Keuper sandstones in Scania have for a long time been regarded as continental deposits. As reasons for this have been stated partly the continental character of the rocks and partly the total absence of fossils. In these facts there is no doubt reason enough to suspect a non-marine formation.

But there is still another factor to consider on judging the forming conditions of the strata, viz. their stratigraphical relation to other sediments, the formation of which appears from the content of fossils. As mentioned above this factor also shows that the continental formation is indubitable. After the deposition of the Keuper beds a marine series of strata is formed during a steady subsidence of the region. The Keuper sediments are superposed by lagoonal and estuarine sediments rich in fossil plants, and these beds are in their turn followed by pure marine formations partly rich in fossils. Consequently the transgression does not occur until after the deposition of the Keuper beds.

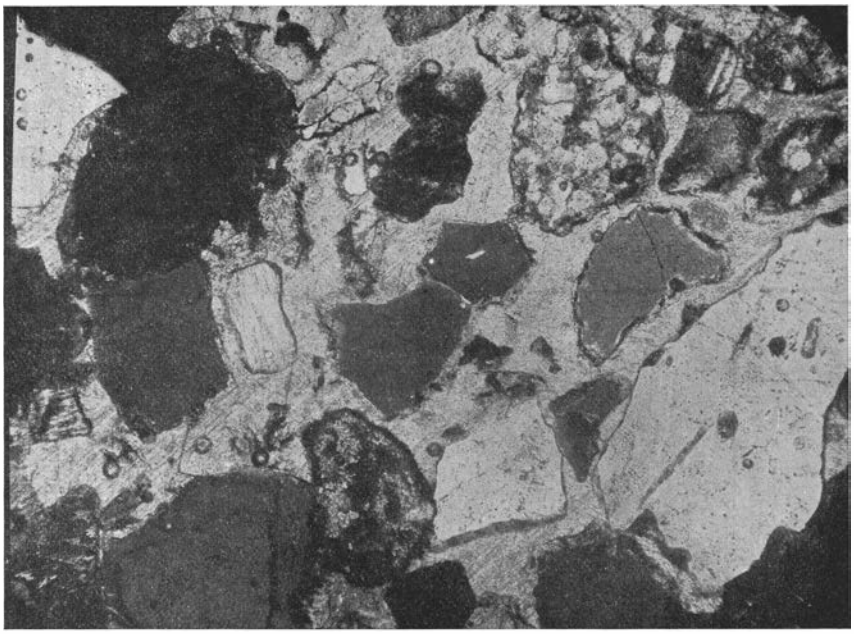

Fig. 107. Calcareous sandstone, red, with coarse-crystalline calcite cement. Keuper. Nyhamn, Scania. (Pr. 668. Pl. 300.) — 50 ×. Nic. +.

If we wish to form a more exact idea of the origin of the Keuper beds, we must study not only the development of the rocks but also their occurrence. It is necessary to follow up a stratigraphical investigation regionally, making it possible to judge the sedimentation all over the region during a certain period. First then can we gain a complete survey of the sedimentation on the land surface on which the Keuper beds were deposited. It is quite outside the compass of this work even to discuss these regional sedimentary conditions but it may be appropriate to draw attention to the different forming conditions affecting the character of the rocks.

The circumstances or factors, which in the first place deserve consideration on investigating the formation of a sedimentary series of strata are the origin (the sediment-yielding factor), the wear, sorting and transport of the material and the conditions of deposition.

On examining the material in the Keuper rocks with regard to its *origin*, one soon notices that pebbles of sedimentary rocks are rare. This is the more remarkable, as the Keuper beds lie wholly in the Silurian region and rest almost everywhere on Cambro-Silurian strata. The only possible explanation of this fact is that the Paleozoic sediments have not endured the strong weathering and the wear to which the material has been exposed. This explanation is also supported by the fact that the most consolidated rock in the Cambro-Silurian of this region, viz. the quartzitic »Hardeberga sandstone» is the sedimentary rock most abundantly present as pebbles in the Keuper conglomerates.

To what extent weathering products of sedimentary rocks form part of the Keuper rocks is more difficult to determine. If the youngest Silurian sediments in the greater part of Scania have been of the same type as those found preserved at Klinta, Öved and Ramsåsa (see p. 190 seq.), they must have been denuded to a large extent before the deposition of the Keuper. Then it would be a matter of course that part of this material had after rearrangement also been included in the Keuper series.

But the conglomerates show that the Archæan has delivered material directly to them and then no doubt also to the more fine-grained rocks. If the Archæan horsts, as the author believes, have existed already in Paleozoic times, the material has not necessarily been transported any longer distance. The sandstone at Nyhamn is only situated 2,5 km SW of the Archæan of Kullen, and the Kågeröd Keuper less than 1 km from the Archæan region of Söderåsen. The above-mentioned series of strata at Klappe is situated about 10 km from the nearest Archæan region, but then this series consists of relatively fine-grained sediments. The same is to a certain extent true of the series of strata at Hoby, though this also contains coarse conglomerates. The locality is situated 15 km NW of Romeleåsen and 22 km SW of the Archæan on Ringsjön, the two nearest places where the material has been available. Certainly, the series of strata at Bälteberga is only 13 km absent from the nearest Archæan field (Söderåsen) but the great development of the conglomerates in this locality is nevertheless astonishing, as the localities situated nearer the Archæan districts often show more fine-grained sediments. This fact proves that we cannot directly determine the distance to the source from the size of the grains.

However, the distances to the nearest possible material source tell us something of the *transport*. In certain cases, for inst. at Bälteberga, the conglomerates must be of fluviatile formation. The beds at Ottarp mentioned above are no doubt also fluviatile. The wear of the material and the stratification indicates a transport in running water. No traces of eolian wear have been found.

The *deposition* has in certain cases taken place in tranquil water. The beds of clay and the alternation between clay and sandstone have arisen during a sedimentation of this kind. In other cases the deposition has been fluviatile.

In many cases the cross-bedded sandstone is no doubt formed in this manner (cf. the Ottarp section). Fluviatile and lacustrine sediments can alternate in the series of strata. This fact as well as the quick variations of the rocks in a horizontal direction show that the sub-aquatic deposition has taken place in scattered smaller basins and at a very slight depth.

Attention has often been called to the fact that the strong colours of the Scanian Keuper beds prove them to be continental deposits. The red clays have been regarded as more or less lateritic sediments and the red sandstones as formed of sand mixed with lateritic material. The author will not dwell on the character of the argillaceous material here, as it will be discussed in connection with the account on the argillaceous rocks of Sweden. The colour of the sandstones has partly been treated of already (p. 205). As is evident from the statements made above the sandstones are to a large extent free from red »lateritic» impurities. The section at Klappe is a good illustration of this. The red clays alternate with gray sandstones. This series of strata conveys the opinion that the material has not been derived from an Archæan region with dominating lateritic weathering. In that case the argillaceous substance in the sandstones ought to have been of the same kind as in the clays. The red colour in certain strata may be derived from periodically precipitated iron oxide. This has been primarily deposited as hydrated oxide of iron and afterwards transformed into ferric oxide. In a number of sandstones, however, it is still present in its primary form, and the overlying Rhætic-Liassic beds show this form almost exclusively.

In this connection it should also be mentioned that the Keuper sandstones often contain an abundance of grains of felspar and lumps of kaolin. In the red sandstones the weathered felspar is often red from impregnation of hæmatite. Nowhere is there to be found such a complete decomposition of the silicates as on lateritization.

On summing up our observations on the formation of the Scanian Keuper beds, we may say that their formation is partly fluviatile and partly lacustrine (possibly also to a smaller extent marine). The bulk of the material is derived from the Archæan region, which may have been exposed to about the same extent as now. Nothing supports the supposition of a lateritization of the Archæan rocks at the time of the Keuper beds' formation or earlier. No traces of continental or marine sediments deposited after the great Silurian regression and before the Keuper period, have been found.

The Rhætic-Liassic Sandstones of Scania.

Strata belonging to the youngest Triassic and oldest Jurassic occur in some scattered regions in the south-western half of Scania. The determination of their age is based on a number of fossil finds. On account of the series of strata containing the only coal worth mining in Scania (and Sweden), it is in literature often called »*the coal-bearing formation of Scania*» or after its stratigraphical position »*the Rhætic-Liassic series of Scania*».

The series of strata continues uniformly without any greater discordances. There is no direct reason to divide it into two halves, one belonging to the Triassic and one to the Jurassic period. But a general change takes place in the course of the sedimentation. The basal beds are rich in clays and contain, besides the coal measures, several layers with well preserved plant fossils. The upper beds, on the contrary, are for the most part developed as sandstones and are poor in plant remains but instead they often contain a fossil marine fauna.

The series of strata varies considerably from one place to another but the different zones can nevertheless be fairly congruent. In his account of the rocks the author will therefore as far as possible follow the scheme of the zones [1].

Scheme on the Rhætic-Liassic deposits of Scania.

Liassic	The zone with *Nilssonia fallax*	SE Scania (Kurremölla)
	The Cardium bed	
	The Ammonites bed	N of Helsingborg and at Höör
	The Avicula bed	
	The Ostrea bed	
	The strata with *Cyclas Nathorsti*	
	The Cardinia bed	
	The Mytilus bed	
Rhætic	The zone with *Nilssonia polymorpha*	Helsingborg
	The zone with *Dictyophyllum acutilobium*	
	The Pullastra bed	
	The zone with *Thaumatopteris Schenki*	Stabbarp
	The zone with *Equisetites gracilis*	The coal district of NW Scania
	The zone with *Lepidopteris Ottonis*	
	The zone with *Camptopteris spiralis*	
	The zone with *Dictyophyllum exile*	

The division into zones does not agree quite satisfactorily with the series of strata, as it only indicates the position of certain fossiliferous strata in the latter and does not divide the series in its entirety. The scheme also requires a revision because the position of certain zones in relation to the other is not established. This may seem peculiar but is due to the fact called attention to previously that certain strata have a local development or a development that changes from place to place and a varying faunistic or floristic admixture. The numerous faults, dividing up the Rhætic-Liassic regions, have of course also made the stratigraphical investigation more difficult.

In spite of the said deficiencies in the scheme we may nevertheless make use of it in the following discussion on the rocks, and possibly the accounts given here of different parts of the series of strata may contribute to a more certain interpretation of the stratigraphical conditions also.

[1] Based on the works of LUNDGREN, ERDMANN and NATHORST (see the list of literature).

The sandstones in the Lower Rhætic.

The Lower Rhætic of Scania is characterized by the coal measures occurring there. In a few places these are subjected to mining, although they never attain any greater thickness. Together with the coal, clays and sandstones occur in varying quantity. At *Billesholm* the sandstones dominate completely but at *Skromberga* the coal lies entirely embedded in clay and shale [1].

In the Höganäs-Billesholm field, the mining district proper in NW Scania, two coal measures besides smaller coal-seams are subject to mining. They are generally divided into several layers by carboniferous shales. The following section from Skromberga shows the relation of the strata to the zones communicated above.

The series of strata at Skromberga (the Sjöcrona shaft)

Sandstone	13.0 m	— — — — —
Fire-clay, gray	60 cm	Zone with *Equisetites gracilis*
Upper coal measure	15 »	— — — — —
Clay, black	250 »	Zone with *Lepidopteris Ottonis*
Sandstone, argillaceous	72 »	— — — — —
Clay and shale	140 »	— — — — —
Lower coal measure	65 »	Zone with *Camptopteris spiralis*
Clay, gray (Klinker clay)	440 »	Zone with *Dictyophyllum exile*
Green clay		Keuper

At *Höganäs* the development of the strata is different but the zones present can nevertheless be identified with those at Skromberga. North of Höganäs the lower measure is outcropping and is worked together with the clays. The series of strata here (at *Margreteberg*) is as follows:

f	Sandstone	> 3 m
e	Lower coal measure (coal and interbedded shale)...	1,38 »
d	Fire-clay	2,00 »
c	Sandstone	1,30 »
b	Clay, black..	1,00 »
a	Clay, gray and yellowish gray	2,50 »

Both the sandstones present in the profile are fine-grained, loose, gray quartz sandstones. The stratification is sometimes indistinct, sometimes very distinct, in certain portions an even parallel-bedding but more frequently a cross-bedding or lenticular lamination. Enclosed dark, argillaceous or carboniferous layers make the stratification very distinct in certain parts of the sandstones.

[1] We beg to refer those interested in the series of strata to ERDMANN's work, 1911—1915, which contains a number of shaft- and drill-logs.

The lower sandstone contains an abundance of vertically standing plant remains (fig. 108). These formations are especially characteristic of the upper part of the sandstone. For the rest this sandstone is relatively pure, almost white, and unstratified. The grains of quartz are not noticeably rounded. They are 0,02—0,03 mm in diameter.

In the lower part of the lower sandstone the rock is more argillaceous. The lamination is here distinct, often very fine. In 10 mm the author has counted up to 33 dark, argillaceous layers, separated by 32 light ones poor in clay (fig. 37).

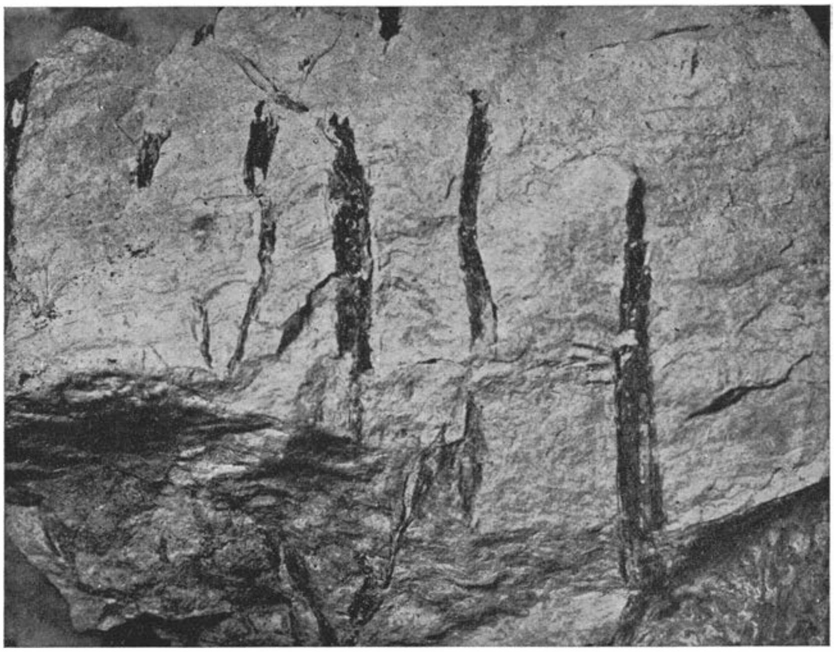

Fig. 108. Sandstone, fine-grained, gray, with vertical, fossil plant fragments. Rhætic. Margreteberg, Höganäs, Scania. — 1/1.

As in the overlying part the rock is also here fine-grained and free from or poor in lime. Occasional plant fragments are also present here.

The sandstone above the coal measure is grayish white with interspersed black grains or dark layers. The bedding is distinct. The stratification is generally uneven, lenticular, or here and there a cross-bedding. The bedding surfaces are covered with dark clayey substance. They are usually full of small pits and show sometimes winding worm trails. The size of the grains is about the same as in the lower sandstone but in certain beds they are somewhat larger, up to 0,2 mm. The sandstone contains a smaller quantity of light mica and some pyrite. On weathering it becomes rust-coloured or yellowish brown.

Ripple marks have been observed in the sandstone above the lower coal measure. Together with the plant fragments, the worm trails and the uneven bedding they show that the strata have been formed in shallow water.

The sandstones above and below the upper measure at Höganäs are light gray or white, fine-grained and of varying purity. One of them, quarried in the eastern part of Höganäs, contains plant remains but is otherwise very pure, white, unstratified and fairly loose. Others are argillaceous or interfoliated by thin layers

Fig. 109. Sandstone series, »Upper Pullastra bed». Rhætic. Ramlösa, Scania. (Section p. 213.)

of clay. These sandstones grade into the shaly ones, usually with uneven bedding surfaces. As a rule they are poor in or free from calcium carbonate but here and there distinctly calcareous beds occur. The content of iron in these gray sandstones is seldom remarkable. Neither pyrite nor siderite is present in any quantity worth mentioning. On weathering the rocks obtain as a rule only a slightly yellow colour from ferric hydroxides.

The sandstones in the Upper Rhætic of Scania.

Among the sandstones in the Upper Rhætic of Scania the *Pullastra bed* deserves special mention. In this bed, or more correctly zone, there is namely a marine fauna, the oldest in the series of strata. Besides a couple of forms of *Pullastra* (*P. elongata* and *P. Heberti*) several other lamellibranchs of the genera *Modiola, Protocardia, Myacites, Pleuromya* and *Ostrea,* occur here.

The Pullastra zone is outcropping at Ramlösa and at the brickyard of Helsingborg. At the first-mentioned place it is at present very easy of access in two cuttings in the Spa park. One of them, called by LUNDGREN »*the lower Pullastra bed*», shows the following series of strata (principally acc. to LUNDGREN 1878, 16).

3	Shale, gray, arenaceous and shaly sandstone with Sandstone, yellow, micaceous in thin out-thinning beds	3,5 m
2	Sandstone, »the lower Pullastra bed»	0,3 »
1	Shale, gray, arenaceous	1,5 »

The bulk of the section is occupied by a shaly, arenaceous-clayey rock of the type often found in the Rhætic of Scania. At a distance this rock shows a distinct horizontal stratification; on closer examination it appears more uneven, almost as if built up of thin lenses or out-thinning layers and laminæ. It is gray or bluish gray in colour. In a bed abundant moulds of *Pullastra elongata* were found.

The lower Pullastra bed is a fairly loose, fine-grained sandstone, light gray or slightly yellow. The quartz grains are slightly rounded, mostly 0,06—0,09 mm in diameter. As a rule the rock is free from or poor in lime but sometimes it contains calcareous nodules. Hard lenticles with a cement of iron oxide are also found. Scales of muscovite are present in small quantities, but they do not give the sandstone any distinct stratification.

The upper Pullastra bed at Ramlösa occurs in a series of strata rich in sandstones. In a section (fig. 109) recently cleaned out, which in 1928 was very easy of access, the author observed the following series of strata:

10	Thin-bedded sandstone (LUNDGREN's stratum 6 = *the upper Pullastra bed*)	65 cm
9	Thick-bedded sandstone (LUNDGREN's stratum 6 = *the upper Pullastra bed*)	35 »
8	Sandstone-shale, white	10 »
7	Loose, cross-bedded sandstone	38 »
6	Sandstone, loose, with lumps of iron oxide (LUNDGREN's stratum 5)	13 »
5	Hard sandstone, rich in oxide of iron	9 »
4	Sandstone-shale and Loose, white sandstone	25 »
3	Hard sandstone (LUNDGREN's stratum 4)..	55 »
2	Loose sandstone-shale (LUNDGREN's stratum 3)	22 »
1	Hard sandstone (LUNDGREN's strata 1 and 2)	100 »

The rocks in the upper Pullastra zone consist of pure or somewhat argillaceous, fine-grained sandstones. Sometimes they are noticeably calcareous, and the rock is then relatively well consolidated. The cement in the sandstones free from lime is usually quartz. It only occurs in a small quantity and never imparts any greater consolidation to the rock. In one bed a cement of iron oxide is abundantly present. This is the hardest in the series of strata. A small content of iron also occurs in the loose sandstones and is seen on weathering, when they take a

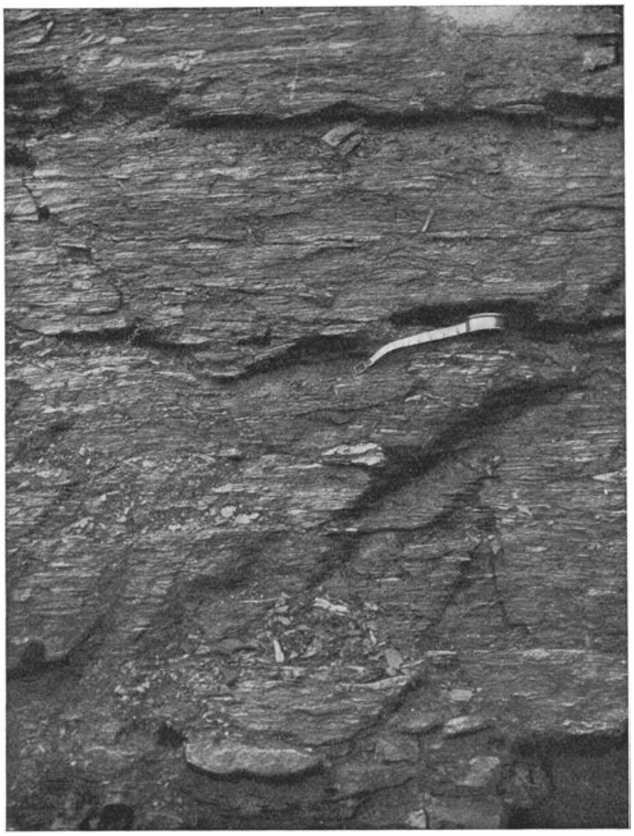

Fig. 110. Arenaceous shale. Rhætic. The brickyard of Helsingborg, Scania.

slightly yellow colour. An analysis of the rock in the upper part of the upper Pullastra bed gave the following result.

