3. Investigations of the Senonian Kristianstad District, S. Sweden

II.

Sedimentology and lithogenesis of the Åhus Series

By

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1. Introduction.

The Senonian Kristianstad district comprises a large part of NE. Scania and parts of W. Blekinge (Fig. 1). It includes sediments of different types. The main components are limestones of various composition and shell beds very similar to those formed during the Quaternary in several rocky regions of Scandinavia. But there are also sandstones and clay sediments; the latter are probably partly limnic. Coarse conglomerates are common in many places of the district, especially in the north. The sediments are in part richly glauconitic and also flint-bearing; the amount of phosphorite is sometimes rather considerable.

The minerogene constituents of the sediments are derived from a deeply kaolinized land surface with a partly broken topography. The biogene components originate from shell-bearing organisms of different animal groups and from organisms encrusted with calcium carbonate; among them are calcareous algae. Calcium carbonate was certainly also formed as a chemical precipitate, probably mainly by the interaction of organisms. Remains of the terrestrial flora are also included in certain deposits, not least pollen grains and spores; many of them are well preserved (cf. ROSS 1949).

The Kristianstad district is of great interest from several geological points of view. It affords, above all, good opportunities for study of the sedimentological results of a transgression over a deeply weathered land surface. Of special interest in this respect is the fact that great quantities of silica were supplied to the sea. It was certainly, in a great measure, fixed as glauconite and flint. Sedimentological studies of such areas are important for the interpretation of the lithogenesis of pre-Cretaceous sedimentary formations where the origin of the minerogene components and their derivative products is often less evident.

Most of the different types of the sediments can be studied in outcrops, and the development of the Senonian in the Kristianstad district can thus be interpreted to a great extent. However, this material is insufficient for a complete interpretation, since all of the sediments are not available in outcrops. This is the case with the much discussed Åhus Sandstone, which was only known as blocks.

These blocks occur mainly at Åhus situated on the coast in the outer part of the Kristianstad district (cf. Fig. 1). The bedrock of the sandstone has been expected to constitute parts of the subground of Åhus. In addition, it might be suggested that many other types of sedimentary rocks of the district would be included in the substrata. In a few words, this stratal sequence could be assumed to be very representative of the Senonian of the Kristianstad district. A boring through this stratal sequence should thus be of great importance. And such a boring has also been made. The bedrock of the Åhus Sandstone was found, and, moreover, as expected, a stratal sequence including most of the sedimentary types mentioned above. In fact, the geological development of the Kristianstad district can be elucidated to some extent from this drill core.

In this paper a description of the sedimentology of the core is made and an interpretation of the lithogenesis of the stratal sequence is given. Investigations of certain groups of fossils in the core are being performed by specialists (foraminifera, bryozoans, diatoms, and pollen and spores); also the minerogene phase is considered (heavy minerals).

Records of these investigations will appear in this series of papers.

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The examination of the drill core is only one aspect of a more far-reaching investigation of the Kristianstad district. Field works have been done for several summers, and a vast collection of fossils and series of rock samples have been assembled and partly examined in the laboratory. When these investigations are finished, the geological development of the district will be discussed.

2. Previous knowledge of the Åhus Sandstone.

In his fundamental investigation of the Åhus Sandstone (1894, p. 494), HENNIG described the petrographic character of the rock in the following way (translation from Swedish): "The rock is a quartz sandstone of median grain size containing small fragments of mussel shells and the like which render it a highly characteristic appearance; the separate particles are cemented by calcite."

Blocks of Åhus Sandstone are rather abundant in some sections within the Åhus village; they are also found in parts of the surroundings. Moreover, some few blocks have been observed in other parts of Scania transported there by the Land Ice (cf. LUNDEGREN 1934 a, p. 275), as well as in Denmark and NE. Germany (HENNIG 1894, p. 494). Earlier, blocks of this sandstone occurred in greater quantities at Åhus, but they have been used up to a great extent as building material (the old Åhus Castle, now in ruins, was, for instance, partly built of this material).

Since only blocks have been accessible for investigation, the knowledge of the sandstone formation has been somewhat vague which appears from the many discussions during the years concerning its genesis and age. However, important facts about the formation have also appeared.

Already NILSSON (1827) examined the fossils in the Åhus Sandstone

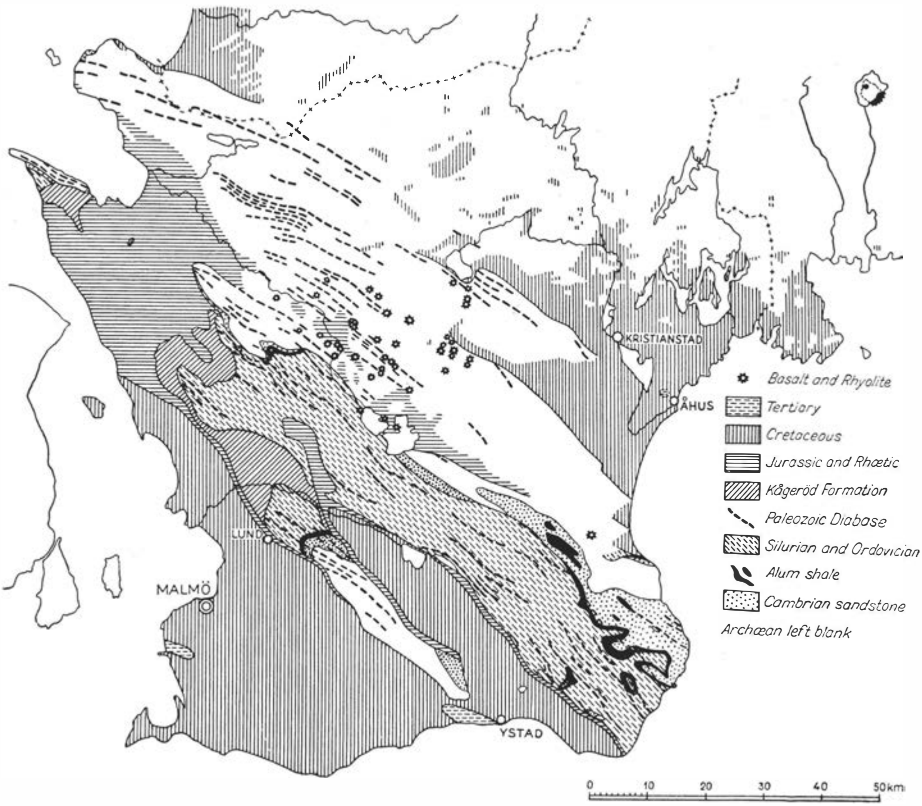

Fig. 1. Geological map of Scania and the W. part of Blekinge, re-drawn from J. EKLUND 1944 (Sveriges Geol. Unders.); slightly revised.

and found, inter alia, the stratigraphically important species *Ostrea lunata* NILSSON.

HENNIG (1894) gave a comprehensive list of macro-fossils; no less than 58 species were observed. The fauna is described as "a peculiar mixture of earlier and later types; i.e. of species, which are considered characteristic of the Mammillatus Chalk as well as others which occur exclusively in the Mucronata Chalk" (op. cit. p. 529). However, HENNIG never observed *Actinocamax mammillatus* or *Belemnitella mucronata* in the sandstone, and neither were these species observed there later. He suggests that "the type of rock which is comprised under the name of Åhus Sandstone began to be formed at least during the Mammillatus period and continued under identical conditions throughout the whole Mucronata period" (l.c.). However, an examination of the stratigraphic distribution of the species according to later statements (HÄGG 1947) shows that none of the species considered by HENNIG as being characteristic of the Mammillatus Chalk are confined to this period, but also occur in the Mucronata Chalk (possibly with exception of the bryozoan *Membraniporella juvenis* HENNIG, which, however, seems to be known outside the Åhus Sandstone only in the form of a small fragment of a juvenile specimen, viz. in a Mammillatus deposit; the stratigraphic range of this species thus seems to be so incompletely known that it has little bearing on the present case). In HENNIG's material there are, in fact, no proofs that the formation of the Åhus Sandstone began in the Mammillatus period.

Concerning the mode of genesis of the Åhus Sandstone, HENNIG considered that it was laid down in shallow water with a salinity inferior to that of the open Cretaceous sea (1894, p. 498). This supposition is based on observations pertinent to the size of bryozoans; HENNIG had previously studied the size of bryozoans in different recent surroundings.

HADDING, in 1927 and 1929, gave a petrographic description of the sandstone and made some considerations as regards its genesis. In the block specimens examined by him the quartz grains are enlarged by secondary growth, and the cement "consists of silica developed as a direct outgrowth of the quartz grains" (1927, p. 28 f., also cf. 1929, p. 254). The sandstone is considered to have been formed as a sand-bar "at a slight depth and in a moving water" (1929, p. 256).

LUNDEGREN, in his monograph on the Kristianstad district (1934 a) also discussed the Åhus Sandstone. He is of the opinion that it is the latest Cretaceous formation of that district, accumulated during the final regression of the Mucronata sea, i.e., according to him, during the Constrictus stage or the Maastrichtian (p. 276–277). LUNDEGREN, moreover, verified the statement by HENNIG that no determinable belemnites have been found in the Åhus Sandstone. As pointed out by LUNDEGREN (l.c.), the Åhus Sandstone has earlier been regarded as the latest formation of the Kristianstad district (NATHORST 1882, STOLLEY 1897). Mislead by data obtained from drillings for water, LUNDEGREN suggested that the bedrock of the Åhus Sandstone should not occur in the substrata of that village (op. cit. p. 278).

HÄGG discussed the Åhus Sandstone on three occasions: 1930, 1935, and 1947. He reported about 60 mollusc and brachiopod species from this sandstone. With regard to its age he shares the opinion of HENNIG, i.e. that the sandstone was formed both during the Mammillatus and the Mucronata periods; this should be indicated by the mollusc and brachiopod fauna. However, this idea is not supported by the data on the general stratigraphic range of these species given by HÄGG in the papers mentioned. According to these data, around 90 per cent of the species should occur from Mammillatus or pre-Mammillatus strata to Mucronata or later (some few of them stated as only probably occurring in the Mucronata Chalk). The remaining species have been found at Åhus and, additionally, only in one or a few other localities, so that their stratigraphic range cannot be said to be sufficiently known. It may be added that about 50 per cent of the species occur in the Constrictus zone or even later strata.

BROTZEN (1945, p. 61) stated in a note that the Åhus Sandstone is "probably sandfacies from Lower Campanian to Lower Maastrichtian".

3. Plan for laboratory investigation.

Both the biogene and the minerogene sedimentary phase have to be considered in lithogenetic investigations.

It was planned that the core should be analysed at each half meter for granulometry of the insoluble residue, porosity, and content of certain chemical elements elucidative of the palaeohydrology. Thin slides should be prepared and determinable macro-fossils examined.

Biogene components.

Zoogene components.

Macro-fossils were decided to be considered for a preliminary dating. Micro-fossils will be treated separately in future special papers.

Some information on the occurrence of shells and shell fragments of molluscs, brachiopods, bryozoans, and ostracods can be gained from thin slides. In this way an idea of the distribution of such micro-fossils as foraminifera and radiolarians can also be obtained.

Phytogene components.

Since algae live in shallow water it is of very great importance to note whether these organisms themselves or traces of boring algae are present in a stratal sequence in order to get an idea of the depth during the sedimentation. Such occurrences have to be observed in thin slides. As a matter of fact, care must be taken to examine whether the algae components are autogene or xenogene.

Chemical components of organic origin.

Some chemical components, entirely or partly of organic origin, are of great importance for the interpretation of the palaeohydrology and the milieu of sedimentation, and have thus to be investigated. It was decided that the content of carbon, sulphur, and phosphorus should be ascertained throughout the stratal sequence.

Carbon.

Carbon is entirely of organic origin. It may be derived mainly from cellulose, lignin, and fat oils. The former, deriving chiefly from vascular plants, form coal substances. Fat oils, which are a common storage nutrition of inferior plants and animals, are also a source of coal substances (gaseous coals), but are more often fluid or appear as impregnations in different types of sediments. They contribute to the black colour of bituminous shales, but may also give sandstones a greyish appearance when the quartz grains are coated with a film of solid hydrocarbons.

The occurrence of both these types of carbon substances is of value for the interpretation of the palaeohydrology. The presence of coal fragments in a sediment indicates that it was deposited in a fairly closed area where the effect of oxidizing was low. Moreover, thin coatings of hydrocarbon around quartz grains indicate that they had been exposed to no or only slight effacing effects in the area of sedimentation. On beaches, film coatings of various kinds (for instance ferric films) are generally destroyed.

In some sections of the Åhus Series the quartz grains are coated with a hydrocarbon film to such an extent that the sandstone is greyish in colour. In other sections of the core the sand is purely white, however. There are also sections containing coal substances.

Sulphur.

The content of sulphur in a sequence of strata is an indicator of the palaeohydrological conditions during the process of sedimentation. A high percentage of sulphur may not only indicate a rich supply of plasma from soft tissues of dead organisms, but also that the water was stagnant.

A high sulphur content may not invariably be due to stagnancy, however. It may be that substances containing sulphur were included in colloids, such as glauconite, and thus prevented from oxidizing. The sediment for the rest may be free from sulphur if settled in a ventilated area. On the other hand, sediments free from sulphur or with a low sulphur content may have accumulated in stagnant water. That can be due to scanty supply or to oxidizing by means of phytal oxygen (algae). The presence of sulphur in glauconite and the occurrence of algae or canals bored by algae can be checked by inspecting microscopical thin slides.

Phosphorus.

Necron and animal excretion products are a most important source of phosphorus in sediments. As appears from several investigations, for instance MÜNSTER STRØM 1936, the phosphorus content increases in stagnant water but not in the sediment contemporaneously accumulated. It is stated that, in eutrophic lakes, precipitation of phosphate is connected with ventilation (EINSELE 1938; also cf. MORTIMER 1941). EINSELE, especially, has studied these problems; his results are, inter alia, the following. As a matter of fact, phosphorus, as well as iron, is enriched in stagnant surroundings in bivalent state. As soon as the water is ventilated and these components are transformed into trivalent states iron phosphate is formed and precipitated at once, as the solubility product is very low. If equivalent amounts of iron and phosphorus are present a light-coloured product is formed. On the other hand, if more than equivalent amounts of iron occur the excess is precipitated as hydrous iron oxide. First phosphate is developed and then hydrous oxide. The covering of the latter renders the product a more or less brownish colour. To EINSELE's results may be added that if there are more than equivalent amounts of phosphorus, the excess may, in the presence of calcium ions, be precipitated as calcium phosphate. Great quantities of phosphorus in relation to iron appear, according to EINSELE, especially in stagnant waters rich in sulphur, since, in this case, iron is withdrawn already in bivalent state as sulphide. If phytal oxygen is produced in stagnant surroundings phosphorus may successively be precipitated as far as iron and calcium (as bicarbonates) are present.

A mere posphorus curve is not sufficient for interpretation of the ancient oxidation—reduction conditions in the water, but has to be compared with other components, especially the sulphur curve and the occurrence of algae (producers of phytal oxygen; their presence checked by inspecting thin slides). Moreover, the effect of redeposition of phosphorus nodules must be considered.

