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THE PRE-QUATERNARY SEDIMENTARY ROCKS OF SWEDEN

BY

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V.

ON THE ORGANIC REMAINS OF THE LIMESTONES

A SHORT REVIEW OF THE LIMESTONE FORMING ORGANISMS

WITH 53 FIGURES IN TEXT

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Preface.

A highly varying formation is characteristic of all groups of sedimentary rocks. In the relatively pure detritus rocks the variations appear essentially in their occurrence, stratification, and magnitude of grains. Variations in chemical or mineralogical composition are also seen but may generally be ascribed to conditions without direct influence on the deposition of the sediments: to the mechanical assortment of detritus during transport. Secondary changes in the deposited sediments are very common but they give us no or only slight guidance in the estimation of the origin of the rocks. The changes in composition and mineral content originating in a diverse weathering of the detritus-yielding rocks are no doubt able to inform us of the climatic conditions prevalent on the formation of the detritus but as a rule they tell us nothing of the conditions controlling the deposition of the material.

Consequently, the variations seen in the sedimentary rocks have arisen in all the periods of the material's development, during the very deposition as well as the time before and after it. Independent of their nature, all these variations must of course be the object of our investigation, and it should also be important for us to establish to which group they belong. Not least interesting are those dependent on and illustrative to the milieu in which the rock was formed. As mentioned above, the latter are principally noticeable in the pure detritus rocks by the size of their grains, the stratification, and the occurrence of the rock. The more autigenic material, organic or inorganic, the sedimentary rock contains, the more noticeable other conditions originating from the milieu of formation will be. We only need to remember the saline sediments, the highly ferruginous sediments, or the autigenic coal sediments. The greatest variations, however, are no doubt found in the calcareous sediments. Among them there are not only forms, which are transitions to the pure detritus rocks by their high content of detritus, but also rocks to an essential extent formed by inorganic precipitation or built up by lime precipitating animals or plants. It will sometimes be found that a number of these different rock-building factors have cooperated in the formation of a sedimentary bed.

On going to make an investigation of the calcareous sediments of Sweden, the author has found it necessary first to begin with a survey of the exceedingly rich material and at the same time to make a preliminary classification of it, without which it is hardly manageable. The preliminary investigation for this purpose has int. al. been intended to determine in what degree the above-mentioned factors — inorganic precipitation, organic formation of limestones, and deposition of detritus — have contributed in building up the calcareous sediments. In the following the organic formation of limestones and its significance for the Swedish series of strata will be illustrated.

The fossils play quite a different and more important part in the limestones than in the sediments discussed before by the author, and attention may therefore be called to the fact that their petrographic significance does not coincide with their stratigraphic one, and that they interest us differently from a geological than from a biological point of view. We must understand this distinction in order not to be drowned in statements lying outside the scope of this investigation.

The introductory survey of the stratigraphic, petrographic, geologic, and biologic importance of the fossils published below contains several facts obvious to the specialists but nevertheless worthy of mention, as experience has taught us that they have often been overlooked by specialists also. In that survey the author has principally intended to state his position towards the question: What facts concerning the fossils are important for the sediment-petrography, and which of them are through this of a universal geological interest?

From a stratigraphic point of view the fossils are in the first place documents of time. The possibility to identify the species present in a series of strata and the knowledge of their vertical distribution enable us to determine the age of the series. Stratigraphically most interesting are fossils of fairly general occurrence, which show a strictly limited and well defined vertical distribution, are easily identified, and besides that distinctly separate from related species with another distribution.

The fossils interest the sediment-petrographer partly as far as they are rock forming, and partly as far as they inform him of the environmental conditions under which the rock was formed. If two kinds of rock are characterized by similar animal forms developed under the same environmental conditions, it is petrographically of minor importance whether these forms belong to the same or different periods. Consequently the stratigrafic significance of the fossils does not coincide with their petrographic one.

From a general geological and paleogeographic point of view it is of a more comprehensive interest, we may say, both stratigraphically and petrographically. Their importance as documents of time is combined with their importance as documents of milieu.

The different significance of the fossils to the biologist and the geologist might be summed up in a few words: it is of the same kind as the biologic resp. geologic significance of the modern animals and plants. It is only the fact that the majority of the properties most important to the biologist have been lost in the fossilification, which has caused a vigourous shifting in the degree of biologic resp. geologic interest between the recent and the fossil flora and fauna.

The better preserved a fossil is, the greater its biological value; the more far-reaching the conclusions that can be drawn as to its histologic and anatomic properties, the better from a biologic point of view. Instead of the few, though distinct characteristics and the occurrence sharply limited in time, which are so important to the stratigrapher, the biologist aims at the completest possible picture of the peculiarities, which show the affinities and development of the fossil organisms.

It is of interest both to the biologist and the sediment-petrographer to establish the environmental conditions under which the fossil organisms lived. The biologist is then chiefly confined to comparisons with modern forms, whereas the geologist is often guided in his judgment by his study of the fossiliferous rocks. The geologist is particularly interested in the environmental character of the population, not of the single species.

The splitting of the paleontology into two separate spheres of interest — the biologic and the geologic — grows more evident according as research goes deeper in these sciences. This should be received with satisfaction by biologists as well as geologists, partly because the biologists will devote themselves more and more to the investigation of the fossil fauna and flora and by this means seek a more general contact with geology, partly because the geologically orientated paleontologists will have better opportunities to attend to problems of geological interest: stratigraphic, sediment-petrographic, and paleogeographic.

Knowledge of fossils is necessary to the stratigrapher as well as to the sediment-petrographer but the mere description of fossils has to such a large extent fallen to the lot of the geologists only because the fossils are generally not so preserved that they have caught the interest of the biologists. This is specially the case in the fossils of the greatest stratigraphic and petrographic interest, i. e. the invertebrates. They will no doubt, however, be more and more subjected to investigations of biological trend.

V.

ON THE ORGANIC REMAINS OF THE LIMESTONES

A SHORT REVIEW OF THE LIMESTONE FORMING ORGANISMS

CONTENTS.

Limestones are produced by the activities of organisms in two ways: — the organisms either deposit calcium carbonate in their own structures; or they cause, for inst. by means of extraction of carbon dioxide, a precipitation of calcium carbonate from saturated solutions. The former mode of formation is seen in nearly all limestones, while the latter is less obvious, though it has no doubt played and still plays a very important rôle.

In the following survey of the limestone-producing forms of plants and animals the author does not aim at the completest possible list of species and genera but will instead try to show the importance of the larger groups as rock formers or as environmental documents. As they are highly varying in the said respect, they will of course also be the object of a more or less detailed account here.

Plants as Limestone Formers.

We know many examples also of higher plants occurring as lime formers but their deposition of calcium carbonate is never of rock-forming importance. As a rule the calcium carbonate will in such cases be precipitated as a consequence of the plant's assimilation of carbon dioxide, more seldom it will be formed through a transformation of the organic calcium compounds previously formed in the plant (Pia 1926, 177). We have no reason to dwell here on the lime forming activity of these plants, which furthermore is not definitely demonstrable in the fossil series of strata. The more reason we have, on the contrary, to discuss here the development of limestones through certain lower plants, i. e. through bacteria and algae of various kinds.

Influence of Bacteria on Deposition of Calcium Carbonate.

A great part of the recent calcareous mud is supposed to have been formed under the influence of bacterial activities, and we are certainly not mistaken in supposing that the fossil limestones also to a large extent developed in a similar manner. As to the older calcareous sediments it is impossible to show directly in each special case that the precipitation of calcium carbonate is a result of bacterial activities, and not of purely inorganic chemical processes, and even in the recent deposits it is often very difficult.[1] Besides that the calcareous mud is generally not homogeneously formed, it can contain carbonate of inorganic origin, for inst. crystals of aragonite or calcite, as well as carbonate resulting from bacterial action, in addition to which there is always a varying amount of calcareous mud formed through destruction of shells, coral stocks or other calcareous fragments of organic origin. In the fossil limestones we find as a rule conditions indicating such a polygenetic origin of the rock, and in the recent ones this may be regarded as directly established (FIELD 1932, 487).

As the limestones deposited by bacterial action as well as those formed by inorganic precipitation are dense, it will, in case of fossil rocks at least, be appropriate to discuss them in one connection without consideration of the degree of organic influence on the formation. Concerning these rocks the author refers to a following part of this work; he will only give a short summary here on the significance of bacteria as limestone formers.

A number of lime-forming bacteria are known but especially one of them, *Pseudomonas (Bacterium) calcis* DREW, is considered to play a more important rôle in the formation of recent marine calcareous mud. This bacterium has the form of a somewhat flattened sphere with a tail-like appendage, which keeps the cell in brisk motion. As the diameter of the sphere is only 1—3 μ, the bacteria are kept suspended in the water until for some reason they have clumped together. The most usual cause of the sedimentation would be that the bacteria collect around small detritus grains and sink with them to the bottom.

The bacteria precipitating calcium carbonate belong to the ammonifying or denitrifying ones. Different kinds are known (PIA 1926, 34) but much remains to find out concerning their activity. It is known, however, that the ammonia or ammonia hydrate produced precipitates calcium carbonate from the calcium bicarbonate and calcium sulphate present in solution in sea-water.

$$CaH_2(CO_3)_2 + 2NH_4OH = CaCO_3 + (NH_4)_2CO_3 + 2H_2O$$
$$(NH_4)_2CO_3 + CaSO_4 = CaCO_3 + (NH_4)_2SO_4.$$

The calcium precipitating bacteria are mainly found in the seas of the warm zones. DREW (1914, 37) found that *B. calcis* grows slowly at 15° C. and not at all at 10° C. From this follows that the bacterium is most abundantly present in the upper waters and never in larger numbers at great depths. Around Tortugas DREW (1914, 36) found about 14.000 colonies per cubic centimeter from the surface to a depth of 500 meters but only 12 colonies in the same volume at 600 meters. The temperature measured at the same time was 15° C. at a depth of

[1] The author is not convinced of a dominating influence of bacteria on the formation of calcareous mud. The investigations at the Carnegie Institution and Scripps Institution in the Tortugas (cf. GEE 1931, 12 and MOBERG 1931, 11) as well as those of BAVENDAMM (1932) are of vital importance for the solving of this problem.

500 meters and 11° C. at 600 meters. The fall in temperature is accompanied by a decrease in the salinity of the water. In the samples rich in calcium bacteria the salinity was not below 36 ‰.

In regions where the calcium bacteria are abundantly present a fine, soft calcareous mud is deposited. Drew (1914, 42) has found 160.000.000 calcium bacteria per cubic centimeter in preparations of such calcareous mud from the Bahama bank. Consequently, the significance of the calcium bacteria must not be overlooked. As said before, it has no doubt been considerable also in older times, specially on the formation of several dense limestones. That the calcium bacteria of the present times are principally confined to the tropical seas is of course a fact worth notice on estimating the fossil calcareous mudstones.

From observations at different places one has come to the conclusion that the number of phyto-plankton in sea-water stands in a certain relation to its content of denitrifying bacteria, i. e. that an increase in bacteria involves a decrease in plankton. Brandt (1904) has given the following explanation: — The plankton lives essentially on nitrates dissolved in the sea-water. According as the nitrates are decomposed by denitrifying bacteria the favourable conditions for the phyto-plankton diminish. The growth of the bacteria is exceedingly more rapid in tropical than in temperate or cold waters, whereas the latter are considerably richer in phyto-plankton. The zoo-plankton being dependent on the phyto-plankton, its source of subsistence, it diminishes or disappears in places where the denitrifying bacteria have become predominant. As the plankton serves directly or indirectly as food for the higher animal life also, it may be expected that formations originating from abundantly occurring denitrifying bacteria, for inst. *B. calcis,* will be relatively poor in animal remains. This is confirmed by the records from recent deposits (cf. Drew 1914, 33—34). On the other hand it must be mentioned that the said circumstances are doubted by some scientists, and that they must by no means be considered as sufficiently investigated (cf. Pia 1926, 35).

Among the fossil sediments in Sweden the chalk may in a higher degree than any of the others be formed by the agency of calcium bacteria or by inorganic precipitation. The fine-grainedness, looseness, and poorness in animal fossils are the same as in the recent calcareous mud. Microscopically the white chalk (sample from Kvarnby) proves to consist mainly of small, rounded grains of calcite, often 1—3 μ in diameter.[1] Considering the exceedingly slight diagenetic transformation of the chalk — we only need to call attention to the often complete absence of cement — we may suppose that the above-mentioned grains of calcite are a primary formation, or that they represent primarily formed units, grains which have by an early diagenesis been converted into crystals of the said size.

[1] Most abundant among the microscopic fossils are the coccoliths (see p. 29), among the macroscopic, sponges.

Algae as Limestone Formers.

Precipitation of calcium carbonate by the activities of certain algae results from their extraction of carbon dioxide from the water. The decrease of carbon dioxide in the water also diminishes its power of dissolving calcium carbonate, and an excess of this salt must therefore be precipitated from a previously saturated solution. The rôle of the algae as limestone formers consequently is that they provide the conditions favourable for an inorganic precipitation. In so far a correspondence exists between the bacterial and the algal activities.

Fig. 1. Algal limestone. Calcareous sinter formed by blue-green algae around grains of gravel and small stones. Recent. Fluvial. Vitabäck, Scania. (Pl. 656.) — 1/1.

As in the case of bacteria, the precipitation of calcium carbonate through algae can take place outside and quite independent of these organisms' own structure. In certain algae, however, it can also take place inside or on the surface of the cellular structure. In such cases certain structural features of the organism can of course be preserved.

Among algae playing an important rôle as rock formers by their lime precipitating activity members of widely differing groups are found. Limestone formers are known among the blue-green algae, *the Cyanophyceae*, among the flagellate unicellular algae, *the Coccolithophoridae*, as well as among the multicellular green and red algae, *the Chlorophyceae* and *Rhodophyceae*. The author will illustrate the occurrence of the different types in the Swedish sediments by a few chosen examples in the following.