Fine-grained, loose, slightly yellow sandstone in »the upper Pullastra bed» at Ramlösa. Analysis by Sv. Palmqvist.

SiO_2	95,16 %
Fe_2O_3	3,95
Al_2O_3	Traces
H_2O	—
	99,11 %

The analysed rock was somewhat micaceous.

As mentioned above, the Pullastra zone is also accessible in the clay-pit at *the brickyard of Helsingborg.* The rocks change noticeably in a horizontal direction and the series of strata is disturbed by several faults. However, a coal measure forms a very good index stratum. In the westernmost, deepest quarry the section fig. 111 was observed in 1928 (section 4 m).

In the beds *a* and *b* the sandstone is fine-grained, gray, indistinctly or unevenly stratified. It contains in the lower beds an abundance of plant fragments (fig. 112).

The conglomerate forms only a thin, out-thinning layer of closely packed, reddish brown pebbles of iron sandstone about 2 cm large (fig. 17, p. 36). The pebbles are rounded but irregular in form. They show no concentrical structure but consist throughout of a uniform, fine-grained ferruginous sandstone. Galena also occurs in the sandstone as coating on the walls of thin fissures.

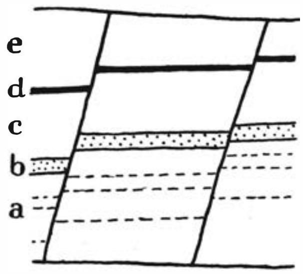

Fig. 111.
e Shale, gray, arenaceous
d Coal measure
c Shale, gray
b Sandstone bed with conglomerate of clay ironstone
a Shale and sandstone

In the easterly parts of the clay-pit the younger strata also are exposed. There the succession is as follows:

Shale, yellow, arenaceous and out-thinning beds of sandstone
Clay ironstone, out-thinning beds or lenses
Shale, gray, partly calcareous, hard, partly arenaceous
Coal measure
Shale, gray

In the sandstone beds above the coal measure NATHORST has found moulds of the same forms as in the lower Pullastra bed at Ramlösa. Ripple marks and worm tracks are often found in the sandstones. Cone-in-cone structure has also been observed in the highly arenaceous beds but is of course principally connected to the calcareous, arenaceous shales.

The sandstones are fairly loose. The grains are indistinctly rounded, somewhat larger in the Pullastra bed (0,06—0,08 mm) than in the other strata (0,02—0,04). The former are also less argillaceous than the latter.

According to the zone scheme two plant-bearing zones (see p. 209) occur in the youngest part of the Rhætic of Scania. They are both developed as shales. But between the Pullastra bed and the Mytilus bed sandstones are abundantly present. They are outcropping at *Helsingborg,* specially in the northern part of the town. From the slope between the tower of Kärnan and Stortorget MOBERG (1907, 279) gives the following section.

E Sandstone, gray, on weathering yellow, interstratified with soft shale 3,20 m
D Sandstone, white, in thick beds .... 3,15 »
C Shale, dark with thin beds of sandstone (partly with marine lamellibranchs) and lenses of clay ironstone .... 2,64 »

B Sandstone, grayish yellow, shaly .... 0,72 m
A Shale, dark (partly with plant remains) with occasional layers of light sandstone .... 1,54 »

From a petrographical as well as a paleontological point of view these beds differ only slightly from those described above. The shells, which occur as moulds in sandstone and clay ironstone, are of the same character (and mainly also the same species) as in the lower Pullastra bed. They are typical shallow water forms.

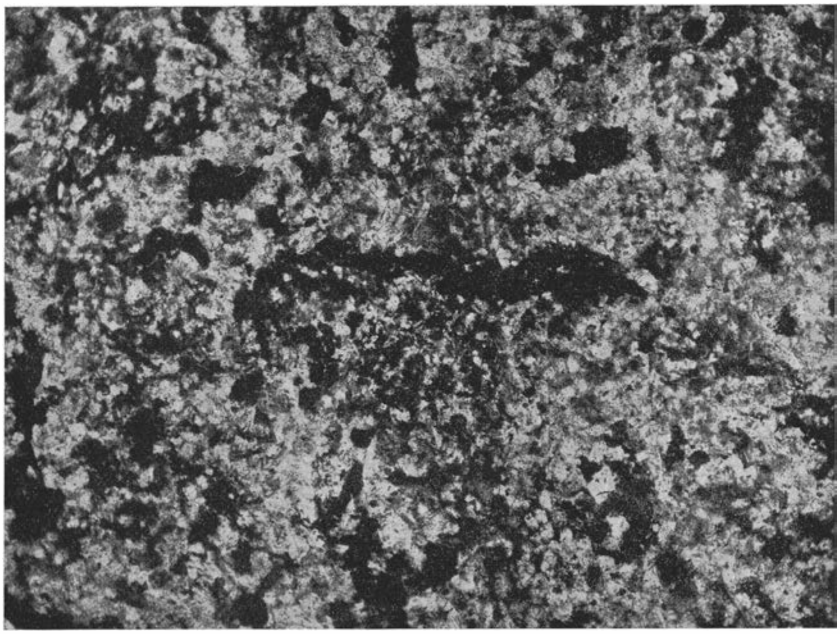

Fig. 112. Argillaceous sandstone, gray, with quartz cement and plant fragments. Rhætic. The brickyard of Helsingborg. (Pr. 673. Pl. 309.) — 60 ×.

Here and there the white sandstone, stratum D in the section, contains laminæ of clay, increasing in number towards the upper part of the stratum. Thin, somewhat rounded clay flakes formed by disintegration of thin clay-beds deposited between the sand-layers, are also found in the sandstone. As will be seen in the following, such clay-flakes and clay-pebbles are typical for several of the sandstones in the Liassic strata of Scania.

Sandstone with distinct parallel-bedding and well developed beds is seen in the railway cutting at *Pålsjö* (fig. 113). Fossils are not yet found in these but there is reason to suppose that the beds belong to the youngest Rhætic. Possibly they are partly of about the same age as the younger strata in the above-mentioned profile from Kärnan. The rock is a fine-grained sandstone, in certain beds fairly consolidated, in others looser.

The sandstones in the Lias of Scania.

The Liassic sandstones occur in three regions: N of Helsingborg, at Höör and in SE Scania. The development differs more or less in the three regions, and it is therefore appropriate to treat them separately.

The Liassic sandstones N of Helsingborg form a direct continuation of the Rhætic sandstones. The rocks are partly similar to those mentioned above. A

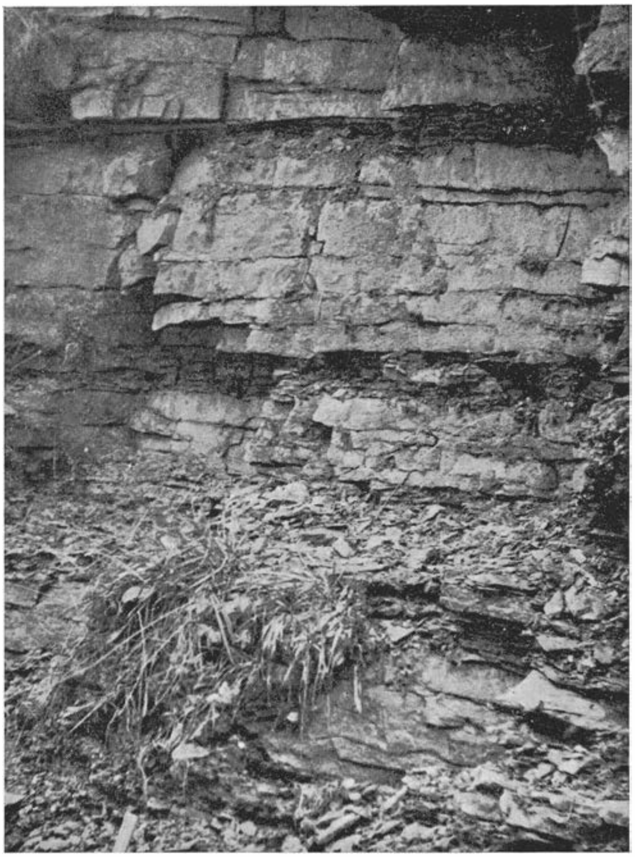

Fig. 113. Argillaceous sandstone beds and shales. Rhætic-Liassic series. Railway cutting, Pålsjö, Helsingborg, Scania. — $^1/_{12}\times$.

short account of the character of the strata and their occurrence at a few localities along the shore N of Helsingborg and at a couple of places E of Viken will be given in the following. The localities are chosen so that they include the beds given in the zone scheme.

On the shore at the fishing-village *Gravarna,* 250 m S of the farm Tinkarp the following strata are found (on the Museum label, »HADDING lokal 11, Gravarna»):

h	Sandstone, light, loose	9	cm
g	Sandstone with clay ironstone	6	»
f		10	»
e	Shaly sandstone, gray, spotted	6	»
d		9	»
c	Sandstone, gray with lumps of clay ironstone	8	»
b	Sandstone, slightly yellow, loose, with ripple marks	7	»
a		7	»

Fig. 114. Gray, shaly sandstone with burrows. Weathered upper bedding plane. Lias. Gravarna 11 e, Scania. — $^{1}/_{1}$.

The lowest sandstone beds are of the common, fine-grained, loose, slightly yellow type, often found in the Rhætic-Liassic series. The grains are somewhat rounded, mostly 0,1—0,2 mm in diameter. Enclosed thin lenses of clay or clay ironstone are not uncommon. They indicate a certain irregular stratification in the beds.

The ripple marks are very indistinct in both beds. The direction of the crests varies highly. On the lower bed it was measured at N 20° E, on the upper at N 40° E in one place and at N 68° W in another. The wave-length is 8—10 cm, the double amplitude 1—1,5 cm. The waves are symmetrical, often anastomosed, here and there interference ripples.

The shaly, gray sandstone (d—f) is of a characteristic, small-spotted appearance.

The grains are angular. They seldom exceed 0,3 mm in diameter. Argillaceous material and scales of mica are fairly abundantly present.

On closer examination the spots on the bedding surfaces prove to be the openings or cross-sections of vertical or inclined tracks. These tracks are cylindrical. On weathered bed surfaces they appear as a central cylinder, 0,8—1,5 mm in diameter, which springs up in a shallow depression or is surrounded by a wider tube 2—4 mm in diameter (fig. 114). The central cylinders are distinctly visible in vertical sections of the beds also. They have a black surface and differ clearly from the surrounding lighter rock. Downwards they deflect from the vertical direction and pass over into horizontal. It has not been possible for me

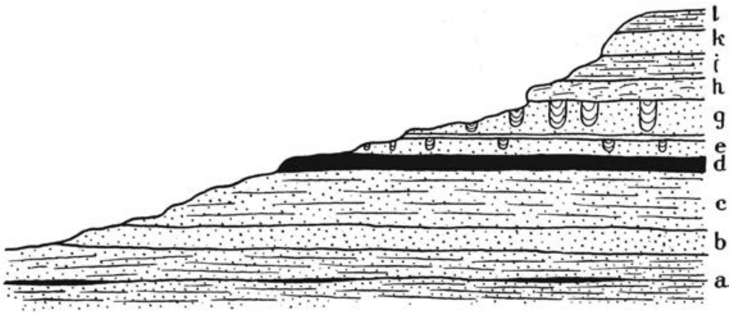

Fig. 115.

l	Shale, gray, arenaceous	—
k	Sandstone, gray or mottled	—
i	Sandstone, shaly, argillaceous, gray and brown	—
h	Sandstone, brown and yellow, *The Mytilus bed*	9 cm
g	Sandstone, gray, argillaceous, with clay ironstone and large *Diplocraterion*	15 »
f	Sandstone, shaly, gray	
e	Sandstone, shaly, gray, with fine and coarse tracks and *Diplocraterion*	6 »
d	Clay ironstone	4 »
c	Sandstone, shaly, hard	14 »
b	Sandstone, gray	6 »
a	Shale, gray, arenaceous and sandstone with ripple marks and layers of clay ironstone	50 »

to follow them farther. Possibly they bend upwards so that the track in its entirety is broadly U-shaped. It is quite certain, that it does not pass into a horizontal, winding track, such being wholly absent in the spotted sandstone beds.

The sandstone with clay ironstone (g) contains only small amounts of larger quartz grains (0,5—2 mm in diameter). The bulk is very fine-grained (diameter of grain $<$ 0,03 mm). Iron oxide occurs partly finely distributed in the mass, partly accumulated in diffuse lumps 0,07—0,15 mm in diameter. In the bed highly ferruginous portions alternate with less ferruginous.

On the shore at *Sofiero*, 125 m S of the mouth of the brook, the strata shown in fig. 115 occur (Hadding's locality 10, Sofiero):

The rocks in the above section are highly calcareous, argillaceous, gray, shaly sandstones with beds or lenses of brown clay ironstone and brown ferruginous sandstone. The stratification is distinct but irregular. The series of strata is of special interest on account of the fossils, tracks and markings occurring in it.

The tracks in stratum *e* consist partly of coarse, winding worm tracks without ornaments (fig. 116), partly of finer tracks with distinct ornamentation. The coarse tracks are cylindrical or slightly compressed. They are 15—20 mm in diameter. They run irregularly in the argillaceous sandstone or on the bedding surfaces.

Fig. 116. Argillaceous, shaly sandstone with coarse worm trails. In the lower part of the fig. a large *Diplocraterion*. Lias. Sofiero, 10 e, Scania. — C:a 1/8.

The fine tracks are the same as described and reproduced by LUNDGREN (1878, 34, pl. II, fig. 91, 92) under the term *Ophiura* sp. They occur on the bedding surfaces, are winding and may often be followed 10—20 cm. They are 2—3 mm wide.

Of almost still greater interest than these tracks are the U-formed burrows occurring in the same and overlying beds, possibly in two different forms. The burrows occur in an entirely different manner here than in the Cambrian sandstone. In the latter they were found in pure, white or slightly coloured sandstones, here they occur in a highly argillaceous and calcareous, loose and shaly sandstone. The structure of the U-shaped burrows, however, is frequently so completely similar to the Cambrian one that it cannot be doubted that they have originated in a similar manner, even though the burrow-building animals have evidently lived in different sediments.

The burrows are often better cemented (with calcite) than the surrounding rock, and on that account they can easily be picked out on the disintegration of the rock. They appear as U's with filling between the limbs. Sometimes calcite

Fig. 117. Sandstone containing abundant marine lamellibranchs. Ostrea layer in the »Mytilus bed». Lias. Gravarna, Scania. — $^1/_1$.

has also cemented the next vicinity around the burrows, especially around the vertical limbs. The formation originating from this is rather peculiar and would be difficult to interpret, if it had not been observed together with the more normally developed burrows.

The *Mytilus bed* is rich in moulds of *Mytilus acuminatis, Ostrea Hisingeri* and other shells (fig. 117). The rock varies somewhat. Sometimes it is relatively coarse but as a rule the grains do not exceed 0,1 mm in diameter. Scales of light mica occur scattered in the rock, sometimes accumulated in such a manner that they cover a bedding surface. The clayey substance is only sparingly present, and in this respect the bed differs from surrounding strata.

The Mytilus bed is to a large extent brown from limonite. Certain parts are firmly cemented by siderite, others are looser. The rock in the latter is slightly yellow.

Two analyses have been made on the rock by Sv. Palmqvist, the one on the dark brown, highly ferruginous part, the other on the light yellow, looser part. After these the following composition is calculated.

The Mytilus bed, Gravarna.

	a. The loose, light yellow part	b. The solid, dark brown part
In HCl undissolved (SiO_2 +)	94,62 %	67,37 %
Fe CO_3	3,37	29,01
Ca CO_3	2,01	3,62
Mg CO_3	—	Traces
	100,00	100,00

The stratification is only slightly pronounced but the rock cleaves readily along the portions rich in shells. The coarse-grained forms of the rock cleave less easily. The shells, the fragments of coal and the clay galls present in the rock have a more or less oblique position in relation to the bedding surfaces.

Like the lower sandstone beds those *above the Mytilus bed* are argillaceous. Clay ironstone occurs as irregular horizontal bands or thin layers and lenses. The size of the grains varies, even in one and the same bed. Certain portions (out-thinning thin layers) have grains 0,05 mm in diameter, others are coarser, with grains 0,1—0,3 mm in diameter.

Above the Mytilus bed follows a thick series of arenaceous shales with embedded sandstone in beds of varying thickness. One of these sandstones has been quarried to a large extent as grindsandstone. There are abandoned quarries both N of Sofiero and at Pålsjö.

The grindsandstone is an even-grained, fairly loose quartz sandstone (fig. 118). In the finer beds the grains are about 0,03 mm, in the coarser mostly 0,06—0,08 mm in diameter. The rock is sometimes pure, almost white, sometimes slightly brownish red of interspersed limonite and hæmatite. In the former case no lamination is visible in the beds, in the latter there is sometimes a very distinct lamination. The pigment is then accumulated in thin layers. Sometimes the lamination is parallel to the bedding surfaces. Secondarily formed infiltration bands are common (fig. 119).

Analysis of slightly pink, micaceous grindsandstone. Hittarp. (Analysis by Sv. Palmqvist).

SiO_2	79,28
Fe_2O_3	12,90
CaO	Traces
K_2O / Na_2O	5,64
H_2O(hydr.)	3,04
	100,86

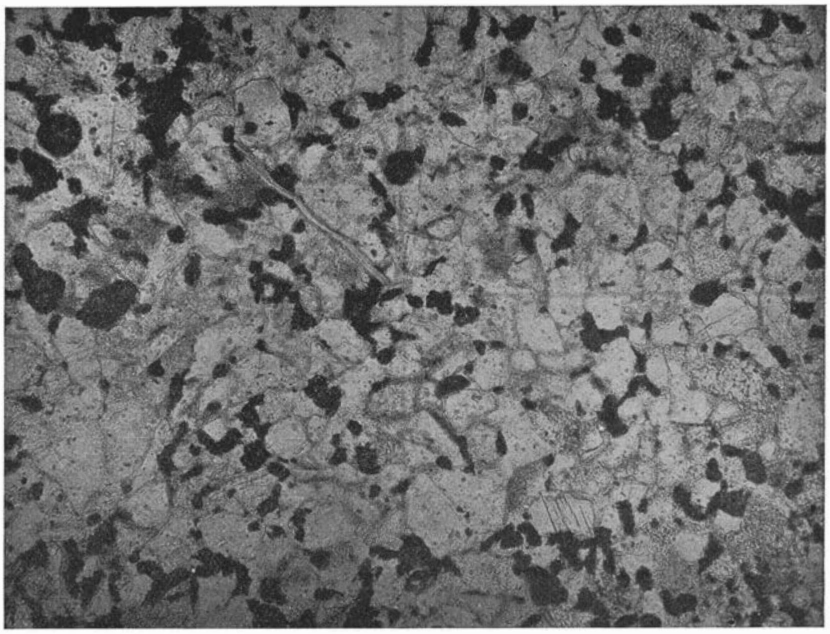

Fig. 118. Grindsandstone. Fine-grained, light red, micaceous sandstone with silica cement. Dark parts = hæmatite. (Analysis pag. 222.) Lias. Hittarp, Scania. (Pr. 2535. Pl. 319.) — 60 ×.