Minerogene components.

The insoluble residue consists mainly of quartz grains. Heavy minerals appear with lower frequency. Glauconite often occurs, sometimes in considerable quantities, and flint is found at a few levels. Phosphoritic nodules and coprolites can also be present.

Since coprolites are organogene and phosphoritic nodules often may be considered organogene, as the phosphorus is mostly of organic origin, these components are not ranged here.

Glauconite is entirely or mainly abiogene. One chemical element may sometimes be of organic origin, viz. potassium (cf. p. 54). As the main component of glauconite (the silica) is obviously abiogene, glauconite is discussed in the present connection. From the same reason flint is also ranged here.

Quartz.

It is of importance to ascertain the frequency and granulometry of the quartz grains and also to examine the roundness of the grains and to note whether they are covered by secondary wrappings of silica or other substances.

In the present case it was decided that the quartz grains should not be separated from the other components of the insoluble residue. This should have required much work since about 370 separations of fairly great samples should have been necessary. The quantities of the non-quartz components are small in relation to those of the quartz with exception for a few samples rich in glauconite.

Heavy minerals.

Heavy minerals can be of importance in locating the parent formation of the minerogene sedimentary phase and in giving some information about the agitation of the water during the sedimentation.

On this occasion it was decided only to determine the total amount of heavy minerals (with exclusion of pyrite, coprolites and phosphoritic nodules which are all newly formed) and to note the main types of minerals. A special investigation of the heavy minerals is being elaborated.

Glauconite.

The problem of glauconite formation has been discussed a great deal but has not been definitely solved. Glauconite is obviously formed in different ways, but the main modes seem to be either transformation of biotite or precipitation of colloidal silica during contemporary adsorption of certain elements, above all iron and potassium. The most important conditions for formation of glauconite in accordance with the latter principle are, in addition to appropriate redox potential conditions, rich supplies of silica, iron, and potassium. The vertical distribution of glauconite in a stratal sequence can thus be informative of the supply of these components.

Silica is freed in great quantities during transgressions over deeply kaolinized land surfaces. Iron compounds are supplied at the same time and possibly certain quantities of potassium (mainly from potassium-bearing mica and feldspar). The content of potassium in sea water is low and may not play any important rôle in glauconite formation. However, great quantities of potassium are stored in phytogene detritus. The elements now mentioned may also be derived from volcanic ash.

The surroundings where glauconite is formed may be ventilated since the iron of glauconite is for the most part ferric. Very likely the precipitation occurs just at the transition from stagnation (when bivalent iron is enriched in the water) to ventilation, judging from the presence of small quantities of bivalent iron in glauconite, which should thus be of residual character.

In the present case great quantities of silica and also certain amounts of iron and potassium may have been brought to the sea during a transgression over the deeply kaolinized land surface. Later phytogene detritus began to be formed. It is of interest to see whether the glauconite in this stratal sequence is distributed in accordance with the aforementioned theoretical conclusions on glauconite formation. For this reason it was decided that the content of glauconite should be ascertained throughout the core.

Flint.

The formation of flint must be connected with high concentrations of silica in the water. The origin of the silica has been discussed on several occasions (cf. p. 97); in my opinion it is, in the present case, derived from the deeply kaolinized land surface. This question and the special conditions, causing precipitation of flint instead of silicate (glauconite or chamosite minerals) were decided to be studied.

Granulometry of the insoluble residue.

Since the consolidated sections of the core could be disintegrated only by solution of the calcareous components, it was decided that the granulometric measurements should invariably comprise only the insoluble residue. The median diameter and the degree of sorting were planned to be calculated on the basis of cumulative curves.

Such granulometric data may contribute to the elucidation of the palaeohydrology and the process of sedimentation.

4. Methods of laboratory investigation.

The core is stored in core cases. Consolidated parts have been divided into sections which, like the sandy parts, are kept in enclosures of paper especially made for this purpose.

The core was, moreover, divided lengthwise. One half was partly used up in analyses, the other remains intact.

Thin slides.

Thin slides were prepared by usual methods. Only consolidated sections were sliced.

Determination of porosity.

Porosity was investigated by means of a modified WASHBURN—BUNTING method (1922). The principle of this is as follows: The sample is placed in an air-tight jar, the air is pumped out, and the jar then supplied with a certain amount of air of prevailing barometric pressure. The pressure in the jar containing the sample is checked before and after supplying the air.

For this procedure the apparatus sketched in Fig. 2 was constructed.

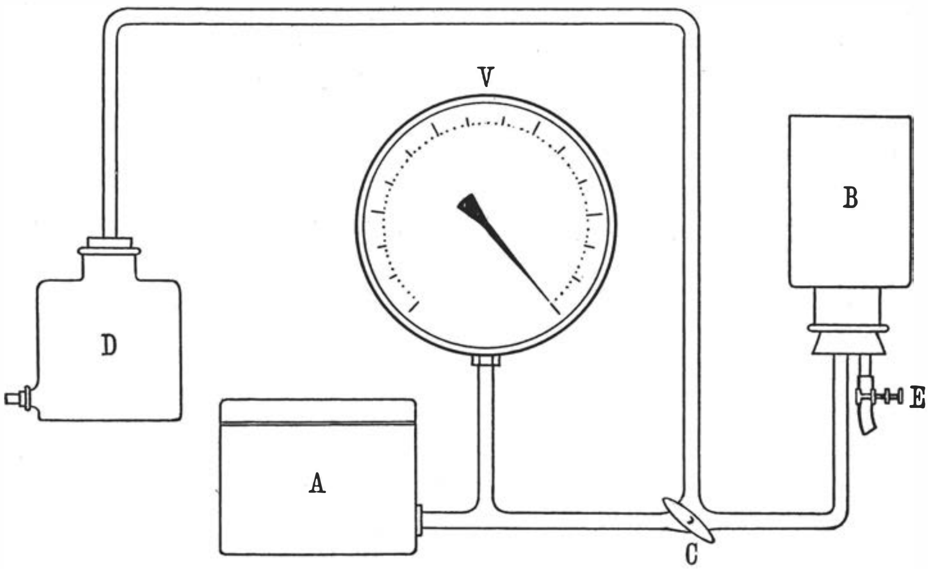

Fig. 2. Schematic drawing of apparatus used for determination of porosity.

The sample is placed in the jar A, which is provided with an air-tight cover and tapped at one side by a connecting tube (see sketch). The air is pumped out with a suction pump (connected to flask D) to a pressure of 700 mm Hg below prevailing barometric pressure. The pressure is indicated by a vacuum-meter (V). Thereafter, a three-way glass stopcock (C) is turned, closing the suction tube and opening the connecting tube between the jar (A) and the flask (B). Before this action, however, the air-intake (E) of the flask (B) was opened and then closed in order to fill the flask with air of prevailing barometric pressure. This air will now flow into the jar (A) until the pressure in both containers is equal. The resulting pressure is indicated by the vacuum-meter. In order to quickly obtain the bulk volume of the sample from these data, a curve was constructed on the basis of measurements of paraffin bodies of known volume. The pressure measured was plotted on the x-axis and the bulk volume on the y-axis. This curve, as a matter of fact, is referable only for a certain initial pressure in the jar (A), and the data have to be correlated with the prevailing barometric pressure.

The absolute volume of the sample was determined by covering it with cellulose lac-varnish and measuring the weight diminution by submerging in water.

$$\text{Porosity} = \frac{\text{Absolute volume} - \text{bulk volume}}{\text{bulk volume}} \times 100.$$

The apparatus was constructed by my collaborators, Mr. J. LUKINS, Dipl. Ing., and Mr. S. FREDÉN.

Determination of granulometry.

The calcium carbonate substances were dissolved in acetic acid and the granulometry of the insoluble residue was ascertained: that of the particles > 0.06 mm by sieving in a shaking machine and that of the particles < 0.06 mm by so-called pipette analyses.

The screen widths of the sieves were chosen in such a way that they constitute the following series: 2—1—0.5—0.25—0.125—0.06 mm.

Determination of the content of heavy minerals and glauconite.

The frequency of these components was determined by means of the apparatus described by HESSLAND, LUKINS, and FREDÉN 1949.

Methods employed in chemical analyses.

Carbon.

Carbon was determined by the direct method.

The carbonatic carbon was expelled with dilute sulphuric acid (1 : 5). Then the organic carbon was oxidized with chromic anhydride and concentrated sulphuric acid during 10 minutes of boiling. This was done in a refraction flask. The gas was cleaned of possibly occurring hydrogen sulphide in a tube containing copper sulphate and pumice, dried in two tubes containing concentrated sulphuric acid and silica gel resp., and absorbed in two tubes with natron asbestos and silica gel. The air was cleaned and dried in absorption tubes before entering the system, and another absorption tube prevented air to enter from the suction side.

Phosphorus.

The molybdate method was used after oxidation in the wet way by means of aqua regia for one hour, followed by two further evaporations to dryness after some nitric acid had been added each time.

Sulphur.

Oxidation in the wet way by means of aqua regia and evaporation to dryness with some hydrochloric acid was followed by immersion in hot water to which 1 cc concentrated hydrochloric acid was added. After filtration iron and aluminum were precipitated with ammonium hydroxide and removed. Sulphur was determined with barium chloride.

Iron.

After digestion of the sample in boiling dilute hydrochloric acid (4—6 hours) the ferric ions were reduced to ferrous stage by means of tin chloride the excess of which was destroyed by mercuric chloride. Titration was made by means of permanganate.

Presentation of analyses.

Porosity and frequency of glauconite, heavy minerals, and chemical components are reproduced by common curves in arithmetic scales.

Granulometry is given as histograms and curves of median diameter and sorting (log quartile deviation). The bars of the histograms have the same breadth since the quotient of two consecutive screen dimensions is invariably 2 (cf. p. 57). The median diameter and sorting were deduced from cumulative curves in accordance with the formulae given by KRUMBEIN and PETTIJOHN 1938, p. 230—231.

5. General appearance of the core.

The diameter of the core is 71 mm from the soil surface to 141.83 m, 61 mm from 141.83 m to 175.70 m, and 51 mm from 175.70 m to 185.60 m.

Non-consolidated sediments between the soil surface and 14.51 m as well as the clayey section 167.1—159.8 were taken up as cores, but sandy sections below 14.51 m had partly to be washed up and sedimented in large tubs; each time only short sections were washed up. In the first case the granulometry was not disarranged, but some disarrangement may not have been quite avoidable in the latter case.

Careful observations of the sediment were made during the drilling, and a profile of the stratal sequence was drawn contemporaneously and checked by remeasurements in the laboratory.

The uppermost 5.63 m is Quaternary. From 5.63 m to 182.86 m is Cretaceous. Below 182.86 m is Archaean.

Archaean.

The Archaean consists of coarsely crystallized granitic gneiss, mainly greyish-reddish in colour. The content of iron-bearing biotite is high; the iron is partly transformed into limonite. The feldspar is weathered to a great extent. The weathering is most pronounced in the uppermost part and along fissures.

Cretaceous.

The sequence of strata is described below in sections.

A more precise knowledge of the Cretaceous part of the core is obtained from the detailed description of the components as ascertained in the laboratory investigation (p. 70 f.).

182.86—173.70.

This section chiefly consists of sand, but also includes clay substances.

182.86—180.4. Sand, slightly yellowish in colour, except for one part which is greyish-green and somewhat clayey (182.5—182.0). Feldspar is abundant and, in the sand, partly coarse; frequency somewhat decreasing upwards. In the clayey stratum the feldspar is more fine-grained; some mica is also here. Particles sharply angular.

180.4—173.7. Whitish sand, including a stratum with kaolin clay (177.1—176.5); the uppermost part of the sand (0.1 m) is consolidated to a sandstone. All particles are sharply angular. The stratum below the kaolin is somewhat different from that above it, and includes not only a considerable quantity of feldspar and rather large quartz particles, but also fine weathering products which give the whitish sediment a somewhat greyish-green hue. The kaolin clay is greyish-green and, in part, purely white. The stratum above the kaolin is coarse white quartz sand with some feldspar and plenty of mica.

173.70—173.58.

Conglomerate, including pebbles of different size and roundness. The maximum diameter observed is about 4 cm. Many of the pebbles are well rounded; among them are quartz pebbles. Moreover, there are large pebbles of quartzite and pure quartz sandstone, as well as large feldspar crystals. The latter are rather deeply glauconitized, but the quartz pebbles are generally coated with only a very thin glauconite film. The quartzite and the sandstone pebbles are not glauconitized. Lumps of purely white kaolin are also included. The cement substance is an ash-grey clay sediment. Many belemnite rostra were found in the conglomerate.

173.58—169.7.

173.58—169.9. Dark green glauconite-bearing sand. Feldspar and clay substances also occur.

169.9—169.7. Greenish sandstone, containing great quantities of glauconite and some fragments of large-sized mussels.

169.7—167.1.

Greyish to slightly yellowish sand, containing only very restricted quantities of feldspar but great quantities of glauconite. The quartz grains are very well-rounded.

167.1—159.8.

This section is distinguished by clay substances.

167.1—165.9. Blackish-grey clayey substances, horizontally cleavable; surfaces covered with scattered, small mica flakes. In the upper part of the stratum current action is indicated.

165.9–159.8. Greyish clayey substances. Distinct current and possibly wave action structures below 164.5 m; above this level there are frequent changes between slight current structures and stagnant water lamination; but towards the upper limit of the section, current and possibly wave action structures are most distinct (especially around 161 m). Mica flakes are abundant, and fragments of shells of large-sized mussels occur (among them is *Inoceramus* sp.).

159.8–134.5.

Whitish and greyish sand, except for the bottom part and one thin layer of calcareous sandstone (153.5–153.3). The median size of the particles varies somewhat at different levels. Most of the particles are rather angular.

134.5–111.8.

Limestone and calcareous sandstone.

134.5–about 130. Calcareous sandstone with upwards increasing content of calcium carbonate. The cement substance is chiefly calcium carbonate mud. Quartz grains are mainly angular.

About 130–about 123. Rather uniform layer of limestone containing great quantities of fragments of bryozoans and also shell fragments; the content of calcium carbonate is high. A few sections strongly recrystallized. A slight impregnation of flint at 126.3 m.

About 123–111.8. Limestone and very calcareous sandstone, both rich in fragments of calcareous organisms and also containing calcium carbonate mud. Several levels recrystallized.

111.8–94.8.

Limestone and highly calcareous sandstone with intercalating calcareous quartz sand layers. The content of calcium carbonate decreases and the thickness of the sand layers increases upwards. In the lower part of the section the frequency of organic debris particles is high and the content of calcium carbonate mud is low. But, the proportions between these components change upwards in favour of the mud.

Slight impregnations of flint occur in the zone 105–100. In the zone (110–)107–99(–95) there are small pebbles of quartz, as a rule rounded (partly well-rounded) and coated with a glauconite film; they are largest at about 101 m (diameter about 0.5–1 cm). The majority of the minor quartz grains are rather angular.

94.8–65.3.