Cyanophyceae (Schizophyceae).

The study of recent formations has shown that the blue-green algae can precipitate calcium carbonate around the algal filaments and in this manner give rise to beds or crusts of limestone. The author has had the opportunity to study a typical formation of this kind at Vitebäck in Scania.[1] Grains of gravel and small stones in

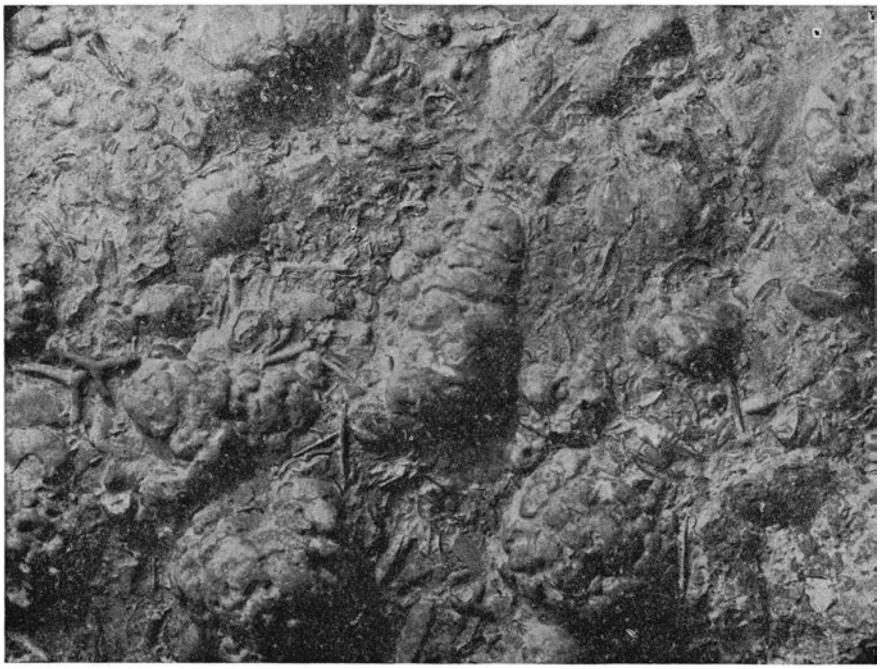

Fig. 2. Sphaerocodium limestone with *Sph. gotlandicum* in a fragment-limestone of crinoids bryozoans, brachiopods, lamellibranchs, ostracods, and trilobites. Eke group. Ronehamn, Gotland. (Pl. 684.) — $^1/_1$.

the fairly swift torrent are covered by algae, which deposit a rhythmically growing calcite crust around the nucleus (fig. 1). In thin sections the algal filaments are distinctly visible, and the radiate, partly concentric structure of the limestone is preserved in places. The study of these sinter formations, however, has also shown that the limestone has not exclusively been deposited around algal filaments: some parts of it are quite different in structure, indicating a different mode of formation. Commonest are dense masses pervaded by irregular algal filaments. These

[1] The interesting occurrence of calcareous sinter at Vitebäck, north of the station of Eriksdal, has not been the object of systematic investigation. K. A. Grönwall called the author's attention to it.

masses were probably formed by chemically inorganic precipitation of calcium carbonate, under bacterial influence, perhaps in the manner mentioned above. Similar depositions of lime have probably been the basis of the suppositions pronounced by several investigators that bacteria and algae often occur in symbiosis during the formation of limestone.[1] Many different kinds of blue-green algae have no doubt also contributed.

Among the fossil sediments in Sweden we find a number of limestones with larger or smaller portions formed by the activity of blue-green algae. Best known

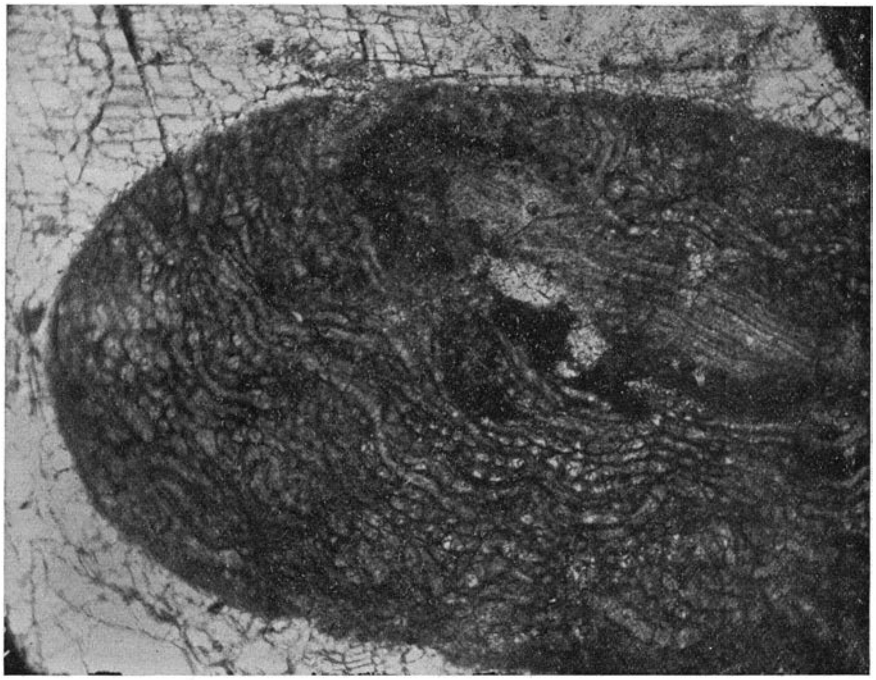

Fig. 3. *Girvanella.* Fragment with typical structure. Möllebos, Gotland. (Pl. 667.) — 60×.

are no doubt the rounded but otherwise irregulary formed grains and pebbles termed *Girvanella* or *Sphaerocodium* (fig. 2—5). They are specially abundant in the Silurian of Scania and Gotland, in some places rock-forming, for inst. at Bjersjölagård in Scania and in the Eke marlstone as well as the Hamra limestone in Gotland.

A closer estimation of the systematic position and mutual relation of the different algal forms is often very uncertain, as the structural features desirable for the estimations have not, or only imperfectly, been preserved by the incrusta-

[1] The author has observed rounded grains of calcium carbonate enclosed in the structureless parts of the limestone, in some cases with radiate structure, in other cases built up of a few crystals of calcite. The grains have always a dense nucleus. They are 0.1—0.3 mm in diameter.

tion of calcium carbonate. When Rothpletz in 1891 made up the genus *Sphaerocodium* of forms belonging to the Alpine Triassic he considered it to belong to *Chlorophyceae*. In his description of the Gotlandic forms (1908) he still maintained this opinion, although Seward (1895) had shown the slight value of the stated generic character. The main point for Rothpletz, however, was that *Girvanella* and *Sphaerocodium* are two different genera (R. 1908, 4), although, as he himself points out (1908, 5) they are quite similar in structure (»Grundgewebe»). By the study of a number of preparations of *Sphaerocodium* from Scania and Gotland the author has had the opportunity of observing the existent variations of struc-

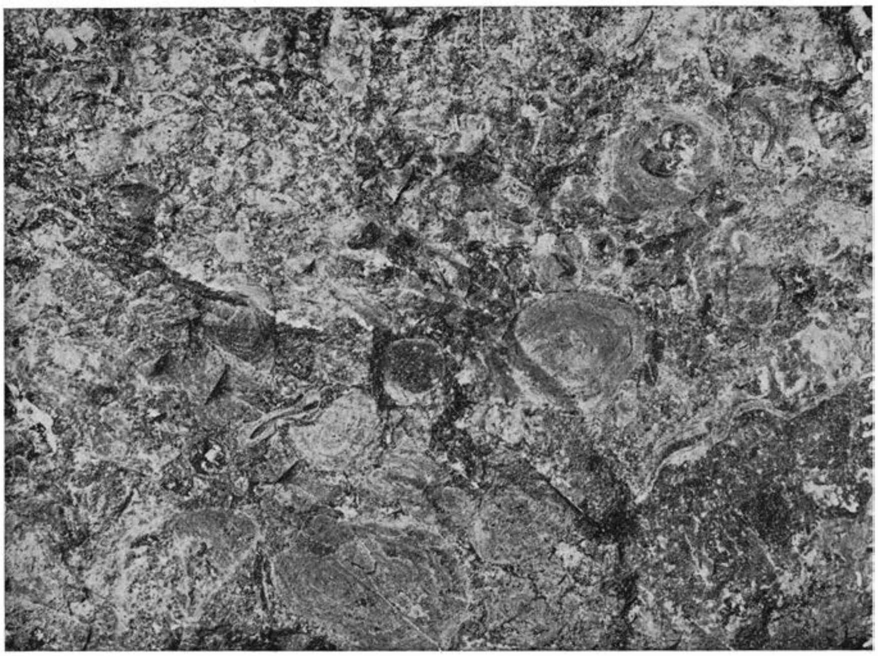

Fig. 4. Sphaerocodium limestone. Bjersjölagård, Scania. (Pl. 652.) — 1/1.

ture, and he could not avoid the reflection that the algal lumps are seldom homogeneously built up. Two or more algal forms have often contributed to the formation of a calcareous ball, and also other organisms seem to have been responsible for the formation of the fossil as well as the recent balls. In consideration of this compound structure the author thinks it fairly absurd to attach particular importance to the specific names of the rounded masses; but from a pure paleobotanical point of view it would be interesting to find out the different forms that have contributed to the formation of the balls. In the material to the author's disposition it has also proved impossible to determine some pebbles as belonging to the genus *Girvanella* and others to *Sphaerocodium*. The uncertainty in the existent generic features is obvious and besides that evident from the statement of ROTHPLETZ (1908, 5) that the Girvanella lumps »aus einem regellosem Gemenge der verschiedenartigsten Algen zusammengesetzt sind», and from the opinion pronounced later by PIA (1926, 52) that »die Sphaerocodien nichts anderes als Verwachsungen mehrerer verschiedenen Arten von *Girvanella* sind».

PIA (1931, 3) also regards the fossil calcareous masses described under the term *Spongiostroma* as algal formations. ROTHPLETZ and other investigators have interpreted these formations as Hydrozoa but their occurrence as well as their

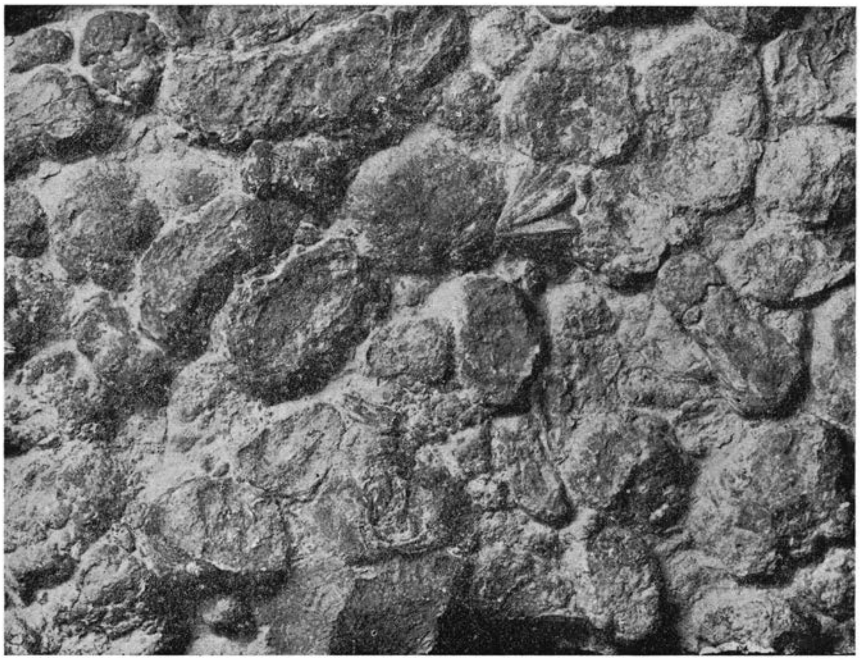

Fig. 5. Sphaerocodium limestone. Weathered bedding plane. Bjersjölagård, Scania. (Pl. 634.) — $^1/_1$.

microscopical features speak more in favour of than against the opinion pronounced by PIA. Spongiostroma limestone is found at different places in the Silurian series of Gotland; it is well developed for inst. at Visby in the Tofta limestone.

On the formations termed *Collenia* and *Cryptozoon* we may be brief, as to our knowledge they do not play any rôle in the sedimentary series of strata in Sweden. Their organic or inorganic formation has been disputed, and so has their position in the organic world after they have definitively been counted in this. After having long been numbered with the Stromatoporoids (NICHOLSON 1878; ROTHPLETZ 1916), these calcareous formations have more and more been regarded as belonging to the vegetable kingdom and then as a rule counted among the lime producing algae (Walcott 1914, Wieland 1914, Pia 1926). Pia thinks that they show a structure mostly reminding us of the blue-green algae. He counts them together with the Stromatoliths in the group of the *Spongiostroma,* while he considers *Girvanella (Sphaerocodium), Mitcheldeania,* a. o. to form the second group, *Porostroma* (Pia 1931, 3).

The Occurrence of the Cyanophyceae in the Fossil Series of Strata of Sweden.

Of the above-mentioned calcareous masses formed by Cyanophyceae *Girvanella (Sphaerocodium)* and *Spongiostroma* occur as rock formers in the Swedish series of strata. They are found in calcareous, well stratified parts of the series with a fairly varying content of clayey matter. Not infrequently the algal lumps lie embedded in a loose, marly mass, from which they are easily separated out, especially on the weathering of the rock. This is for inst. the case in the Sphaerocodium beds of the Eke marl (cf. Munthe 1921, 29, fig. 20), in certain Girvanella beds at Bjersjölagård, and certain Spongiostroma beds in the neighbourhood of Visby. In other cases the calcareous balls lie in a dense, solid, relatively pure limestone (for inst. in some parts of the Spongiostroma beds at Visby). The thickness of the beds varies from a few centimeters up to more than a meter.