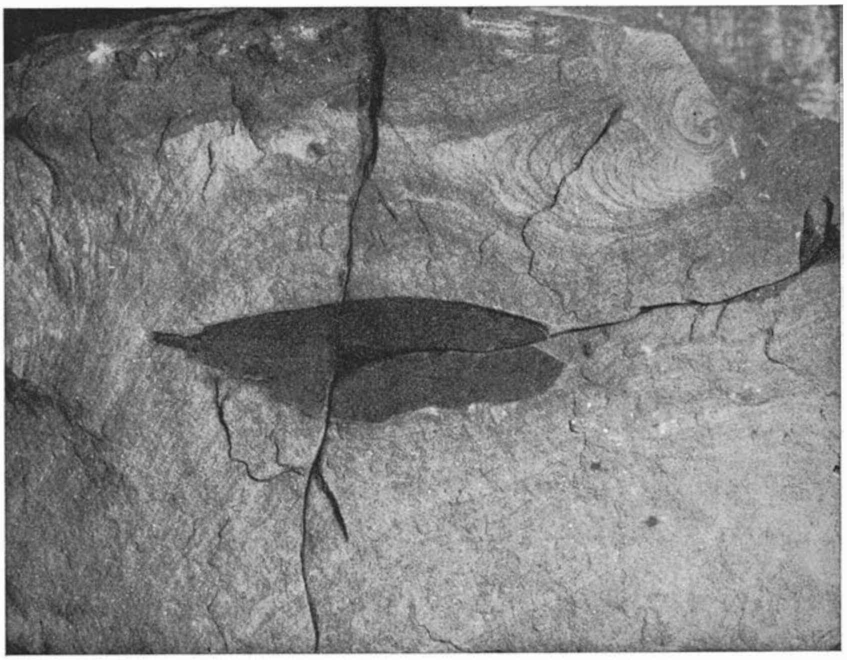

Fig. 119. Grindsandstone with a fragment of *Sagenopteris rhoifolia*. Lias. Pålsjö, Helsingborg, Scania. — $^{1}/_{1}$.

In the upper part of the grindsandstone, on the boundary towards the overlying arenaceous shale, moulds of *Cardinia Follini*, a lamellibranch also present in the Höör sandstone (see p. 229), are found. It is not improbable that this mollusc is a brackish-water form (see LUNDGREN 1881, 40). At any rate the strata above the Cardinia bed are less marine in character than those previously described. These strata are rich in plant remains (*Sagenopteris Nilssoniana* and others), and in the next younger fossiliferous bed a fresh-water shell, *Cyclas Nathorsti*, occurs.

Fig. 120. Diplocraterion sandstone. Porous, comparatively pure quartz sandstone. Lias. Hittarp, 5 c, Scania.

Besides at Sofiero the bed with *Cyclas Nathorsti* also occurs 8—10 km further north, at Brandstorp and Teppehusen. In both places the marine sedimentation has been succeeded by a lacustrine, no doubt formed in the neighbourhood of a shore. Between the north and south localities for the Cyclas Nathorsti bed is a region in which the marine sedimentation continued for some longer time. The beds at Hittarp, Kulla Gunnarstorp, Döshult and Dompäng belong to this younger, marine part of the series af strata.

Between Sofiero and Kulla Gunnarstorp the following strata are outcropping on the shore, close to the southernmost houses of *Hittarp* (HADDING locality 5 Hittarp):

g	Sandstone, white or slightly yellow, thick-bedded	60 cm
f	Sandstone, thin-bedded, with clay galls, conglomerate-like	
e	Sandstone, thick-bedded, loose, yellow	

d	Sandstone with clay galls	10 cm
c	Diplocraterion sandstone	
b	Sandstone with clay galls	
a	Sandstone, thick-bedded, yellow	$>$ 30 »

The relatively thick-bedded sandstone, occurring on several levels, is a loose, cross-bedded sandstone without tracks or fossils.

The sandstones with the clay galls are more thin-bedded but equally loose. When the galls occur in larger quantities the rock is conglomerate-like. The clay galls are rounded with an elliptical cross-section. They may be hard, highly ferruginous, changing into clay ironstone, or soft, plastic. Where the rock is exposed to the waves, the galls have been washed away from the sandstone and the rock is full of holes after them.

Like the above-mentioned beds the *Diplocraterion bed* is a yellow, fairly loose sandstone. Its thickness varies from 2 to 4 cm. The grains are 0,3—0,5 mm in diameter.

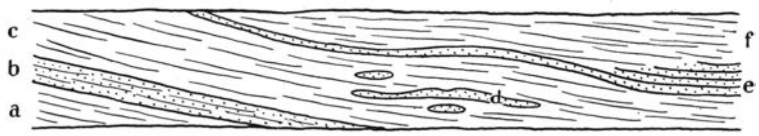

Fig. 121. Section through the Liassic strata on the shore S of Kulla Gunnarstorp. (Loc. 3). Horizontal scale: vertical scale about 1 : 20.

The Diplocraterion burrows are abundantly present (fig. 120). They are very distinct and sometimes fairly broadening at the ends. Not infrequently the central core is found surrounded by concentric rings.

Between the Diplocraterion bed and the underlying sandstone with clay galls an out-thinning thin layer of clay occurs. It has been possible to trace part of the Diplocraterion burrows down into this clay-bed but not further down, into the underlying sandstone.

In the Diplocraterion burrows occurring in the bed mentioned above, the distance between the limbs is about 2,5 cm. The form is not the same as that mentioned before from Sofiero (locality 10, stratum f). In the latter the limbs are about 6,5 cm apart.

On the shore immediately south of *Kulla Gunnarstorp* the following series of strata is found in a cliff about 1,5 m high (HADDING locality 3, Kulla Gunnarstorp, fig. 121):

f Sandstone, gray, loose.

e Sandstone, fine-grained, hard, highly ferruginous (*the Avicula bed*).

c Arenaceous shale, gray, with irregular stratification. In this lenses of sandstone, highly ferruginous (*the Ostrea bed* = *d* in the profile).

b Sandstone, gray, fine-grained, in thin beds.

a Arenaceous shale, gray, with irregular stratification.

The shales (*a* and *c*) consist of alternating light, highly arenaceous and dark, highly argillaceous beds, out-thinning, with uneven bedding surfaces. The rocks are somewhat ferruginous, especially in the highly argillaceous parts. Fine tracks of the same type as that mentioned from the strata at Sofiero (p. 220) are found in the shales.

Light mica is fairly abundantly present at certain places in the rock, both in the argillaceous and in the purely arenaceous parts. Fragments of coal occur only sparingly.

Fig. 122. Siderite rock, partly arenaceous, partly argillaceous (clay ironstone) in arenaceous shale. Lias. Ostrea bed. Kulla Gunnarstorp (loc. 3, c and d), Scania. — C:a $^1/_{20}$.

The Ostrea bed forms uneven, out-thinning layers in the arenaceous shale (fig. 122). The rock is a siderite-cemented sandstone of varying coarseness. In certain parts it is fairly coarse-grained, — the quartz grains are up to 1 mm in diameter — in other parts the grains are less than 0,1 mm in diameter.

The finer grains are angular. The cement is so abundantly present that the grains do not touch each other. It consists exclusively of fine-crystalline siderite.

Small lumps of dense or arenaceous clay ironstone are present in the rock. Moulds of shells (among others *Ostrea Hisingeri*) occur unevenly distributed in the bed, sometimes strongly accumulated.

In this bed the author has also observed a *Diplocraterion* form with 2,5 cm between the limbs. Possibly the form is the same as at Hittarp (see p. 225).

The Avicula bed is a very even- and fine-grained sandstone with cement of

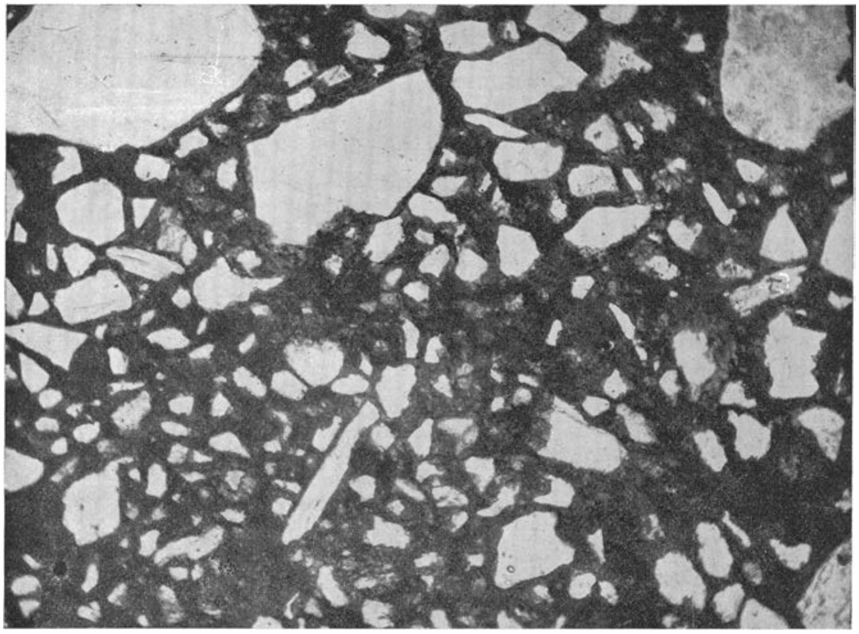

Fig. 123. Siderite sandstone, with marine lamellibranchs. Grains angular. Siderite cement partly decomposed to limonite. Lias. Avicula bed. Kulla Gunnarstorp, Scania. (Pr. 2537. Pl. 289.) — 60 ×.

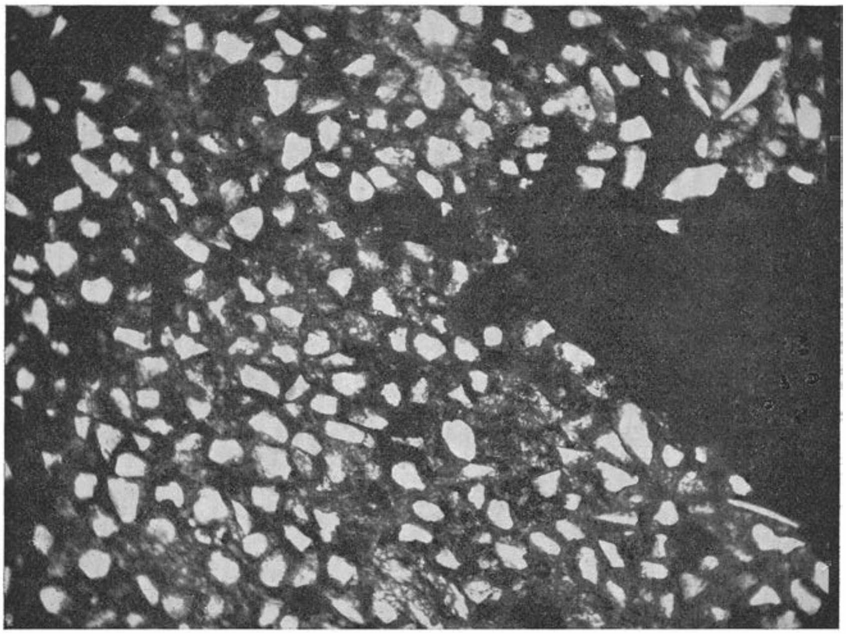

Fig. 124. Siderite sandstone, fine-grained, with lumps of clay ironstone (dark). Lias. Avicula bed. Kulla Gunnarstorp, Scania. (Pr. 2550. Pl. 296.) — 60 ×.

siderite (figg. 123—124). The grains of quartz are angular, in most beds about 0,1 mm in diameter. The thickness of the beds varies from 3 to 30 cm. The bedding is very distinct but no lamination can be traced in the beds. The rock is hard and splits in sharp-edged fragments. The colour of a fresh fracture surface is brownish-gray and of a weathered surface reddish brown or rusty.

Moulds of shells (among others *Avicula inaequivalvis*) are sparingly present.

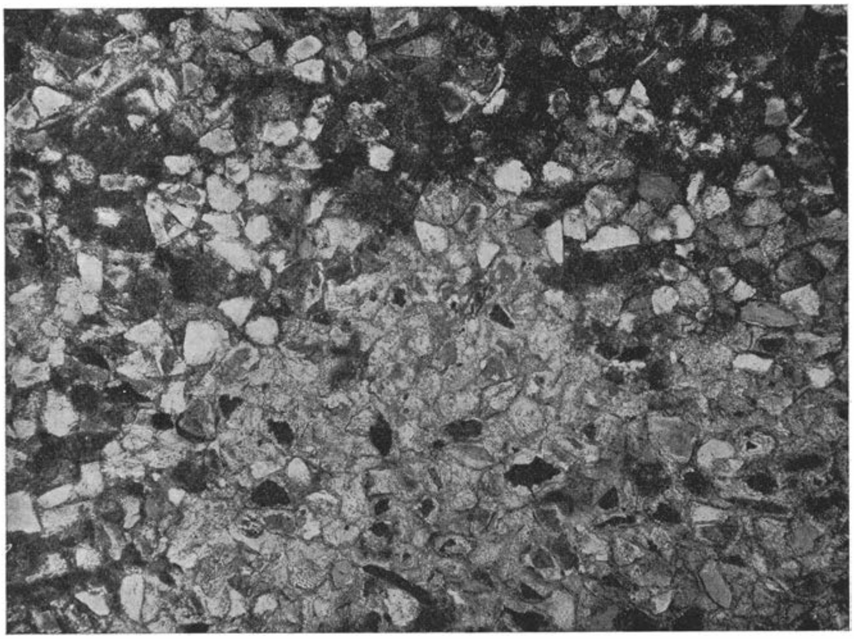

Fig. 125. Calcareous sandstone with large calcite crystals. Fine-grained, argillaceous. Lias. Dompäng, Scania. (Pr. 2536. Pl. 324.) — 50 ×. Nic. +.

N of the above-mentioned section W of Kulla Gunnarstorp a light yellow, loose sandstone is exposed on the shore (Hadding locality 2, W of Kulla Gunnarstorp). The series of strata is divided by faults, on which account the mutual age relation between the different parts is not quite clear. One of the middle portions confined by faults consists of a conglomerate-like sandstone with pebbles of clay ironstone or ferruginous clay. The rock is a fairly coarse quartz sandstone (diameter of grain 0,5—1,5 mm) with fragments of coal.

A sandstone series about 10 m thick is exposed in a brook ravine in the park of Kulla Gunnarstorp (loc. 1). The rock is a coarse, loose sandstone. Several of the beds are distinctly cross-laminated. The majority of the quartz grains are 0,5—2 mm in diameter. Limonite occurs in small quantities as matrix and cement.

The rock is of the same type as in the coarser parts of the last-described locality (loc. 2). A perfectly similar rock has also been observed in the cliff E of the fishing village of Hittarp, at *Hjelmshult* and SE of *Döshult*. In the two last-mentioned places the sandstone is quarried to road gravel. It is so loose that it can be worked with a spade and can easily be crumbled to loose sand in the hand. The bedding is not always distinct. In the sand-pit SE of Döshult fairly abundant fragments of wood are found on certain levels, not infrequently in pieces 2—5 dm in length.

The above-mentioned sandstone is no doubt a delta formation. It has no pronounced marine character. Its formation has taken place on the recession of the sea from the region. It appears, however, as if a new transgression has occurred: both at *Dompäng* (immediately N of Hjelmshult) and at *Döshult* marine strata have been found, which very likely are the youngest Liassic formations in this part of Scania. The strata contain an abundance of Ammonites (among others *Ammonites Bucklandi*) and lamellibranchs (*Ostrea, Lima, Pecten,* etc.).

The last-mentioned marine strata have been termed »*the Ammonites bed*». They are only present in a narrow zone, and probably the marine sedimentation of this time has not in this region widely exceeded the area in which the Ammonites bed occurs.

In contradistinction to the older Liassic strata the rock is often highly calcareous (fig. 125). In an analysed sample (from Dompäng) the content of $CaCO_3$ was found to amount to 49,64 %. The rock is sometimes developed as a grayish green, arenaceous marlstone, sometimes as a brown, calcareous clay ironstone. The enclosed calcareous shells are often well preserved.

The Höör Sandstone.

In the Archæan region N and NW of Lake Ringsjön a gray or white quartz sandstone is outcropping in a number of places. It is best known from the neighbourhood of Höör, where it has been quarried since the Middle Ages. After its occurrence it is termed *Höör sandstone.*

Owing to the finds of a number of fossils it has been possible to determine the geological age of the Höör sandstone. Among the fossils *Cardinia Follini* (fig. 126) may be mentioned, the same form as that occurring in the Liassic strata N of Helsingborg. As pointed out before this species is probably a brackish water form. Marine fossils have also been found in the Höör sandstone, among others *Avicula inaequivalvis, Ostrea* and *Pecten.* These forms are partly the same as those occurring in the upper Liassic strata N of Helsingborg (in the Ostrea and Avicula beds).

Consequently the Höör sandstone is a Liassic deposition formed at the same time as the strata described above. It is, however, otherwise developed than these and on that account it deserves a special chapter.

The rocks in the Höör sandstone are poor in mud and iron. The sandstones are generally free from calcium carbonate also. The size of the grains varies but the rock is seldom of the fine-grained type so common in the Liassic series N of Helsingborg.

As a rule the lowest part of the Höör sandstone, resting directly on the gneiss, is felspathic or even rich in felspar (fig. 127). This arkose, often coarse and sometimes conglomerate-bearing (see HADDING 1927, 104), has been quarried for the manufacture of millstones. In spite of the felspar being to a large extent kaolinized, the rock is well consolidated. This is due to an abundance of quartz cement. The kaolin is often silicified.

Fig. 126. Höör sandstone. Fine-grained quartz sandstone with moulds of *Cardinia*. Lias. Julaftonshus, Scania. — $^1/_1$.

The arkose occurs in beds, often separated by thin layers of clay (see the section, HADDING, 1927, 107). A distinct lamination is seldom found in the beds.

In the upper part the sandstone is more fine-grained. The content of felspar is less marked and the stratification often finer. Thick beds of the fine-grained form have been found. Thus for inst. the upper sandstone layer in the Stanstorpa pit at Höör is about 5 m thick. It is divided into a few beds.

The fine-grained Höör sandstone contains sometimes distinctly rounded, sometimes more angular grains of quartz. Their size varies from 0,05 to 0,15 mm. Largest and best rounded are the grains in the fossil-free, pure sandstones (for inst. nearest Höör). The rocks with marine fossils found farthest north are most fine-grained, with the least worn grains. This sandstone is also the only one containing finer mud in any noticeable quantity.

Together with the fossils mentioned above, the Höör sandstone also contains plant fossils, at some places in large quantities. Among them *Nilssonia brevis*, *Equisetites scanicus* and *Sagenopteris Nilssoniana* may be mentioned. As a rule only impressions or flattened casts of the plants are found but carbonized remains also occur. Thin coal measures are also known from the Höör sandstone, for inst. from the Ormanäs pit, where the succession of strata according to *Erdmann* (1911—1915, 39) is as follows:

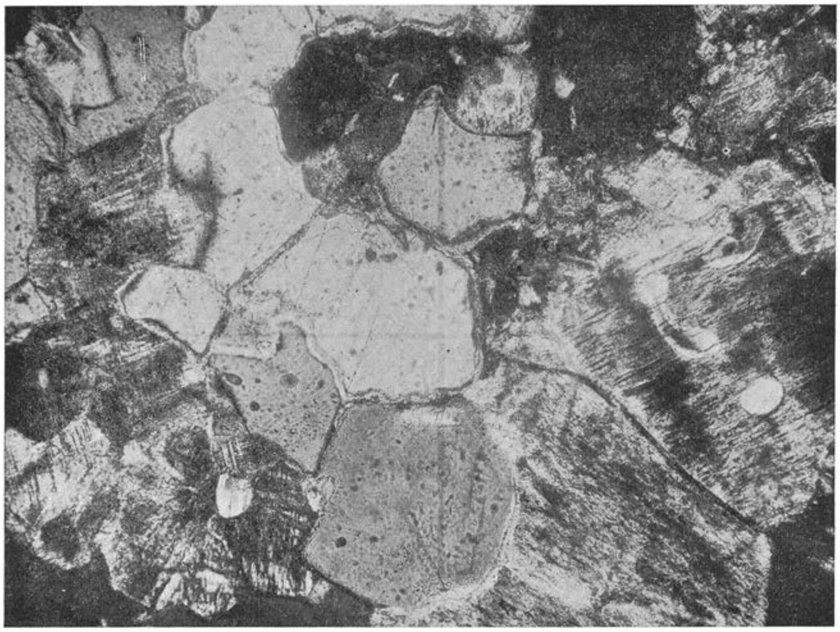

Fig. 127. Höör sandstone. Arkose. Lias. Höör. (Pr. 2720. Pl. 298.) — 50 ×. Nic. +.