Calcareous quartz sand with some fairly thin intercalating calcareous sandstone layers. The minor quartz grains are rather angular for the most part. Glauconitized quartz grains occur in small numbers up to about 80 m. Calcareous fragments of organisms constitute a considerable part of the calcareous sandstones up to about 85 m, but diminish thereafter. Calcium carbonate mud, on the other hand, forms an increasing part up to this level, and is later the main calcareous substance in the sandstone strata.

65.3–43.1.

Limestone and highly calcareous sandstone. The calcareous substance consists of calcareous mud to a great extent; the content of shell fragments increases upwards. Flint was found at the following levels: 57.6, 56.5, 54.7, 52.97–52.78, and 43.7 m. At all levels except that of 52.97–52.78 only small impregnations occur. The flint is of the type common to the Kristianstad district (Hanaskog flint). At the level 57.5–57 there are somewhat larger quartz grains coated with a glauconite film.

43.1–28.

Calcareous sandstone and calcareous quartz sand. The calcareous substance consists of calcium carbonate mud and shell fragments.

43.1–37.3. Frequent alternations between sandstone strata and thin layers of sand.

37.3–28. Continuous sandstone layer.

28–top of the Cretaceous.

Mainly calcareous quartz sand with intercalating thin layers of hard, calcareous sandstone. The calcareous substance of the sandstone is, as a rule, highly recrystallized (especially at the level 23.8–23.7). The sandstone includes great quantities of thin and fragile shell fragments. Such fragments also occur in the sand. Many of them, and also thicker ones, are blackish, which may indicate that they have been washed out of clay layers; the black colour may be due to resistent polysulphides (cf. HESSLAND 1943, p. 136). Especially from about the 20 m level and upwards the sand is rich in larval oyster shells. The quartz grains are generally fairly well rounded; some of them are enlarged by secondary growth. The shell fragments in the upper part of the section are worn and rounded to a great extent.

Quaternary.

The section 0–1.90 is sand, brownish in different shades. A prominent black layer occurs at 0.80–0.92; the granulometric sorting is rather poor. This layer is probably a culture stratum.

The section 1.90—5.63 consists of ice lake sediments and includes a layer with boulders and pebbles (4.6—5.0). The main part of this layer is fine-sand and *mo* (ATTERBERG's classification), just as in the sub- and superjacent strata. The boulders and pebbles are of different petrographic types. An Åhus Sandstone boulder (thickness 0.12 m) was drilled through at 4.58—4.70, and a flint boulder at 4.95—5.0 (flint of the common Kristianstad district type). Archaean pebbles occur also.

The boundary between the Quaternary ice lake sediment and the sand of the Cretaceous Åhus Series is very distinct.

The content of calcium carbonate in the Quaternary sediments is fairly high, except for the section 0—1.5, which is practically non-calcareous. In the remaining part there is 18—54 % of calcium carbonate (maximum at 4 m).

Glauconite occurs in small quantities at some levels (max. 0.5 % at 3.5 m).

Heavy minerals (mostly magnetite and ilmenite) are sometimes abundant (at 2 m 4.2 %, which is the highest value observed in the core).

Mica occurs throughout the Quaternary layer and is most common at 2—3 m depth.

The sediment in the zone 0—1.90 is redeposited, but this is obviously not the case with the underlying section (the ice lake sediment).

This sediment was certainly derived from the Baltic Ice, which does not seem to have transgressed the place where the drilling was made. But the ice front may not have been very distant judging from the position of the terminal moraines just N of Åhus (also cf. WENNBERG 1949, Pl. 11) and the fact that the bottom-most part of the ice lake sediment includes some rather coarse-grained strata. The boulders and pebbles seem to have been carried there by ice-bergs.

The knowledge of the action in the Kristianstad district of the great Land Ice coming across Småland is scanty. However, it may not have been very violent, since loose Cretaceous shell deposits, Cretaceous and Tertiary clay sediments as well as Cretaceous sand of the Åhus Series have been left.

6. The range of the Åhus Sandstone in the core.

According to HENNIG's definition quoted above (p. 48), the Åhus Sandstone is a quartz sandstone cemented by calcite and "containing small fragments of mussel shells and the like which render it a highly characteristic appearance." He also mentions that glauconite is absent and that the quartz grains are angular. HADDING (1929, p. 254) also states that glauconite is absent and points out the characteristic admixture of shell fragments. However, he found that the cement is quartz and that the grains are rounded, owing to secondary growth.

LUNDEGREN (1934 a, p. 275) has observed blocks of Åhus Sandstone with quartz cement as well as such with partly quartz and partly calcite cement. He also quotes an earlier observation by HENNIG, viz. that the sediment in closed shells is considerably more calcareous than the surrounding rock. From this he concludes that the content of calcium carbonate in the latter had been higher originally but that it had been leached out.

Thus the blocks investigated are of different composition, mainly with regard to the cement substance. Whether this difference is original is questionable. It may be suggested that the original calcareous cement was leached out and replaced by silica according to the following formula (CORRENS 1939, p. 260):

$$H_2SiO_3 + CaCO_3 \rightleftarrows Ca^{\cdot\cdot} + CO_3'' + SiO_2 + H_2O$$

Whether this occurred in the bedrock or later in the blocks is, as a matter of fact, impossible to decide at present. If the first alternative is true, the Åhus Sandstone is rather heterogeneous in petrographic respect. In the core there are no strata with quartz cement.

The consolidated strata from about 28 m and upwards are hard, calcareous sandstone characterized by fragments of shells of the type mentioned above. Moreover, also in accordance with the statements above, glauconite is practically absent. Some of the quartz grains are enlarged by secondary growth. This type of sandstone is different from the calciferous sandstones in the underlying parts of the core and from the non-calcareous sands and sandstones in the bottom-most part of the stratal sequence; the latter certainly correspond to the Holma and Ryedal Sandstones. The sandstones from about the 28 m level and topwards have thus to be called Åhus Sandstone. The whole stratal sequence may be mentioned the Åhus Series.

7. Water-yield in the stratal sequence.

The stratal sequence is in part richly water-yielding, viz. in the following horizons:

7.0– 9.2
15.2– 16.7
24.8– 25.4
around 100
134.9–141.4
169.9–170.4
180.4–182.0
182.5–182.9

The greatest water-yield occurs in the sections 169.9–170.4 and 182.5 –182.9.

Observations of the height of the water in the well were made every day at the beginning of the operations.

During the drilling down to 169.9 m the height of the water-level was every morning 3.76 m below soil surface, but at that level it rose to 2.80 m and then sank to the previous one. The water-yield was very abundant judging from the fact that the cement was carried away by the water at several cementations. When 182.5 m was reached at the boring the water-level rose up to 0.2 m above soil surface but sank successively to 1.40 m below this one. From this water-yielding layer 50 l per minute were pumped for another drilling without change of the water-level.

Most of the water wells at Åhus are about 25—30 m deep.

It can be expected that a formation such as the one now discussed should yield water at several levels since porous layers intercalate with more or less impenetratable strata (cf. the porosity curve). The hard Åhus Sandstone is only inconsiderably penetratable; the clayey strata in the lower part of the stratal sequence are, likewise, impenetratable to a high degree.

The water-yield seems to be regulated by two different principles in different sections of the sequence of strata.

In the upper part, the water-yielding layers are situated upon strata which are difficult to penetrate; but in the lower part, at least the most abundant water-yielding layers are overlain by such strata. In the former case, the thin strata of Åhus Sandstone seem to be effective beds against percolating water, judging from the fact that the overlying sand layers are in part richly water-yielding. The water-yield is most abundant in the lowermost of the three chief water-yielding horizons within the part of the stratal sequence where Åhus Sandstone occurs (from about 28 m and topwards). It is no accident that most of the wells with perforated tubes extend to 25—30 m. A good drinking-water can also be expected there: the content of calcium carbonate in the water-yielding sediment is low, as well as the content of sulphur and iron.

The water-yielding layers in the lower part of the stratal sequence seem to be strongly influenced by an artesian effect. The water-yielding sediment in the zone 134.9—141.5 is overlain by a limestone stratum. The rise of the water-level in the well which was noted as the level 169.9—170.4 was reached, occurred just after a 20 cm thick stratum of glauconite sandstone had been penetrated. The other rise, which extended to 20 cm above soil surface (182.5—182.9), occurred when a thin kaolin-bearing layer had been pierced.

8. Comparison with a previous deep-boring at Åhus.

In a survey of the geological formations in Scania ERDMANN (1911—1915, p. 58) made some notes on the stratal sequence at Åhus. This information is based on data obtained by a boring for water in 1903.

This boring which reached a depth of 204 m was a pile boring. ERDMANN had about 20 samples of the powdered rock and one sample including rock fragments of 2—13 mm diameter at his disposal. I have found that this well is identical with that which was made in connection with the alcohol factory at the present railway coal depot. It is situated 230 m N to W of the present boring place. The soil surface at this spot is situated 1 m above that of the new bore hole.

ERDMANN's samples of the powdered rock originate from the section 70—190 m; no samples had been taken from the overlying part of the stratal sequence. The sample including rock fragments of 2—13 mm diameter was taken from the bottom-most part of the well (204 m).

The interpretation of the stratal sequence as given by ERDMANN must necessarily be somewhat vague and uncertain, partly because there are no samples from great sections of the stratal sequence and partly because the powdered rock samples may not be perfectly reliable and representative of the rock. The original granulometry had been changed during the boring and the fine-particles had been removed by the wash-water to a great extent. The statements by ERDMANN have also been somewhat misinterpreted (LUNDEGREN 1934 a, p. 278). However, as the stratal sequence has become better known from the present core drilling, it is possible to interpret the data obtained from the previous boring with some greater amount of certainty. They are, in fact, a rather valuable complement to the present investigation.

No more definite information could be obtained from the part of the stratal sequence above 157.5 m, so a comparison with the core is not possible within this section.

The clay stratum in ERDMANN's boring (157.5—160.5) may correspond to the clayey core section 167.1—159.8 (*a* in Fig. 3).

The section 160.5—162.3 is stated "to consist mainly of small, black glauconite grains and looks like a nearly greyish-black sand". It may correspond to the richly glauconite-bearing section 169.7—167.1 in the core (stratum *b* in Fig. 3).

The section 162.3—165.5 in the ERDMANN boring "consists of 4/5 of quartz grains and of 1/5 of black glauconite grains in addition to some few

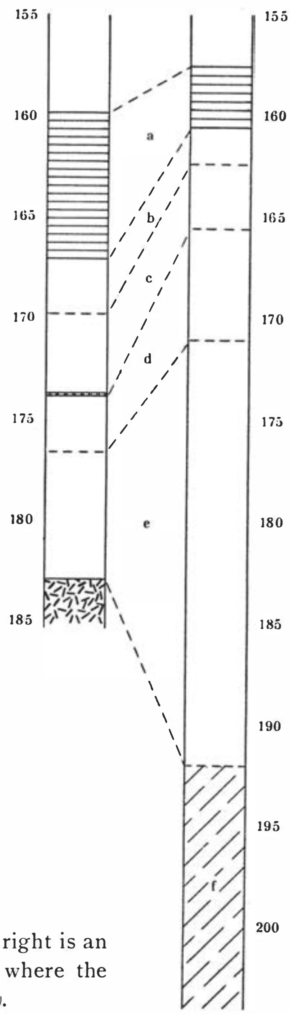

Fig. 3. The profile to the left refers to the core; that to the right is an attempt at reconstructing the stratal sequence in the place where the boring of 1903 was made (cf. discussion in the text).

Cretaceous fragments of calcium carbonate; the layer was said to have appeared as quicksand at the boring". This sediment (*c* in Fig. 3) may correspond to that one which occurs in the section 173.58—169.7 of the core (just above the conglomerate).

Also the subjacent section in ERDMANN's series (165.5—171) is possibly recognizable in the core, viz. in the mainly coarse sediment in the section 176.5—173.7, which is rich in feldspar and contains fairly great quantities of mica (*d* in Fig. 3). This part of the ERDMANN series is distinguished by the fact "that white and rose-coloured mica is added as a new constituent". ERDMANN suggested that the rock consists of "a white coarse mica-sandstone or mica-quartzite".

The granitic gneiss which appears at 182.86 m in the core was not found in the boring of 1903. This boring finished in mica-quartzite at 204 m which, according to ERDMANN, began at 192 m. The quartzite (*f* in Fig. 3) was stated by ERDMANN to be very similar to "the one which is referable to the Archaean", and which is mentioned by him to occur in some localities N and S of Åhus.

Very little is known of the lithologic character of the section 171—192. Those three samples which were obtained from 173—190 m consist of "a fine sandlike powder, and do not give any guidance for judging the character of the rock from which they originate". It is conceivable that they correspond to the sand which occurs next upon the Archaean in the core (*e* in Fig. 3).

9. Macro-fossils in the core.

Whole shells and large shell fragments were extracted from the core, but the fragments have not yet been entirely investigated. However, several fossils of stratigraphic importance were found.

Macro-fossils appear in the conglomerate at 173.7—173.58 for the first time.

Belemnites.

?*Actinocamax westfalicus* SCHLÜTER or *A. westfalicus-granulatus* STOLLEY. Several belemnite rostra occur in the conglomerate, but they are poorly preserved, except one. Unfortunately, however, the alveolar end of this specimen was cut off during the drilling and the pointed end has been slightly blunted, so that its identity is not quite clear. The length is 40 mm, and the greatest diameter is 7.5 mm. The pointed end is gently tapering, and the alveolar end is very slightly slendering. The rostrum is easily cleavable lengthwise. This specimen is very similar to *A. westfalicus* or *A. westfalicus-granulatus*.

Another specimen probably referable to the same species was found somewhat above the conglomerate (at 168.5 m).

?*Actinocamax granulatus* BLAINVILLE. Within the section 154—148 there were found two defective adult specimens and a few defective juvenile ones, which, judging from the granulose surface, may be *Actinocamax granulatus*. The determination is somewhat uncertain since no alveols were preserved.

Actinocamax verus MILLER. This is the most abundant of the belemnite species observed. Three specimens were found in the zone 169—167, i.e. somewhat above the conglomerate, and then it appears rather constantly up to about 135 m. In sum, 21 specimens were observed. The greatest frequency is in the zone 153—147, where 12 specimens were found. The largest specimens, however, derive from the 169—167 m zone.

Actinocamax quadratus (BLAINVILLE). Three rostra of young specimens with well preserved alveols were found in the zone 130.4—129.7.

Actinocamax mammillatus (NILSSON). Eight rostra of adult and somewhat younger specimens were observed within the section 132—85. The first specimens to appear are fairly small, but at 100 m a very large specimen was observed.

Belemnitella mucronata (SCHLOTHEIM). A large specimen was found at 54.7 m. Another younger specimen, probably referable to this species, derives from the same level (only the pointed end being preserved).

Bivalves.

Inoceramus lingua GOLDFUSS is of importance from a stratigraphic point of view. It appears frequently at the level 163.9—163.6.

Other lamellibranchs observed are of little stratigraphic importance since they have a wide vertical distribution (cf. HÄGG 1947).

Fragments of *Inoceramus* sp. occur in the section 173—169.