All the above-mentioned Silurian rocks formed by the activity of Cyanophyceae are marine. This is also the case in other similar Paleozoic sediments, which are rich in blue-green algae. It is in so far remarkable, as the modern Cyanophyceae as well as Quaternary and Tertiary limestones deposited by the action of such are essentially limnic. As far as is known no deposition of limestone through Cyanophyceae takes place in the modern seas and on the whole it may be questionable, whether in the seas it is caused by extraction of carbon dioxide in the above-mentioned manner, which is characteristic of an essential part of the lacustrine and fluviatile formation of limestone. The question now presents itself of necessity, whether the early marine occurrence of the Cyanophyceae is connected with the fact that the chemical character of the sea-water during e. g. the Paleozoic has been different from the present one. The author will here only call attention to the significance of the said fact for the estimation of the paleogeographical conditions, under which the Paleozoic Cyanophyceae limestones were formed; concerning the chemical changes of the sea-water he refers to the fairly rich literature (Daly 1910, Clarke 1924, Walther 1927, Pia 1931, a. o.).

For the estimation of the environmental conditions under which the Sphaerocodium and Spongiostroma limestones in Gotland and Scania were formed, it is of interest to subject the series of strata in which they occur to a more detailed investigation. The author will return to this in his account of the different rocks. We shall here only mention partly the high percentage of lime and extreme abundance of fossils in the series of strata indicating a formation in relatively warm water, and partly the frequently observed occurrence of the algal limestone in immediate connection with sandstones and oolites, indicating a formation in very shallow water. Contrary to the sandstones and oolites, the said algal limestones often contain large quantities of clayey matter, showing that they were formed in relatively tranquil water. In series containing reefs for inst. in Gotland, *Sphaerocodium* and *Spongiostroma* mainly occur between the reef horizons but not at all or only in small quantities in the reefs and in the stratified limestones immediately surrounding them.

Chlorophyceae.

In the fossil sediments of Sweden we find several forms of limestone forming green algae, both *Dasycladaceae* (Siphoneae) and *Codiaceae* as well as *Cha-*

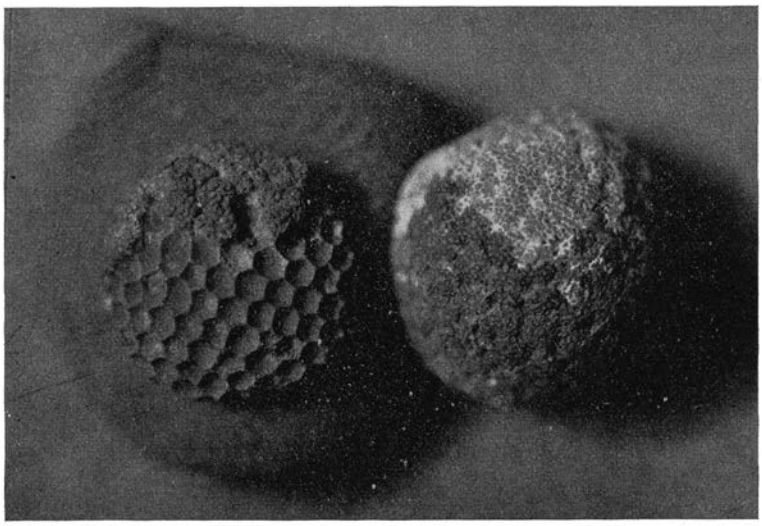

Fig. 6. *Cyclocrinus*. From erratic blocks. Island of Sylt. Coll. STOLLEY. (Pl. 665.) — 4 ×.

raceae.[1] For the present, however, only members of the two first-mentioned groups have been found in the pre-Quaternary Swedish sediments.

Of the Dasycladaceae occurring in Swedish sediments the genus *Rhabdoporella* is of interest as rock former also, though in this respect it cannot cope with the above-mentioned Cyanophyceae. From a number of different places, ROTHPLETZ who has investigated the calcareous algae in the limestones of Gotland has demonstrated Rhabdoporella forms, sometimes occurring in such numbers that he thought it appropriate to term the rock »Siphoneenkalkstein». The short, thin-walled lime tubes seldom reach 0.5 mm in diameter and are macroscopically not very conspicuous. They are never so closely packed that they form the bulk of the rock but as dominating fossil they nevertheless characterize it. Microscopically

[1] The author has followed the disposition made by PIA in 1926. It differs in some cases from the system advanced by other investigators of algae.

the radiate structure and perforation of the tubes are generally visible, unless the rock has undergone a strong crystallization.

The Rhabdoporella tubes occur in the Silurian beds of Gotland together with fragments of blue-green algae *(Sphaerocodium),* though not in larger numbers in the Cyanophyceae beds proper. The Rhabdoporella tubes are always fragmentary and are never in their position of growth. In places of abundant occurrence the tubes are secondarily enriched.

The Rhabdoporella beds are marly, as are also a great part of the Cyanophyceae limestones. They are no doubt also formed under practically the same environmental conditions as these.

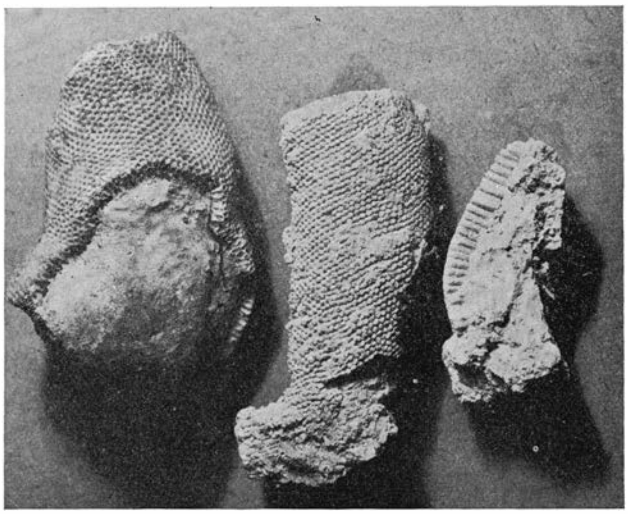

Fig. 7. *Aphrocallistes* (see note 1, p. 20). To the left the siliceous skeleton. Quadratus limestone. Obery. In the middle and to the right calcareous moulds. Danian. Limhamn, Scania. (Pl. 670.) — 1/1.

Besides *Rhabdoporella* a few other calcareous tubes formed by Dasycladaceae occur in the Cambro-Silurian beds of Sweden. Thus STOLLEY mentions that the Chasmops limestone contains an abundance of thin-walled, ramified tubes of *Vermiporella,* sometimes occurring together with thick-walled, simple tubes of *Dasyporella.* The author has no material from beds in situ which illustrates the occurrence of these algal limestones.[1] But he has had a number of erratic stones for the most part collected by STOLLEY at his disposal, which show the nature of these rocks. In some of them the said tubes, especially *Vermiporella,* are present in such numbers that they form an essential part of the rock. Judging from the petrographic character and the fossil content of the blocks, the Vermiporella limestone is mainly derived from the East Balticum and from the bottom of the

[1] ROTHPLETZ mentions (1913, 27) a couple of isolated samples of *Vermiporella* from Gotland.

Baltic. The Vermiporella flora had its strongest development during the deposition of the Lykholmer beds (Stolley 1897, 120). An abundance of *Paleoporella* (see below) and a smaller number of *Dasyporella, Rhabdoporella,* and *Cyclocrinus* are sometimes found together with *Vermiporella.*

Cyclocrinus and related species (*Coelosphaeridium, Mastopora,* etc.) are of no consequence as rock formers in the Swedish series of strata but by their characteristic and conspicuous appearance (fig. 6) they form a rather marked ingredient of the Cambro-Silurian algal flora. A number of species are known from erratic blocks (Stolley 1896, a. o.). In outcropping strata these algae have been abundantly found in the East Balticum, particularly in the Wesenberg beds (»Wesenberger Cyclocrinuskalk»). In Sweden the author knows them from the Leptaena limestone in Dalecarlia.

Of the above-mentioned Dasycladaceae *Vermiporella* is the oldest and *Rhabdoporella* the youngest type. Their vertical distribution is extensive: the upper part of the Ordovician and the greater part of the Silurian. Their occurrence and enrichment in sediments of a certain definite character but of varying age show that these algae attained their strongest development under certain definite milieu conditions. The Vermiporella beds are dense or micro-crystalline, relatively pure limestones, petrographically not unlike the Paleoporella limestones (see p. 21). They were formed in a more detritus-free and deeper water than the majority of the contemporaneous sediments in Sweden. Their other forming conditions are not evident from their occurrence in the Swedish series of strata.[1]

Several lime-forming genera occur among the recent *Codiaceae.* Best known and most important as rock former is *Halimeda.* The different forms of this genus are composed of a number of more or less calcified discs connected by non-calcified fibres. The lime was deposited around considerably ramified and matted filaments. On fossilification corresponding open or filled canals are found in the interior of the lime bodies.

Among the green algae found in the older sediments of Sweden there is a long known genus, *Paleoporella,* which probably belongs to the group *Codiaceae* but has nevertheless often been regarded as belonging to *Dasycladaceae.* Thus

[1] In the Danian limestones we sometimes find a fossil, which considerably reminds us of certain Dasycladaceae, particularly of the genera *Triploporella* and *Goniolina.* Its form is rather varying but mostly cylindrical or clublike. The fossil consists of a hollow body or crust of calcium carbonate. It is built up of radially arranged, crypto-crystalline prisms or cylinders, about 1 mm in diameter and 2—4 mm long (fig. 7). Deecke (1901) described the fossil under the name *Hexagonaria* as a green alga but almost immediately afterwards Geinitz (1901) was able to prove, with the support of F. E. Schultze, that it was the cast of a siliceous sponge, *Aphrocallistes,* the entire siliceous skeleton of which had afterwards been dissolved. Ravn (1912, 58) says that he has found impressions of sponge needles in some of the staves, and on that account he accedes to the interpretation of Geinitz-Schultze. The author has in vain looked for sponge needles in the fairly abundant material from Limhamn but he nevertheless considers himself unable to doubt the correctness of the interpretation of Geinitz and Ravn. In fig. 7 we find a couple of reproductions, partly of the fossil in question and partly of a species of *Aphrocallistes* in which the siliceous skeleton is preserved.

Stolley (1898, 25) considered *Paleoporella* to be closely related to the genus *Cymopolia*. The ramification of the canals in the body, however, makes the relationship to *Halimeda* and the fossil genera *Gymnocodium* and *Boueina* more obvious (cf. Pia 1926, p. 108 and 133 as well as fig. 39 and 62).

In the Cambro-Silurian of Sweden *Paleoporella* occurs as small cylindrical or barrel-shaped tubes (fig. 8), sometimes found in such a mutual connection that it may be inferred that this alga was articulated in the same manner as *Halimeda*. As the above-mentioned green algae, *Paleoporella* has only seldom

Fig. 8. Paleoporella limestone. Erratic block. Kiel. Coll. Stolley. (Pl. 658.) — 1/1.

been found in the outcropping Swedish series of strata but all the more frequently in the erratic blocks. The genus has proved to be rock-forming in many cases, perhaps in a still higher degree than the above-mentioned Dasycladacean genus *Vermiporella*. Stolley (1897) thinks that *Paleoporella* reached its highest development during the youngest part of the Ordovician. Its occurrence in the Leptaena limestone of Dalecarlia (Stolley 1897, 125) agrees well with this opinion.

The forms of Paleoporella belong to a milieu of formation not essentially differing from that of the Leptaena limestone. Consequently they seem to have developed in the same milieu as the genus *Halimeda*, which principally occurs in the warm waters, especially in tranquil regions protected against breakers and on coral reefs (Pia 1926, 133).

Among the Codiaceae ROTHPLETZ (1913, 16) counted the genus *Hedströmia*, and he describes two species from the Silurian of Gotland. Externally the Gotlandic forms remind us of the genus *Halimeda*. The branches are chain-like articulated and dichotomously or polychotomously ramified. The separate parts are rounded cylindrical and show, in their cellular filaments, a beginning of the ramification.

Hedströmia occurs together with *Spongiostroma, Sphaerocodium,* and *Solenopora*. The genus is sometimes rock-forming, it has carpeted parts of the sea bottom and covered the coral reefs. The Hedströmia limestone is remarkably poor in detritus and, as pointed out before by ROTHPLETZ, the genus may consequently have developed in relatively pure water. It should, however, be noticed that the branches often occur as secondary deposits.

All recent forms of green algae belonging to the family *Characeae* grow in fresh or brackish water. They play an important part in the formation of calcareous mud. In post-glacial and late-glacial deposits they are often abundantly present, as for inst. in the calcareous mud at Toppeladugård (HOLST 1906). At the brickyard of Bjeresjöholm the author has observed a calcareous mud rich in Characeae, which is enclosed between moraine beds.[1] Characeae have been found in Tertiary as well as in older and younger Mesozoic strata. It is very interesting that the undoubtedly marine genus *Trochiliscus* occurring in the Devonian is closely related to the Characeae (PIA 1926, 143). Thus we have here another example that modern fresh water forms can be represented in older formations by related marine ones.

No Characeae have hitherto been found in the pre-Quaternary sediments of Sweden.

Rhodophyceae.