Arkose, hard	240	cm
Clay, carboniferous	3—18	»
Coal	3—6	»
Sandstone, with fossil branches and trunks	24	»
Shale	3—5	»
Sandstone, with fragments of coal	90	»
Gneiss	—	

In the NW part of the sandstone region one finds an abundance of boulders of fine-grained sandstone replete with impressions of plants but devoid of carbonic matter. The walls of the cavities after the plants are often coated with small crystals of quartz. The rock is hard and splintery but cleaves readily along the planes in which the plants have lain. Like the sandstone with the marine shells it does not contain mud in any noticeable quantity. The bedding surfaces and the walls of the cavities, however, are often brown from hydrated iron oxide, which only occurs as an exceedingly thin film seldom covering the entire surfaces. An analysis of the white and slightly brown sandstone at Julaftonshus, containing moulds of plants and abundant moulds of *Cardinia Follini* (fig. 126), showed that the content of iron oxide amounted to 5,07 %. The content of SiO_2 was determined to 94,31 %. The presence of CaO could not be proved.[1]

The Liassic Sandstones in South-eastern Scania.

In south-eastern Scania Liassic strata have been found at a number of places between Tosterup and Kurremölla.[2] All the localities are situated between the Silurian region in the NE and the Cretaceous region in the SW. They are to be found in a narrow zone running NW-SE, probably demarcated by faults. The beds are generally tilted, sometimes inverted. On this account it is often impossible to determine the mutual position and age of the outcropping strata. In the region, well covered by drift, the exposed sections are also very insignificant, on which account we shall here describe only a few of the rocks occurring in the region, viz.: —

white, loose sandstones;
orange-coloured and red, loose sandstones;
grayish green and olive-coloured calcareous sandstones;
rust-coloured, sideritic and limonitic sandstones.

The white sandstones have been observed in several cuttings. The rock is often so loose that it can be crumbled with the fingers. The grains of quartz are distinctly rounded. The size of the grains varies but as a rule the rock is fine-grained. In the big sand-pit at Kurremölla the grains are 0,1—0,2 mm in diameter.

The rock contains an abundance of white, argillaceous matter (kaolin) and frequently also small scales of light mica.

Here and there the rock shows a fine lamination. Where the mica is accumulated in larger quantities on the bedding surfaces the rock breaks up in thin slabs.

The orange-coloured and red sandstones occur together with the white. They differ from the latter only by a pigmentation from oxide or hydroxide of iron. This pigmentation is often limited to the upper part of the series of strata, and it may therefore be supposed to originate from secondary infiltration of ferruginous solutions. In spite of this infiltration the rock is still loose.

On account of the pigment having been absorbed in different degrees in the arenaceous and the argillaceous parts of the rock this often shows an exceedingly

[1] The analysis was made by Sv. Palmqvist.

[2] Keuper beds and a plant-bearing clay of Upper Rhætic age have also been observed in this region. Consequently the series of strata is considerablv larger than the directly observed strata show.

beautiful stratification. Thus a fine parallel lamination may be found here as in the white sandstone.

Together with the fine-grained, loose, white and orange-coloured sandstones white, gray, orange-coloured and black clays occur. Occasionally we also find small layers of coal.

The grayish green and olive-coloured calcareous sandstones form solid beds. On weathering, however, the rock is altered into a looser, rust-coloured limonitic sandstone.

Fig. 128. Sandstone white, porous. Lias. Kurremölla, Scania. — $^1/_1$.

In a couple of samples from Högabränte in Fyledalen (the Fyle valley) the rock consists of a middle-coarse sandstone. The quartz grains are somewhat rounded, mostly 0,5—0,8 mm in diameter. Grains of felspar are abundantly present, mostly microcline but some plagioclase also.

Together with the grains of quartz and felspar fragments of a fine-grained, limonite-cemented argillaceous rock are sparingly found. These fragments are rounded and of the same size as the quartz grains.

The cement occupies an essential part of the rock and often forms a matrix between the grains separating them so that they do not always come in contact with each other. In the fresh rock the cement consists of fine-crystalline calcite. On weathering the calcite is replaced by limonite.

Beds rich in fossils are present in the calcareous sandstone. The same fossils are of course found (as moulds) in the limonitic sandstone formed out of the calcareous sandstone during its weathering. In reality the fossils found in the Lias of south-eastern Scania lie to a large extent enclosed in rust-coloured limonitic sandstones. Whether these have always been formed out of calcareous sandstones, we do not know but in many cases it has been possible to show the relatively fresh, calcareous, brownish green nucleus in the rock.

The fossils are marine. A number of different forms have been found (see MOBERG 1888). The lamellibranchs in particular are abundantly present, among others species belonging to the genera *Ostrea, Pecten, Limea, Avicula, Astarte,*

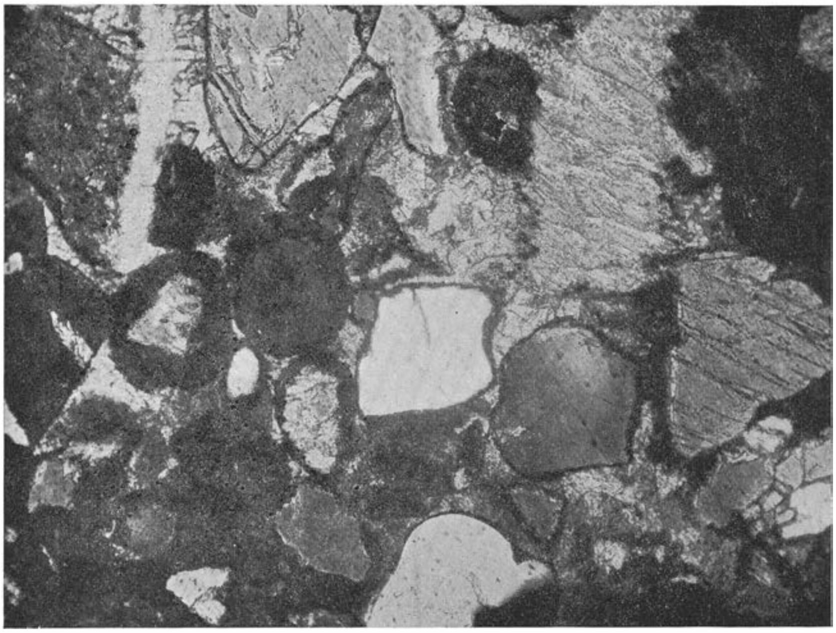

Fig. 129. Siderite sandstone, partly oolitic. Lias. Högabränte, Fyledal, Scania. (Pr. 2538. Pl. 315.) — 50 ×. Nic. +.

Pleuromya, Cardium. After the last-mentioned genus the layers have been called »the Cardium bed». Of the cephalopods partly bèlemnites, partly an ammonite, *Aegoceras Jamesoni* Sow., have been found. Fragments of crinoids, remains of fishes and worm tracks also deserve to be mentioned from these strata.

Here and there in the sandstone oolitic limonite, with a quartz grain as nucleus, are also to be found. As a rule the ooids (= the oolite grains) show an elliptical cross section. The longer diagonal is about 0,3 mm. The thickness of the limonitic crust varies. If the quartz grain, the nucleus, is small in size, the crust is thicker than when the quartz grain is larger. The crust around the larger grains is reduced to a thin pellicle.

The oolitic sandstone resembles macroscopically to a large extent an iron oolite occurring in the same series of strata. In this rock quartz occurs only infrequently as nucleus in the ooids. Otherwise these are of the same size, form and character in the two rocks. In the unaltered oolite the grains lie embedded in an olive-green, singly refracting mass.

Rust-coloured, sideritic and limonitic sandstones are very abundantly present in the Lias of south-eastern Scania. As shown above the limonitic sandstones have partly been formed by alteration of calcareous sandstones. This may, however, not always be the case. A large amount of the iron content of the rocks has no doubt been deposited simultaneously with the deposition of their arenaceous and argillaceous material.

It is often difficult to decide in which form the iron has first been accumulated in these sediments. There is, however, ample opportunity to observe how the sideritic sandstones are changed into limonitic on weathering. It may therefore be called in question if the limonitic sandstone is a primary formation.

As a rule the sideritic sandstones are somewhat calcareous. A sideritic sandstone occurring at Kurremölla contains fossil shells. The calcareous matter in these shells is a relatively coarse-crystalline calcite and is no doubt recrystallized. The shells are filled with siderite, partly granular, partly radial in structure. Calcite crystals (from the shells) protrude into this siderite. Consequently the recrystallization of the calcite has taken place before the formation of the siderite.

The siderite in the above-mentioned rock also forms matrix and cement. The development is the same as in the interior mould of the shells. As the matrix occupies a relatively large part of the sandstone, it must have been present at the time of the deposition of the sand. The siderite, on the other hand, being, in its present crystalline form, a later formation, the matrix must have been different in character when it was formed. If we suppose that it has primarily consisted of calcium carbonate, the occurrence of iron in the series of strata is not explained nor the fact that the shells have not changed into carbonate of iron when the surrounding matrix underwent this metasomatism. Nowhere have the shells been preserved on the alteration of the calcareous sandstones mentioned above (p. 234). Curiously enough, the author has never observed any changing of calcium carbonate into iron carbonate in these rocks but we may almost venture to presume that it has taken place on a fairly large scale. A later alteration into iron hydroxide has obliterated the traces of calcite.

Thus nothing is to be found in the rocks directly favouring the opinion that the sideritic sandstones have originally been formed as calcareous sandstones. On the other hand we must find the source of iron in the sandstones, and in the series of strata discussed here it cannot be derived from any other rocks in the series than the ferruginous themselves.

It was mentioned above that the ooids of the iron oolite sometimes lie embedded in a green, singly refracting mass. In the same rock it is to be seen how this mass has partly been changed into siderite, partly into limonite (and hæmatite). On the other hand small remains of the green matter may be found in the interior of sideritic sandstone beds. Consequently there is hardly any doubt that the siderite has been formed from the green substance. This, of course, is then the source of the content of iron in the rocks. What mineral is there then a question of here?

We need not seek long to find that of all known minerals only one is identifiable with the optically isotropic in question here. This mineral is *greenalite,* hitherto only known from the pre-Cambrian, iron-bearing rocks of the Mesabi Range in Minnesota (see LEITH 1903).

The greenalite is a mineral reminding us in certain respects of the glauconite. Chemically it differs from the glauconite by not being potassic and optically by its single refraction. In the Mesabi district it occurs together with layers of slate and quartzite. In the form of small green grains embedded in chert it forms a green rock. The greenalite alters easily *int. al.* to iron oxide and hydrated iron oxide.

As the greenalite at Kurremölla has hitherto only been observed in the oolitic iron rocks and not in the sandstones, the author will desist here from a more detailed account of its character and occurrence. It has been mentioned in this work as the probable source of the ferruginous matter that plays such an important rôle in the sandstones also in their present more or less altered form.

Among the limonitic sandstones in the Lias of SE Scania a type occurs which may be regarded as a fine-grained variety of the mud-cake conglomerate present in the same series of strata (HADDING 1927, 109). The rock consists of about 2 mm large quartz grains and grains of light yellow, fairly loose, limonitic substance embedded in an often hard, dark brown, dense limonite forming matrix and cement. The grains of iron hydroxide have a firm crust of the same kind as the matrix and as a rule completely grown together with this. On splitting the rock one therefore obtains a cross-section through the grains.

The content of sand in the ferruginous sandstones varies. As a rule the grains are not so closely crowded that they touch each other. From a sample of a sideritic sandstone of ordinary type the following composition was obtained (Analysis by Sv. PALMQVIST):

SiO_2 (+ the other in HCl insoluble part)	47,50	%
$Fe\ CO_3$	47,88	
$Ca\ CO_3$	4,62	
	100,00	

The formation of the Rhætic-Liassic sandstones of NW Scania.

In the preceding an account has been given of the character of the Rhætic-Liassic sandstones and their occurrence in the series of strata. From the facts related certain immediate conclusions may be drawn as to the forming conditions of the rocks. In discussing these conditions, however, it would be suitable to simplify and abridge the exposition by choosing the types represented in the series of strata and discussing their formation instead of dwelling on each separate, more or less peculiarly developed bed.

The types from NW Scania to be discussed below with regard to their formation are as follows:

A. The sandstones of the series rich in coal.
B. The sandstones with marine fossils.
C. The sandstones rich in tracks.
D. The marly sandstones.
E. The coarse, cross-bedded sandstones.
F. The sandstones rich in iron.

Rocks of the one or the other type are often found in several different levels. Consequently the types of rock are not characteristic of a certain time. They vary with time and place according to the change of the forming conditions.

A. *The formation of the sandstones of the series rich in coal.*

The strongest enriching of carbonic matter in the Rhætic-Liassic strata of Scania is found in the lower part of the series. The sandstones in this part of the series are fine-grained, white or gray, sometimes mixed with fragments of coal.

The content of clay varies, the content of lime is always small, often too small to be determined with certainty. The content of iron is slight. Where it is more noticeable it is generally found in the form of pyrite.

In the pure forms the stratification is indistinct, in the argillaceous often very pronounced. In the latter case it is generally uneven, with out-thinning thin layers or small lenses (lenticular bedding). Sometimes the beds are distinctly cross-bedded. Ripple marks are found here and there in these beds.

The plant fossils enclosed in the sandstone are partly washed out (leaves and other fragments) partly roots, stems and other parts of plants, that have been embedded in the sand without being detached and transported. The latter are often placed at right angles to the bedding planes.

From the character of the strata we may infer that they have been deposited in a shallow and relatively tranquil water. The fine-grainedness and the content of clay imply a deposition in a region where neither waves, tidal currents nor other currents have been strong enough to carry away the material. The uneven stratification, the plants *in situ* and the ripple marks show that the deposition must have taken place in very shallow water.

The simultaneous occurrence of the strata in a fairly extensive region (the distance between Höganäs and Skromberga is 35 km) shows that this region has formed a shallow and sheltered basin, in which a sedimentation of the said kind could take place.

Was then this basin continental or marine? Probably marine. The strong oxidation, characteristic of the continental sediments deposited in the same basin, ceases with the occurrence of the carbonic admixtures, while simultaneously the formerly relatively high content of lime and iron is reduced to a minimum. The deposition of lime- and iron-compounds during the continental era was after the beginning of the marine, plant-bearing, changed into a removing of such, perhaps also from already deposited sediments.

The new character of the sediments in the series of strata cannot be explained by the supposition of a change in the character of the detritus caused for inst. by a variation in the climatic conditions. A climatic change must not therefore be excluded. But it cannot have caused such a rapid change in the sedimentary rocks as that found.

Geologically a marine transgression over a flat shore region or a lacustrine basin near a shore ought, on the other hand, to have occurred spontaneously. The effects of the transgression ought in the first place to be chemical-biological. Consequently the changes in the content of vegetable matter, lime and iron and the variations in colour due to them agree with the supposition of a transition from continental to marine facies.

On judging the conditions under which the sandstones discussed here have been formed, it is of very great interest to know the character of the fossil plants enclosed in the series of strata (fossil animals have only been found occasionally).

The fossil flora contains both vascular cryptogams (ferns and horsetail-like forms) and cycadophytes, ginkgos and conifers. Thanks to the investigations of Nathorst the flora is well known. According to his investigations, the plants have not only changed from time to time but have also differed somewhat in different parts of the region. Thus for inst. are the forms of plants considerably more numerous in the southern (Bjuv) than in the northern (Höganäs) part of the region.

Of special interest is the testimony of the flora as to the character of the sedimentary region. Several of the forms described have no doubt been carried out to the place of deposition with running water and are consequently of no importance in this case. Others on the contrary are typical representatives of a marsh or lagoon vegetation. According to Nathorst (1878 a, 8) *Dictyophyllum* and *Sagenopteris* belong among them. These two genera are abundantly represented at Bjuv but are only sparingly present at Höganäs. From this one may venture to infer that the southern part of the Rhætic-Liassic region has been more marshy in character than its northern part. Probably the latter has been situated nearer the open sea. On the other hand the southern part has perhaps had a more brackish water from the afflux of running water.

An investigation made by Gertz (1928, 145) on the structure of certain Rhætic plants is of interest in this respect. It is shown in this that they exhibit features characteristic of typical representatives of the mangrove vegetation. From this Gertz infers that the Rhætic region in NW Scania has been a mangrove marsh.

It has been mentioned repeatedly above that the impure sandstones as a rule show a distinct but uneven (lenticular) stratification, sometimes resembling cross-bedding. This tells us that parts of the deposited, fine sediments have repeatedly been whirled up and redeposited in the region. Thus the water has not been standing, even though the current has not been strong enough to carry away the mud. At certain places and certain times, however, the transporting power of the water has been greater. This may be inferred from the fact that sandstones of clean-washed sand also occur in the series of strata. It would of course be of great interest to follow the distribution of these sandstones, as we by that means could form a more certain idea of the mode of formation. The pure, white sandstone observed east of Höganäs seems to have a fairly limited distribution. Possibly it has been deposited in one of the gullies connecting the inner more or less marshy region with the sea.

At several places lenses of pure sandstone have of old been observed in the muddier beds. At Bjuv they are even found in the coal-measure. As a rule they are only one or two metres large but at Bjuv it has been possible to follow a lens about 30 m. It was 9 m broad at the most and 0,3—1,5 m thick. NATHORST (1878, b, 7) supposes — a supposition which also seems most plausible to the present author — that these pure sandstone lenses have been formed in gullies cutting through the marsh.

Regarding the no doubt varying sedimentary conditions dominating in the different parts of the region one understands that variations must exist in the thickness as well as in the character of the strata. However, one may draw certain conclusions from the thickness of the strata as to the supply of sediments in the different parts of the region. NATHORST (1910, 499) has called attention to the fact that the supply of detritus has been greater in the northern than in the southern part of the region. The vertical distance between the upper and the lower coal seam at Höganäs (the Gustaf Adolf shaft) is acc. to the sections of ERDMANN (1911—1915, pl. 14) 32 m, at Billesholm (the Berg shaft) 8 m, at Bjuv (shaft No. III) 3 m, at Ormastorp (the Carl Cervin shaft) 0,8 m. Both NATHORST and ERDMANN look upon this as evidence that the sediments originate from a region situated in the north. The author is not inclined to consider the problem so simple.

If the greater thickness is due to a sedimentation near the shore, this should also be noticeable in the coarseness of the material. The thicker deposition nearer the shore ought to be more coarse-grained than the thinner one formed at a greater distance from land. On comparing the series of strata at Höganäs with those mentioned in the southern part of the region this fact ought to be very distinct. But on examining the rocks we do not find what we might expect. The rocks of the Höganäs field are as fine-grained as those in the other regions.

The cause of the strong sedimentation in the Höganäs field must therefore be sought for in other circumstances. From a general point of view the extent of the sedimentation may be said to be due to the supply of sediments and the deposition (and retention) of the material. The fragments of plants may of course have been carried or washed about in the entire region. The deposited layers of the muddy sediments have also, as mentioned above, been perpetually washed up, probably by tidal waves. Thus the water has been muddy in the entire region. The size of the grains in the deposited material is dependent on the movement of the water. Where the currents have been stronger only the coarser parts have sunk to the bottom, forming a relatively pure sandstone. Where the currents have been slower the mud has also been deposited, forming an argillaceous sandstone or clayey rock.

The currents have, as the rocks show, varied with time and place. They have no doubt been strongly affected by the vegetation and the configuration of the bottom. The latter is probably the cause of the strong sedimentation in the Höganäs region in the lower Rhætic. We may imagine the bottom formed into a natural »mud-trap».

Though the author cannot enter on an analysis of the paleogeographical conditions here (they will be treated of in a later volume in one connection), he cannot forbear to point out that the coal region in NW Scania during the Rhætic Lias was surrounded by an Archaean region, the margins of which did not essentially differ from the present. The horsts surrounding it were no doubt fully developed already in Paleozoic time, even though the faultings along the old weak zones have continued. The bay of Skelderviken existed for a long time as a rift-valley and the Cambro-Silurian strata, possibly deposited there, had been eroded before the Rhætic transgression. Thus north of the Höganäs field only a smaller Archaean region existed, Kullen, which rose above the Rhætic sea and its shallow bay as an island. The proper affluents and the supply of material to this bay must therefore originate from the region to the east. Close to Söderåsen (at Billesholm) one also finds a coarser material throughout than at the somewhat more distant places (Bjuv and Skromberga). As mentioned above, however, other factors play a greater rôle in the sedimentation.