Pecten species occur in different sections of the core. *P. levis* NILSSON is the most common. It was observed in the zones 62—57 and 52—47. Some of the *Pecten* fragments appearing in other horizons are possibly referable to this species; such fragments occur both just above the conglomerate (at the depth 169—167) and in the uppermost part of the Cretaceous section of the core. Moreover, fragments of the following species were found: *P. serratus* NILSSON (62—57), *P. virgatus* NILSSON (62—57), and *P. subaratus* NILSSON (20—15).

Lima is represented by *L. semisulcata* (NILSSON) at 119 m.

Ostrea appears in the zone 76—69 (a few indeterminable fragments), but it occurs chiefly between 25 m and the top of the Cretaceous with increasing frequency upwards. These specimens are larval. They belong to *O. semiplana* SOWERBY for the most part. One larval shell was identified as *O. cornuarietis* (NILSSON).

Scaphopods.

Dentalium sp. appears in a fragmentary state in the zones 153—147 and 142—137.

Brachiopods.

Terebratula praelustris LUNDGREN is represented by some specimens in the zone 52—41.

Fragments of Terebratulids were found in the zone 69—62.

Bryozoans.

Different undetermined species were observed in the following zones: 169—167 (fragments rounded by wave action); at about 130—100; 62—57 (on *Pecten* shells); and 20 to the top of the Cretaceous (fragments rounded by wave action in the uppermost part of the layer).

Polychaets.

Spirorbis sp. occurs on *Pecten* shells in the zone 62—57.

Echinoderms.

Spines are frequent from 25 m depth to the top of the Cretaceous; fragments of plates were observed in the zone 15—10.

Vertebrates.

Shark's teeth were found in the following zones: 169—167 (fairly abundant and worn by wave action); 153—147; and at different levels between 115 and 100 m.

10. Dating of the stratal sequence.

The stratigraphy of the Kristianstad district is mainly based on belemnites. Since long, Mammillatus and Mucronata Chalks have been discerned. LUNDEGREN (1930 and 1934 a) showed that the zone with *Actinocamax westfalicus* (the Emscher) is also represented. However, the Granulatus Chalk, or the Santonian, has not previously been observed within the district.

The Mammillatus Chalk was by BROTZEN (cf. 1945, p. 37 f.) paralleled mainly with the lower Campanian. The upper Campanian was considered as succeeded by the Maastrichtian; this zone corresponds to the Constrictus zone (also cf. op. cit. p. 21 and 41).

A rough dating of the stratal sequence of the core can be made on the basis of the macro-fossils observed.

The zone 153—147 may be chosen as starting level for the dating.

Actinocamax verus is abundant in this zone which may thus be considered to be of middle or upper Santonian age, since, according to LUNDEGREN 1935 (Fig. 3, p. 11), this species is most abundant there; it may occur also in strata referable to the lower Santonian and the Emscher period but is very scarce, however.

Inoceramus lingua is abundant somewhat below this zone, viz. at 163.9–163.6. It has been found, in Germany, in the upper part of the middle Santonian (the Marsupites zone) and in the upper Santonian (the Binodosus zone); in Sweden, it is stated to be distinctive for the Binodosus zone (cf. HÄGG 1935, p. 10 and 28; LUNDEGREN 1935, p. 11). However, as the species is reported both from the middle and the upper Santonian in Germany it is, for the present, somewhat uncertain whether the section 164–147 can be referred to both of these Santonian zones or to one of them.

The age of the underlying sediments cannot, on the basis of the present macro-fossils, be ascertained with certainty, since the only ones found there are not definitely identifiable.

The conglomerate at 173.70–173.58 which includes several belemnite rostra probably referable to *Actinocamax westfalicus* or *A. westfalicus-granulatus* may, on account of these belemnites, be lower Santonian or the uppermost part of the Emscher (cf. LUNDEGREN 1935, p. 7). The 10 m thick layer between the *Inoceramus lingua* stratum (middle or upper Santonian) and the conglomerate should thus represent a relatively long period; and this is not unlikely since the sediment is clay and water-worn sand, the latter indicating that the supply of particles was small and the sedimentation slow.

The age of the feldspar-bearing layer between the bedrock and the conglomerate is impossible to determine since no fossils were found there. The sedimentation per time unit of a sediment of this type may have been rapid, but great masses were accumulated (10 m in thickness; in ERDMANN's well probably > 25 m, cf. p. 66). The whole process may have taken a rather long time, and the consideration may not be excluded that the Åhus area was inundated in the Emscher period. The Emscher is represented by deposits at the foot of Mt Nävlingeåsen, about 30 km from Åhus (LUNDEGREN 1934 a, p. 153).

Let us now return to the richly *A. verus*-bearing section 153–147, which was interpreted to belong to the upper or middle Santonian, and discuss the age of the overlying part of the stratal sequence.

A. verus is fairly common up to around 135 m, uppermost find at 131.9 m, where it disappears and is succeeded by *A. mammillatus* and *A. quadratus*, which appear mainly contemporaneously (lowermost find of *A. mammillatus* at 131.6 m and of *A. quadratus* at 130.4 m). The boundary Santonian/Campanian may thus be suggested to occur at about 130 m.

A. quadratus was only observed around 130 m which is in accordance with the observations made by LUNDEGREN (1934 a, p. 285), viz. that he found this species only in the lower part of the Mammillatus deposit in the Ivö Island. HÄGG (1947, p. 116), on the other hand, partly basing his opinion on a statement by BROTZEN, considered that *A. quadratus* occurs also in the upper part of the Mammillatus Chalk.

The lower limit of the lower Campanian (Mammillatus Chalk), as just established, is fairly distinct. However, the upper limit is not so easily distinguishable.

The uppermost find of *A. mammillatus* was made at 84.3 m, and *Belemnitella mucronata* was found lowest at about 55 m. Around this latter level flint is developed.[1] Characteristic Mucronata calcareous mud chalk had begun to be rather abundant some 10 m lower. The expansion of a middle Campanian transgression which is generally considered to indicate the boundary Mammillatus/Mucronata Chalks (cf. LUNDEGREN 1934 a, p. 293) is not proved in the present case.

As a matter of fact, *B. mucronata* has been stated to occur in several zones below the Mucronata Chalk, but it becomes frequent in this chalk after having appeared sporadically. It may, practically, be considered an index fossil of the Mucronata Chalk (cf. LUNDEGREN 1934 a, p. 286). However, the border Mammillatus/Mucronata Chalks is generally established by the disappearance of *A. mammillatus*. Since this species was found up to about 85 m, the Mammillatus zone extends at least up to this level. On the other hand, it does not extend to about the 55 m level where the Mucronata zone may be considered to be proved. The border may be situated somewhere within the division 85—55, and it might have been more precisely established if belemnites had been found there.

The macro-fossils in the Åhus Sandstone section (from about 28 m and upwards; cf. p. 63) are not sufficient for a dating. However, abundant finds of *Ostrea lunata* in blocks of Åhus Sandstone indicate that it is referable to the Constrictus zone. This is scarcely contradicted by the fauna for the the rest (cf. p. 50 f.).

11. Special lithologic investigation.

Descriptive part.

Porosity.

Archaean.

Porosity is low, only about 11 %.

[1] Flint is practically restricted to the Mucronata Chalk in the Kristianstad district. LUNDEGREN (1934 a, p. 279) has even referred non-fossiliferous sediments to the Mucronata Chalk only because they contain flint. A certain amount of care must be taken in such cases, however, since flint may occur also in the Mammillatus Chalk, though not in such great quantities as in the Mucronata Chalk. In the core small quantities of flint occur at about 100–105 m and 126 m.

Cretaceous.

182.86–167.5. Highest porosity in the stratal sequence: 40–46 %.

167–166. Low porosity: about 11 %.

165.5–134.5. Porosity high and very constant, especially in the section 156–134.5 (40 %), except for one occasional minimum at 153.5 m (27 %); in the section 165.5–156 the curve fluctuates gently between 35 and 40 %.

134–98.5. Porosity for the most part lower than in the underlying section, but more variable: from 9 to 41 %. The amplitude and density of variation is greatest in the upper part (103–98.5).

98–65.5. High and fairly constant porosity, about 41 %; some occasional minima occur (28–33 %).

65–29. Changes relatively small and gentle (porosity about 25–37 %; min. 20 %, max. 41 %).

28.5–24.5. Very sharp changes between minima of lowest 10 % and maxima of generally about 40 %.

24–top of the Cretaceous. Mainly about 40 % with distinct, sudden minima (13–22 %).

Quaternary.

Sharp changes between 11 and 40 %.

Granulometry of the insoluble residue.

Median diameter of particles.

Cretaceous.

182.86–167.5. Two divisions of this section are discernible, distinctly parted by a horizon (177.0–176.5) with a very low median diameter (0.08 mm).

The median diameter of the lower division is inferior to that of the upper. In the lower it is 0.16–0.25 mm (except at 182: 0.09 mm) and in the upper 0.23–0.44 mm (mean about 0.32 mm).

167.0–160. The median diameter is very low: between 0.02 and 0.05 mm (on an average 0.03 mm), except the levels 164.5 and 165 (0.115 and 0.185 mm, resp.).

159.5–102.5. The curve fluctuates gently in this section. Median diameter is for the most part about 0.15–0.25 mm, but higher and lower values occur sometimes (max. 0.31 mm, min. 0.06 mm). There is a general increase up to about 142 m (an occasional high value at 154.5 m, however), but then there is a general decrease up to 129.5 m (a deviation from this development is represented by the maximum at 135.5–134.5). From 129.5 to 113.5 the curve mainly ascends. In the division 113.5–102.5 it fluctuates somewhat, but, on the whole, the course neither descends nor ascends.

102–66.5. This section is characterized by great fluctuations. The main part of the curve runs within the limits 0.15 and 0.30 mm, but minima of 0.1 mm and maxima of up to about 0.7 mm occur.

66–28.5. The variations are very small in this section. In the division 50.5–28.5 the curve varies only between 0.17 and 0.22 mm. In the division 66–50.5 the curve runs mainly between 0.16 and 0.21 mm, except for the horizon 58–56.5, where a maximum of 0.30 mm is developed.

28–top of the Cretaceous. The median diameter has increased in relation to the underlying section. The increase appears suddenly. In the lower division (up to 15 m) the mean median diameter is about 0.4 mm, but the fluctuations are fairly large (max. 0.57 mm, min. 0.24 mm). In the division above 15 m the mean median diameter is about 0.27 mm, except for a few distinct maxima in the upper part (max. 0.54 mm).

Quaternary.

In the lower part the curve decreases steadily, and then the median diameter is sometimes very low (min. 0.1 mm).

Log quartile deviation.

Cretaceous.

The fluctuations of this curve are mostly large and distinct. Regular correspondence with the curve of the median diameter does not occur. There are conformities but also contrarieties. Inter alia, some great maxima have no correspondences in the median diameter curve.

The section 44–28.5 is remarkably different from the remaining part of the curve. The mean is low and the fluctuations are small, i.e. the sorting is good throughout. The underlying stratum (around 50 m) is, on the contrary, poorly sorted. A corresponding development, though less distinct, can be seen in a lower part of the core, viz. in the section 127–115. The clayey section 167–160 is mostly very poorly sorted but there are some great fluctuations (better sorting at 166.5 m and 165–164.5).

Quaternary.

The sorting is mostly poor, especially in the middle and lower parts.

Heavy minerals.

The heavy minerals mainly consist of magnetite, ilmenite, garnet, zircon, rutil, pyrite, and phosphorite. Pyrite and phosphorite are not included in the sum of heavy minerals (cf. p. 54).

Archaean.

The content is low, about 0.2 % of the sediment. Mainly the same assemblage as in the Cretaceous and Quaternary sections of the core was observed (pyrite and phosphorite absent).

Cretaceous.

The greatest part of the curve is inferior to 1 %. In a few sections it runs between 1 and 2 %. At one level (94.5 m) it reaches 3 %.

182.86–176.5. The curve does not exceed 0.2 %.

176–167.5. In the division 170.5–169.5 heavy minerals are practically absent. Below this one, part of the frequency extends to about 1 %; above this horizon, on the other hand, it is about 0.5 %.

167–160. Heavy minerals are practically absent.

159.5–150. The frequency never exceeds 0.6 %.

149.5–133.5. The curve runs between 0.5 and 1.6 %.

133–123. No higher values than 0.3 %.

122.5–55. Fairly dense and partly rather large fluctuations (about 0.1–1.5 %; two maxima larger, viz. 3 % at 94.5 m and 1.7 % at 80 m).

54.5–42.5. The curve invariably runs below 0.5 %, for the most part between 0 and 0.3 %.

42–26. For the greater part the curve varies between 0.3 and 1.3 % (one maximum of 1.4 % at 28.5 m). In the middle of the section (35–33) it varies between 1.5 and 2 %.

25.5–16. The curve is very low, not exceeding 0.15 %.

15.5–top of the Cretaceous. Frequency somewhat variable, but generally about 0.5 %; two higher values observed (at 15 m 1 % and at 12 m 1.2 %).

Quaternary.

Relatively small values in the lower part, but in the upper there are two pronounced maxima (at 2 m 4.2 % and at 0.85 m 1.3 %).

Glauconite.

Archaean.

No glauconite.

Cretaceous.

182.86–173.5. No glauconite.

173–165. Extremely sharp fluctuations: from 0 % to 57 %. Three pronounced maxima observed.

164.5–160. No glauconite.

159.5–132.5. Average glauconite content fairly high. Three zones with high percentages occur, separated by zones with low values, viz.:

159.5–157.5 (max. at 159: 6 %),

156–146 (includes a few minima; highest values at 150: 10.5 %),

142–132.5 (max. at 138: 11 %).

132–54.5. The main part of the curve runs below 2 %. A few higher values observed, the highest at 95.5 m (5.7 %). Four different zones discernible:

132—123. The curve descends continuously from the subjacent maximum (decrease within the zone: 1.6—0.2 %).

122.5—109.5. Fairly sharp fluctuations; lowest value 0.4 %, highest 3.5 %.

109—100. Few and small fluctuations (0.3—1.0 %).

99.5—54.5. Two distinct maxima occur in the lower part. In the zone 81—77 the frequency is invariably low (0.5—1 %). From 66 m the curve decreases to 0 at 54.5 m.

54—top of the Cretaceous. No glauconite, except occasional small occurrences (maximum 0.3 %).

Quaternary.

Glauconite occurs in small quantities; highest value 0.5 %.

Calcareous substances.

Archaean.

No calcium carbonate.

Cretaceous.

182.86—176.5. No calcium carbonate.

176—153. Three different divisions can be discerned here:

176—165.5. The curve rises gently, except for the zone 173.5—169.5, where a low and broad maximum is formed.

165—156.5. Rather high content of calcareous substances (mean about 40 %; max. 57.5 %). A section with lower values occurs in the middle of the zone (min. at 160: 19.5 %).

156—153. Rather low percentage, except for one maximum (at 153.5: 33.5 %).

152.5—134.5. The percentage is very low with insignificant fluctuations; the curve varies between 2 and 8 %. The division 146—134.5 consists of three zones with practically constant percentages of calcium carbonate within each zone.

134—122.5. The curve forms a broad and great maximum. In the division 129.5—123 the percentage varies between 82 and 96 %.