As limestone formers the red algae, the *Rhodophyceae*, play a greater rôle in the modern seas than the *Chlorophyceae* and *Cyanophyceae*. In older geologic periods it has not been quite the same. It suffices to call attention to the abundant appearance of the Cyanophyceae (*Girvanella, Spongiostroma*, a. o.) during the Silurian, which lacks correspondence in modern formations. But Rhodophyceae are not absent in older deposits; as the other algal groups they can be traced back to the Cambro-Silurian.

Among the red algae, limestone formers are mainly found in the family

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[1] On the author's visit in 1915 the Characean mud at Bjeresjöholm was laid bare as a lens about 10 m broad and 0.1 m thick. Together with the lime-coated Chara nuts small molluscs *(Limnea pereger, L. ovata, Valvata piscinalis, V. cristata, Pisidium sp., Sphaerium corneum)* and ostracod shells were fairly abundant.

Corallinaceae. The calcium carbonate is deposited around the cells and the cellular tissue is also visible in fossil forms, unless the calcareous mass has undergone a strong recrystallization, which is by no means uncommon. Several of the modern genera are well known as important limestone formers, particularly *Lithothamnium* but also *Lithophyllum, Melobesia, Corallina, Amphiroa,* a. o. All of them have a common mode of growth in so far as they spread over the sea bottom binding together the substratum (of gravel, coral fragments, calcareous shells, etc.) at the same time as they are firmly fastened to it. They never occur on loose mud but very often on rocks and coral reefs. From the crust attached to the bottom or rocky walls aculeate processes *(Lithothamnium)* or slender branches *(Corallina, Amphiroa)* grow out. Forms of the last-mentioned development require a relatively tranquil water or sheltered position (sufficiently great depth) to thrive, whereas the other forms also occur on shores with heavy breakers.

We know fairly little of the occurrence of the said genera of red algae in older formations. *Lithothamnium* occurs as rock former in the Tertiary and Cretaceous deposits but hitherto it is not found in the fossil sediments of Sweden. A related genus, *Solenopora,* that appears as early as in the Ordovician, is abundantly present in the Silurian beds of Gotland, from which Rothpletz (1913) describes four different species. *Solenopora* is usually found together with other calcareous algae *(Sphaerocodium, Spongiostroma, Hedströmia).* Macroscopically it differs from *Lithothamnium* by its less extended, more rounded form, microscopically int. al. by its coarser cellular tissue.

The present lime-producing red algae occur in all the seas from the polar regions to the equator. Whether the fossil ones have had a similar distribution is still uncertain. The Swedish series of strata in which they have been observed were all marine and no doubt deposited in relatively warm water.

As the above-mentioned algae have been grown on to the sea bottom, they have as a rule been embedded in the sediments at their place of growth, and this naturally increases their importance as environmental documents. In the same manner as other plants they have been dependent on the sunlight for their development, and on that account they cannot have grown at great depths. Modern forms of the genera *Lithothamnium* and *Corallina* are mainly found at smaller depths than 50 m (cf. Walther 1893/1894, 108), often only slightly below the surface of the sea. The fossil forms also occur in typical shallow water sediments.

Coccolithophorideae.

Besides the above-mentioned limestone-forming algae growing, all of them, at the bottom of lakes or seas, there is a group occurring as marine plankton. A few fresh water forms, for inst. the genus *Phacotus,* belong to the same group but they play no greater rôle as rock formers and will therefore be left out of account here. (Concerning this genus we refer to Lagerheim 1902 and Pia 1926.)

The marine forms, on the contrary, are of no small petrographical interest, and their occurrence in the fossil series of strata of Sweden deserves to be mentioned.

The dominant rock in the Danian of Scania is a dense, distinctly stratified limestone, generally termed Saltholm limestone. RÖRDAM (1897, 75) proposed that the rock should be called Coccolith limestone. It must not, however, be inferred from this name that the bulk of the rock is built-up of coccoliths, even if RÖRDAM and later on HENNIG (1899 c, 61) express this opinion. In all the samples of the rock examined by the author demonstrable coccoliths play a conspicuous though not an important part. Apparently at least, they are less abundantly present than the foraminifera. The bulk of the rock consists of a microcrystalline, formless calcitic mass. This has obviously undergone a recrystallization after the deposition, and for that reason it is difficult to give an opinion of its primary character. It is not improbable that it has partly been deposited under the influence of bacteria. Part of it consists of redeposited calcareous mud.

Coccoliths are also present in the chalk, as abundantly as in the Saltholm limestone at least. The lime particles in the former rock are not cemented and little diagenetically transformed, and this is no doubt the reason why the coccoliths are more prominent or better preserved there than in the Saltholm limestone. As mentioned before, the bulk of the rock consists in this case also of small, roundedly prismatic grains of calcite, 1—3 μ long (fig. 9), probably formed under the influence of lime-precipitating bacteria (see p. 11).[1]

Whether and to what extent coccoliths have contributed to the formation of other Swedish limestones than those mentioned above, is not known. The older limestones, for inst. in the Silurian, are generally so strongly transformed that we cannot expect to find other structural features preserved in them than those of considerably larger lime bodies.

Though the coccoliths of the Cretaceous limestones differ in structure from the recent ones, we may nevertheless with CAYEUX (1916, 331—332) regard them as related. This does not imply that they have developed in a similar milieu but other circumstances speak in favour of that theory. Of the modern Coccolithophorideae the rhabdoliths are confined to the warm waters with a temperature exceeding 18.5° C., whereas the coccoliths occur in temperate as well as in

[1] RÖRDAM and HENNIG have probably also regarded the small, rounded crystals of calcite as coccoliths. They are perhaps partly right, for there are coccoliths of about the same size as the said crystals. These small coccoliths have the same oval form as the larger ones and consist, in the same manner, of a calcareous ring, the radiate structure of which is distinctly visible between crossed nicols. In the smallest coccoliths the hole in the middle of the ring is very small, much smaller than the thickness of the ring, which varies between 1—2 μ. In the »large» coccoliths the inner diameter of the ring is often more than 5 times the thickness of the ring. In chalk from Rügen, which is considerably richer in coccoliths than the Scanian chalk and contrary to this also contains rhabdoliths, all the transitions between larger and smaller coccoliths are found. A further investigation of these coccoliths and their relation to the smallest calcite bodies might be of considerable interest.

warm waters, though not in larger numbers in waters with a lower temperature than 7.5° C. According to Böggild (1900) coccoliths occur immediately north and south of Iceland, whereas rhabdoliths are absent in both places.

The Coccolithophorideae are typical plankton organisms, and as such they develop essentially in the surface waters. They are found in great numbers down to 50 m but at 100 m they are already scarce. From the surface waters, however, a continuous shower of coccoliths descends towards the bottom. Lohmann calcu-

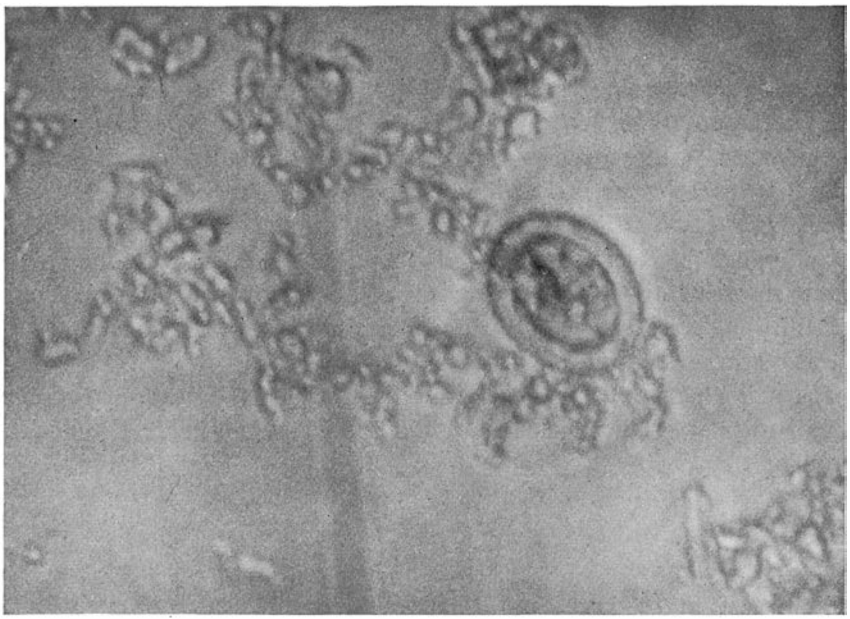

Fig. 9. Coccolith and small calcite crystals. Chalk. Kvarnby, Scania. — 2000 ×.

lated (1909, 399) that a water layer with a surface of 1 m^2 was passed by 2800 millions of coccoliths a day, which means a possible deposition of 1000 000 000 000 by the year and square meter.[1] However, to obtain a layer a cm thick with this rate of deposition requires a time of 10 000 years. Lohmann thinks that during older geologic periods the deposition of coccoliths took place on a larger scale, and in consideration of for inst. the great thickness of the coccolith-rich Cretaceous rocks we must absolutely agree with him.

The Coccolithophorideae have been found in most kinds of marine sediments except the detritus deposits proper along the shores. Coccoliths are found in small numbers as far down as in the red deep-sea clay at a depth of more than 6 000 m (Lohmann 1903) while they are most abundant in the globigerina ooze. Up to 70 per cent of this ooze can consist of coccoliths, and on that account the

[1] Later on Lohmann (1912) considered this number to represent the deposition of two years.

term »Coccolith ooze» would be correct in such cases (LOHMANN 1912). Though the author, as remarked above, thinks it uncertain that the Swedish-Danish »Coccolith limestone» deserves this name, both this and the chalk show that the Coccolithophorideae play an important part as limestone formers also in the fossil Swedish series of strata.

Limestone Formation by the Action of Animals.

It suffices to remember the coral reefs, the shell beds, the bryozoan or foraminiferal limestones in order to understand that the animals can occur as limestone formers on a large scale. The limestone is generally not built up by a particular species or even a particular genus, on the contrary it consists as a rule of a number of different lime-secreting animal forms. Even those which have not supplied any larger amount of the material of the rock may nevertheless be of great interest for the interpretation of its conditions of formation. On the study of the limestones as well as of other sediments it is absolutely necessary to notice the scarcer organisms also.

The following survey of different animal forms as limestone formers and of their significance for the formation of the fossil sediments of Sweden comprises these groups:

I. Protozoa.
Foraminifera.

II. Coelenterata.
Spongiae: *Calcispongiae.*
Cnidaria: *Anthozoa* and *Hydrozoa.*

III. Echinodermata.
Pelmatozoa: *Crinoidea* and *Cystoidea.*
Echinoidea.

IV. Vermes.

V. Molluscoidea.
Bryozoa.
Brachiopoda.

VI. Mollusca.
Lamellibranchiata.
Gastropoda.
Cephalopoda.

VII. Arthropoda.
Crustacea.
Entomostraca: *Ostracoda* and *Trilobitæ.*
Malacostraca: *Decapoda.*

Foraminifera.

The foraminifera belong to the most numerous and wide-spread animal fossils. Their calcareous shells are found in all formations, and they are often rock-forming. They have, however, been fairly unnoticed in the Swedish series of strata and do not play the same rôle there as in many other places. This is no doubt partly dependent on the fact that Sweden has no sediments preserved from the periods, during which the foraminifera attained their most vigorous development. An abundance of foraminifera are, however, found in the Senonian and Danian limestones as well as in the Tertiary blocks, and in the following their occurrence in these rocks vill be discussed somewhat more in detail. None of the forms from the older Paleozoic mentioned from other quarters has been observed by the author in the Ordovician or Silurian limestones.

The *Tertiary*, probably Eocene rocks particularly abundant in southern Scania consist of glauconite-bearing sandstone and limestone. Both rocks, especially the last-mentioned, contain foraminifera in such numbers that they always attract attention in thin sections. The observed forms belong mainly to the families *Lagenidae, Textularidae,* and *Globigerinidae,* and the genera *Robulus, Orbulina,* and *Globigerina* are particularly prominent. Besides foraminifera the rocks contain abundant fragments of echinoderms, bryozoa, gastropods, and lamellibranchs, generally rounded and obviously, as the glauconite grains, secondarily enriched. A not inconsiderable part of the rock is often occupied by small grains of impure, structureless calcite, in its existent form probably of coprogenic nature. The Tertiary foraminifera-bearing rocks of Scania are marine and deposited at a slight depth in a relatively agitated water more or less rich in detritus.[1]

The younger Danian limestones are richer in foraminifera than any other Swedish rock studied by the author and they may well be regarded as rock formers there. With regard to the foraminiferal fauna these limestone (for inst. the beds immediately below the Paleocene beds at Klagshamn) are closely related to the lower Crania limestone at Copenhagen, which might well also be termed Foraminiferal limestone (RÖRDAM 1897, 70, ROSENKRANTZ 1920, 12). In these rocks too the families *Lagenidae, Textularidae,* and *Globigerinidae* prevail.

Beds rich in foraminifera are relatively poor in other fossils. Bryozoa are

[1] From the small remainder of Paleocene at Klagshamn HOLST and GRÖNWALL (1907, 12) mention a number of foraminifera, together with vigorously rolled fragments of echinoderms, brachiopods, and lamellibranchs. The Danish Paleocene strata also contain an abundance of foraminifera (FRANKE 1927 and GRÖNWALL and HARDER 1907, 21).

most abundant, fragments of echinoderms scarcer. For the rest the rock is built up of glauconite in varying quantity and small structureless calcite grains of the same character as in the Tertiary blocks mentioned above. It is exceedingly poor in detritus but must nevertheless have been formed at a small depth. This is evident partly from the nature of the rock, specially from its fossil fragments strongly worn by redeposition, partly from its very pronounced corrosion surface, which forms the limit of the strata towards the Paleocene glauconitic sand.