Summarizing the result of the above discussion we may say that the sandstones deposited in the lower Rhætic of Scania are not of a normal marine character. They are deposited in a shallow, partly swampy, sheltered shore region, possibly with mangrove vegetation. The varying nature of the material is due to varying current conditions, dependent in their turn on variations in the connection of the region with the sea and in the configuration of the bottom.

B. *The formation of the Rhætic-Liassic sandstones with marine lamellibranchs.*

Marine lamellibranchs do not occur in the sandstones in the carboniferous parts of the series of strata. Thus, we do not find them in the lower Rhætic nor in the parts of the upper Rhætic and lower Lias containing coal-seams or shales rich in coal. But the shell beds are not completely free from plant fragments. In one case only is the shell-bearing bed rich in plant fragments: the Cardinia bed, but in this case there is reason to suppose that the fauna is not marine but rather contains brackish water forms.

The majority of the beds with marine molluscs consists of a relatively pure, indistinctly stratified sandstone. As a rule these beds are embedded in more argillaceous strata. The sandstones are usually poor in or free from lime but not infrequently ferruginous. The content of clay is smaller in the shell-bearing beds than in the surrounding rocks.

In one and the same bed the content of shells is of varying richness at different places. At one place the bed may be found replete with them, while at another they are only sparingly present. It would of course be of the greatest interest to follow a bed for a longer distance in order to investigate the horizontal distribution of the shells. The investigation would, however, require such extensive work as to make it impossible in this connection. But the author has paid attention to the question and he has found that not only the number of individuals but also the number of species varies from place to place.

This is not in any way remarkable, in reality it only reflects the recent conditions. It is, however, deserving of attention in the stratigraphical studies. A careful investigation of this fact may probably lead to a revision of the stratigraphical scheme of the Scanian Rhætic-Liassic series.

The formation of the sandstones with marine fossils is in so far immediately evident in the character of the rocks as this shows that the sand has been deposited in an open water, in which the current has been so strong that no or only a slight deposition of mud has taken place. As soon as the deposition of mud has increased again, the molluscs have disappeared.

Consequently the occurrence of the shells indicates a period with more moving water. In most sedimentary series of strata this means a period with shallower water, i. e. an elevation of land. In the cases discussed here, on the other hand, it is rather of contrary significance. First after a repeated subsidence of land did the sea currents move in the Rhætic-Liassic region. First then was the swampy vegetation forced aside and first then were the beds with marine shells deposited.

After the subsidence of land in the youngest Rhætic an elevation occurred in the oldest part of the Lias. In the series of strata it is indicated by beds rich in plants, brackish-water layers (the Cardinia bed) and fresh-water deposits (the beds with *Cyclas Nathorsti*). If the previously given stratigraphical scheme (see p. 209) is correct, this elevation of land was succeeded by a new depression with marine sedimentation (the Ostrea and Avicula beds). If however a future investigation shows that the Mytilus bed and the Ostrea bed are different forms of the same strata and like the Avicula bed older than the grindsandstone and the said brackish-water and fresh-water deposits, the elevation of land indicates the end of the marine sedimentation in the region of Helsingborg.

We may sum up our opinion of the said rocks as follows:

The Rhætic-Liassic sandstones with marine lamellibranchs are formed in a shallow, moving water, probably as freely situated bars. They were formed at the maximum subsidence of land.

The formation of the Rhætic-Liassic sandstones with tracks and marks.

Several of the sandstone beds in the Rhætic-Lias of Scania contain tracks or marks valuable also for the interpretation of the formation of the rocks. Worm trails and other tracks and marks made by animals, ripple marks and mud cracks are all of interest.

The trails and tracks only occur in the argillaceous sandstones or the arenaceous clayey rocks. They consist partly of winding worm trails of different thickness, partly of elevated, ornamented tracks. The latter occur only on the bedding surfaces, the former also irregularly traversing the muddy rocks. Both types are formed in shallow water.

Tubes built by organisms occur as U-shaped formations, partly like those mentioned before from the Lower Cambrian sandstones under the term *Diplocraterion*. A form of *Arenicolites* is also present. This is not the place to enter on a description of these different U-shaped formations. Like the trails they indicate a formation in shallow water. In contradistinction to the trails and tracks, however, they occur mostly in pure sandstones. The surrounding beds contain here and there ripple marks and clay galls. In one case only has *Diplocraterion* been observed in highly ferruginous sandstone.

The ripple marks are symmetrical and relatively short-wavy. Interference marks are common. The formation has occurred in a relatively slight surging of waves, for inst. in a flat shore region.

Small *clay galls* or rounded clay flakes occur in several sandstone beds. Sometimes the clay is loose, plastic, sometimes hard and also highly ferruginous (clay ironstone). The galls and »pebbles» are only present in pure, relatively coarse sandstones, not in muddy ones. They have evidently been rounded in connection with the embedding in the sand or during the transport. The galls and »pebbles» are parts of disintegrated strata, cracked by desiccation or partly suspended and washed away by increased movement in the water, while other parts have been preserved (parts which have already obtained a certain solidity). Sometimes the lumps of clay are so abundantly present that they form conglomerate beds. Like the above-mentioned tracks and marks they show that *the rock has been formed in a shallow, moving water.*

The formation of the marly Liassic sandstones.

The Rhætic-Liassic rocks of Scania are generally poor in or free from lime. It is only in a few of the youngest beds a more obvious content of lime is found, for inst. in the Ammonites bed at Dompäng. The carbonate there is not present as a calcite cement in a sandstone but as a calcareous clay, a marl or marly sandstone. The content of lime is no doubt primary. The rocks contain fossils (Ammonites and lamellibranchs) with the calcareous shell preserved.

As the detritus material washed out into the sea has no doubt been fairly uniform during the formation of the Liassic strata of NW Scania, the obvious change in the chemical character of the rocks, occurring with the formation of the beds rich in lime, must be due to a change in the deposition basin itself. Instead of a dissolution of the calcium carbonate possibly present in the deposited sediments (in the shells of the bivalves also) a deposition of the carbonate takes place. The reason may for inst. be a decreased content of carbon dioxide in the water.

Of the distribution of the calcareous beds we know almost nothing. They have only been observed outcropping at Dompäng. On that account it is difficult to express an opinion of their horizontal distribution and relation to other rocks in the series of strata.

Besides the said lime-rich beds in the upper part of the Lias of NW Scania calcareous beds occur at different places in the Rhætic-Liassic series. At the brickyard of Helsingborg these calcareous strata are partly developed as cone-in-cone. As they do not contain sandgrains in sufficiently large quantities for them to be counted among the sandstones, we shall not dwell on them here.

The formation of the coarse, cross-bedded sandstones in the Lias of north-western Scania.

In the middle-coarse or coarse-grained sandstones, occurring partly as single beds, partly as a thick series in the upper part of the Lias of Scania, a very pronounced cross-bedding is often found. This should not be mistaken for the uneven stratification (the lenticular stratification) of the fine-grained or argillaceous sandstones in for inst. the lower Rhætic. This is indicated by layers of clay or thin layers richer in iron. Generally it is due to a partial suspension of already deposited more horizontal layers.

The cross-bedding in the coarser sandstones is marked by changes in the coarseness of the material. Relatively horizontal parts alternate with dipping ones. Lenses of coarse or fine material lie enclosed in sand of a different coarseness or with a different stratification.

Sometimes an almost rhythmic alternation of parallel- and cross-laminated parts is found. This is the case for inst. at Hjelmshult. The rock is remarkably even-grained (fig. 130).

The coarseness of the material, its occurrence in frequently very thick beds, the character of the stratification, all indicates a deposition by running water in deltas.[1]

The occurrence of these delta deposits as the uppermost part of the series of rocks deposited in NW Scania during the Rhætic Lias is perfectly natural. During the continued elevation of land it became less and less possible for the basin already silted up to serve as settling basin. The finer material did not settle but was carried away or partly deposited in locally occurring, still existing depressions. The coarser material was deposited in deltas close to the receding shore-line.

During this period the region undoubtedly showed a strong variation in the sedimentation. Outside the deltas, parallel-stratified sandstones were deposited. However, it is not possible for us to judge these circumstances perfectly until

[1] The even-grained, cross-bedded forms are possibly eolian.

we have formed a certain opinion of the horizontal changes of the strata, especially by drillings. We must be satisfied here to establish *the strata's nature of deltas and delta-like shore deposits from the last period of the Liassic regression.*

It deserves to be emphasized in this connection that conglomerates are absent in the coarse sandstones discussed above. In this respect, then, the youngest Liassic strata show the same peculiarity as other series formed during the great regressions.

Fossils are also absent in the cross-bedded sandstones, irrespective of the fragments and larger pieces of fossil wood, sometimes (for inst. N of Djuramåsa)

Fig. 130. Cross lamination in Liassic sandstone. Hjelmshult, Scania. — C:a 1/5.

occurring embedded in the sand. The pieces of wood have obviously been transported a long distance before the embedding.

A study of the cross-bedded sandstones also gives valuable aid to the investigation of the streams and routes of transport in the region of sedimentation. The dipping lamina inform us of the direction of the currents and from where the material is next derived. This direction is, as might be expected, rather varying. In one and the same delta an incline in different directions is to be found. From the different observations the structure of the delta may be constructed and consequently the probable direction of the sandbearing stream determined. By this means a possibility is eventually gained to decide where the detritus-delivering land region was situated. To draw any conclusions in the last-mentioned respect from occasional observations on the dip conditions of the strata is difficult and not advisable. Attention may, however, be called here to the fact that the dip is generally southerly in the two places (Hjelmshult and N of Djuramåsa), where the coarse, cross-bedded sandstones are best exposed.

The formation of the highly ferruginous sandstones in the Lias of north-western Scania.

Regarding this formation we must distinguish the sandstones with primary content of iron from those in which the iron compounds are only secondarily present. In the latter the presence of the iron compounds do not tell us anything of the formation of the original rock, and they might therefore have been left out of account in the discussion of this formation. It is, however, often difficult to decide at what time the iron compounds have appeared in the sandstones, and for that reason the author has not been able wholly to stick to the said grouping. Under these circumstances he has found it most appropriate to choose representative types and examine to what extent their formation can be deduced from the character and occurrence of the rock.[1]

Simplest to interpret are the sporadic, diffusely limited nodules of siderite or limonite. In these the concretionary enriching of the iron compound is obvious. How early after the deposition of the bed this concretionary formation has taken place can not as a rule be decided. Sometimes, however, these concretions are found detached from their primary surroundings and accumulated into conglomerates. As these conglomerates do not contain other nodules than the said concretions, these must have been the only firm parts in the series of sediments broken up in connection with the formation of conglomerate. This shows, on the other hand, that the formation of the said concretions, i. e. the deposition of iron, has taken place before the sediments have yet had time to consolidate, i. e. at a very early stage of the formation of the rocks.

According to the experience of the author the concretionary, highly ferruginous parts are not connected to sandstones formed in a certain manner. In several cases, however, it has been possible to prove a distinct content of lime in these rocks (see below).

Often the content of iron in the sandstones is not enriched in nodules of distinctly concretionary type but accumulated in *indistinctly limited portions.* These may be fairly widely distributed horizontally without vertically occupying more than a fraction of the bed in which they occur. In one and the same bed two or more such highly ferruginous portions may sometimes be observed.

In the author's opinion there is in this case also a secondary deposition of iron compounds. This is not evident from the development but certainly from the difference in occurrence of the highly ferruginous parts. These are specially frequent in the beds rich in shells of marine lamellibranchs, for inst. in the Mytilus bed. In the parts where the deposition of iron is slightest it is found

[1] A more detailed account of the iron compounds present in the sediments, their formation, primary character and alterations is planned for a future part of this series.

to be limited to the bivalve shells. The calcium carbonate in these is replaced by a brown, ferruginous matter, perhaps primary siderite but most frequently altered into limonite.

The next step in the deposition of iron is traced in the rocks where a cementation with limonite or some other iron compound is found nearest around the shells. Where this cementation has spread further we have the rock of the above described character.

The fact that the deposition of iron in the said beds has occurred more horizontally than concentrically around a nucleus (shell) is no doubt due not only to the shells lying accumulated on certain levels but also to the circulation of the ferruginous solutions being most facile on these levels. This is directly shown in the beds where the deposition of iron is mainly limited to the relatively coarse laminae and is wholly absent in the more fine-grained or argillaceous.

Of possibly still greater significance for the distribution of the ferruginous matter in a sandstone bed are the primary variations in the percentage of lime. As mentioned above the first deposition of iron in the shell-bearing sandstones occurred in such a manner that the calcareous matter of the shells was replaced by an iron compound. We may venture to infer that the calcium carbonate occurring in different manners must also give way to the more difficultly soluble carbonate of iron. In certain cases the shell-bearing beds have contained a slight content of calcite-cement in the sand surrounding the calcareous shells. This calcite has existed before the interaction between the carbonate of calcium and the ferruginous solution took place. No doubt such a secondarily deposited, fine-divided and fine-grained calcite has more easily changed than the most durable parts of the shells. A similar case is met with in the marly sandstone at Dompäng. In this the calcareous shells are often unaltered in nodules of clay ironstone, formed in the marl by the replacement of the calcium carbonate by carbonate of iron.

In this connection attention should be drawn to the fact that the shells in the shell-bearing beds are generally not preserved in their original thickness but as a rule only as thin pellicles. Is this due to the shells being thinner through dissolution of the calcium carbonate before the beginning of the alteration into siderite? In this case the original ornamentation on the shells would be destroyed by corrosion. Now, the sculpture is as a rule exceedingly distinct and thus the superficial layer has at any rate been preserved. Here and there the mould of both the exterior and interior part is distinctly visible.

The fact that only the superficial layer is preserved may be explained by different circumstances. This is not the proper place to enter on a discussion of these and the author will therefore only mention those appearing most probable to him. The interaction between the carbonate of lime in the shells and the ferruginous solution does not begin in the interior of the shells but on their surface. By the transformation of the superficial layer into carbonate of iron the interaction between the solution and the interior of the shells is prevented.

The precipitation of carbonate of iron will therefore, if continued, occur in the rock around the shells. When the precipitation stops and eventually a dissolution begins a large part of the content of iron remains in the form of hydrated iron oxide but the carbonate of lime is entirely dissolved. Then only a thin mould or cast of the surface preserved in iron hydroxide remains of the shells.[1]

Besides the just mentioned types of highly ferruginous sandstones in the Rhætic-Liassic series of NW Scania still another occurs: *the siderite sandstones proper*. They are developed as fine-grained, even-grained sandstones with a remarkably evenly distributed cement of siderite (cf. the Avicula bed, p. 226). The rocks occur in extended beds of relatively uniform thickness and separated by more argillaceous layers. It is only on the bedding surfaces and at the cracks traversing the beds that a transformation of the siderite into iron oxide or hydrated iron oxide is found.

It seems difficult to the author to look upon the content of iron in these sandstones as a secondary formation. The distribution of the siderite is so uniform that we find no parallel to it in the rocks discussed above.

The iron compound formed at the same time as the sand was deposited, may have consisted of iron hydroxide, silicate or carbonate. In nature there are several instances of deposited hydrated iron oxide and silicate of iron having been converted into carbonate of iron. How this transformation has occurred we shall not dwell on here. It is, however, seldom so complete that the primary material can not be traced (see below p. 250). The Avicula bed and other similar siderite sandstones in the Lias of Scania show no traces whatever of such a transformation and therefore the carbonate of iron is very likely a primary formation. It has probably been directly precipitated from a solution of ferrous bicarbonate by loss of carbon dioxide. In this case, however, carbon dioxide-absorbing vegetation in the water can not have caused or facilitated the precipitation.

As shown above, ferruginous sandstones of different types have been formed in the Rhætic-Liassic series of NW Scania. The conditions for their formation have, as we see, been of different kinds. In all instances, however, the deposition has occurred in shallow water. It is remarkable that highly ferruginous strata are wholly absent in the Höör sandstone but that such are very abundantly present in the Lias of SE Scania, though partly in an entirely different development (iron oolite and greenalite-bearing rocks) from that in the above discussed region. The highly ferruginous Archaean region has no doubt delivered ferruginous water in an equally high degree to the different Rhætic-Liassic regions. The quantitative and qualitative variation in the deposition must then be wholly ascribed to the local conditions for the deposition of iron.

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[1] Of course a dissolution of calcium carbonate from the rock (the sand) may also have taken place before the addition of the iron compounds. In the first place the carbonate occurring as cement or matrix ought to have been dissolved. However, a strong lixiviation should have been visible on the surfaces of the shells also. As these show no corrosion, we may infer that no stronger dissolution of calcite has occurred.

The formation of the Höör sandstone.

The rocks in the Rhætic-Liassic region in NW Scania discussed above are for the most part fine-grained. Sandstones with grains 0.05—0.5 mm in diameter form, together with still more fine-grained, arenaceous or highly argillaceous sediments, the bulk of the series of strata. First in the uppermost part of this do somewhat coarser sandstones occur in greater quantities. We may take for granted that the fine material is suspended from a weathering gravel, which has also contained coarser grains. One might expect to find rocks constructed of this coarser material at the border parts of the Rhætic-Liassic region, for inst. at Höganäs and Billesholm. Nevertheless, one looks in vain for these coarse rocks at these places. On that account there is hardly any doubt that the weathering products underwent a primary sorting before the fine parts of them lodged in the Rhætic-Liassic region mentioned above.

Where did this sorting occur? It must have been somewhere between the place where the fine-grained sediments were deposited and the place from which the weathering products are derived. Considering the great thickness of the Rhætic-Liassic series we may infer that the material can not be derived from the relatively small Archaean horsts immediately surrounding the basin of sedimentation. The source of the material must be looked for in the large Archaean region to the NE and E. In this the coarser parts of the weathering gravel have no doubt also remained.

It may seem almost impossible to find these coarse sediments, which have probably been scattered in the larger and smaller settling basins which the streams have had to pass. They have probably fallen a victim to the denudation and entered into other (new) sediments. What now remains in the southernmost part of the Archaean region is only a trifle and belongs, as far as we know, entirely to the Lias. The rocks consist of conglomerates, arkoses and coarse sandstones. They belong to the series termed Höör sandstone (see p. 229).

The region in which the Höör sandstone was deposited has had its deepest lying parts to the NW and its highest lying to the SE during the time of deposition as is now also the case. A general transportation of material from the SE towards the NW has taken place but argillaceous matter has nevertheless also been periodically deposited in the SE region rich in coarse sediments. In the NW part of the region, which contains fine-grained sandstones with marine fossils, a connection with the Helsingborg region has probably existed. If this connection was open already during the Rhætic, a great part of the sedimentary material has probably been carried that way to the last-mentioned region.[1]

One of the most characteristic features of the Höör sandstone is its deficiency in calcium- and iron-compounds. In this respect it corresponds with the previously

[1] It would be interesting to see what relation there is between the Höör sandstone and the younger, relatively coarse delta deposits in the upper Lias of the Helsingborg field. Is the material in the latter derived from the sedimentary region of the Höör sandstone, is it derived from more distant places and has been transported over the same, or has it come from elsewhere?

discussed, plant-bearing series of strata in the Helsingborg region. No doubt the reason of this has been similarity in forming condition. The Höör sandstone also contains plant remains though not in any greater quantity. The water in which the deposition has taken place, has probably been relatively rich in carbon dioxide and has consequently counteracted the precipitation of calcite or siderite. It has rather acted dissolving on calcareous and ferriferous minerals.

The Höör sandstone is a marine deposit. Not only the marine fauna in the more fine-grained sandstones but also the character, stratification and occurrence of the rocks favour this opinion. Probably, however, the deep and shallow bay in which the sandstone was deposited has also had important affluents and on that account a brackish water. *Cardinia Follini* among the fossil forms of the Höör sandstone also speaks for this.

Sometimes the locally occurring enrichment of plant fragments gives the sandstone a certain similarity to corresponding strata in the Helsingborg field. The cement of quartz, abundantly present in the Höör sandstone, distinguishes it from the Liassic sandstones in other regions. This attribute, however, is not primarily due to peculiar conditions of deposition, the cement being an exclusively secondary formation in these sandstones. But it is probable that the deposition of silica has been facilitated and increased thanks to the sedimentary conditions not allowing argillaceous matter and iron compounds to be deposited in any larger quantity in the Höör sandstone, particularly not as matrix between the sand-grains.