122—66. This section is characterized by very pronounced and generally rapid changes in frequency (max. 87 % at 109 m and min. 13 % at 75 m). In a few divisions the fluctuations are much smaller (for instance 94.5—90 and 80—77).

In the division 122—109 the main course of the curve increases (max. at 109: 87 %), but in 108.5—66 it decreases, especially to about 90 m.

65.5—41.5. Fairly high values and relatively moderate fluctuations. Except for the divisions 65.5—64.5 and 43—41.5, the frequency is about 50—80 %; between 55 and 47.5 it is about 60—80 %, and between 45 and 44 about 70—80 %.

41—24.5. Extremely dense and pronounced changes, especially in the upper part of the section. Maximum frequency of calcareous substances 63 % (40 m), minimum frequency 10 % (25 m).

24—top of the Cretaceous. The main part of the curve runs between 10 and 20 %. One single lower value (8 % at 9 m) and several very distinct higher ones appear (max. 60 % at 7 m).

Quaternary.

The curve increases upwards to 4 m (53.5 %) but decreases rapidly thereafter to 1.5 m, where it practically vanishes.

Carbon (Given as C).

182.86—167.5. No carbon content except two very low values at 183—182 and 176.5 m, resp.

167—148. In the zone 167—162 the curve rises rapidly to 0.2 % (166.5), and then varies between 0.1 and 0.2 %; in 161.5—148 it sinks rather regularly from about 0.1 % to 0 (one higher value at 149.5, viz. 0.1 %).

147.5—77. Fairly small and gentle fluctuations, for the most part between 0.1 and 0.3 %; in a few cases the curve runs somewhat below 0.1 %.

76.5—25. In this section are the highest values in the core. Different divisions are discernible:

76.5—61.5. Relatively small fluctuations (in the zone 76.5—65.5 frequency about 0.3—0.4 %; in 65—61.5 about 0.4—0.55 %).

61—49. The main part of the curve runs at about 0.7 % (max. 0.74 at 53.5); two minima observed in this division: one at 59 m (0.41 %) and another at 51 m (0.55 %).

48.5—25. The curve decreases upwards with pronounced fluctuations in some parts; however, a deviation from this development appears in the zone 39—35 where very high values occur (0.68—0.75 %, except for the level 36 m [0.18 %]).

24.5—top of the Cretaceous. Low frequency and small fluctuations, mainly between 0.05 and 0.1 %; a few values > 0.1 % occur.

Quaternary.

Frequency mainly increasing, but rather large fluctuations; maximum in the dark stratum at 0.8—0.9 m (0.54 %).

Phosphorus (Given as P_2O_5).

Archaean.

The percentage is very low: 0.02 %.

Cretaceous.

182.86–173.5. Percentage very low: 0.01–0.03 %.

173–166. High values predominate in this section, for the most part about 0.3–0.7 %. At 170 m a great maximum (1.26 %).

165.5–162. Low but fairly fluctuating values (0.06–0.25 %).

161.5–153.5. High values with three distinct maxima (160: 0.56 %; 157: 0.77 %; 154: 1.22 %).

153–134.5. Moderate and fairly constant values, varying around 0.2 %.

134–50. Rather low values; the curve runs to somewhat different heights in different divisions of the section:

134–102.5. Low values: between 0.05 and 0.15 %, except in the zone 129.5–125.5 where the curve runs below 0.05 %.

102–84. Somewhat higher values: between 0.1 and 0.2 %.

83.5–50. The curve runs low, mainly between 0.05 and 0.15 %.

49.5–top of the Cretaceous. Very low values; the curve almost invariably runs below 0.05 %.

Quaternary.

Higher values than in the underlying strata; variations between 0.04 and 0.17 %.

Sulphur (Given as S).

Archaean.

No sulphur.

Cretaceous.

182.86–167.5. The curve rises abruptly, forming a maximum at 177.5 m (1.0 %), but descends from this level to 175 m (0.16 %). Low values upwards, except one maximum at 173.5 (0.7 %).

167.0–159.5. Tremendous changes in frequency. Four maxima observed (166: 3.9 %; 164: 4.4 %; 162: 2.45 %; 160: 2.4 %). Minima very low: 0.2–0.4 %.

159.0–top of the Cretaceous. Low frequency throughout this sequence: mostly around and below 0.2 %, for great parts below 0.1 %. Occasionally the frequency rises to about 0.4 % (in the zone 78–76).

Quaternary.

Sulphur practically absent.

Iron (Given as Fe).

Archaean.

The content of iron is 0.2–0.4 %.

Cretaceous.

The iron curve is superior to the sulphur curve, but otherwise both curves are almost conformable to one another.

Quaternary.

As the content of iron increases, the sulphur curve decreases.

Comparative part.

In the following survey the curves are compared to each other, with the exception of the iron curve, which conforms to the sulphur curve.

Porosity.

When the sediment is non-calcareous or the calcium carbonate content is low porosity is mainly proportional to the size of the particles of the insoluble residue. Thus, porosity is low when the sediment is fine-grained, and vice versa (cf. the section 176—166).

In those cases when the calcium carbonate content is high the size of the particles of the insoluble residue is of little importance for assessing the degree of porosity, since they constitute only a minor part of the sediment, and the pore volumes, furthermore, are more or less filled with calcium carbonate. The degree of porosity is here inverse to the calcium carbonate content. In this stratal sequence it is very common that an increase of the calcium carbonate content corresponds with a decrease in the porosity. As an illustration of the relation between content of calcium carbonate and porosity, it may be mentioned that in the stratum above the section 165—159.5 the size of particles increased but porosity decreased contemporaneously with an increase in the calcium carbonate content.

However, in fine-grained sediments it can be observed that porosity is increased in spite of the fact that the calcium carbonate content is increased. A lower degree of porosity should have been expected. An explanation may possibly be that the fine minerogene particles served as nuclei for precipitation of calcium carbonate, so that the particles, becoming larger, thus caused the porosity to increase (cf. section 165—159.5).

Granulometry.

The relations between granulometry and the components analysed are mentioned in the discussions of the relations of each separate component.

Heavy minerals.

Granulometry. The heavy mineral curve conforms well with that of the median diameter up to about 50 m, but above this level the main courses of the curves are contrary.

As for sorting, it is obvious that in divisions with especially poor sorting heavy minerals are few or absent. A correspondence does not invariably occur in case of moderate sorting. In divisions with good sorting there is sometimes a high content of heavy minerals, such as the section 43—29. A high content of heavy minerals, however, is not always associated with good sorting.

Glauconite. In the section 170—53.5 there is a good correspondence in the main course of the curves and some correspondence in details. Above and below this section there is no conformity. Below 170 m a section with a high heavy mineral content was formed prior to the formation of glauconite (176—173.5). At the first glauconite maximum (173—170.5) the content of heavy minerals is low. Above 53.5 m (where continuous glauconite deposition had ceased) there are sections with high contents of heavy minerals but practically no glauconite.

Calcium carbonate. Contrarieties between the main courses of the curves are very common and may also occur with regard to minor features of the curves. In the section 24—19 contrarieties were not observed.

Carbon. In the lower part of the stratal sequence there is some degree of contrariety, but contrarieties are less regular in the upper part.

Phosphorus. The heavy mineral curve is unaffected by the high phosphorus values (the greatest phosphorus maximum, however, corresponds with a very low value for heavy minerals). In zones with very low heavy mineral frequency the content of phosphorus is likewise low.

Sulphur. Below about 120 m whole sections of the curves are contrary (very distinctive for the section 166.5—160, where high sulphur values occur, but heavy minerals are practically absent).

Glauconite.

Granulometry. No regular relation to the median diameter curve occurs. The two lower ones of the great glauconite maxima appear just below the fine-grained section 167—159.5, but the third (upper) falls within this section. Nor can a regular correspondence to the sorting curve be traced.

Heavy minerals. Cf. above.

Calcium carbonate. The glauconite curve runs contrarily to the calcium carbonate curve to a very great extent. This is particulary the case in the section 160—120. Contrarieties are clearly visible also with regard to most of the details. Above this section, where the glauconite content is low, there is no regularity in the main courses of the curves, and conformities as well as contrarieties in details occur.

Carbon. No regular correspondence. The carbon curve begins practically above the greatest glauconite maximum.

Phosphorus. The high values of both glauconite and phosphorus occur in the same section, viz. 173.5— about 125. However, as a rule, maxima and minima are not contemporary; very often the fluctuations are contrary. A striking example of this occurs at 170 m, where a distinct minimum of the glauconite curve corresponds to an equally distinct maximum of that of phosphorus.

In the section above 125 m there is no regular correspondence between the curves.

Sulphur. The curves of glauconite and sulphur are mainly contrary to each other even in the section above 159.5 where both components are relatively infrequent. The contrarieties appear most distinctly and regularly in sections with high values of the components, especially in those parts of the section 167.5—159.5 where glauconite occurs. In the section below 167.5 very high glauconite contents correspond to low sulphur values, and, conversely, sulphur is fairly abundant where glauconite is absent.

Calcareous substances.

Porosity. Cf. p. 77.

Granulometry. The main courses of the calcium carbonate curve and that of the median diameter of the insoluble residue are contrary to a great extent. In those sections where the calcium carbonate content is high, the median diameter, as a rule, is relatively low, and vice versa. In very many cases there are contrarieties also in the details. But there are several examples of indifferences, and in some cases conformities occur.

Concerning the sorting curve, no regular correspondence exists with regard to the main courses or to the details. There are several examples to indicate that a poor sorting corresponds to a high percentage of calcium carbonate. But this is not of general occurrence. It also happens that a poor sorting is corresponded by a low percentage of calcium carbonate, and that the curves run quite independently.

Heavy minerals. Cf. p. 78.

Glauconite. Cf. p. 78.

Carbon. There is no regularity between the curves of calcium carbonate and carbon. In the section 66—46 the carbon curve runs high like the calcium carbonate curve, but this seems to be a coincidence.

Phosphorus and sulphur. No regular correspondence discernible.

Carbon.

Granulometry. The main fluctuations of the median diameter curve are chiefly contrary to those of the carbon curve (higher contents of carbon in fine-grained sections). The rise of the carbon curve begins exactly in the fine-grained sediment at 167.0, and the division with the high carbon content in the upper part of the core falls within a section with relatively small-sized particles. On the other hand, the low carbon content in the overlying section corresponds with a relatively high median diameter.

Regular correspondence to the sorting curve does not seem to exist.

Heavy minerals. Cf. p. 78.

Glauconite. Cf. p. 78.

Calcium carbonate. Cf. p. 79.

Phosphorus and sulphur. No regularity ascertainable.

Phosphorus.

Granulometry. No regularity discernible.

Heavy minerals. Cf. p. 78.

Glauconite. Cf. p. 78.

Calcium carbonate. Cf. p. 79.

Carbon. Cf. above.

Sulphur. No regularities ascertainable. The high sulphur values in the lower part of the core are mostly corresponded by a low phosphorus content. But pronounced contemporary maxima occur occasionally, such as at 160 m.

Sulphur.

Granulometry. High contents of sulphur occur in the fine-grained section 167—160, but the median diameter is sometimes indifferent to great occasional minima of sulphur (164—160). Less pronounced contrarieties of the curves occur in the section 135—127 and below 167 m.

The high sulphur values between 167 and 160 m are mostly corresponded by poor sorting (and vice versa); however, exceptions occur (cf. 162—161.5 and 165.5 m). In the remaining part of the stratal sequence sorting is often poor when the sulphur curve forms maxima.

Heavy minerals. Cf. p. 78.

Glauconite. Cf. p. 79.

Calcium carbonate. Cf. p. 79.

Carbon. Cf. above.

Phosphorus. Cf. above.

Summary.

The above comparisons show that several curves run independently of each other, whereas others are contrary (entirely or partly), and a few correspond more or less completely.

Irregular relations.

Heavy minerals — glauconite (above and below section 170—53.5)

Heavy minerals — carbon (upper part of stratal sequence)
Glauconite — granulometry
Glauconite — calcium carbonate (above 120 m where glauconite content is mainly low)
Glauconite — carbon
Glauconite — phosphorus (at low values of these components)
Calcium carbonate — sorting
Calcium carbonate — carbon
Calcium carbonate — phosphorus
Calcium carbonate — sulphur
Carbon — sorting
Carbon — phosphorus
Carbon — sulphur
Phosphorus — granulometry
Phosphorus — sulphur (except the section 167.5—161).

With regard to the following components correspondence might possibly be expected:

Heavy minerals — glauconite (autogene glauconite considered)
Glauconite and phosphorus — granulometry, i.e. high contents correspond to proportionally large median diameter and good sorting, and vice versa (autogene glauconite and phosphorus precipitates considered)
Carbon — sulphur
Carbon — sorting (high carbon content — poor sorting, and vice versa).

As a high content of heavy minerals, a large median diameter, and good sorting may most often be associated with ventilated surroundings, glauconite (which includes more ferric than ferrous silicate) might be expected to have been formed abundantly when the heavy mineral content is high, the median diameter large, and the sorting good. As a matter of fact, this appears when glauconite occurs in greater quantities and is mainly autogene (cf. p. 82 f.).

The irregularities in this respect in the section below 170 m are possibly connected with the supply of potassium, which, in its turn, to a great extent may depend on the production of phytogene detritus (cf. p. 54). The proportionally high content of heavy minerals in the zone 176—173.5 might have been corresponded by a high content of glauconite if the access to potassium in the form of phytogene detritus had been sufficient during this early stage of the transgression. The irregularities in the section above 53.5 m, on the other hand, may possibly be due to deficiency of silica so that only small quantities of glauconite were formed; moreover, the glauconite in this section is certainly redeposited to a great deal, so that comparisons with the granulometry are scarcely reliable.

Carbon and sulphur might be expected to occur together, since they generally accumulate in the same type of surroundings. Some correspondence can be traced, but owing to the low content of sulphur above 160 m it is difficult to make statements as to details of the curves.

Contrarieties.

Porosity — calcium carbonate (except possibly at small size of the insoluble particles)

Heavy minerals — median diameter (above 50 m)

Heavy minerals — calcium carbonate

Heavy minerals — carbon (less regular in upper part of stratal sequence)

Heavy minerals — phosphorus (referable to the highest phosphorus value)

Heavy minerals — sulphur (below 120 m)

Glauconite — calcium carbonate (referable to the section below 120 m where high values of glauconite occur)

Glauconite — sulphur

Calcium carbonate — median diameter

Carbon — median diameter

Phosphorus — sulphur (in the section 167.5–161)

Sulphur — median diameter (however, indifference of median diameter to sulphur fluctuations in the division 164–160).

Contrarieties between most of these components can be expected; concerning the relation between heavy minerals and the median diameter above the 50 m level, conformity might be suggested to occur there as in the remaining part of the stratal sequence (cf. below and p. 83).

Some interesting information may be obtained from the divergences mentioned, especially with regard to the formation of the calcareous substances.

It is conceivable that a low content of heavy minerals and a small median diameter indicate little agitation of the water. This is supported by the fact that the stagnancy elements sulphur and carbon are most often abundant or relatively frequent when heavy minerals are few and the median diameter is small. The fact that sulphur is contrary to glauconite (which may be formed in ventilated water), points in the same direction. The circumstance that higher frequencies of calcium carbonate, like sulphur and carbon, correspond to a small median diameter, a low heavy mineral frequency, and, like sulphur, to a low glauconite content, indicates that calcium carbonate was formed to a great extent in little agitated surroundings.