The bulk of the Danian series in Scania consists of Saltholm limestone, in which embeddings or inclusions of Faxe limestone and bryozoan limestone occur. The Saltholm limestone is sometimes called coccolith limestone and has been discussed above in the account of the occurrence of coccoliths in the Swedish sediments. The Faxe limestone, which is also called coral limestone, and the bryozoan limestone will be further discussed in the account of the occurrence of corals and bryozoa. We shall only say a few words here on the occurrence of the foraminifera in these rocks.

As shown above, the Saltholm limestone consists mainly of exceedingly small grains of calcite, probably formed by the action of algae (bacteria and Coccolithophorideae) and by inorganic precipitation. In the dense mass of such grains larger coccoliths and foraminifera are distinguishable, the latter generally in somewhat greater numbers than the former but none of them rock formers in the proper sense of the word. The foraminifera belong to several different genera but most abundant are the individuals belonging to the family *Globigerinidae* (fig. 10).[1]

In the Faxe limestone the foraminifera are found in the dense matrix between the coral stocks. This matrix has practically the same character as the Saltholm limestone surrounding the reefs, and it contains the same foraminifera and coccoliths as the latter rock.

In the bryozoan limestone the foraminifera occur in the same manner as in the Faxe limestone, i. e. in the matrix. As this plays a relatively unimportant rôle, with the bryozoan fragments forming the bulk of the rock, the occurrence of foraminifera in this rock is easily overlooked.

The Saltholm limestone with the reefs of coral limestone and the beds of bryozoan limestone enclosed in it is formed at a relatively slight depth, and consequently the foraminifera belong, also in these rocks, to sediments deposited in shallow regions not far from the shore.

The Swedish Senonian rocks seldom contain foraminifera in larger numbers.[2] They are most abundant in the glauconite-bearing arenaceous limestone of Köpinge, especially in its sand-poorer beds. Sporadic specimens of foraminifera have been found at many places in shell fragment limestone from north-western

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[1] Besides the species mentioned by MUNTHE (1896, 26) HENNIG (1899 c, 153) reports a few more, determined by V. MADSEN.

[2] A few genera and species have been determined by MUNTHE (1896).

Scania as well as in the dense matrix of the conglomerates (for inst. at Barnakälla, Balsberg, V. Olinge, and Bjärnum).

It might be expected that the white, pure chalk would essentially consist of foraminifera. This is not the case. The chalk in Scania is in fact remarkably poor in these fossils. There is consequently no reason to look upon this rock as a Mesozoic correspondence to the recent globigerina ooze, which is evident even from the fact that the chalk was formed at a relatively slight depth (cf. VOIGT 1930, 407).

As is evident from the preceding, the investigation of the Swedish sediments as to their content of foraminifera has shown that these fossils only exceptionally

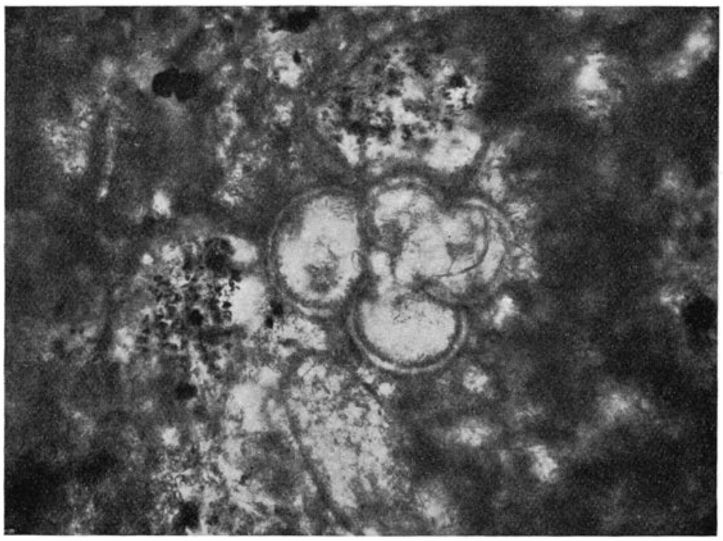

Fig. 10. Saltholm limestone, dense, with foraminifera *(Globigerina)*. Danian. Limhamn, Scania. (Pl. 663.) — 250 ×.

play a rôle as rock formers. It is only in the youngest Danian limestone in Scania that they occupy a larger part of the rock. This is, however, no real foraminiferal limestone as the Eocene Nummulitic limestone or the Paleozoic Fusulina limestone. All the foraminifera in the Danian limestone are very small also, seldom exceeding 0.2 mm in length, and on that account they are easily overlooked on a macroscopic examination of the rock.

No greater importance can be ascribed to the foraminifera in the Swedish series of strata as environmental documents. In most cases they are unmistakeably in secondary place of deposition: the benthogenic as well as the planktogenic forms have been subjected to transportation before the eventual embedding. The extent of this cannot be decided in each special case, hardly even approximately estimated for the present, but it has no doubt been so considerable that it would be incorrect to draw any general conclusions from the content of foraminifera in the rocks as to their milieu of development (depth, temperature, etc.). It is, however, of paleogeographical interest to follow the different species of foraminifera regionally in each special zone and subdivision of this, and even if their importance for the Swedish sediments seems to be slight, they deserve to be noticed in a higher degree than hitherto.

Calcispongiae.

The calcareous sponges cannot be counted among the animal groups of greater importance as limestone formers. They are also far less noticed than the silicious sponges. This is no doubt partly due to the fact that they are little suited to be preserved by fossilification, but probably also to their far less common and more restricted occurrence in the fossil series of strata. In Sweden we know them only from the Senonian-Danian limestones.

No investigation of the Swedish calcareous sponges has ever been made, but HENNIG (1899, 102) has collected some material for this purpose. The material is stored in the geologic-mineralogic institute of Lund and as might be expected it shows that the Swedish forms agree well with the Danish ones. Richest represented in species as well as in individuals is the genus *Porosphaera,* occurring both in the Senonian and Danian strata (fig. 11). There are numerous samples from the chalk but only a few from the Saltholm limestone, the Faxe limestone, and the shell fragment limestone of north-eastern Scania.

A systematic investigation of the content of calcareous sponges in the Swedish series of strata would no doubt show that they are far more common than is evident from earlier investigations.[1] They do not, however, occur as rock formers

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[1] A certain difficulty in identifying the sponges has contributed to the fairly considerable defectiveness in our knowledge of the distribution of this animal group. As is evident from BRÜNNICH NIELSEN'S survey (1929) the genus *Porosphaera* STEINMANN for inst. was first interpreted as belonging to the hydrocorals, more definitely to the family *Milleporidae,* to which it was also counted by STOLLEY (1892, 271). At times the genus has also been referred to the foraminifera (PARKER and JONES 1860, 30) or to the bryozoa (QUENSTEDT 1879, 262), and HINDE (1904) seems to be the first who established their character of calcareous sponges. In this connection attention should be called to the fact that BRÜNNICH NIELSEN also regards as calcareous sponges the genera *Neuropora* BRAUN and *Spinopora* BLAINVILLE, described by HENNIG (1893 and 1894, 25—27) as bryozoa from the Senonian of Scania. GREGORY (1909, 125) pointed out that they could not be bryozoa, he did not, however, regard the two genera as sponges but as milleporoids.

It is most important for the identification of the calcareous sponges that we can show the presence of the spicules forming the solid framework, the skeleton, in the structure. In many cases these needles will be scattered when the soft parts in which they have lain embedded disintegrate (see for inst. HINDE 1889, 357). When enclosed in a limestone, these needles are easily overlooked. They consist of calcite and as shown by SOLLAS (1885, 378), they are practically insoluble in water, and there is consequently every reason to look for them in deposits containing calcareous sponges. It is remarkable that the needles of the calcareous sponges do not change during the fossilification. Thus e. g. CAYEUX (1916, 406) mentions needles from the Cenomanian as fresh as in recent calcareous sponges.

in a strict sense but together with the remaining fossil content they possibly may contribute to the interpretation of the milieu in which the rocks were formed. As far as the author knows all the fossil calcareous sponges belong to marine shallow water sediments, where they occur together with echinoderms, bryozoans, brachiopods, and gastropods.[1] According to RAUFF (1913, 120) the recent forms belong to the littoral as well as the sublittoral zone, and several species seem to occur exclusively about the low tide level. The rocks in which

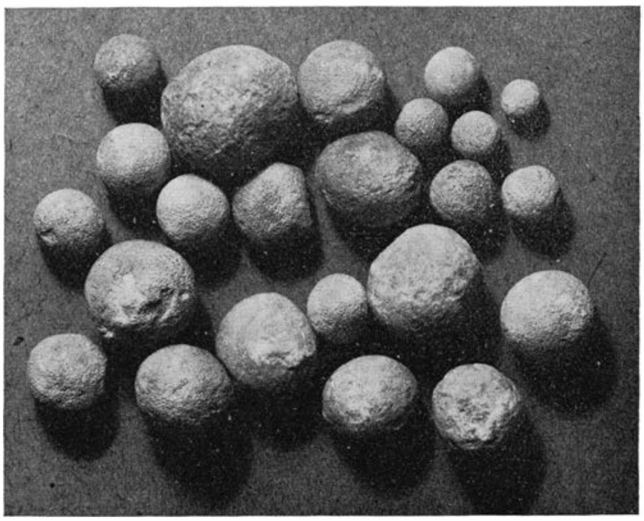

Fig. 11. *Porosphaera.* Calcareous sponge. Senonian chalk. Kvarnby, Scania. (Pl. 671.) — 1/1.

the fossil calcareous sponges are found can be petrographically highly varying: sandy, argillaceous or calcareous, but their development and occurrence generally show that they have also been formed at or slightly below the low tide level. Thus RAUFF (1913, 120) mentions as typical among rocks containing cal-

In cases when the skeleton has not desintegrated the needles have been cemented by a granular or radiate calcite formed in the family *Lithoninae* while the animal lived, in others essentially by precipitation of calcite around the needles after the death of the animal. This precipitation of calcite probably takes place under the influence of the disintegration of the organic substance. Particles of mud, foraminiferal shells, etc. washed into the sponge are also cemented, together with the needles. Such inclusions are also known from recent calcareous sponges (HAECKEL, II, acc. to RAUFF 1913, 120).

On looking for sponges it should also be noticed that they are frequently grown on to other animals, for inst. to crustaceans, lamellibranchs, gastropods, bryozoans, and corals, and that their external form can be highly varying (MAAS 1912, 1045).

[1] Detailed researches on the sponges and their developmental conditions have been published by several scientists, among which the author specially refers to SCHRAMMEN (1912) and HINDE (1900, 50) for a comparison with the described Swedish conditions.

careous sponges: — coral limestone, oolite, conglomerate-like calcareous sand, fragment limestone, and tufaceous marl. The Swedish limestones, in which calcareous sponges have hitherto been found, belong in some cases to one of these types (the Faxe limestone, the shell fragment limestone), in other cases they are of a quite different character (the chalk, the Saltholm limestone). In these cases the sponges confirm our opinion that the chalk and the Saltholm limestone have also been formed at a relatively slight depth.

MAAS (1912, 1045—1046) connects the occurrence of the recent sponges at greater or smaller depths with their need of agitated water. As extremes he mentions on the one hand the silicious sponges, the *Hexactinellida,* occurring at great depths and on the other the calcareous sponges and silicious cup sponges occurring in the tidal zone. He calls attention to the wide distribution of the sponges and, in connection with this, to their frequently obvious insusceptibility to changes of temperature.

The calcareous sponges are of course dependent on a calcareous water for their construction. MAAS (1912, 1045) mentions that the recent sponges can not extract the lime, unless it is present in the water as carbonate, not from a solution of calcium sulphate. On that account the sponges obviously must be susceptible to changes in the salinity of the water. A closer study of the fossil calcareous sponges and their occurrence may possibly be of great significance for the investigation of the paleogeographical conditions under which the sponge-bearing series of strata were formed.

Anthozoa.

The character of the corals as lime-secreting organisms is so often described in detail and so generally known that it may be passed by here. The significance of the corals for the construction of the coral reefs and other limestones is, however, still obscure in many respects, sometimes overestimated and sometimes underestimated. It also varies widely with time and place. In the following the author will examine the problem of the significance of a few separate groups as rock formers, and he can then base his opinion on his own observations on Swedish coral reefs for a long sequence of years. A summary of the faunistic stock-taking of these reefs, however, should be deferred to a later part of this work in which the different rocks, in this case principally the reef limestones, will be discussed.

The corals are of importance as rock formers, not only on account of their own power of lime-secreting but also because they make other, organic or inorganic, formations of limestone possible. We know that the coral reefs are a favoured habitat of organisms of different kinds, and the study of the fossil reefs shows us that this has always been the case. Shells and other calcareous formations from these organisms often occupy a larger portion of the reef than the corals themselves. Calcareous mud, fragments, and cementing calcite, which fill up the space between the coral stocks and the different calcareous fossils grown on to them, also play a very important rôle.

If we regard the corals in view of their above-mentioned double task as rock formers, we find that they are of very different significance. Most important are the reef builders proper, while the simple corals are of least consequence. In many cases the calcareous skeleton of the latter, built by one individual, has lain loose on the sea bottom, possibly on a reef, and as rock formers those forms are of course not more important than other loose fossil fragments, for inst. of crustaceans, echinoderms, a. o. The ramified or cover-like spread types forming colonies often constitute, in connection with other calcareous organisms (calcareous algae, hydrocorals, etc.) the solid frame-work of the reefs and form at the same time a substratum for the sedimentation occurring in the region.

The broad zone of calcareous sand and mud surrounding the living reefs is characteristic of the modern atolls. These loose sediments are formed through disintegration of the reefs by wave action and the term coral sand may therefore be appropriate, even if, as WALTHER (1919, 677) remarks, identifiable corals are sought for in vain in them. This calcareous fragment mass plays a very important part in the present formation of sediments, and for that reason it is of great interest to study the corresponding formations around the fossil reefs enclosed in older series of strata. It may then immediately be pointed out that the fossil reefs are in many cases almost entirely devoid of an enclosing zone of calcareous sand, or else they are of a different character than that found in the modern reefs. We shall, however, return to these matters in the account of the rocks and proceed here to an examination of the petrographical and geological significance of the different coral groups.