The formation of the Liassic sandstones in south-eastern Scania.

As shown in the preceding the sandstones in the Lias of SE Scania are partly of a quite different character from the rocks in the Helsingborg and Höör regions. The coal-seams, the white, loose sandstones and the argillaceous rocks are partly common features and will not be discussed here. Peculiar to SE Scania, the Fyledal region, is the great and partly characteristic development of the highly ferruginous sediments. These are sometimes real ironstones, sometimes sandstones rich in iron. It would of course have been most correct to treat of these rocks in one connection, especially when it is a question of finding out their forming conditions. It is also the purpose of the author to discuss these problems more in detail and more uniformly in connection with the account of the occurrence of the iron compounds in the Swedish sediments. From obvious reasons he will only examine the forming conditions of the ferruginous sandstones here.

In the numerous but insignificant cuttings in which the Liassic strata in SE Scania are exposed the rocks are as a rule strongly weathered. The iron then always occurs in the form of hydrated iron oxide. In most cases there is no possibility to decide directly in which form the iron has first occurred and consequently no conclusions can be drawn from their character as to their forming conditions. Occasionally certain special circumstances or characteristics in their formation may be inferred from the structure of the rock in other respects. The highly ferruginous »mud-cake» conglomerates previously mentioned by the author are of this type (Hadding 1927, 109).

Of greatest interest for the interpretation of the forming conditions are of course the cuttings with relatively fresh rocks.

An abundance of calcite is sometimes found in the relatively fresh parts of the sandstones rich in iron, sometimes siderite and not infrequently grains of oolite. In certain places the latter are present in such quantities that they form whole beds, and then greenalite also occurs as cement. As already mentioned (p. 236) the iron in these rocks has been primarily deposited partly as greenalite, partly as oolitic chamosite. With regard to the forming conditions the following may be noted.

Though the strata are for the most part devoid of a marine character, they must nevertheless partly be a submarine formation. The fossils are evidence of this, even though they, like the mud-cake conglomerates, owe their bed-shaped occurrence to occasional floods and heavy waves. The oolites speak for a formation in very shallow water and the mud-cake conglomerates for occasional drying.

The change in the series of strata from iron- and lime-free, carboniferous rocks to ferruginous and calcareous, non-plant-bearing strata shows that the (water in the) basin of deposition has changed its character. The water rich in vegetation and probably in carbon dioxide has been displaced by a water free from plants and poor in carbon dioxide. The deposition of calcium carbonate has been made possible and has also taken place to a far larger extent than is indicated by the present content of lime in the rocks.

Obviously the above-mentioned sedimentary conditions have been highly favourable to a deposition of iron compounds. To what extent a primary deposition of iron in form of siderite or limonite has taken place we do not know. These minerals are abundantly present but are, as far as can be seen, of secondary formation. Of primary formation, on the contrary, are the oolitic chamosite and the green cementing mass, the dense greenalite. We must therefore presume that these minerals have had the same forming conditions as those sketched above, viz. a shallow shore region with water poor in or free from carbon dioxide. That an abundant supply of both iron and lime compounds has taken place is quite natural, the basin of deposition being situated in the region of the lime- and iron-rich Silurian deposits (the Colonus shale and the Öved-Ramsåsa formations) and in the neighbourhood of an Archaean region rich in ferruginous water.

The Cretaceous Sandstones of Sweden.

In the Swedish Cretaceous deposits the sandstones only play a minor rôle. They are found in the lowest parts of the series of strata that were formed during the transgression of the Cretaceous sea, further they are found as fragments of the same basal deposits, included in conglomerates, and finally they also occur locally in the upper part of the series of strata. These sandstones have partly been discussed in connection with the conglomerates (Hadding 1927 112 seq.) and we may refer concerning them to the description already made. This holds true of the Senonian sandstones in SE Scania as well as of the basal sandstones in NE Scania. They will only be shortly mentioned in the following. The thickest and best preserved of the sandstones in the Cretaceous of Sweden is the calcareous sandstone in the upper Senonian of SE Scania, the so-called Köpinge sandstone.

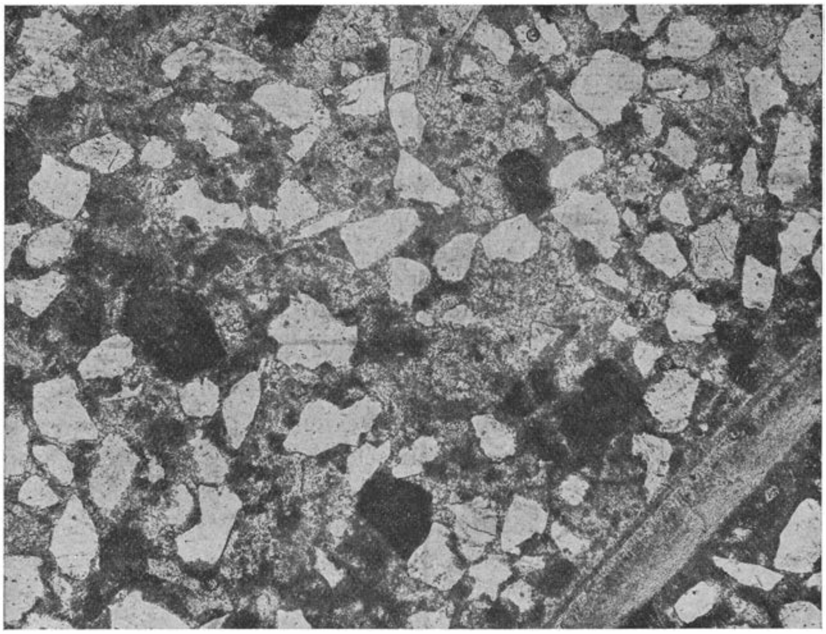

Fig. 131. »Köpinge sandstone». Calcareous sandstone or arenaceous limestone. Fossiliferous. Quartz grains small, angular. Senonian; zone with *Belemnitella mucronata*. Köpinge, Scania. (Pr. 2627. Pl. 397.) — 60 ×.

The sandstones in the Senonian of south-eastern Scania.

In *the Tosterup field* the Liassic strata are directly superposed by a white sandstone with *Actinocamax westphalicus*. The rock consists of pure quartz sand with relatively large grains, mostly 1—2 mm in diameter. The grains are well rounded. The cement consists of calcite. The rock grades into a conglomerate, the Westphalicus conglomerate (Hadding 1927, 113).

The lower, coarse sandstone beds grade upwards into more fine-grained ones. In the zone with *Actinocamax verus* the quartz grains are about 0,1—0,2 mm in diameter, in the next younger zone with *Actinocamax mammillatus* they are generally 0,01—0,1 mm. Argillaceous matter and grains of glauconite are also present in the latter sandstone. The cement throughout is calcite. The next younger zone, that with *Belemnitella mucronata*, is developed as a glauconite-bearing calcareous sandstone, the Köpinge sandstone.

The Köpinge sandstone or the sandy limestone is a slightly yellow, fairly loose, highly calcareous sandstone or arenaceous limestone. As a rule it is developed into distinct beds but without finer stratification. The grains of quartz occur in varying quantities. They are about 0.1 mm in diameter and angular or sub-rounded in form (fig. 131).

Glauconite is always present in the rock, sometimes abundantly. The grains are often cracked at the edge in a manner fairly common in limestones but never seen in pure sandstones.

The content of calcite varies but is always so large that the grains of quartz lie embedded in it without touching each other to any greater extent. The mass is distinctly crystalline.

The rock contains scattered foraminifera and of larger fossils among others *Ammonites Stobaei*, echinoderms, brachiopods, lamellibranchs and teeth of mosasaurs. Fragments of land plants have also been found.

The formation of the Senonian sandstones in south-eastern Scania.

All the Cretaceous sandstones of south-eastern Scania have a pronounced marine character. They all contain marine fossils and form a continuous series deposited in a gradually more submerged region. The basal, coarse sandstones are formed on the shore of the Senonian sea, the next ones in somewhat deeper water but these also, no doubt, at only a slight depth and near the shore.

It is specially remarkable that the Senonian rocks of SE Scania contain more detritus than the corresponding rocks in other regions of Scania, regardless of the basal deposits in the Kristianstad region (and the Åhus sandstone, if this does not belong to the basal deposits). The material has principally been derived from the older sedimentary rocks of the neighbourhood, the Cambro-Silurian, Keuper and Lias.

The sandstones in the Senonian of north-eastern Scania.

The Senonian strata in NE Scania are mainly developed as a shell-fragment-limestone with more or less finely divided material. Sometimes this limestone, with or without basal conglomerate, rests directly on the gneiss, in other places it is separated from this by a sandstone. This sandstone is principally known from erratic blocks. After two more remarkable occurrences it has been termed *Holma sandstone* or *Ryedal sandstone*, the former from the eastern side of the Ifö Lake, the latter from western Blekinge. In the kaolin- and limestone quarries at Ifö the same formation occurs but as a loose sand or a soft clay replacing this. The Åhus sandstone occupies a more independent position in the series of strata (cf. GRÖNVALL 1915, 174; HENNIG 1910, 642).

The Ryedal sandstone is a pure white, loose quartz sandstone. The grains are about 0.2—0.3 mm in diameter. The matrix is absent and the cement, quartz, is as a rule only sparingly present. Some portions are better cemented, quartzitic in appearance and very hard. No fossils have been observed in this rock.

The Holma sandstone is exactly like the Ryedal sandstone and as this loose and free from fossils.

The sandstone pebbles in the Cretaceous conglomerates of NE Scania are of the same type. Sometimes, however, an abundance of secondarily formed quartz is found in them, partly as secondary growth of the quartz grains, partly as larger crystals enclosing a number of quartz grains. Thus in the conglomerate

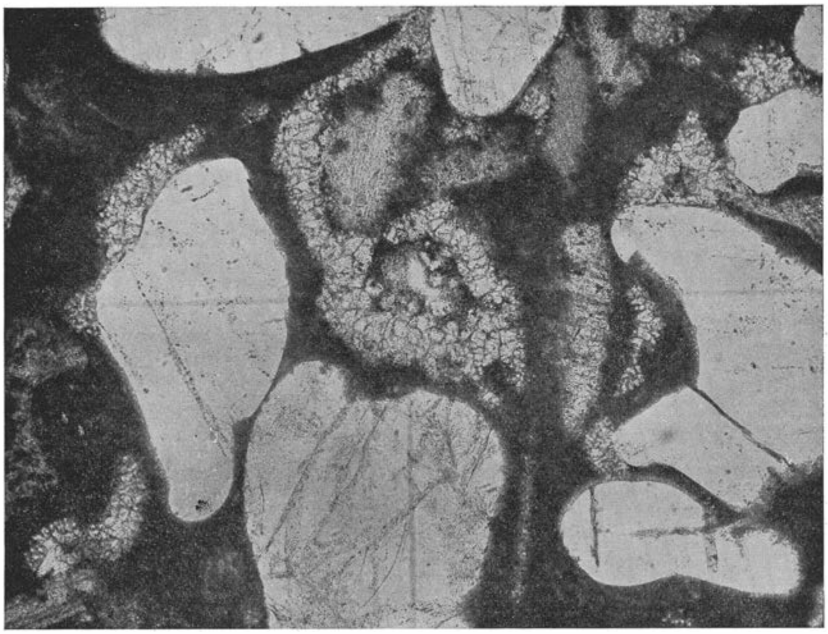

Fig. 132. Calcareous and argillaceous sandstone. Quartz grains large, rounded and corroded. Calcite matrix and cement partly argillaceous and crypto-crystalline, partly pure and distinctly crystalline. Senonian. Filkesboda, Scania. (Pr. 794. Pl. 306.) — 60 ×.

at *Filkesboda* the sandstone pebbles are constructed of quartz grains 0.05—0.3 mm in diameter and secondarily formed quartz crystals up to 10 mm long.

The formation of the above-mentioned sandstones has taken place during the transgression of the Cretaceous sea over the more or less weathered Archæan bed-rock. Traces of the same rocks are found all over a large part of the present Cretaceous region in NE Scania. Where the sandstone is now absent it may have been broken down in connection with a Senonian formation of conglomerate (Hadding 1927, 142, a. o.) or it may never have been formed. In the former case, if the rock has already been cemented, it has been included as pebbles in the conglomerate, or if it has been insufficiently cemented, it has been washed away as loose sand which has been deposited elsewhere.

Has there been no deposition of sand at a place during the transgression, it may be due to the local conditions. The bed-rock has either been solid or unfavourably situated for the deposition (much exposed to the waves or on a steep shore). The sedimentary conditions may also have been such that a more fine-grained material has been deposited. This is for inst. the case in the northern part of the island of Ifö. In certain places there the limestone rests on a substratum of clay, in others, on the contrary, of sand.

As to their formation the said Cretaceous sandstones are alike. All of them have been formed on or near the shore of the transgressing Cretaceous sea. The conditions have been unfavourable for the development of the fauna. No deposition of lime or iron has taken place. Thus the conditions remind us in a certain degree of those prevalent during the formation of the pure, white Liassic sandstones. It is remarkable that the grains of felspar are absent or very uncommon in these sandstones, while they are on the contrary relatively abundantly present in the matrix of the conglomerates containing the sandstone blocks.

The Åhus sandstone is, in certain forms, of the same character as the abovementioned white, loose sandstones. As a rule, however, it is more solid and gray in colour. The quartz grains are distinctly rounded but irregularly enlarged by secondary growth (figg. 133—134). Sometimes they are up to 1 mm in diameter but more frequently 0.5—0.7 mm. Grains of felspar, mainly microcline, are sparingly present.

No finer matrix exists between the grains of quartz. The rounded grains, on the other hand, show as a rule a thin coating of an exceedingly finely divided (clayey?) substance, which indicates the limit between the original grains and peripheral parts arisen by secondary growth. By means of this coating the sandstone obtains a gray colour definitely distinguishing it from the pure white sandstones at Holma, Ryedal, etc.

The cement in the Åhus sandstone consists of quartz in all the samples examined by the author. As a rule it is abundantly present, on which account the rock is relatively solid and sometimes quartzitic in appearance. According to Hennig (1894, 496) calcite may also occur as cement, and then the rock is less solid.

In the Åhus sandstone scattered fragments of fossils are found, principally of lamellibranchs but also of echinoderms, bryozoa, brachiopods, a. o. The shells and other fragments are usually well preserved and, where they occur in larger quantities, give the rock a high content of lime (Hennig states 62 % $CaCO_3$). Glauconite is absent.

The stratigraphical conditions of the Åhus sandstone are unknown, the rock being found only in erratic blocks. But the fauna in these blocks informs us that the sandstone corresponds to a large part of the series of strata, which in the rest of the region is developed as shell-fragment-limestone. Of the 58 species from the sandstone, which have been described by Hennig, 12 are representative of the zone with *Actinocamax mammillatus* and the same number of the zone with *Belemnitella mucronata.* Consequently both zones are represented in the sandstone.

Fig. 133. »Åhus sandstone». Quartz sandstone with secondarily enlarged quartz grains. Shell fragments covered by small calcite crystals. Cretaceous, Upper Senonian. Åhus, Scania. (Pr. 778. Pl. 292.) — 60 ×.

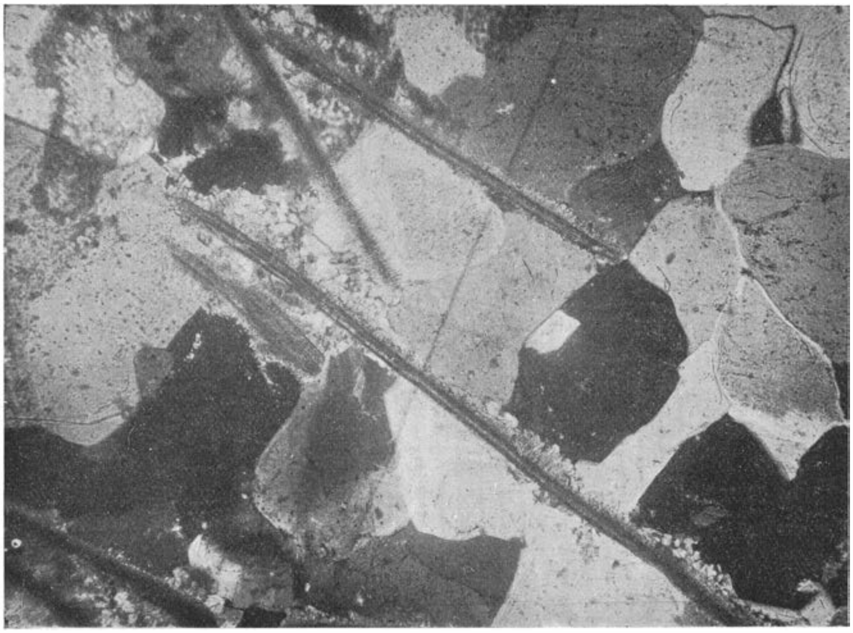

Fig. 134. »Åhus sandstone». (Pr. 788. Pl. 293.) — 50 ×. Nic. +.

The formation of the Ahus sandstone is not least interesting on account of the rock being so entirely different from the shell-fragment-limestone formed at the same time and in the same region (the Kristianstad field). The author has already had the opportunity to illustrate this fact (HADDING 1927, 29). As it has not been possible to study any occurrence of outcropping sandstone, it is fairly useless to attempt to find out its relation to the limestones. HENNIG considered the sandstone to be is a shallow water formation. He thought that the sand-grains had been stirred up by the waves and then worn against each other and rounded. Further he pointed out that the water had not been sufficiently tranquil (deep) for the formation of glauconite. Though the author can not endorse the argumentation in these particulars, he nevertheless considers it indisputable that the rock is marine, and that the formation has taken place at a slight depth and in a moving water. It may, however, be called in question whether the currents have been stronger in the place where the Åhus sandstone was deposited than in the places where the shell-fragment-limestone was deposited. The Ignaberga limestone consists of relatively large fragments of shells and intermixed with them grains of sand, often considerably coarser than the grains in the Åhus sandstone. Finer grains of sand and argillaceous matter are not as foreign to this rock as to the Åhus sandstone but they are not present in larger quantities here than in most coarse-grained sediments.

HENNIG believed it was possible to infer from the development of the bryozoa occurring in the Åhus sandstone that this rock was formed in a less saline, probably brackish water, while the shell-fragment-limestone was formed in a water with higher salinity. This is difficult to explain, as it must be remembered that Åhus is the point in the Cretaceous region of NE Scania which lies farthest away from the probable shore of the Cretaceous sea. It would be most probable that the sandstone had been formed as a sand-bar with a relatively open site, unless a land region had existed SE of the present shore.

From a paleogeographical point of view it is of the greatest interest to follow a zone, for inst. the zone with *Belemnitella mucronata* (see p. 39)[1]. In north-eastern (as well as north-western) Scania this is developed as a shell-fragment-limestone, locally developed at Åhus as a fairly coarse, shell-bearing quartz sandstone without glauconite. To the south the fragment-limestone is fine-grained and arenaceous and grades into the relatively glauconite-rich Köpinge sandstone, a calcareous sandstone or an arenaceous limestone. The distribution of this is limited to the south-eastern part of Scania. On following the Mucronata zone to the west, it will be found developed as writing chalk, as shown by the drillings. No doubt this facies of the zone is considerably wider distributed than the first-mentioned. As to the forming conditions we may infer that the writing chalk is formed at a greater depth than the Köpinge sandstone and this at a greater depth than the Åhus sandstone and the shell-fragment-limestone.

[1] See also GRÖNWALL 1912.