Correspondences.

Porosity — median diameter (low porosity corresponds to small median diameter and high porosity to large median diameter)

Heavy minerals — median diameter (up to the 50 m level)

Heavy minerals — sorting (few heavy minerals — poor sorting)

Heavy minerals — glauconite (170—53.5)
Heavy minerals — phosphorus (at low values)
Glauconite — phosphorus (high values in the same zone but details most often contrary).

This survey completes the records obtained from the above survey of contrarieties, inasmuch as the amount of heavy minerals increases with an increasing median diameter, and that the heavy mineral content is high when glauconite is abundant.

The fact that glauconite and phosphorus appear in the same zone may be in accordance with the theories that they were formed on account of similar redox developments, i.e. when stagnation turned over into ventilation (cf. p. 52 f. and 54). Irregularities and independencies in the relations between phosphorus and heavy minerals may possibly be in part due to the fact that the precipitation of phosphorus may have occurred prior to the strongest movements in the water, during which the maximum enrichment of heavy minerals can be expected. Correspondence at low values may often be a consequence of enrichment (phosphorite heavy).

12. Examination of thin slides.

Shell fragments (mainly mussels).

Shell fragments occur from the conglomerate at 173.70—173.58 to the top of the Cretaceous. They are abundant in the section 131—100, in some zones within the section 63—44, and invariably above 28 m.

Echinoderms.

Fragments were observed in most samples in the section 127—37, and, moreover, at 157—156. They are fairly common at about 127—100 and 64—50.

Bryozoans.

Single fragments of bryozoans were observed at great depths (168 and 156 m), but they are rather common from about 130 to 52 m (most abundant at about 129—115); some scattered specimens appear up to 34 m.

Foraminifera.

Foraminiferal shells occur in all samples from 165 m to the top of the Cretaceous (redeposited Cretaceous foraminifera also can be found in the Quaternary). They are especially abundant in the zone 165—162. It is a striking fact that not a single foraminiferal shell was observed in samples below 165 m. The majority of the invading great masses between 165.5 and 165 m are young Globigerinidae types.

Radiolarians.

Radiolarians occur in scattered samples from 164.5 to 26 m. In a few zones they were found in all samples, viz. 164.5—158, 102—95, and 64—51.

Lithothamniaceans.

Fragments of lithothamniaceans were observed in several samples between 157 and 25 m. They occur continuously in the section 129—108 and are especially abundant in the zone 120—115 as well as at the level 108. A shorter but less frequent continuous sequence appears in the zone 22—16.

Diatoms.

Some careful separations of clayey substance from the zone 167.1—159.8 have been made in order to investigate whether diatoms occur there, but the result was negative. However, in a thin slide from the level 161.2 one single diatom was observed (Fig. 4).

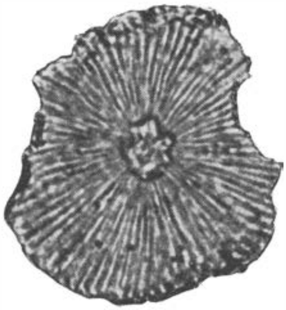

Fig. 4. Diatom from the 161.2 m level; to the left and right covered by foreign substances. Discussion in text. 380 ×.

This seems to be the first find of Cretaceous diatoms in Sweden. According to Dr. A. CLEVE-EULER, it may be a *Melosira*, somewhat reminiscent of the early Tertiary *M. clavigera* GRUN. The diameter is about 105 μ, and, at the margin, the radiating ribs are about 2.5/10 μ (corresponding measurements of *M. clavigera* from pictures in VAN HEURCK 1880—85: 60—90 μ, 2—2.5 ribs per 10 μ).

Upper Cretaceous diatoms have been reported from several foreign localities, but most of them seem to be somewhat uncertain as to their age. However, a diatom flora investigated by SCHULZ (1935) seems to be definitely referable to the Senonian. In this case the diatoms were extracted from Senonian flint boulders found on the North German coast. As a matter of fact, this investigation will be of great interest for the future research of the diatoms in the Åhus core.

Penetrative algae.

Canals bored by algae are not always clearly visible, since they are often not filled with a coloured substance. At careful examination even these non-filled canals may be discerned, however. In the filled canals the filling substance is generally glauconite, but may also be pyrite.

The canals are fairly wide and do not form a dense network. They were possibly caused by green-algae, judging from the thickness of the threads (cf. HESSLAND 1949 a [p. 419] with bibliography).

13. Interpretation of lithogenesis and changes of level.

Conclusions on lithogenesis and changes of level should be based on investigations of several cores. Data are more likely to be incorrectly explained if such discussions are confined to one single core. In the present case the genesis of several sections may be explained in more than one way.

In the following interpretation of the lithogenesis and the changes of level during the accumulation of the Åhus Series these questions are discussed in sections mainly in accordance with the division of the core which is to be found in the general and special descriptions in the preceding pages.

182.86–173.7 (feldspar-bearing sand).

Great quantities of sediments were certainly freed from the deeply weathered Archaean during the initial phase of the transgression. The feldspar-bearing sediment (about 9 m thick) resting on the Archaean obviously consists of such material. It is very similar to the underlying Archaean in petrographic respect. The presence of strongly weathered and thus easily destructible feldspar grains indicates that the accumulation was rapid and that the transport was short. This is supported by the fact that the feldspar grains as well as the quartz grains are angular.

The bottom sediment of the stratal sequence at the spot where ERDMANN made his boring in 1903 (p. 64 f.) seems to be much thicker than that at the place of the core drilling (probably 25 m or more). Whether the sediment at the former place is derived from the granitic gneiss or from a mica quartzite of the type mentioned by ERDMANN (cf. p. 66) is not known. The fact that it seems to be without feldspar to a great extent does not exclude the possibility that it originated from the granitic gneiss. The feldspar could have been much weathered and thus was readily subject to mechanical destruction, so that it may have been carried away entirely. Such a far-reaching detraction occurred during the deposition of the upper part of the bottom layer in the core (see below). This obviously also happened during the accumulation of the so-called Holma and Ryedal Sandstones which, because of their composition and position in the stratal sequence, certainly correspond to the bottom sediments of the Åhus Series.

The bottom sediment in the core is not homogeneous throughout. As mentioned, the content of feldspar diminishes upwards; the number of large mica flakes increases, on the contrary. The very uppermost part is consolidated to a sandstone.

The diminishing content of feldspar may indicate that the sediment was more effectively washed at a later stage. Also the following facts point in this direction: the median diameter increased, but the sorting was better, and the content of sulphur decreased; heavy minerals were enriched. The reason for the more effective washing may be either that the weathering products in general began to run short, and/or that the depth of the water diminished. This latter phenomenon is often caused by the fact that the rapidity in the subsidence of the earth's crust diminishes during continuous sedimentation, or that the accumulation of sediments is so rapid that the depth of water diminishes in spite of a constant subsidence of the earth's crust.

The alternative that the weathering products in general began to run short may be excluded, especially judging from the fact that great quantities of glauconite were formed later. The formation of glauconite postulates, inter alia, a rich supply of silica, and this was certainly derived from the weathered Archaean during periods of transgression. In other words: intact weathering products did occur within this area but they only became accessible during later transgressions. The more effective washing was thus most likely caused by a diminished rapidity of transgression and subsidence which resulted in a diminished supply of sediments and a thorough washing in a shallow area.

The reason for the fact that glauconite was not formed during the accumulation of the section 182.86–173.7 (except in extremely small quantities in the uppermost part of the section) was possibly that the supply of potassium in this early stage was too scanty which, in turn, may be referable to an insufficient production of phytogene detritus (cf. p. 54 and 81). But, as a matter of fact, formation of glauconite is strictly confined to marine milieus. The consideration that this premise was not fulfilled may perhaps not be quite neglected. Yet, indications of salt water in this period seem to exist (cf. p. 87; conditions for precipitation of kaolin).

However, the change upwards in the composition of the sediment of this section was not continuous. This is manifested by strata of fine-sediments (182.5–182.0 and 177.1–176.5). The sorting is poor at both these levels. These sediments thus scarcely accumulated because of a gravitative dispersal of the particles in an area with traversing currents but may have settled in closed basins. A distinct increase of the carbon curve at the upper level possibly also indicates that the accumulation occurred just in this type of surroundings. There can be different reasons for the appearance of such basins. The cause can be temporary regressions, or the area can have happened to be isolated by rearrangement of sediments. During the period now discussed great sediment masses were on the move and bars could easily appear. It is scarcely probable that regressions should be the reason since kaolin constitutes an important part of these sediments, and, as a matter of fact, supply of kaolin rather indicates transgressions.

The water may have been salt during the periods of enclosure. The fine-grained sediments, especially the white redeposited kaolin which occurs in the section 177.1–176.5, scarcely could have been deposited in fresh water but rather in salt water, the electrolytes of which could cause the agglutination and precipitation of the extremely fine kaolin ooze.

Animal life may not have been so insignificant during the early stage now discussed as might appear from the fact that shells and other organic substances of calcium carbonate seem to be completely lacking. The sulphur curve is proportionally high, which may be due to the fact that several dead bodies of non-shell-bearing organisms were embedded. As known, there exists an abundant animal life in fairly movable sand masses.

173.70–173.58 (conglomerate).

As discussed above, the decrease of feldspar upwards in the section below the conglomerate possibly indicates that the supply of sediments and the intensity of the subsidence of the earth's crust diminished at the end of this period. The formation of the conglomerate seems to have been the culmination of this development; the conglomerate was obviously accumulated on the shore. However, the shore may not have had this position any longer time, judging from the fact that many of the rolled pebbles of the conglomerate consist of easily destructible material, such as aggregates of weathered feldspar crystals and loose sandstone (obviously eroded from the consolidated zone just below the conglomerate). Lumps of pure kaolin are also included. The roundness of the quartz pebbles may partly have been developed earlier; as can be observed, quartz pebbles are sometimes fairly well rounded already when freed from the weathered Archaean.

The relatively high sulphur content in the conglomerate derives from pyrite lumps, enclosed in the clayey cement substance.

The communication with the sea during this period is proved by several belemnite rostra, probably of *Actinocamax westfalicus* or *A. westfalicus-granulatus* which indicate lower Santonian or upper Emscher.

173.58–167.1 (mainly richly glauconite-bearing sand with inconsiderable or no content of feldspar; particles rounded).

During this period the transgression may have continued again. This is possibly indicated by the important deposition of glauconite. However, the transgression certainly caused only a slight increase of the depth of the water, and it seems to have ceased towards the end of the period. Practically all the time there was vivid motion in the water.

These conditions are manifested in the curves in the following way: the median diameter of the insoluble residue has diminished (porosity has partly increased), the sorting has been better, and the content of sulphur and carbon is low.

Calcium carbonate has increased (especially up to about 170 m; thereafter some decrease); this is connected with the initial settling of a shell fauna.

Certain dissimilarities with regard to the composition and structure of the sediment below and above the consolidated stratum 169.9—169.7 are elucidative of the development. Below this stratum there occur some feldspar and clayey substances, the latter of the same appearance as that which constitutes the cement of the conglomerate; the quartz particles are well rounded. Above the stratum, on the other hand, feldspar is very restricted, clay substances lacking, and the quartz grains are very well rounded. This indicates that the washing was more effective.

The transgression seems to have started just after the formation of the conglomerate and may soon have reached intact weathering material. This may be indicated by the important deposition of glauconite which began at 173 m; most of this glauconite was probably newly formed (especially the quantities deposited in the beginning of the period; later probably some redeposition), and the great quantities of silica required for this process were certainly supplied because of the fact that the weathered Archaean was mobilized. The glauconite grains have v-shaped dehydration cracks possibly caused by a high salinity of the water (cf. HESSLAND 1949 b, p. 45). High salinity (electrolytic effect) was probably also the reason for the settling of clay substances during the first stage of the transgression.

The fact that fine-particles diminished upwards in the section can be explained by the circumstance that smaller quantities were supplied or that the sediment was more effectively washed than earlier.

The very high content of phosphorus in this section is probably another consequence of the transgression. Phosphorus may have been enriched in the water of enclosed basins and then precipitated when these were ventilated during the transgression. The phosphorus fixed in this way was embedded in the sediment as diffuse impregnations and phosphoritic nodules. However, some enrichment of phosphoritic nodules may have occurred, especially during the later part of the period (170—167).

In the present case there is reason to suggest that areas with stagnant water could easily be formed. The water was shallow, and in the great movable sand masses stagnation areas could appear for longer or shorter periods. The fact that such basins really existed is possibly indicated in the section 173.58–170, where the sediment includes redeposited lumps of clay particles very likely derived from these basins.

The transgression seems to have continued also during the formation of the later part of the section (170–167). The high content of glauconite may indicate this development. Like parts of the phosphoritic nodules, glauconite may have been enriched, but the main cause of the high frequency may have been a large scale new formation. The silica required was obviously supplied as a result of the transgression, continuing so that further parts of the weathered Archaean could be attacked by erosion.

However, the transgression seems to have been moderate. Judging from the fact that the washing was effective throughout the stage, the water may have been shallow; the supply of sediment was apparently just sufficient to neutralize the subsidence. Washing should not have been so effective if the supply of sediments had been very abundant and the subsidence rapid. On the contrary, the supply of sediments and the velocity of subsidence (and consequently the transgression) may have been moderate.

Just in the upper part of the section the stagnation which distinguishes the first part of the following stage is possibly forecast by the fact that the sulphur curve begins to rise (additionally, the carbon curve ascends gently).

167.1–159.8 (clayey sediments).

167.1–165.9. The dark clayey sediment of this zone accumulated during stagnation: median diameter small (porosity very low), sorting mostly very poor, no heavy minerals, considerable carbon content, high sulphur content, low phosphorus content. Glauconite or other silicious precipitates are practically absent which indicates that water rich in silica was not supplied. This stagnation may have been caused by an enclosure of the area on account of regression or because sediments were accumulated in a blockading position. In the proceeding development there is nothing that suggests a decrease of the depth of water; the rising sulphur curve in the upper part of this section may only indicate that a blockade of the area was beginning. From the subsequent labile development there are signs neither of transgressions (probably with the exception of the level 165.5–164.5) nor of regressions until possibly towards the end of the period from which traces of transgression seem to occur. The enclosure thus may have been caused by blockading sediments.

165.9–159.8. This grey clayey stratum is a typical ventilated sediment in the zone 165.5–164.5 with current bedding, low sulphur content, slight temporary decrease of carbon, relatively large median diameter (at the levels 165.0 and 164.5), and progressively better sorting.

The absolute blockade of the area seems to have finished during the development of this zone. Between 165.5 and 165 m the sudden and very great invasion of young Globigerinidae occurred (cf. p. 83 f.). Their appearance as well as the presence of radiolarians from 164.5 m indicates that oceanic water streamed in. The occasional mighty increase of glauconite in the zone 165.5—165.0 possibly indicates that the inflow of oceanic water was caused by an occasional transgression with supply of silica from the weathering mantle.