Of the corals occurring in the Swedish sediments *Tetracoralla,* belonging to the class *Zoantharia* and extinct already during the Paleozoic, are common in the Cambro-Silurian deposits, while *Hexacoralla,* belonging to the same class and occurring first during the Mesozoic, characterize the reefs in the Swedish Cretaceous deposits. *Heliolitida* and *Tabulata,* the position of which are disputed, play a very prominent rôle in the Swedish Silurian reefs, and a few genera of the class *Alcyonaria (Octocoralla)* constitute an essential part of the Danian reefs. As is seen from the following survey, the different groups and genera are of a widely varying significance as rock formers. For the estimation of the environmental conditions under which the rock was formed their occurrence is always of interest.

Tetracoralla.

The forms belonging to *Tetracoralla* are mostly simple corals of the type called cup corals (fig. 12). These are not reef builders and are only of slight importance as rock formers. They are not characteristic of the reef limestones either but occur preferably in stratified and very often in marly series of strata. They occur, however, most abundantly in places where they have been secondarily enriched together with brachiopod shells, crinoidal or other fossil fragments. This enrichment has been the easier as these corals have generally occurred in a loose calcareous mud (see further p. 35).

Of Tetracoralla the families *Zaphrentidae, Cyathophyllidae,* and *Calceolidae* are most abundant in the Swedish series of strata.

Fig. 12. Small cup corals (*Zaphrentis*) from Silurian marlstone. Gotland. (Pl. 673.) — 1/1.

The different genera and species show a varying vertical and horizontal distribution. The characteristic and from the oldest Silurian strata of Gotland well known forms of the genera *Palaeocyclus* and *Goniophyllum* have a very restricted vertical distribution and are good index fossils, the former for the Lower, the latter for the Lower and Upper Visby marl. Several other genera are also strictly confined to one or a couple of zones: thus *Dinophyllum* and *Holophragma* are only found in the oldest zones of the Silurian of Gotland, *Zaphrentis* and *Lindstroemia* in somewhat younger strata (the Slite group) and *Rizophyllum* in later deposited sediments (the Hemse group and Eke marl). A wider distribution is shown by the genera *Acervularia* and *Cyathophyllum,* the former occurring in several zones in the middle part of the Gotlandic Silurian, the latter in the Upper Ordovician and parts of the Silurian, in Gotland mainly in the Upper Visby marl. Most widely spread is the genus *Ptychophyllum,* which is fairly commonly represented from the Middle Ordovician up to the upper part of the Silurian (see HEDE 1921).

Tetracoralla would have been of petrographical interest, if they could give us any informations on the conditions under which the sediments were formed But no investigation of the conditions under which the different species and genera lived, has hitherto been made, and it is only possible to carry out this by the study of the sediments in which they occur. In the following a few general conclusions will be stated as to the environmental conditions under which the Swedish Silurian forms of Tetracoralla occurred, conclusions which are based on observations made by the author during his stratigraphic studies.

In the marlstones of Gotland Tetracoralla are often found in the position and place they occupied while the animal lived. The large cone-shaped *Omphyma* forms are often placed just as they were when the mud layer grew around the living coral. Not infrequently we find these corals with their root-like appendages undamaged. In the same manner the other cup corals may be found in the marl

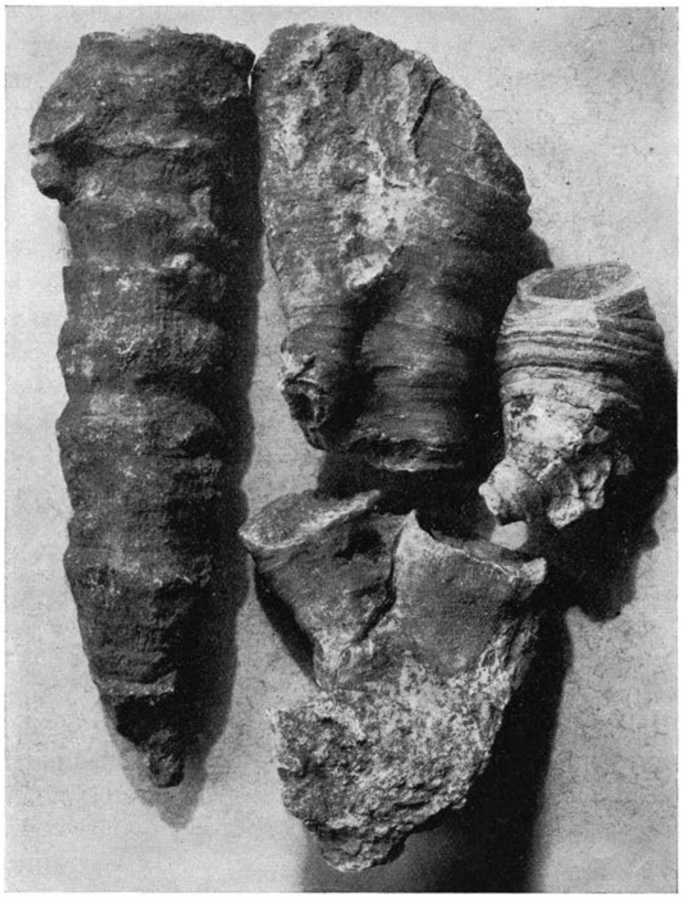

Fig. 13. Simple and compound Tetracoralla (*Cystiphyllum cylindricum* LONSD.). Silurian marl. Gotland. (Pl. 676.) — $^1/_1$.

beds. Whenever the fossil is met with thus in situ it is evident that the rock has been formed in the very milieu in which the coral has lived. We know nothing primarily of the latter in this special case, as the entire animal group (Tetracoralla) to which the said organism belongs is long since extinct, but the rock tells us a great deal about the milieu of formation and at the same time about the animal's conditions of life.

We can infer from the nature of the rocks that the Tetracoralla have as a rule lived in tranquil, protected parts of the sea, where a deposition of calcareous and argillaceous mud could take place. In so far Tetracoralla have developed in the same milieu as many modern simple corals of the order Hexacoralla. The larger and heavier, often cone-shaped forms have partly been immersed in the mud, the light or tabularly extended ones (for inst. *Palaeocyclus*) have remained above the mud surface.[1] If the velocity of the current has increased, the deposition of mud has ceased and from time to time the deposited mud has been washed away, leaving the corals free on the sea bottom. Almost everywhere in the Silurian series of Gotland the author has observed Tetracoralla enriched in this manner, together with other corals, crinoids, brachiopods, lamellibranchs, gastropods, and crustaceans. These intraformational »fossil conglomerates» must originate from a change in the conditions characterizing the milieu proper of the Tetracoralla, but they have nevertheless been formed at practically the same depth, at which the corals lived and the marly beds were deposited. The »conglomerates» as well as their fossil populations show that these sediments were deposited in shallow water. Consequently Tetracoralla, as most modern corals, have thrived at a relatively slight depth.[2] The high content of lime in the beds in which the Tetracoralla occur, indicates that they have lived in a relatively warm water.

It may thus be inferred from the above facts that, in the same manner as recent and fossil reef-forming corals, the Tetracoralla present in the Silurian strata of Sweden have thrived in warm water and at a slight depth, but that, contrary to the reef builders, the former have only lived where clayey mud has constituted an essential part of the bottom deposit. Whereever Tetracoralla occur in rocks free from or poor in clay there is reason to investigate whether they do not occur in secondary place of deposition (secondarily enriched). This is generally the case, and the mode of occurrence bears evidence of a negative sedimentation and a gap in the series of strata.

What is said above of Tetracoralla holds practically true of all the genera of that class observed in the Cambro-Silurian of Sweden but particularly of the simple corals. The compound forms, for inst. *Acervularia* (fig. 14 and 15) and *Cyathophyllum*, sometimes occur in a manner showing that they lived in a more mud-free milieu. These genera thus approach the reef-forming corals not only by their form (the formation of colonies) but also by their occurrence.

Hexacoralla.

Hexacoralla occur in many places in the Swedish Cretaceous deposits, viz. in the Senonian as sparingly occurring simple corals and in the Danian partly as reef-forming, ramified stocks, partly as simple corals. The Senonian forms consti-

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[1] The slow current, which supplied the corals with the food required, possibly also led to the formation of their frequently horn-like bent form (cf. Zittel 1921, 96).

[2] The recent simple corals of *Hexacoralla* are sometimes termed deep-sea corals, because they are also found in mud at relatively great depths. Thus Walther (1893/94, 269) states that the genus *Caryophyllia* lives at a depth of 1—2740 m and *Bathyactis* at 90 to 5000 m.

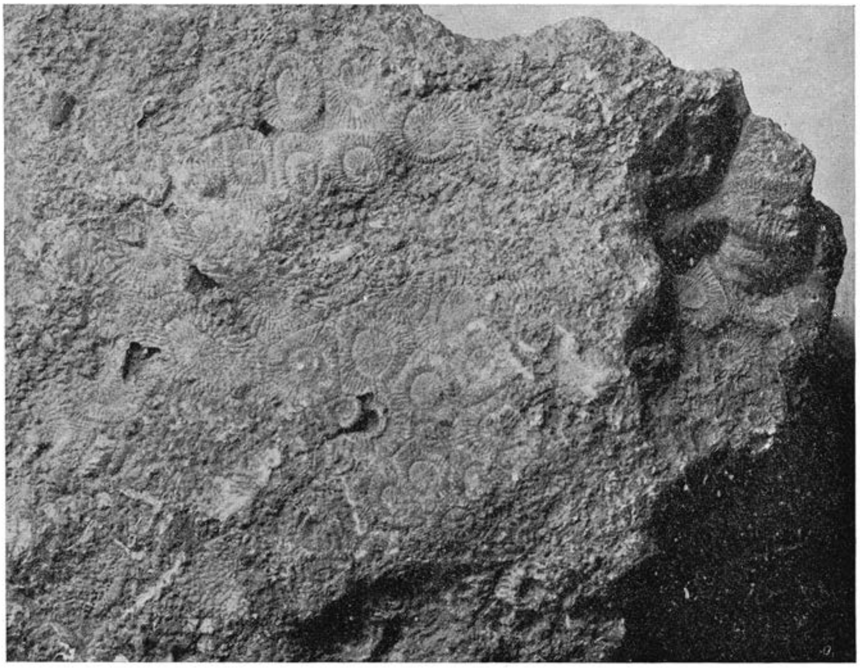

Fig. 14. Compound Tetracoralla (*Acervularia*) Silurian. Gotland. (Pl. 678.) — 1/1. See also fig. 15.

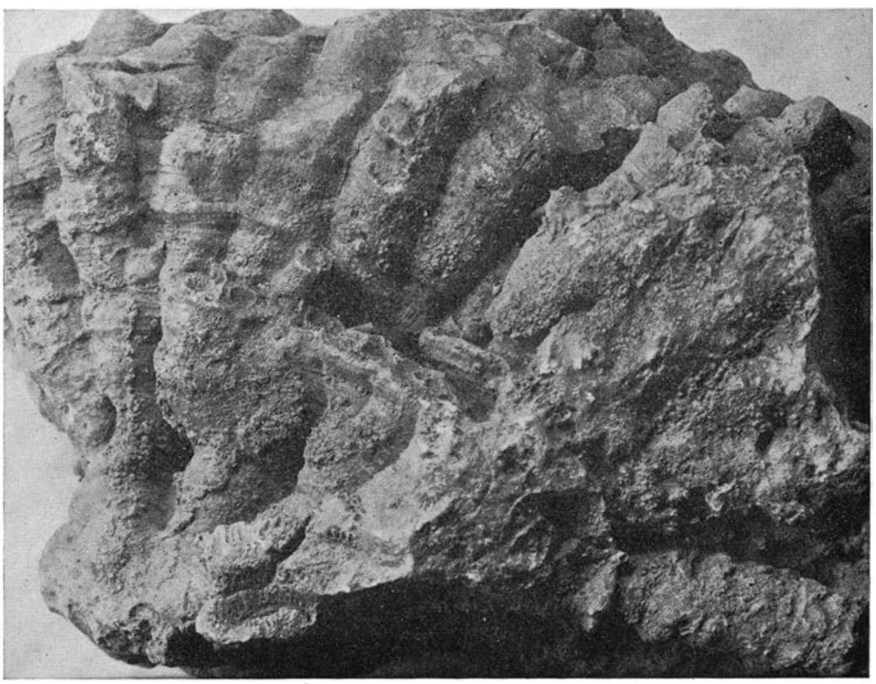

Fig. 15. Compound Tetracoralla (*Acervularia*). Lateral view of the coral stock fig. 14. (Pl. 677.) — 1/1.

tute such an unimportant portion of the highly fossiliferous rocks in which they are found, that they are left out of account here. The Danian forms deserve the more to be mentioned.