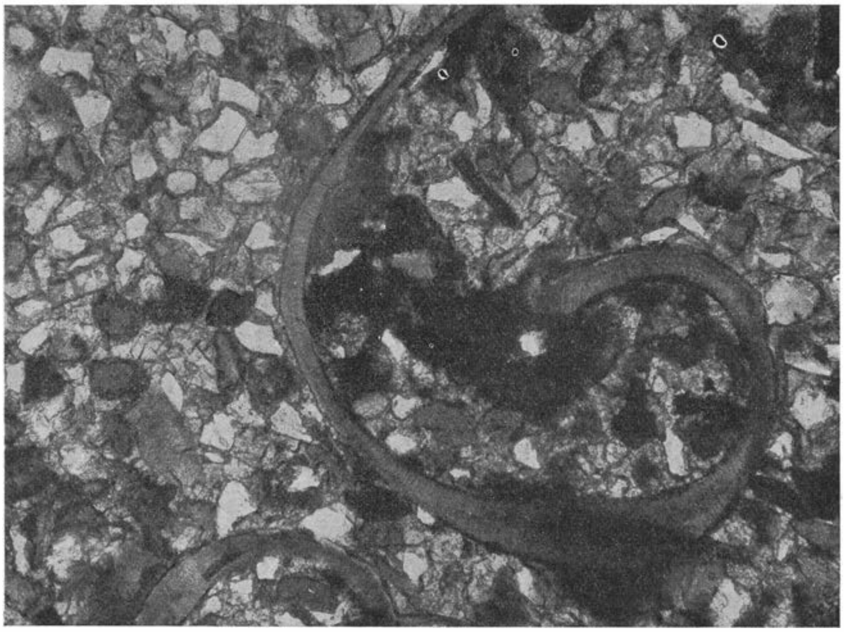

Fig. 135. Calcareous sandstone, glauconite-bearing. Small gastropods and lamellibranchs occur abundantly in the rock. Tertiary. Erratic boulder. Ystad, Scania. (Pr. 2258. Pl. 376.) — 60 ×.

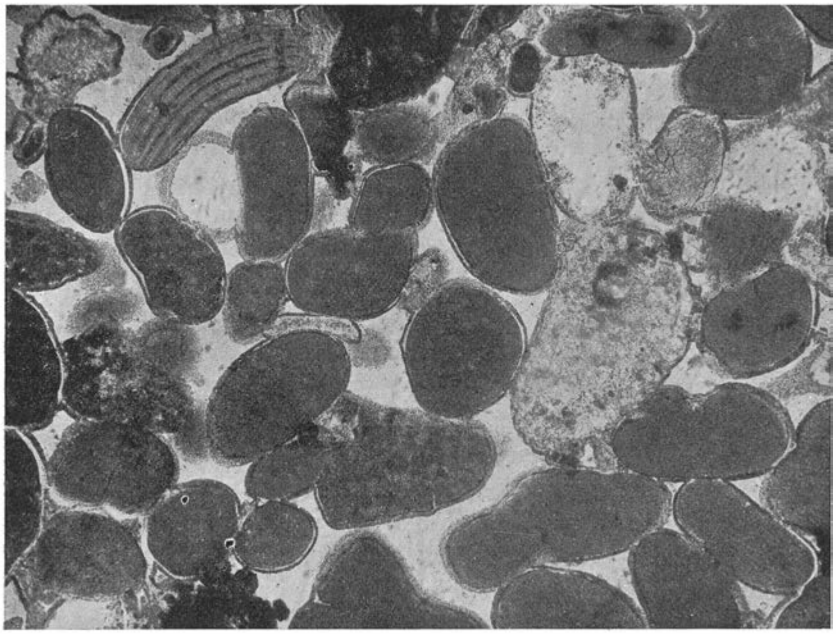

Fig. 136. Glauconite sandstone. Tertiary. Erratic boulder, Ystad, Scania (Pr. 2259. Pl. 375.) — 60 ×.

The Blocks of Tertiary Sandstone in Scania.

Tertiary rocks are outcropping only in small quantities in Sweden. A few scattered occurrences of igneous rocks belong to them, among others the »basalts» of Scania and the tuffs accompanying these. A small occurrence of Paleocene marl at Klagshamn, directly superposing the Danian limestone (see Holst and Grönwall 1907), is, regardless of the tuffs, the only sedimentary rock of Tertiary age found in situ. In southern Scania, however, especially at Ystad, Tertiary sandstones and limestones have been found as erratic blocks in such a quantity that the rocks must be supposed to be formed in the immediate neighbourhood of the locality. For this reason they will be mentioned shortly here.

The Tertiary blocks are somewhat varying in their petrographical character: sometimes they are pure quartz sandstones and sometimes calcareous sandstones or arenaceous limestones, occasionally also rich in argillaceous matter. Glauconite is seldom absent and in certain rocks this mineral occurs in such abundance that it forms the bulk of the rock (fig. 136). Limonite is not infrequently present in considerable quantities.

In the sandstones the quartz grains are as a rule angular or sub-rounded (fig. 135). They seldom exceed 0.1 mm in diameter. The grains in the quartz sandstones show secondary growth. In the calcareous sandstones the calcite is fine-crystalline and occurs as matrix and cement.

The development of the glauconite varies with the character of the rock. This mineral occurs in the quartz sandstones as diffusely limited, irregular, green portions squeezed in between the grains of quartz. In the highly calcareous sandstones, on the contrary, the glauconite is found in the form of well demarcated, rounded grains (fig. 136), often cracked at the edge.

Together with the glauconite, small grains of phosphorite or phosphatized fragments of shells are also found.

As a rule the Tertiary blocks are rich in fossil fragments, principally shells of lamellibranchs (figg. 137—138). They sometimes occur in such quantities that they form an essential part of the rock. Not infrequently do they almost entirely cover the bedding surfaces.

The blocks generally show a distinct stratification and cleave in large, even slabs. However, more compact blocks that cleave with difficulty have also been found.

The formation of the Tertiary sandstones has no doubt taken place at a relatively slight depth. The content of fossils as well as the clastic components indicate this. In certain forms the rock is petrographically closely allied to the Köpinge sandstone and has probably had the same forming conditions as this. The fauna in the blocks still awaits investigation and on that account we do not know with certainty from which time the different blocks originate. Some of them, however, are no doubt Eocene. According to Lundgren (1882, 33) they contain int. al. *Turritella edita* Sow., *T. hybrida* Desh. and *Corbula Lamarckii* Desh. (See also Holst 1902, 9 and Grönwall 1904, 435.)

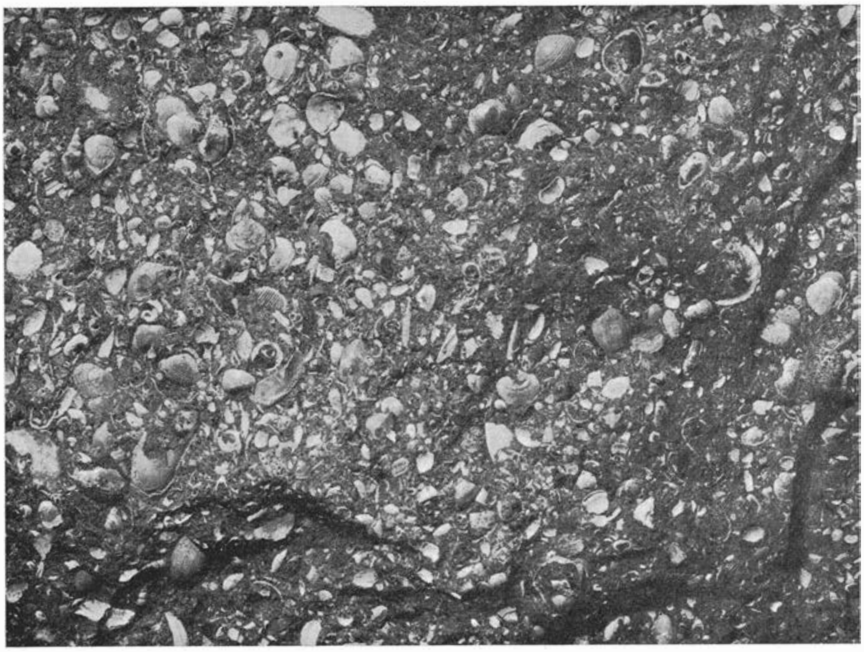

Fig. 137. Calcareous sandstone, fine-grained, argillaceous. Highly fossiliferous. Tertiary. Erratic stone. Ystad, Scania. (Pl. 231.) — $^1/_1$.

Fig. 138. Ferruginous sandstone, glauconite-bearing. Highly fossiliferous. Tertiary. Erratic stone. Ystad, Scania. (Pl. 232.) — $^1/_1$.

The Classification and Nomenclature of the Sandstones. I.

Relations between the Classification and the Petrographical Character and Stratigraphical Occurrence of the Sandstones.

On classifying the sandstones it is undeniably most natural to follow the great division of sediments a step further. The grouping in conglomerates, sandstones, argillaceous and calcareous sediments is made after the petrographical character of the rocks and the same differentiating principle may of course be used in dividing the different groups.

Another ground of classification applicable to all sedimentary rocks is the stratigraphical. In the following we shall illustrate the advantages and disadvantages of the classification after these different grounds.

Before entering on a discussion of the classification of the sandstones, a few words may be said as to their nomenclature. As a rule the nomenclature of the rocks has arisen and arises without the least thought of their systematic position. (Besides, the same holds also true of the minerals and in the vegetable and animal kingdoms.) Many of these terms have now entered into the mind of every geologist in such a degree that he involuntarily connects the term with the conception of a certain kind of rock in a well known systematic position. This is for inst. the case with »granite», »foyaite», a. o. As long as a rock is less known, its name is not understood in this manner. Certainly such terms as »malchite» or »helsinkite» do not in the majority of geologists call forth either the image of the rock or a conception of its place in the system. In spite of this disadvantage the said terms are undeniably preferable to the awkward, not to say impossible, proposals proffered in the attempts to force a description of the rock into its nomenclature.

In a certain degree the sedimentary rocks occupy a more favourable position, as the nomenclature may often be suitably adapted to the character of the rock. »Sandstone» is an example of this, and so are »calcareous sandstone», »sideritic sandstone», »glauconitic sandstone», a. o. It is, however, hardly imaginable that this principle can be consequently followed without leading to such absurd terms as those sometimes given to igneous rocks.

This is hardly the place to discuss the best way in which to obtain a uniform and good nomenclature. The author will elsewhere give a few points of view in this question. But the sense or range of certain terms will be illustrated here.

A common way of naming a rock (or a mineral) is to call it after the locality in which it occurs (malchite, christobalite). A certain analogy to this is found in such a term as »Hardeberga sandstone», by which a white, quartzitic sandstone of Lower Cambrian age is meant. This term is applied not only to the rock at Hardeberga but also to corresponding, similarly developed rocks in other places. If the age-limitation were rejected, the term would obtain a wider application. A more distinct characterization (marine, parallell-bedded, etc.) would increase the value of the term and make it worth being generally spread, possibly abbreviated to »Hardebergite». The analogy to the nomenclature of the igneous rocks would then be obvious. It is, however, far from desirable.

But many names after a locality have a smaller range than the above-mentioned. »Öved sandstone» only means the red or variegated Downtonian sandstone at Öved. Perfectly similar sandstones from the same stratigraphical level occur for inst. at Klinta and Ramsåsa but it has been found best to call them »Klinta sandstone» and »Ramsåsa sandstone». Such terms are naturally of no greater interest, as they only designate a place in which the rock occurs in situ.

From a petrographical point of view the terms including rocks of varying nature are also fairly valueless. They bear mainly on the stratigraphical and local distribution, rather than on the petrographical character. A term of this type is »Dala sandstone», referring to an Algonkian sandstone in Dalecarlia and neighbouring provinces. Other diffuse terms of the same type are »Mälar sandstone» and »Kalmarsund sandstone». In spite of being devoid of a more general interest, these terms are nevertheless of a certain local value.

In the nomenclature of the sandstones terms which indicate some component typical to the rock are found to a large extent. Sometimes the term refers to the cement (for inst. calcareous sandstone), in other cases to inclusions or occasional constituents (for inst. glauconitic sandstone). Sometimes doubt can arise as to the meaning of the term. Thus phosphoritic sandstone may designate a sand cemented by phosphorite as well as a sandstone containing phosphorite nodules. It would be very desirable that the nomenclature underwent a revision or was made more uniform and distinct. For this work, however, a co-operation between scientists of different countries would be desirable.

After these short comments on the nomenclature we will pass on to a discussion of the classification of the sandstones.

A classification of the sandstones according to their *petrographical character* is possible and is also made use of, even in more than one form. For this division the one or the other characteristic may be used as a ground of classification, for inst. the size of the grains, their kind, the kind of cement, the inclusions, etc.

If *the size of the grains* is chosen as a ground of classification, we may continue the division of the conglomerates after the same principle (see HADDING 1927, 145) and thus create a connected series of rocks from the coarsest conglomerates down to the argillaceous sediments. Proposals for such classifications of the arenaceous sediments have been proffered from different quarters. Those propounded by WENTWORTH (1922) and ATTERBERG (1903), the latter for the loose deposits, will be quoted here. (Cf. also UDDEN 1914 and TWENHOFEL 1926, 154).

WENTWORTH 1922.

The Aggregate	The indurated rock	Limiting dimensions	
Granule gravel	Granule conglomerate	4—2	mm
Very coarse sand	Very coarse sandstone	2—1	»
Coarse sand	Coarse sandstone	1—$^1/_2$	»
Medium sand	Medium sandstone	$^1/_2$—$^1/_4$	»
Fine sand	Fine sandstone	$^1/_4$—$^1/_8$	»
Very fine sand	Very fine sandstone	$^1/_8$—$^1/_{16}$	»
Silt	Siltstone	$^1/_{16}$—$^1/_{256}$	»
Clay	Claystone	$^1/_{256}$— — —	

ATTERBERG 1903.

Block	> 20	cm	— — — — — — — — — —		
Sten	2—20	»	— — — — — — — — — —		
Grus	2—20	mm	— — — — — — — — — —		
Sand	0,2—2	»	Grand sand	0,7—2,0	mm
			Common sand	0,2—0,7	»
Mo	0,02—0,2	»	Fimma	0,07—0,2	»
			Mjäla	0,02—0,07	»
Lättler	0,002—0,02	»	Vesa	0,007—0,02	»
			Mjuna	0,002—0,007	»
Ler (Clay)	< 0,002	»	— — — — — — — — — —		

On a classification of the sandstones according to the size of the grains a certain method or principle for the fixation or statement of this must be chosen. For the grains in a sandstone are never all of the same size. There is a certain maximum size of the grains and besides the larger grains there are always smaller ones of varying diameter. The bulk of the grains are not found among the largest or smallest grains in the sandstone but a little below the maximum limit. The author has already (p. 12) spoken in favour of making the size of the bulk of the grains a measure for the relative coarseness of the sandstone when this is stated by a numerical value. It is of course also possible to quote the size of the largest grains instead. A value is then often obtained which better shows the transporting power of the medium of deposition. On the other hand accidental circumstances may also have caused the occurrence of the largest grains.

Whether we choose the one or the other way of stating the relative coarseness of the rock, we must be satisfied with approximate values. These are in themselves of no greater value, as they do not tell us anything else of the character of the rock. Sandstones with grains of a certain size may be formed in almost any way. It is of greater interest to determine the percentage of grains of different size. Such an investigation often informs us of the forming conditions. In eolian sand the sorting is better than in that transported by water. The bulk of the grains are fairly uniform in size. The sand deposited on an open shore is better sorted than that deposited in more closed basins, and that deposited in running water shows as a rule strong variations in the size of the grains. Diagrams of the sand's composition of grains of different size therefore show different characteristics for different modes of formation. (Cf. UDDEN 1914).

The classification of the sandstones according to the size of the grains is made more difficult by the strong variations often shown in the diameter of the grains even in one and the same bed and still more frequently in a series of beds with similar formation. For the said reasons it is no doubt most advisable not to base the classification exclusively on the size of the grains in the rock. But together with other qualities it may contribute to the solution of the problems concerning the formation of the rock.

A classification of the sandstones according to the form of the grains or, to be more exact, after their slighter or stronger wear is valueless. The cause of this is partly that the wear has not always taken place in connection with the final deposition of the grains. It may represent an earlier epoch in the transport from the parent rock to the sandstone's place of formation. Consequently the form in these cases is in no way characteristic of the rock or of material deposited in a certain manner. On the other hand grains of different form (different wear) occur in one and the same rock, and this also implies a difficulty in judging the rounding or wear to which the grains have been subjected. Often, however, the different degree of rounding shown by the grains may be a good guidance in judging the medium of transport. The grains in the eolian sand are better rounded throughout than in sand equally coarse but transported by water. (On the wear and rounding of the sandgrains see p. 11. I beg to refer those interested in the problem to GALLOWAY 1922, TWENHOFEL 1926 and to works quoted by the latter.)

A classification of the sandstones according to the minerals forming an essential part of the grains is excluded for the reason that quartz grains in most cases form the bulk of the rock. The only mineral besides quartz occurring more generally and in abundant quantities in the sandstones is felspar, especially microcline. We can not draw a distinct line between arkoses and other sandstones, for the non-arkosic sandstones also almost always contain some felspar.

The grouping of the sandstones according to the nature of their cement is often found, though not completely followed up. This classification gives us two large groups of sandstones, quartz (or siliceous) sandstones and calcite (or calcareous) sandstones as well as a few more sparingly represented (siderite sandstone, limonite sandstone, etc. See p. 17). The greatest disadvantage of this classification is that it is based on a secondary quality in the rock. Besides that the cement may be of different kinds in one and the same rock and may also be subjected to changes (see p. 23, 24 a. o.). This gives us no or only slight information on the formation of the rock.

Of greater interest in the last-mentioned respect is the matrix and the inclusions present in several sandstones. A grouping of certain interest may be made as follows: pure sandstones, (primarily) calcareous, argillaceous, (primarily) ferruginous, bituminous, glauconitic, phosphoritic, etc. But the different groups grade into each other in such a manner that it would be unimaginable to build up a clear system on this ground of classification.

It may be unnecessary to enter on a further discussion of the petrographical characteristics as a possible ground of classification. It is evident already from the short survey given that such a ground can not be thought of. The petrographical qualities enable us to judge the formation of the sandstones but separately they do not suffice to give a systematic survey of the rocks.

A classification of the sandstones according to their *stratigraphical occurrence* is not excluded from a petrographical point of view. The conglomerates may be divided into basal and intraformational conglomerates and a corresponding grouping of the sandstones is not out of question (see p. 267). The division into stratigraphical units (stages, zones, beds, etc.) is only of stratigraphical interest.

The Classification of the Sandstones. II.

Relations between the Classification and the Formation of the Sandstones.

A classification of the sandstones according to the mode of formation is of practical importance only in so far as this can be seen from the petrographical character and the occurrence of the sandstones. To judge the possibility of a classification based on the mode of formation we must therefore first examine how the different forming conditions reveal themselves in the rock. From this point of view we shall examine the circumstances connected with the derivation, transport and wear, deposition and diagenesis of the material.

On the estimation of several sandstones *the origin* or *derivation of the material* may be wholly left out of account. This is for inst. often the case when the rock only contains quartz grains or when transport, wear and deposition have left so distinct traces on the rock that its formation may be judged from them.

Sometimes, however, the derivation of the rock material is of greater interest. This is the case partly when the material contains grains, the parent rock of which may be established with certainty, partly when the connection between the sandstone and the primary rock is evident from their mutual occurrence in the field.

As a rule the basal arkoses are distinctly separated from their substratum, the often strongly weathered bedrock. The connection between the rocks, however, is quite obvious. The content of minerals is uniform irrespective of the arkose having lost part of the finest material during the suspension. Where this remains the material has not been suspended. The weathering gravel is in situ, and the arkose formed by this grades without distinct limit into the primary rock.

After the character and occurrence of the arkose we can therefore decide whether it is built up of non-rearranged weathering gravel (residual in the sense proper) or whether the material has been sorted before the deposition. In the latter case a slighter or stronger wear and sorting of the material shows under which conditions the deposition took place.

Consequently the derivation of the material should be viewed in connection with the character of the material, if we wish to form an opinion of the significance of the derivation. This holds also true when the sandstone contains scattered grains of some mineral, the parent rock of which can be identified. Not only the way but also the means of transport may under favourable circumstances be determined on the one hand from the place of origin and its position in relation to the place of deposition, on the other hand from the character of the primary material as compared with the character of the deposited sand.

Of still greater importance to the classification of the sandstones according to the forming conditions is the different *wear and sorting of the material.* These namely reflect partly the means and conditions of transport, partly the conditions of deposition also. They enable us to classify the sandstones as follows:

- Continental
  - Residual
  - Fluviatile
  - Lacustrine
  - Eolian
  - Glacial
- Marine
  - Littoral
  - Sublittoral

This classification is practically the same as that obtained by the study of the recent sand layers. It may of course be extended by further division of the different groups and introduction of certain special forms, for inst. the sandstones formed by pyroclastic material.