In the zone 164.5—159.8 real evidences of transgression cannot be seen; the practical absence of glauconite (scattered grains observed in thin slides) may indicate that considerable changes of level did not occur during this period. Connection with the ocean continued to be established judging from the fact that radiolarians and foraminifera are included in the sediment. The rapid changes in the concentration of sulphur give indication of several intermittent breaks of the enclosure. Towards the end of the period (especially at the level 161) distinct signs of current and wave action were formed. The renewed transgression during the following period was possibly forecast now. Successively the blockading sediment masses may have been broken down so that the basin thus ceased to exist. Glauconite soon began to accumulate and this is a most characteristic component of the section deposited just after the clayey layer now discussed.

Just after the great invasion of foraminifera at the level 165.5—165.0 *Inoceramus lingua* appeared abundantly (164—163.5) indicating that this section is most likely referable to the upper or possibly the middle Santonian.

159.8—134.5 (mainly sand with a few consolidated strata).

The transgression seems to have expanded when this section was accumulated. Glauconite was laid down in rather great quantities already from the beginning, and great masses of quartz sand soon began to be deposited. After a rise in the very beginning the calcium carbonate curve decreases rapidly in the lower part of the section and continues to be low thereafter. This, of course, may simply not be referable to unfavourable ecological conditions for shell-bearing organisms, or to the fact that the intensity of calcium carbonate precipitation was small, but may be due to the great supply of minerogene particles.

The inundated parts of the weathered Archaean thus seem to have been powerfully eroded. Several reasons indicate that there were vivid movements in the water in this period: the median diameter increased at once and the sorting was better; the carbon and sulphur curves are mostly low; the content of heavy minerals is fairly considerable.

The phosphorus content, owing mainly to the presence of phosphoritic nodules and partly to coprolites, is high in the lower part but decreases upwards. Phosphorus, enriched in the water during the previous period of stagnation, seems to have been precipitated at the overturn to ventilation. Later, enrichment of phosphoritic grains may have occurred; coprolites were also formed (high content at 154 m).

The water seems to have been shallow, judging from the fact that fragments of lithothamniaceans and shells bored by algae were observed in thin slides from the lower part of this and the overlying section. There is scarcely reason to suggest that the depth of water was much different during the deposition of the intervening sand masses of which no slides were made. The fact that the formation of glauconite successively diminished during the later part of the period may be due to a diminished supply of silica, owing either to the fact that the weathered Archaean of this region began to be used up, or that the transgression ceased so that the still existing parts of the weathered rocks were beyond reach of the erosion. The development during the following period of accumulation indicates how these things were.

In the section now discussed *Actinocamax verus* is common, but it was not observed at higher levels. In accordance with that and with the fact that *Actinocamax mammillatus* and *A. quadratus* appear just above the section, it may be concluded that it is referable to the upper Santonian.

134.5—94.8 (mainly limestone and calcareous sandstone).

The development which began during the final phase of the preceding period graded into that discussed below.

The frequency of glauconite continued to diminish up to 123 m where it is practically lacking. Contemporaneously the content of quartz and heavy minerals descended to very low values whereas the content of calcium carbonate is very high.

The fact that the glauconite content is low in the whole section may indicate that the weathered Archaean had been eroded away for the most part. Since the supply of weathering debris particles thus probably diminished very much the water may have been clear. Possibly favoured by this and by lively water movements an abundant life of lime-encrusted organisms was developed. Their remains are especially numerous in the zone 130—123. However, remains of organisms diminished later, whereas calcareous ooze was settled in increasing quantities.

Bryozoans and calcareous algae as well as the other fossils are fragmentary. Fragments, especially of molluscan shells and bryozoans, and to a rather great extent also of calcareous algae, constitute the main part of the sediment in the zone 130—120. Fragments of calcareous algae are more numerous in the zone 120—115.

The limestone is probably chiefly allogene and may be regarded as a shell bed. It is conceivable that the fragments of bryozoans and calcareous algae originated from reefs where water movements certainly were vivid. In the necrotope, on the other hand, the water seems to have been less agitated, at least during earlier stages of the accumulation; later, water movements apparently increased. The carbon curve is proportionally high (to 122 m); the content of heavy minerals is low (to 123 m); the phosphorus curve is low (rises at 125 m); however, the sulphur curve is relatively high only in the beginning, but descends and is low from 127 m. Moreover, the sorting of the insoluble residue was not very good in the beginning but from 126.5 m it was progressively better up to 115 m, whereafter it was less good, however; the median diameter was relatively low to begin with but increased upwards.

The upwards increasing frequency of fragments of calcareous algae (max. 120—115) may indicate that the water grew shallower. The decrease of the depth seems to have continued also thereafter, judging from the fact that the frequency of shells bored by algae is considerably higher in the zone 115—110 than earlier. The presence of large quartz particles in the section 110—95 supports the suggestion that the depth still diminished; especially the high frequency of such particles at 101 m may have been brought about in shore position.

Great areas with intact weathering material do not seem to have occurred at that time, but smaller parts may have existed judging from the fact that some glauconite was probably still being formed. Parts of the quartz grains are, moreover, angular and may have derived from newly freed sediments. Others are rounded and may have been redeposited possibly several times.

94.8—65.3 (mainly sand).

With respect to the composition of the sediment this section is similar to the upper part of the preceding one. Especially below the 70 m level it is distinguished by great and dense changes with regard to size and sorting of the particles of the insoluble residue. The changes of the calcium carbonate content are also dense and great, and the frequency of heavy minerals fluctuates much. The sulphur curve is partly low but also shows some higher values. The phosphorus curve is proportionally high but varying; the phosphorus appears both as phosphoritic nodules and coprolites.

The sedimentation may have occurred in a shallow area with heavy changes in the movements of the water. The presence of lithothamniaceans and single bored shell fragments indicates that the water was shallow. These fossils may not be autogene but, on the other hand, they may not have been removed very much in vertical direction since this region may have been fairly flat at this time. The phosphoritic nodules are probably in part redeposited from other strata, but new formation of phosphorite may also have occurred in this sandy area where stagnant basins could easily appear in which phosphorus was enriched and later precipitated when the sand masses happened to be rearranged and ventilated water streamed in.

Vivid movements in the water with rearrangements of sediments may also have caused the formation of the thin strata with a higher content of calcium carbonate. In the present day such enrichments of calcareous substances can often be observed to be developed in shallow areas under such conditions.

The transgression and the supply of sediments seem to have continued mainly as in the later part of the previous period. Glauconite and phosphorite may partly have been newly formed and partly redeposited; quartz particles may have been carried there partly from remaining sections of the weathered Archaean and partly by accumulation of particles freed earlier.

Somewhat above the 70 m level the agitated development of the median diameter curve ceased and a long period with only small fluctuations in the course of this curve began.

65.3—28 (mainly calcareous ooze limestone and calcareous ooze sandstone, partly with flint).

As mentioned previously, calcareous ooze began to accumulate already in the zone 134—130, but during the following accumulation of fragmentary limestone only small quantities were deposited. Thereafter the precipitation increased, whereas the frequency of fragments decreased. In the section between 80—85 and 28 m calcareous ooze constitutes a great part of the sediment, especially in the division 65.3—43.1; pure calcareous ooze does not appear, however. Calcareous ooze is also included in the consolidated strata above 28 m.

The origin of calcareous ooze (both marine and lacustrine) has been much discussed, and different opinions have appeared. This question has been examined from a chemical point of view as well as on the basis of biological observations. Some students consider the precipitation as the result of purely abiogene processes, whilst others regard it as biogene, especially caused by bacterial action.

In their classical paper on *The rôle of inorganic agencies in the deposition of calcium carbonate* (1916), where this question was examined from chemical viewpoints, JOHNSTON and WILLIAMSON summarize (p. 739): "The abstraction of CO_2 from a saturated solution results ultimately, then, in the deposition of $CaCO_3$, no matter what the agency which abstracts the CO_2. This agency may be a diminished proportion of CO_2 in the air, or a higher temperature, or both; or it may be organisms which make use of the CO_2 in their vital processes, or the production by bacterial action of ammonia, which indirectly achieves the same result; or, in short, it may be any way in which the concentration of CO_2 may possibly be diminished. Consequently, if the surface layers of the sea are saturated, as we believe they are[1], precipitation of $CaCO_3$ will be brought about wherever any of the foregoing agencies are operative." They suggest, however, that the abundance of plant organisms in the localities where precipitation of $CaCO_3$ occurs is due to the presence of CO_2 which is freed in every preci-

[1] This was corroborated by WATTENBERG 1937.

pitation of calcium carbonate. "The physico-chemical factors are in themselves competent to account for the precipitation of $CaCO_3$ on a large scale —likewise for its re-solution" (p. 742).

A. HEIM (1924) has pointed out that recent calcareous sediments, such as at least part of the so-called *Globigerina* ooze, and a great many dense limestones mainly consist of calcareous precipitates. The precipitation is considered to be brought about when deep water with dissolved calcium carbonate streams upwards (decrease of pressure) or towards the tropics (increase of temperature). In those places, on the other hand, where the hydrostatic pressure is high and the temperature low calcareous substances can be dissolved; HEIM speaks of the calcium carbonate cycle. WATTENBERG (1937) has shown that such deep water dissolution takes place in the western half of the Atlantic Ocean (below 2000 m).

Calcareous ooze may be formed not only because of these physico-chemical processes but may also be precipitated mechanically. It has been shown experimentally by WATTENBERG and TIMMERMANN (1936) that calcium carbonate can be precipitated when supersaturated sea water is shaken with powdered calcium carbonate; the latter is considered to serve as nuclei for the precipitation.

Discussions on precipitation of calcium carbonate by means of bacteria actually began after the investigations of DREW on this subject had been published in 1911–1914. DREW thought that denitrifying bacteria have special ability of such precipitation. However, bacteriological investigations in the laboratory have proved that also other types of bacteria have the same ability (cf. below). Many students are of the opinion that bacterial precipitation does not occur in Nature, or that it only plays a subordinate rôle. However, in certain areas this process seems to be of some importance, for instance in parts of the Great Bahama Bank.

This bank has been investigated on several occasions. Especially the white calcareous silt (the so-called drewite) has been given much attention. It has been reported as being poor in bacteria (FIELD and collaborators 1931, p. 776), but in the calcareous mud of little agitated parts they occur in great numbers (BAVENDAMM 1932). The action of denitrifying bacteria has certainly contributed to the formation of the silt, and so may also be the case with the abundant ureabacteria, sulphate-reducing bacteria, and cellulose and hemicellulose destroying bacteria, as held by WAKSMAN and BAVENDAMM (in FIELD and collaborators 1931, p. 776; BAVENDAMM 1932; also cf. ZOBELL 1946). However, the precipitation may scarcely be exclusively biogene but also abiogene. The bank is bordered to the west by the deep Santaren Channel ($>$ 400 fathoms), from where water can ascend to the bank which is covered with only a few fathoms of water. Then calcium carbonate may be precipitated because of the diminished pressure and the increased temperature, in accordance with the above-mentioned postulates of HEIM.

The Bahama and Bermuda Banks consist not only of calcareous silt but also of other sediments, as appears, inter alia, from the descriptions by BIGELOW (1905) and THORP (1936). However, calcareous silt is often included in these sediments; thus, shell sand is in every case admixed with a considerable quantity, according to BIGELOW. He thought that the silt results from mechanical destruction of submarine limestone rocks by means of water (op. cit. p. 582). As just mentioned, the silt may not be formed in this way. On the other hand, calcareous silt particles are, in fact, in many cases brought about by mechanical destruction of shells and other biogene calcareous substances; such silt constitutes, for instance, a fairly considerable part of some Quaternary shell beds in Bohuslän, W. Sweden; especially if the main substance of the bed consists of *Corallina* debris.

Considering now the Kristianstad area and the section of the Åhus drill core under discussion, the calcareous ooze can have been formed in one or more of the following ways: physico-chemical precipitation; precipitation as a result of bacterial or other phytal action; or mechanical destruction of calcareous substances.

The last-mentioned alternative will be discussed first. The first premise to be fulfilled in this case is that there were calcareous deposits present which could be destructed. The main formations which can be thought of in the Kristianstad area are shell beds. But shell beds are generally submarine accumulations which have to be raised to the sea level to be destroyed mechanically. However, the changes of level during the period now discussed were transgressive so that the shell beds were even more subsided and thus brought beyond the reach of the disintegrating mechanical forces. But, as mentioned above, it is true that the material of shell beds can be worn during the very accumulation so that a fine calcareous silt is developed. However, larger quantities are not formed in this way, and they are, moreover, generally included in the shell beds, but in the Kristianstad area very great quantities of ooze were accumulated in open areas far from shell beds. Thus, mechanical destruction is scarcely responsible for the formation of the calcareous silt in this area, or it may only have played a subordinate rôle.

Secondly, we shall consider the possibility that physico-chemical processes have caused the precipitation of the calcareous ooze. In that case the question is whether water from greater depths (i.e. water under a high hydrostatic pressure and with low temperature) ascended to the shallow Kristianstad area so that calcium carbonate dissolved in this water was precipitated on account of diminished hydrostatic pressure and increased temperature. The area was certainly in communication with the ocean during the deposition of the calcareous ooze, but it was situated in a remote corner, and the precipitation most likely occurred before the oceanic water had reached the Kristianstad area; I suppose that the precipitates constitute part of the contemporary Senonian writing chalk situated to the south and west outside the Kristianstad area.

Now it remains to consider whether bacterial and/or other phytal processes have caused the precipitation. There are reasons favouring the idea that the action of decomposing bacteria was vivid: organisms of different kinds were abundant in the area and the great quantities of dead organic substances had to be dissolved. Among these bacteria denitrifying types must have been very abundant, and they were probably responsible for a great part of the calcium carbonate precipitation. Also the process of carbon dioxide assimilation by algae may have caused precipitation.

As a matter of fact, the content of calcium carbonate in the water must have been successively renewed as the precipitation continued. A certain amount may have been supplied with inflowing water from the ocean, but the main part most probably came from sources within the area. Many such sources existed there, viz. shell beds and other calcareous layers. There were also solvents present: acidic products formed during decomposition, above all carbonic acid (CO_2 also produced by the respiration of animals and plants).

From the above considerations it appears that the precipitation of calcareous ooze within the Kristianstad area may have been brought about mainly by bacterial and other phytal action and, to a less extent, in a mechanical way.

It is an interesting fact that the course of the carbon curve is very similar to the frequency of the calcareous ooze. The carbon curve forms a broad maximum in the zone 61—49 where calcareous ooze is especially abundant. To a great extent the carbon may be derived from those organisms supposed to have caused the lime precipitation (concerning the composition of such organisms, cf. ZoBELL 1946, p. 145). Carbonaceous matter seems to be characteristic of the calcareous ooze of the Great Bahama Bank (FIELD and collaborators 1931, p. 777).

In addition to the abundance of calcareous ooze and the relatively high carbon content the section now discussed is distinguished by a great uniformity with regard to the median diameter of the insoluble residue. The sorting is not so uniform, however; mostly it is rather good, but in parts of the zone with the greatest frequency of calcareous ooze it is poor.