In the always distinctly stratified Saltholm limestone, the principal rock of the Swedish Danian, larger and smaller bodies of unstratified limestone, of old termed Faxe limestone, are to be found. The frame-work in this limestone consists of ramified coral stocks (fig. 16), mainly of the genera *Dendrophyllia*

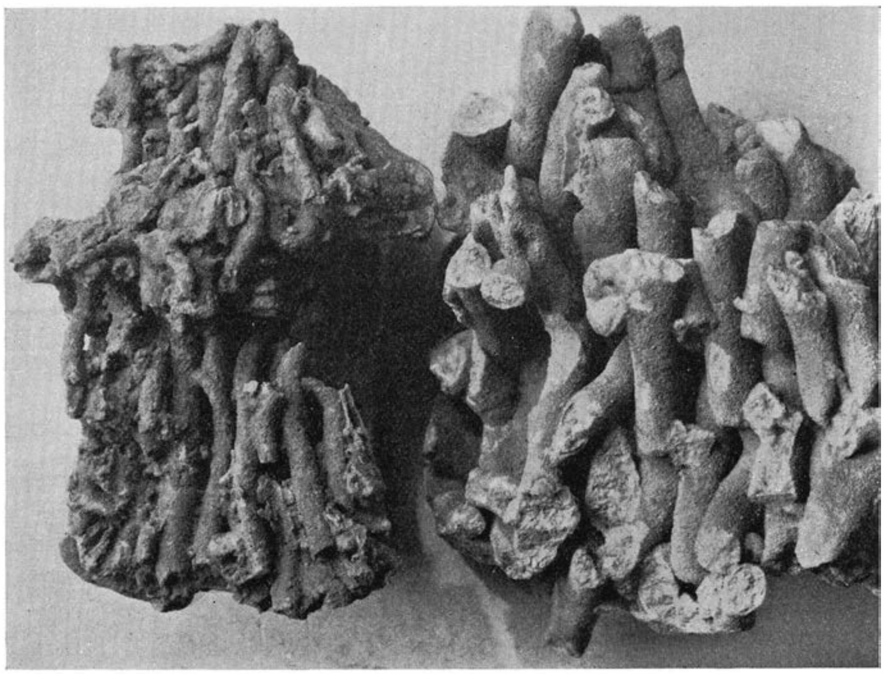

Fig. 16. Compound ramified Hexacoralla (*Dendrophyllia candelabrum* HNG and *Calamophyllia* (*Haplophyllia*) *faxensis* BECK, Faxe. Danian. (Pl. 686.) — $^1/_1$.

and *Calamophyllia*.[1] Simple corals, particularly of the genus *Parasmilia* are found grown on to these stocks (fig. 17). The frame-work of the reef contains, besides these corals, remains of several other animal forms: — *Alcyonaria* (see p. 40), *Hydrocoralla, Serpula*, crinoids, etc. In spite of this abundance of lime-forming organisms the bulk of the complete reef consists of a fine calcareous mud deposited between the different branches of the reef frame. In this calcareous mud we find an abundance of remains of a benthogenic fauna, containing int. al. some detached simple corals of the class Hexacoralla, for inst. members of the genera *Ceratotrochus* and *Smilotrochus* (fig. 17).

[1] The common form *Caryophyllia faxensis* BECK has been referred to different genera: *Calamophyllia* D'ORBIGNY 1848, *Rhabdophyllia* MILNE & HAIME 1854, *Lobopsammia* HENNIG 1899, *Haplophyllia* BR. NIELSEN 1922.

It is evident from the preceding that the Faxe limestone is a typical coral limestone, and that Hexacoralla play a very prominent part in the construction of the reefs.

The corals of the Faxe limestone are also important as environmental documents. They are so modern in character that we may venture to infer that they lived under practically the same conditions as the recent species related to them. The coral reefs enclosed in the Danian limestones are specially important for the estimation of the depth at which these sediments were deposited. Certainly, we cannot positively tell at which depth the Faxe limestone was formed, but there

Fig. 17. Simple Hexacoralla. (*Parasmilia Lindströmi* HNG and *Smilotrochus faxensis* FORCHH. & STEENSTR. Danian. Limhamn. (Pl. 674.) — $^1/_1$.

is reason to suppose that it was not, as the majority of the recent coral reefs, formed at or immediately below the low tide level. Some of the genera found in the limestone are also represented in the recent deposits, in which they occur in large numbers at a depth of 100—500 m. WALTHER (1893/94, 278 seq.) states the following depths: — *Dendrophyllia* 1—1371 m, *Dendrophyllia Goesi* 73—273 m, *Parasmilia Lymani* 104—236 m, *P. fecunda* 328—548 m, *Ceratotrochus* 548 m. All the forms occur in warm waters.

In the same manner as the recent corals the reef-forming ones of the Faxe limestone have developed in a water relatively free from detritus, which is evident from the fact that the limestone only contains small amounts of clayey mud and sand. At Limhamn in Scania, however, the content of detritus is somewhat higher than at Faxe in Zealand.

On studying the Hexacoralla in the Faxe limestone one is surprised at their different preservation. The simple corals are often well preserved but we seldom see more than the mould of the branched stocks. It lies near to associate this with a primarily different deposition of calcium carbonate. Our knowledge of the solubility of aragonite and calcite tells us that the colony-forming types were probably produced as aragonite and some of the others as calcite. It is, however, difficult to express any opinion on this question without first making a detailed investigation of the structure in the fossil remains of these corals. Böggild (1930, 241), certainly, has examined a few species from the Danian of Denmark, int. al. members of the genera *Ceratotrochus* and *Parasmilia,* and has found a calcitic development in all of them but in a great many he also found aragonitic forms. Consequently, the question of the primary formation of the carbonate as calcite or aragonite is still open as regards some of the said simple corals. As to the other Hexacorals in the Faxe limestone there is no reason to suppose that they were formed as calcite, and in cases where the stems are preserved they show such a coarse-crystalline calcite that it must be secondarily formed, probably after aragonite. As far as we know, all the recent Hexacoralla are formed as aragonite.[1]

Alcyonaria.

In the Danian limestones of Scania a few coral genera of the class *Alcyonaria* occur. Through accounts made by Hennig (1899 b, 5—8) and Brünnich Nielsen (1913, 1917 and 1918) we have obtained a short characterization of the observed species. A systematic paleontological investigation might, however, still yield diverse interesting novelties. No investigation of the petrographical significance of the observed species has hitherto been made.

The majority of the forms do not occur in such numbers that they are of importance as rock formers. An exception is formed by the genera *Moltkia* and *Gorgonella,* sometimes so abundantly represented that they locally characterize the rock (fig. 18). The root portions can be spread over large surfaces, and the calcareous axes often attain a considerable thickness. By secondarily deposited calcareous layers the different articulations of the axes are connected and long branches formed, which sometimes, on account of the secondary lime cover, run together into thick lumps (fig. 19).

The Alcyonaria forms in the Swedish Danian limestones are so well preserved that they must primarily have been built up of calcite, in the same manner as recent forms of this class of corals. Whether they agree with the recent forms by their high content of magnesia also, is not yet established by analyses.[2]

[1] Meigen examined a score of modern *Zoantharia* and found that all of them consist of aragonite (Clarke and Wheeler 1917, 52), neither was there any calcitic form among the recent corals examined by Böggild (1930, 241). See also Johnstrup 1864.

[2] The recent Alcyonaria analysed by Clarke and Wheeler (1917, 16) showed a content of $MgCO_3$ of 6—16 per cent. Analyses of fossil Swedish Alcyonaria will be published in the description of the rocks. Branches of *Moltkia Isis* from Limhamn, analysed by Sv. Palmqvist, had a content of MgO of about 1 per cent.

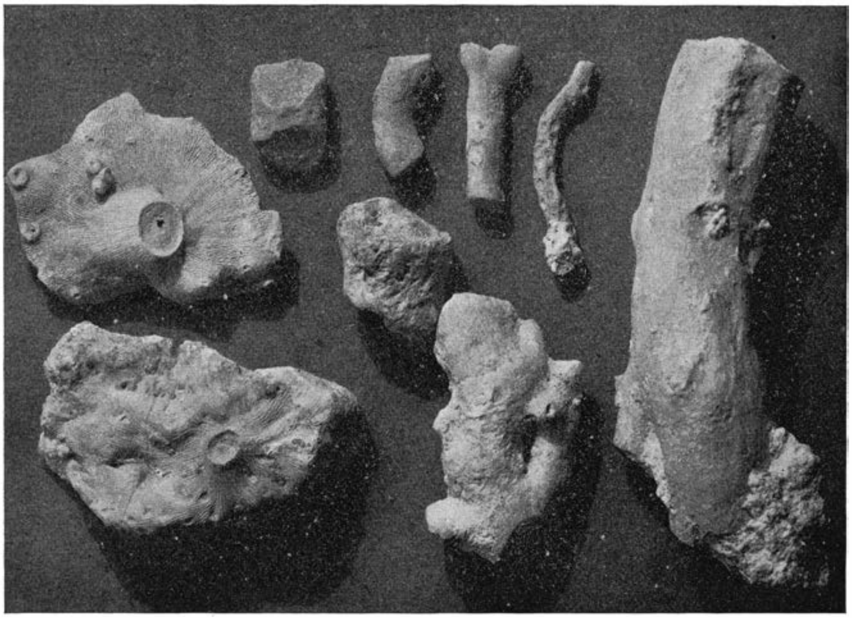

Fig. 18. Roots and branches of the calcareous skeleton of an Alcyonaria (*Moltkia Isis* STEENSTR. Danian. Limhamn. (Pl. 675.) — $^1/_1$.

Fig. 19. Alcyonaria lump with bryozoans. Danian. Limhamn. (Pl. 641.) — $^1/_1$.

The modern Alcyonaria are sometimes found at a depth of only a few meters but they belong as a rule to greater depths, often 200—400 m below the surface of the sea. The agreement between these numbers and those quoted above for Hexacoralla favours the opinion that the forms occurring in the Danian have developed at practically the same depth as the recent ones.

Recent Alcyonaria occur both in warm and cold parts of the seas. They are found in tropical seas as well as further north, in the warm surface waters as well as the cold waters at greater depths. CLARKE and WHEELER (1917, 17) believe to have found a decided relation between the content of $MgCO_3$ in the analysed forms and the temperature of their development: Alcyonaria from cold parts of the sea (northerly or deep) have a low content of magnesia, whereas those from warmer regions show a high content. Not least in consideration of this fact will it be of interest also to examine the chemical composition of the fossil forms.

In the Danian of Scania Alcyonaria occur not only on the coral reefs but also in the bryozoan and the Saltholm limestone. The animals have lived in a water free from mud, and even after their death and the destruction of the soft parts the calcareous stocks have in many cases lain free, forming an appropriate hold for colonies of bryozoa and serpula tubes. The lime cover on the coarser lumps of Alcyonaria reminds us in a high degree of algal limestone, and it is not improbable that it was formed by the action of algae. In this connection attention should be called to the fact that recent Alcyonaria to a large extent live in symbiosis with algae (GARDINER 1931, 86).

Heliolitida.

The corals of greatest importance as rock formers in the Silurian of Gotland do not belong to the groups mentioned above. Their structure is at any rate so unique that they cannot with certainty be counted either among Zoantharia or Alcyonaria. They are not mutually similar either but we must distinguish two classes among them: — Heliolitida and Tabulata.

Heliolitida are compound forms with stocks of varying shape: — sponge-shaped, cushion-shaped, tabular, etc. All show a number of fine coenenchymal tubes and among them scattered, wider polyp tubes (calicles). The species occurring in Sweden are exceedingly well described by LINDSTRÖM (1899), who has also essentially helped to clear up the relation between Heliolitida and other corals.

Heliolitida occur as early as in the Ordovician but the group attains its full development first in the Silurian. The best represented genera are *Heliolites* and *Plasmopora,* the former of which is known not only from almost the entire Gotlandic series of strata but also from the Silurian beds in Scania, Dalecarlia, and Jemtland.

Heliolitida often occur in the reef limestones, and together with stromatoporoids, bryozoans, and crinoids they constitute an important portion of these rocks. They are, however, equally often found in the stratified marlstones together with brachiopods, lamellibranchs, trilobites, a. o. Consequently, Heliolitida have not been particularly susceptible to the variations in the environmental conditions which have given rise to a series of petrographically widely differing rocks in for inst. the Silurian of Gotland. The only parts of this, that do not (primarily) contain any corals are the sandstones and oolites.

All the Heliolitida occurring in Swedish series of strata have lived in shallow water, in many cases no doubt at a very slight depth but never at or immediately below the low tide level. They have obviously preferred a tranquil water and have not been impeded in their development by a certain content of mud in the water or a moderate deposition of fine detritus.

Tabulata.

A number of the most remarked and, from a petrographical point of view, most important species of the Swedish Silurian belong to this group of corals. Tabulata are often developed in large stocks, sometimes compact, as for inst. in *Favositidae* (fig. 20), sometimes ramified, as in *Syringoporidae*. They are not only themselves important as rock formers, many are also specially suited by their structure to accumulate and retain the loose mud, washed along over the colonies. The conditions for inst. in *Halysites* is characteristic: in the cells formed between the flattened, united tubes of the colonies a fine clayey mud is almost always found, even if the coral occurs in a relatively detritus-free part of the series of strata.

Tabulata occur in the Swedish series as early as in the Middle Ordovician (the Chasmops limestone) but as Heliolitida they reach their strongest development first during the Silurian. The genera *Favosites* and *Halysites* are best represented but several others must be counted among the more important fossils of the Silurian strata. Thus certain species of e. g. the genus *Syringopora* are reef builders on a large scale.

Members of the above-mentioned genera and other Tabulata are found in varying numbers in the reef limestones of Gotland. Equally often, however, these corals are met with in the stratified limestones and marlstones.[1] On the whole Tabulata occur together with Heliolitida and have consequently developed in the same milieu as these corals.

Hydrozoa.

The fossil Hydrozoa belong to one of the animal groups least known from a paleontological and biological point of view. As will be seen below, they are, however, of great importance from a geological and specially from a petrographical point of view. Among the limestone formers in the Swedish series of strata the class is represented both by hydrocorals and stromatoporoids.

[1] *Tabulata* show a very great development in the oldest Silurian stratified limestones of Norderön in Jemtland (Hadding 1927, 36).