On the investigation of the Swedish Paleozoic and Mesozoic sandstones described in the preceding the author has as a rule believed he was able to draw certain conclusions as to the formation. In most cases, however, the investigation has led to the supposition of a formation defined otherwise than in the above scheme.

A summary and classification of the Swedish Paleozoic and Mesozoic sandstones according to their forming conditions, such as these have been interpreted in the preceding, give us the following scheme:

I. Marine sandstones.
   A. Sandstones formed during transgression.
      1. Sandstones formed in shallow water partly in the littoral zone.
         a. Sandstones formed on an open shore.
         b. Sandstones formed in estuaries or lagoonal basins.
      2. Sandstones formed in somewhat deeper water outside the littoral zone.
   B. Sandstones formed during oscillation.
      1. By enriching of the coarser material of already deposited sediments (negative sedimentation).

2. By new deposition of mainly coarser material (at a slight depth on an open shore).
3. By deposition of less sorted material (in a basin more or less enclosed by elevation of land).

C. Sandstones formed during regression.
1—3 As the preceding, B.

D. Sandstones formed independent of displacement of shore-line.

E. Brackish water sandstones.

II. Continental sandstones.

A. Residual sandstones.

B. Fluviatile sandstones.

C. Lacustrine sandstones.

D. Eolian sandstones.

E. Glacial sandstones.

In the following we shall investigate the possibility to carry out this classification practically and to find out to what extent it may be simplified and made more extensive at the same time as the different forms are defined as distinctly as possible.

The division into *marine* and *continental* sandstones may be difficult to accomplish. Several subaquatic sandstones contain neither fossils, tracks nor minerals indicating whether they are lacustrine or marine formations. If we only know of single beds or loose pieces of such a rock, we can not decide to which of the two said principal groups the rock belongs.

In most cases the marine or continental formation of the separate rocks may be inferred from the character of the series of strata. Sometimes, however, this character is less clear. The series may be devoid of positive signs of a marine or continental formation. Sometimes it also happens that some parts of it are marine, others continental in character. This is for inst. the case in the Visingsö series. There are examples in the Swedish series of strata that one part of the series is continental, another part formed in brackish water and a third part marine (the Keuper-Lias series in Scania). In such a series a sandstone in itself undefined in character should of course be estimated after the character of the nearest surrounding strata.

In spite of the difficulties which in certain cases, the grouping in marine and continental rocks undeniably offers, it is nevertheless in the majority of cases easy to accomplish. We shall no doubt also find new ways to decide the character in those rocks whose character now seems obscure to us. We know that the formation of autochthonous minerals does not occur uniformly in the marine and lacustrine sediments. A further investigation of this, followed up through recent as well as fossil sediments, will undoubtedly be of great interest and significance for the interpretation of the sedimentary conditions.

In this connection we will call to mind the well known fact that the continental sediments are often highly coloured, mostly red, yellow and brown but in conformity to the marine also white and green. The Scanian Keuper sandstones, the continental character of which is hardly to be doubted, are excellent examples of this. In the Swedish sediments there are also good examples of the fact that the regression sandstones are often as highly coloured as the continental sediments. We may only remember the Öved sandstone, the Ramsåsa sandstone, the grindsandstone of Dalecarlia, all of which are red or red and white and formed during the regression at the end of the Silurian time. The same is found in the youngest Lias of Scania. The sandstones originating from the Liassic regression are red, yellow or brown in colour. These highly coloured sandstones are not, as might perhaps be suspected, continental beds deposited above the marine series after the regression. To a large extent they are fossiliferous and the fossils are marine throughout. The high colour in the regression sediments is due to the sediments being brought, after the deposition, above the surface of the sea and like many continental sediments exposed to a stronger oxidation than other marine sediments. Like continental sediments they have also to a large extent been percolated by ferruginous water. From this is derived the content of iron oxide and hydroxides which give the rocks their red, yellow or brown colour.

A division of the marine sandstones into those formed during a displacement of the shore-line and those formed independent of such is well-grounded. In this case there is a direct correspondence to the earlier discussed classification of the conglomerates (HADDING 1927, 148 seq.). As this classification is, partly at least, connected with a formation at or in the littoral zone, it is only suitable for the coarse sediments (conglomerates and sandstones). Other sediments are not in the same degree influenced by displacements of the shore-line.

On the classification of the marine sandstones formed in connection with a displacement of the shore-line the tripartition into transgression-, oscillation- and regression-sandstones proposed by the author may be easily followed up. To perform this division it is at least equally necessary to have a knowledge of the stratigraphical occurrence of the rocks as of their petrographical character. It is evident from what was said above of the regression sandstone (often highly coloured) that the petrographical character differs in a certain degree in the three groups. The majority of the arkoses belongs to the transgression group. As a rule one finds in the two other groups a well sorted material and often small grains of sedimentary rocks but seldom felspar and only in small fragments.

As transgression sandstones we should designate the entire connected series of sandstones forming the base of a marine series of strata. That the rocks in such series can be highly varying we have seen in many instances in the series of strata already discussed. It suffices to remember the varying development of the Lower Cambrian sandstones in Scania.

Among the transgression sandstones we can distinguish the basal sandstones proper, the other littoral zone sandstones and the sublittoral sandstones.

The basal sandstones proper are often highly felspathic basal arkoses (Gislöv). But sometimes they are relatively poor in felspar. Then they can either contain some fine-crystalline weathering products, for inst. kaolin, chlorite, mica and iron compounds (Rekarekroken), or they can consist of a well worn, pure sand. This may be felspathic (Lugnås), sometimes it also contains fragments of older sedimentary rocks from the same series of strata (the Obolus sandstone in Dalecarlia). In the latter case the sandstone is a fine-grained equivalent to an intraformational conglomerate with its sedimentary base removed by erosion (HADDING 1927, 149).

The basal conglomerates proper are mostly littoral, but the littoral sandstones are not always basal sandstones. The middle parts of a series of transgression sandstones also frequently contain littoral sandstones and occasionally they are also found in the upper parts of the series. Sometimes these younger littoral sandstones are developed as arkoses but more frequently as coarse sandstones poor in felspar and here and there conglomerate-bearing. Fine-grained sandstones and argillaceous rocks interstratified with these may also be littoral. There are good examples of this *int. al.* at Brantevik. Mud-cracks, »rain impressions» and various tracks bear witness to the littoral character of the strata.

Where the littoral sandstones lie enclosed in sublittoral they have of course been formed during an occasional elevation of land. They may therefore be counted among the oscillation sandstones. However, the author considers it more suitable not to disconnect them from other transgression sandstones. Every greater transgression taking place during repeated oscillations, it is quite natural that the transgression series contains oscillation rocks partly formed in the first epoch of the oscillation, viz. during the elevation of land (= elements of regression, often formed by negative sedimentation), and partly in the latter epoch, viz. during the subsidence of land (= elements of transgression). The character of the rock depends on the general conditions created during the oscillation. If the deposition has taken place in an open water also after the elevation of land, the shallowing has caused a better sorting and stronger wear of the material, which has been more and more deprived of the fine-grained parts. If, on the other hand, the elevation of land has caused not only a shallowing of the sedimentation basin but also its shutting off from the open sea, more muddy rocks with only slight wear of the material are found in the sediments deposited during the oscillation. The Swedish sediments show many examples of both these types of oscillation sandstones.

The sublittoral sandstones in the transgression series cannot always be distinguished from the littoral but in most cases it may nevertheless be possible to decide whether the rock is littoral or sublittoral in character. Fine-grainedness, even stratification and a relatively good sorting of the material characterize the majority of the sublittoral sandstones. In the opinion of the author the occurrence of autochthonous glauconite and phosphorite indicates a sublittoral formation. Secondarily occurring glauconite and phosphorite, on the contrary, are found in the littoral sediments also.

Among the sublittoral transgression sandstones the following types have often been observed: pure sandstones, argillaceous or muddy sandstones, glauconite sandstones, phosphorite sandstones, and different fossiliferous sandstones.

The sublittoral pure sandstones are fine- and even-grained. The beds are of varying thickness. No finer stratification is noticeable unless the rock has been divided into thin layers by clay laminae, mica scales or the like.

The fine matter in the clayey or muddy sandstones is sometimes unevenly or irregularly distributed and sometimes accumulated in thin layers, separated by purer sand. In the latter case the rock shows a fine parallel stratification.

Glauconite and phosporite occur primarily in both pure and argillaceous sublittoral sandstones. Both minerals may also occur secondarily in the sublittoral sandstones as well as in the littoral.

The oscillation sandstones are formed during an occasional elevation of land (soon compensated by a submergence of land). They may show the same character as the transgression sandstones. In contradistinction to these, however, they occur in the middle part of the series of strata and are separated from both the transgression and the regression sandstones by other sediments. The sandstones formed during an oscillation of land are consequently intraformational.

The intraformational oscillation sandstones formed by primary sedimentation are partly pure (free from clay and mud). They are then formed on an open shore with currents and good sorting of the material. Part of the oscillation sandstones, however, are clayey or muddy. They are formed in less moving water either at a greater depth than those mentioned above or in a basin relatively shut off during the oscillation. As a rule the differences in sorting and stratification enable us to determine under which conditions the one or the other of these rocks has been formed.

Negative sedimentation can also take place during an oscillation, mostly, of course, in its first epoch, the occasional elevation of land. Part of the deposited sediments is washed away and the remains are reassorted and rearranged. In this manner a pure sandstone may have been formed from an arenaceous clay and a coarse sand from a fine-grained sandstone with only a slight content of coarser grains. Beds rich in glauconite are often formed in the same manner. An account has already been given of the formation of conglomerates by negative sedimentation. Attention should be called here to the fact that nodules of phosphorite have also often been enriched in this manner. Then they generally lie embedded in a more coarse-grained material than that in or on which they were formed.

A secondary sorting and rearrangement of already deposited material is no doubt extremely common. The purer portions of sand often found in the muddy sandstones, and the coarser layers occurring in relatively fine-grained beds may often be directly ascribed to a negative sedimentation. The rocks formed wholly by negative sedimentation contain no other elements than those found in the reassorted sediments. The character of these may often be inferred from the development of the underlying strata. If the rearranged sediments also contain new elements, the negative sedimentation has probably not been solely dominant. In this case a supply (a positive sedimentation) has also taken place. In rocks formed in this manner the newly added elements are coarser than the material simultaneously washed away from the sediments first deposited.

As mentioned above the enrichment of sand grains by a negative sedimentation has generally occurred during the elevation epoch of an oscillation of land. From the Swedish sediments, however, we also know cases in which the coarser material has been enriched during the epoch of submergence (cf. p. 241). The cause of this, at the first glance, unnatural process is in reality quite natural. The often very muddy sand, built up of an unsorted material which is deposited in lagoonal or otherwise more or less secluded basins, frequently becomes exposed to waves and currents on a submergence of land. This can result in a suspension of the deposited material, a washing away of the particles of mud and the formation of a purer sandstone.

On account of the above mentioned an intraformational oscillation sandstone formed wholly or partly by negative sedimentation cannot be said to show directly that an elevation of land has taken place. It may also indicate a submergence of land. As a rule the mode of formation may be inferred without difficulty from the character of the strata above and below the sandstone.

The term »regression sandstones» may be used of all the sandstones included in the sandstone series terminating a series of strata at the top. Among these sandstones different types are found which are formed under as varying local conditions as the transgression and oscillation sandstones. For the regressions as well as the transgressions generally take place under repeated oscillations.

On the whole the regression sandstones form a series, with those formed at the greatest depth at the bottom and the littoral at the top. Thus far the regression series is a reversed transgression series. However, the littoral »top beds» in the regression series show no resemblance to the littoral basal beds in the transgression series, at any rate not when the latter are typically developed as arkose or coarse sandstones and conglomerates. The youngest strata in the regression sandstones are relatively fine-grained and principally built up of rearranged material from earlier deposited sediments. A negative sedimentation, with rearrangement and enrichment of the coarser material, may be characteristic of the formation of several regression sandstones.

The sedimentation region drained by the regression has no doubt in many cases delivered the material for eolian formations and for fluviatile also. Cross-bedded sandstones are in reality also found to a large extent together with the regression sandstones (cf. *int. al.* p. 243).

As already mentioned (p. 267), the most pronounced difference between the regression sandstones and other marine sandstones is to be found in the continental features of the former.

According to the classification and terminology used here by the author, marine sandstones, formed independent of a displacement of the shore-line, are always intraformational unless they occur quite isolated, i. e. without any connection with other sediments belonging to the same series of strata. The deposition of sand may be caused by: — varying supply of sand (in its turn caused by for inst. a change in the position of the mouth of a river), variation in currents, shallowing by continuous sedimentation, occasional transport of earlier deposited sand (for inst. by heavy waves), transport by icebergs and floes, or transport by wind. In most cases it may be difficult to decide in which of these (or other) modes a sandstone of the group discussed here has been formed. The eolian material may perhaps be easily enough demonstrated on account of its strong wear, the ice-rafted also, on account of its slight wear and deficient sorting. But only with many difficulties and detailed studies of the rocks' horizontal development would it be possible to identify the other types.

In the above division of the marine sandstones we observe the difference between a classification of the sedimentary rocks gained by the study of the fossil sediments and that attained by an exclusive study of the recent ones. The sand in and outside the present littoral zone we do not judge as a sand formed during transgression, oscillation or regression. We regard it as formed independent of displacements of the shoreline. But turning to the fossil series of strata we find that the sandstones for the most part belong to some of the groups here designated as transgression-, oscillation- and regression-sandstones. If we could have studied these fossil sandstones during their formation, they would no doubt have made the same impression on us as the recent ones now do, i. e. we should not be clear as to their relation to other sediments.

The above-mentioned different conditions for the classification of fossil sandstones and recent sand make it more difficult to gain a classification that is perfectly satisfactory for all arenaceous sediments. A first division into littoral and sublittoral might be accomplished for the recent as well as the fossil sandstones. A further division after the relation to other sediments might then be followed up for the fossil ones. In spite of the advantage this would imply the author has considered the arrangement applied here to be preferable, as it takes in the first place the geologically more important moments in the formation of the rock into account. In cases where we gain more information from the fossil than from the recent rocks we should not neglect or depreciate the testimony of the former on account of our inability to obtain the same knowledge from the latter.

In one case only are brackish water sandstones demonstrated among the Paleozoic and Mesozoic sandstones of Sweden, viz. in the Lias of Scania. Consequently the author cannot from his own observations judge the different types occurring of these sandstones. Probably they show the same changes as the marine. Only by their fossil fauna or flora would it be possible to distinguish them with certainty from marine sandstones.

The continental sandstones are not as well represented as the marine in Sweden's Paleozoic and Mesozoic series of strata. On that account the author has not had the opportunity in the preceding to discuss the no doubt abundant forms of these sediments also. The grouping made of them must therefore also be more summary.

The residual sandstones generally occur at the bottom of a series of strata. As a rule they are separated from the quite intact weathering gravel[1] by a distinct boundary surface but grade upwards into marine basal arkoses or other sediments. An incomplete or indistinct sorting and no or only slight wear of the material are characteristic of the residual sandstones. Otherwise they show the same characteristics as those common to other continental sediments, for inst. high colours.

Sandstones formed in river beds (erosion gullies) are not often found in the fossil Swedish series of strata, these being essentially marine. There are, however, examples of such from the Rhaetic-Liassic strata, in which the sand is mixed with coarse, well rounded pebbles (see also p. 239).

The fluviatile sandstones in the Keuper of Scania are better developed. In the strata at Ottarp for inst. the material is an obvious fluviatile deposit (see p. 207—208).

Among the fluviatile deposits we should also count the relatively fine-grained, cross-bedded sandstone beds occurring in several places in the Keuper series and often interstratified with conglomerate beds. The cross-bedded coarse sandstones in the Lower Cambrian sandstone at for inst. Brantevik are perhaps delta deposits. They occur together with littoral (marine) deposits. Whether the thick series of cross-bedded sand-beds in the upper part of the Liassic series (for inst. at Hjelmshult) are fluviatile or eolian is more difficult to decide (see p. 243).

The character of the lacustrine sediments is partly dependent on the size of the basin in which they have been formed. The larger the lake basin, the greater the resemblance of the deposits to the marine ones, especially with regard to the sorting, distribution and stratification of the material. In small lakes the changes are as a rule slighter, the sorting less thorough and the stratification uneven. The depth of the basin and the currents through it are important for the sorting and stratification. The quantity and nature of the material supplied as well as the biological conditions in the lake naturally influence the lake sediments in a high degree. A detailed study of the fossil lacustrine sediments will no doubt very essentially increase our knowledge of the forming conditions of such sediments.

Lacustrine sandstones are found in the Swedish series of strata discussed here in the Keuper beds of Scania in the Visingsö series and in certain Cambro-Silurian strata in Middle and North Sweden.

In the Keuper the lacustrine sandstones occur together with lacustrine clays and fluviatile sandstones. These formations are typically continental in character.

[1] It does not seem appropriate to the author to count this also among the sedimentary rocks.

The continental sediments present in the Cambro-Silurian are mainly included in the sparagmite formation. The calcareous and argillaceous sandstones (the Hede limestone) should in the first place be interpreted as lacustrine formations in this but besides them a large part also of the other even-grained and parallel-bedded sandstones and quartzites. That a great part of the material in these is of glacial origin (which the author considers probable) offers no objection to the fact that it has been finally deposited in lake basins or in the sea. The difference between these sediments and other continental deposits (slighter oxidation and weathering) is practically the same as that found between the post-glacial sediments in for inst. Sweden and the sediments formed simultaneously and in the same manner (lacustrine, marine, etc.) in regions outside that of the glacial deposits.

Eolian sandstones occur in the Swedish Paleozoic and Mesozoic series of strata but they play no greater rôle in them. Typical eolian material and wind-polished blocks have been found in the Lower Cambrian (see p. 123). Beds with exceedingly well rounded — no doubt by eolian wear — grains of quartz are met with everywhere in the series. Such material is also found intermingled in sandstones built up of more angular grains and plainly marine in formation.

No typical glacial sediments have been found in the series of strata discussed here. As mentioned above, however, the sediments in the sparagmite formation are partly of such a character that they may be interpreted as formed by glacial material (cf. also p. 170 and Hadding 1927, 71 and 155).

On summing up the above related points of view on the formation of the sandstones, we obtain a classification of these rocks according to their formation. No doubt this classification will in many cases prove impossible to accomplish (for inst. in the recent sediments; cf. p. 271). On the other hand a grouping according to external characteristics only is unsatisfactory, even though easily performed. The project of classification of the sandstones given below may, from this point of view, deserve to be taken into consideration. Can it, in addition to that, help to create an interest for investigations on the possibilities to obtain a suitable classification of the sedimentary rocks, it has fulfilled its object. Its inherent irregularity is due to the above-mentioned circumstances (p. 272).

A Project of Classification of the Sandstones.

A. Marine sandstones (and brackish water sandstones).
- I. Sandstones formed in connection with a displacement of the shore-line.
  - a) Transgression sandstones = the sandstones of the basal series.
    - 1) Basal sandstones.
      - α) Basal arkoses.
      - β) Basal sandstones poor in felspar.
    - 2) Younger littoral sandstones in the transgression series.
      - α) Younger transgression arkoses.
      - β) Younger felspar-free transgression sandstones, littoral in character.

3) Sublittoral transgression sandstones (pure, argillaceous, glauconitic, phosphoritic, a. o.).

b) Oscillation sandstones = intraformational sandstones.

1) By positive sedimentation, generally formed during elevation.

α) Sublittoral.

β) Littoral, often formed in lagoons.

2) By negative sedimentation, formed during elevation or during depression.

α) Littoral and sublittoral, formed during elevation.

β) Sublittoral, formed during depression (primary lagoonal formation).

c) Regression sandstones = top series sandstones formed by positive or negative sedimentation.

1) Sublittoral regression sandstones.

2) Littoral regression sandstones.

II. Marine sandstones formed independent of displacements of the shore-line. Mostly intraformational.

1) Formed by occasional washing away (redeposition) of sand.

2) Formed on account of generally increased supply of sand.

3) Formed on account of change in sedimentary conditions, often caused by shallowing by sedimentation.

4) Formed of sand transported by drift-ice.

5) Formed of sand transported by wind.

B. Continental sandstones.

I. Residual sandstones.

II. Fluviatile sandstones.

III. Lacustrine sandstones.

IV. Glacial sandstones.

V. Eolian sandstones.

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Index.

* See the notes on the figures.

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