Two further features are characteristic: glauconite was deposited in the beginning but the accumulation ceased at a depth of about 54 m whereas flint was formed around this level.

Part of the glauconite may have been redeposited from earlier strata, but part may have been newly formed. The fact that glauconite accumulated continuously for some time, though in decreasing quantities, possibly indicates that remains of the weathered Archaean surface were still accessible to marine action offering silica for the formation of glauconite.

It is of great interest that flint was formed just as the accumulation of glauconite ceased.

The genesis of flint has been much discussed. Generally three possibilities are considered: it is formed of silica derived from silicious skeletons of organisms; or the silica is directly supplied to the water from some inorganic source; or the flint is a metasomatic product.

Formation of flint and allied rocks according to the first theory has certainly occurred on a large scale but may have been of less importance than the second one in the Kristianstad area. I think that the silica in this case was directly supplied from inorganic sources for the most part. It may have flocculated primarily from the sea water, but silicic acid may also have substituted calcareous substances in accordance with the formula on p. 63.

With regard to inorganic sources of silica it has been thought to have been supplied by rivers or by submarine volcanic exhalations. However, supply by rivers generally seems to be too small to be of any importance for formation of flint (cf. CORRENS 1924, p. 30 and 1939, p. 217), and supply by volcanic exhalations may occur only in exceptional cases and there is no reason to consider this possibility with regard to the Kristianstad area. Here was another source of silica, viz. the weathered Archaean surface. The silica both of the glauconite and the flint may have originated from this one.

Considering the conditions of precipitation it has appeared that the concentration of the supplied silica is of great importance; CORRENS (1924, p. 31) has shown (in supplying alkali silicate) that flocculation occurs at higher concentrations. With regard to the fact that the sea water must have received much silica during the erosion of the weathering mantle in the Kristianstad area, an abundant precipitation may have been brought about off the shore. But iron was also yielded from the weathered Archaean, and since hydrous iron oxide is a hydrophobic colloid and thus only little transportable it may have remained near the shore, where, under appropriate redox potential conditions, it probably formed glauconite together with the newly released silica.

However, since silica is usually hydrophylic and therefore readily transportable, part of it may have been carried from the shore, and, in absence of greater quantities of iron compounds and under special pH conditions, probably precipitated as more or less pure silica colloids which were later dehydrated and transformed into flint. Within the pH limits of 5—9 SiO_2-sols are stated to be rather easily soluble (CORRENS 1939, p. 129), and experiments have shown that dilute sols do not flocculate when added to sea water (the pH somewhat higher than 8), but an optimum of flocculation is stated to appear at pH-values of 10—11 (CORRENS 1924, p. 29).

In the Kristianstad area not only great quantities of silica may have been supplied, as mentioned above, but there may also have been good possibilities for high pH-values to appear locally during the formation of the calcareous ooze. Very likely ammonia was produced in this process (cf. p. 96), and it may have been locally concentrated in periods of tranquility (cf. the curves: carbon content high, sorting poor, practically no heavy minerals).

Replacement of calcareous substances by means of silicic acid as suggested above (p. 63 and 97), which may be observed at several levels within this division of the core, may have been readily brought about in these little agitated surroundings where silica could remain and where calcareous substances, moreover, to a great deal were present in an easily attackable state.

The water may not only have been tranquil to a great extent but also shallow judging from the fact that lithothamniaceans and shells bored by algae are rather common.

The strata above the 43 m level seem to have been deposited under somewhat changed conditions. Mineral particles with practically the same median diameter as earlier were accumulated but sorting had become much better and the content of heavy minerals had increased. Calcareous ooze was laid down on a smaller scale than previously. Moreover, the changes in the proportions of calcium carbonate and mineral particles are dense and large. These facts indicate a lively agitation of the water.

The section now discussed (65.3—28) is referable to the Mucronata Chalk.

28—the upper limit of the Cretaceous (sand and thin layers of hard calcareous sandstone).

During this period mainly sand was deposited with intercalating thin layers rich in calcium carbonate. The frequency of calcareous ooze had diminished very much but that of shells, these to a great extent very thin and fragile, had increased. Many of the shells had obviously been washed out from fine-sediment biotopes (cf. p. 61).

Secondarily the thin calcareous layers have been hardened by recrystallisation and part of the quartz particles have received a wrapping of silica (the latter fact has scarcely affected the main course of the granulometric curves).

The movements of the water were obviously lively as indicated by low sulphur and carbon values, and by the insoluble residue which is distinguished by a large median diameter and mostly relatively good sorting.

Comprehensive redeposition may have occurred during this period judging from many dense and distinct changes with regard to size and sorting of the insoluble residue, and from the occurrence of several thin strata of enriched calcareous substances (cf. p. 92—93). The sand masses, especially above the 20 m level, give the impression of having accumulated rapidly. The water was certainly shallow as indicated by the presence of lithothamniaceans and shells bored by algae. The ecological conditions for animal life seem to have deteriorated above the 20 m level judging from the fact that the great quantities of molluscan shells which occur in the sand (mainly oysters) are of young specimens.

The development during this period may scarcely have been a regression; no decrease of the depth can be ascertained. The sedimentation simply seems to have ceased when the epeirogenetic subsidence, which had continued during the accumulation of the whole Åhus Series, now finally finished.

14. Summary.

The Åhus Series is indicated to have accumulated in shallow water in a gradually subsiding area. The velocity of subsidence seems to have been somewhat varying during the earlier part of the sedimentation. The accumulation simply may have ceased when the subsidence of the area finally finished.

The Cretaceous stratal sequence at the place of the boring is about 177 m. Its lowermost part seems to be referable to the Emscher or the lower Santonian (Granulatus Chalk). The middle Santonian is possibly also represented. The presence of the upper Santonian as well as the lower and upper Campanian (Mammillatus and Mucronata Chalks) is established. The uppermost part of the stratal sequence (the Åhus Sandstone) seems to be referable to the Maastrichtian.

The inundated region was deeply kaolinized and the minerogene phase of the Åhus Series most likely consists of particles freed from the weathering mantle and of products which include silica derived from it.

The lowermost part of the stratal sequence consists of feldspar-bearing sand, including a few layers containing redeposited kaolin. The sand layer was certainly rapidly accumulated, washed out from the deeply weathered Archaean which is a coarsely crystalline granitic gneiss. This accumulation was finished with the development of a conglomerate and an overlying layer of well rounded particles with a low content of feldspar in the lower part and practically without feldspar in the upper. Thereafter clayey sediments were settled obviously in a newly formed basin. In the beginning it seems to have been effectively separated from the ocean but later connection was intermittingly re-established. After the development of the conglomerate very great quantities of glauconite were accumulated, viz. in the poorly feldspar-bearing sand and at one level in the lower part of the clayey stratum.

The first macro-fossils occur in the conglomerate and great quantities of pelagic micro-fossils appeared suddenly at the same time as the glauconitic horizon in the clayey section was laid down.

The final break of the isolation of the basin was possibly caused by an intensified subsidence of the earth's crust. During the subsequent period great quantities of quartz sand and glauconite were deposited. But, gradually the biogene sedimentation became predominant and a

limestone was formed (maximally 96 % $CaCO_3$). The biogene components consist mainly of bryozoans, molluscs, and lithothamniaceans. However, the sedimentation soon was agitated with sharp changes between layers of quartz sand and calcareous sandstone. Calcareous ooze had begun to be settled prior to this development and now successively it took considerable proportions, especially in the section 65—43 m (upper Campanian). In this case it may chiefly be regarded as a result of the vital action by decomposition organisms, inter alia denitrifying bacteria. At this time the continuous deposition of glauconite ceased and, instead, flint was formed.

During the later part of the accumulation (above about 28 m) comprehensive redeposition seems to have occurred, and shells, in part washed out from fine-sediment biotopes, were gathered in thin layers which later were hardened by recrystallisation. These hard layers rich in thin and fragile shell fragments have to be referred to the so-called Åhus Sandstone.

This brief account of the interpretation of the genesis of the Åhus Series is based on analyses of components elucidative of the palæohydrology and the sedimentation. They comprise the whole stratal column and include both the minerogene and the biogene sedimentary phase. The residue insoluble in acetic acid was examined granulometrically; on the basis of cumulative curves the median diameter and sorting were calculated. The contents of heavy minerals and glauconite were established separately. Moreover, the frequency of the following components was investigated: calcium carbonate, carbon, phosphorus, sulphur, and iron. The sulphur and carbon curves are well-known indicators of the agitation of the water. Hydrocarbon films coating quartz grains give part of the sand a greyish hue. A certain relation between the content of calcareous ooze and carbon can be discerned, and this is possibly due to the fact that the carbon just derived from the organisms (probably mainly bacteria) which may have been responsible for the main precipitation of the calcareous ooze. Phosphorus seems to have been precipitated when stagnant water rich in phosphorus was mixed with inflowing ventilated water (parts of the phosphorus curve also reproduce to a great extent the enrichment of phosphoritic nodules and the presence of phosphatized coprolites). The composition of the sediment was, moreover, studied in series of thin slides where, inter alia, the presence of organisms indicating the depth of the water was observed, viz. calcareous and penetrating algae. Macro-fossils were determined to constitute the base for a dating.

Much importance was attached to the vertical distribution of glauconite in the sequence of strata (the frequency established with a dielectric method of separation). As the silica and also the iron necessary for the formation of the glauconite may be derived from the weathered Archaean surface, an abundant formation of glauconite may in this case indicate transgressive movements, provided that other conditions for formation of glauconite were present (above all a rich supply of potassium, a marine milieu, and appropriate redox potential conditions; from this and especially another still unpublished investigation by the author it seems to appear that concretionary glauconite [which is the type in point here] was formed at the overturn from stagnation into ventilation).

Furthermore, the certainly important rôle in formation of flint played by decomposing bacteria was considered. By their action inter alia ammonia was produced which may have caused such high local pH-values that colloidal silica supplied in great quantities from the weathering mantle was flocculated. These bacteria may also have been instrumental in the flint formation in another indirect way, inasmuch as they very likely contributed to the precipitation of calcareous ooze. As a matter of fact, this state of $CaCO_3$ must have been very suitable in the process of replacement of this substance by SiO_2, which seems to have occurred to a great extent in the present case.

15. Acknowledgements.

The boring began in August 1947 and was finished in August 1948 after a pause during the winter months. The work has thus taken an exceptionally long time. This was due to the technical difficulties connected with a core drilling in this formation which includes both weakly consolidated and unconsolidated sediments.

The boring was made by the Svenska Diamantbergborrningsaktiebolaget; and Statens Naturvetenskapliga Forskningsråd (the Swedish Natural Science Research Council) paid the costs. The Council also contributed to the wages to assistants in the laboratory work.

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Institute of Palæontology, Uppsala University, July 1949.

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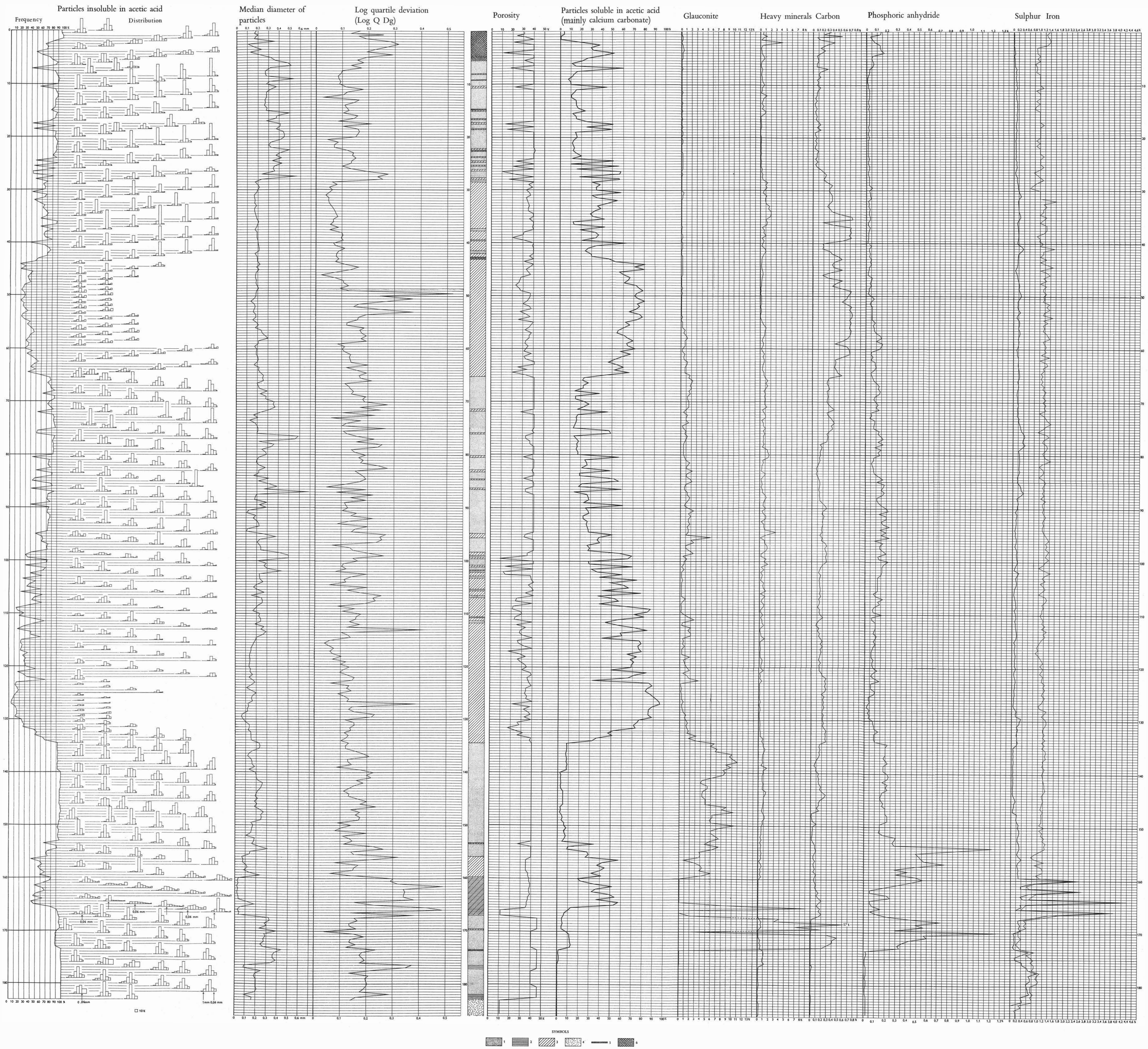
17. Explanation of plate.

Stratal sequence and distribution of components according to heads in the plate. Symbols:

1. Unconsolidated section (calciferous quartz sand).
2. Clayey sediment section.
3. Consolidated section.
4. Archaean.
5. Conglomerate.
6. Quaternary.


Particles insoluble in acetic acid
Frequency
Distribution
Median diameter of particles
Log quartile deviation (Log Q Dg)
Porosity
Particles soluble in acetic acid (mainly calcium carbonate)
Glauconite
Heavy minerals
Carbon
Phosphoric anhydride
Sulphur
Iron
SYMBOLS