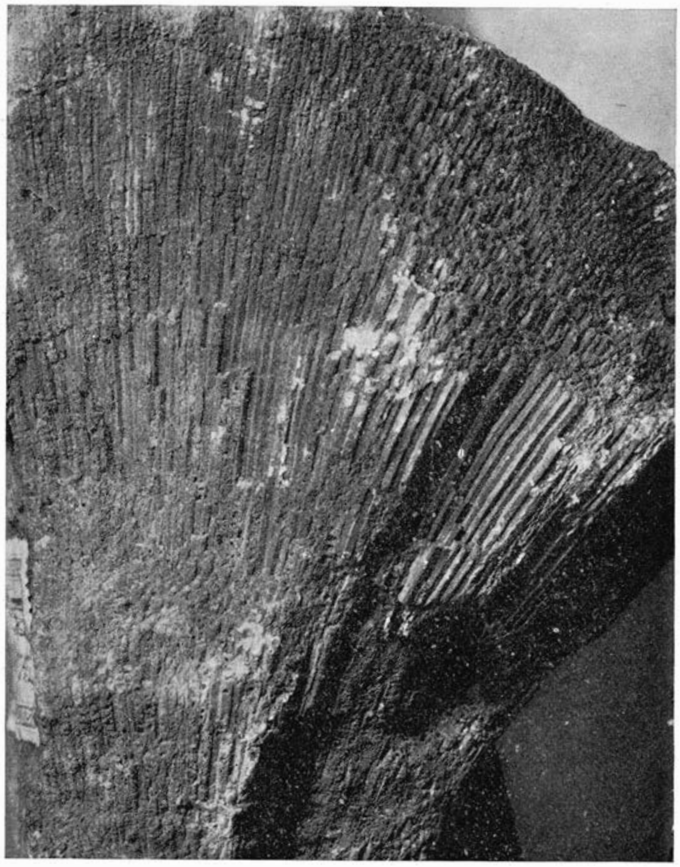

Fig. 20. Tabulate coral, compact stock (*Favosites*). Silurian. Bjersjölagård, Scania. (Pl. 679.) — 1/1.

Fig. 21. Silurian coral reef. Tabulata and Heliolitida together with stromatoporoids a. o. Holmestrand, Norway. Foto. 1912.

Hydrocorallinae.

In recent reefs the Hydrocoralla frequently occupy a very prominent place. They occur in all the coral reefs of the Atlantic as well as in the Indian Ocean and the Pacific. DARWIN (1889, 9) found that on the Keeling atoll in the Indian Ocean Hydrocoralla of the genus *Millepora* were only surpassed by the Hexacoralla *Porites* as reef builders, and the same observation was made by GREELEY on the Brazilian coral reefs (BRANNER 1904, 272). The Hydrocoralla often occur in meter-sized, tabularly extended colonies at and immediately below the low tide level. Their calcareous frame is harder and more resistant than that of the corals,

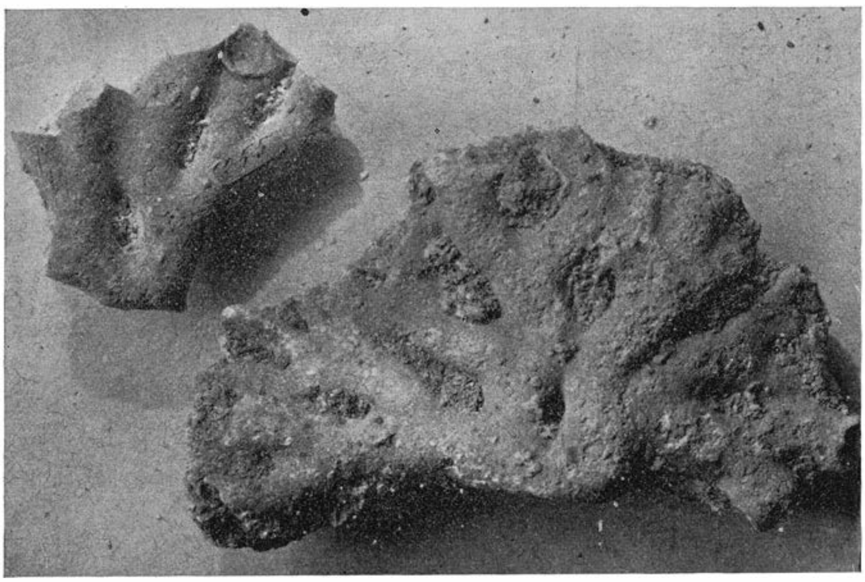

Fig. 22. Fragment of Hydrocoral (*Sporadopora?*). Senonian shell fragment limestone. Ignaberga, Scania. (Pl. 688.) — $^1/_1$.

and on that account they often become almost the sole occupants of the breaker zone on the outside of the reefs.

Hydrocoralla occur in the fossil Quaternary reefs in the same manner and numbers as in the modern ones, and they are relatively common in the Tertiary also. From the Mesozoic strata, on the contrary, they are only slightly known. Quite recently, however, BRÜNNICH NIELSEN (1919) showed a Hydrocoralla fauna fairly rich in species in the Danish Cretaceous deposits, more exactly in the coral limestone at Faxe. Several species occurring at Faxe are also found at Limhamn. However interesting those findings are in themselves, they have not altered our opinion of the content of rock-forming fossils in the Faxe limestone. For the Hydrocoralla are by no means of the same consequence in this limestone as in the modern reefs. As far as we know, the Mesozoic forms occur as a rule only sparingly and in small colonies, with narrow, only a few cm long branches.[1]

Stromatoporida.

In the older Paleozoic the stromatoporoids played a very important part as reef builders. There is reason to say that they constitute the bulk of most Silurian reefs. By studying the Gotlandic reefs in detail the author has collected

Fig. 23. Stromatoporoid. Basal view. Silurian. Bjersjölagård, Scania. (Pl. 635.) — $^1/_1$.

a rich material for the illustration of this and for the estimation of the mutual rôle played by the stromatoporoids, corals, and other organisms in the construction of the reefs. We shall have the opportunity of returning to these observations on the description of the rocks and shall here only give a short summary of the general occurrence of the stromatoporoids.

In his study of the Swedish Silurian reefs the author has as a rule found that the smaller the content of detritus is in a reef or a part of it, the higher its content of stromatoporoids. The content of detritus in the reefs increases in the same degree as the stromatoporoids give way to corals. This is partly due to

[1] In the bryozoan limestones at Limhamn (Danian) the author has observed abundant branches of Hydrocoralla.

the shape of the said organisms, partly perhaps to their milieu of development. The stromatoporoids have large and relatively even surfaces, and in comparison with the ramified and unevenly growing corals they are little suited to retain the mud washed across the reefs. Probably they have also essentially developed in a milieu in which only a small amount of mud could be deposited. Whether the stromatoporoids have, in the same manner as the modern Hydrocorals (for inst. *Millepora alcicornis*), endured strong breakers and thrived in them better

Fig. 24. Reef limestone with stromatoporoid. Silurian. Visby, Gotland. (Pl. 648.) — 1/1.

than the corals, the author is not able to decide for the present; a continued investigation of the relatively accessible Gotlandic reefs may, however, give an answer to this question also.

The stromatoporoids, however, are not exclusively found in pure limestones but to a large extent in more or less marly rocks also. We often find alternating stromatoporoid-bearing, highly calcareous and stromatoporoid-free, marly beds, indicating that the stromatoporoids have in these cases also essentially developed in periods and places with no or only slight deposition of mud.

Nowhere in the Swedish series of strata are the stromatoporoids as abundantly present as in Gotland but they constitute a considerable portion of the limestones in other places also, for inst. in the Leptaena limestone of Dalecarlia and in the youngest Silurian limestone at Bjersjölagård in Scania. At the latter place they occur in distinctly stratified sediments relatively rich in detritus.[1]

Echinodermata.

The calcareous plates and spines of the fossil echinoderms are always easily observed in the sedimentary rocks, because they, contrary to other organic calcareous formations, are not fine-crystalline but consist of large crystals of calcite. Macroscopically these crystals are specially conspicuous by their cleavage planes, microscopically they are recognizable by the simultaneous extinction in the entire fossil fragment. In this respect all the fossil echinoderms mentioned below are alike.

Most classes of echinoderms are represented in the Swedish sediments but only *Crinoidea, Cystoidea,* and *Echinoidea* occur as rock formers or in such a manner that they deserve to be taken up for discussion here.[2] All three groups of animals are more characterized by an occasional and local flourishing than an even distribution, though this is also seen in some series of strata. Such rocks as the Gotlandic crinoidal limestones, the Oelandic cystidean limestones, or the Scanian echinoidal »conglomerates» are typical examples of the rôle played by the said organisms for the formation of limestone.

Crinoidea.

Crinoids occur both in the Paleozoic and the Mesozoic series of strata but in Sweden they are found in larger quantities only in the youngest Ordovician and the Silurian, principally in Gotland.[3]

The reef limestones in Gotland are generally enclosed by distinctly bedded limestones built up mainly of crinoidal fragments. These limestones are easy of access in a number of cliffs (klintar) and show a wide distribution and considerable thickness. There is certainly no place on our earth that would offer us a better opportunity to study the results of the crinoidal limestone formation.

The crinoidal limestones may well be called fragment limestones or organogenic conglomerates (fig. 25). They consist namely almost exclusively of discs

[1] The Swedish stromatoporoids have not yet been subjected to a systematic investigation, and only a couple of species (of the genera *Labechia* and *Clathrodictyon*) have been identified. They are often strongly recrystallized but a material suitable for investigation may without difficulty be produced, chiefly from the marly series of strata.

[2] *Asteroidea* are known in Sweden from the Paleozoic as well as the Mesozoic sediments, *Blastoidea* from the Cambro-Silurian.

[3] The occurrence of *Antedon impressa* Carp. from the Senonian shell fragment limestone and *Cyathidium Holopus* Steenstr. in the Danian limestones of Scania ought to be mentioned (cf. Hennig 1899 c, p. 150 and 166; Grönwall photo. ibid. p. 167).

and plates detached from each other, scattered, and often distinctly worn by washing. Well preserved crowns and long stems, known int. al. through descriptions of ANGELIN (1878) and BATHER (1893), are not found in these rocks but in marlstones. The latter were formed in more tranquil water than the pure crinoidal limestones, and after the death of the animals the sea-lilies were embedded in the bottom mud. Is the sedimentation uninterrupted and is the deposited mud allowed to solidify around the crinoids without being disturbed, these will remain as undamaged as they were on the embedding.

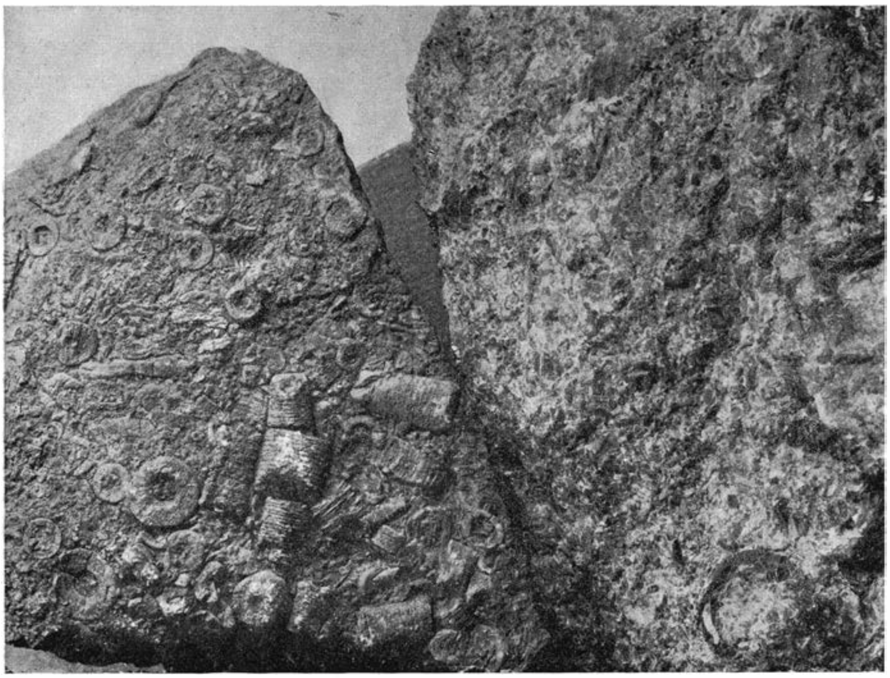

Fig. 25. Crinoidal limestone. Silurian. Left: sample from Bjersjölagård, Scania. Right: sample from Hoburgen, Gotland. (Pl. 682.) — $^1/_1$.

The result will be quite different, if the deposition of detritus ceases and the deposited mud is partly washed away. The crinoids will then lie free on the sea bottom, disintegrate, and form a fragment limestone of the above-mentioned type.

A comparison between the two above-mentioned rocks, the marls with scattered, well preserved crinoids and the relatively detritus-free limestones almost wholly built up of crinoid fragments, will guide us in our estimation of the conditions under which the crinoids lived and the crinoidal limestones were formed. A comparison between these rocks and those immediately surrounding them increases our possibilities of determining the milieu of formation.

As mentioned above, the crinoidal limestones enclose the reefs and not infrequently dovetail into them. Consequently they were formed in about the same milieu as the reefs. Their formation may have begun before and finished after that of the reefs. Where this has been the case the crinoidal limestones form the transition between the stratified, more or less calcareous marlstones and the unstratified reef limestones. It is often noticeable in the series of strata that the content of clay and the beds of marl decrease and the beds of limestone increase in thickness and numbers according as we approach the crinoidal limestone. The decrease in the deposition of clayey detritus can in this case be due only to an increased agitation of the water. The conglomerate-like enrichment of the fragments in a number of crinoidal limestones is a further proof of this.

The intensification of the movement of the water, that must have occurred with the abundant appearance of crinoids, may have been due to change in level, more exactly to an elevation of the sea bottom. A depression in this region and under the given conditions could never have resulted in a decrease in the deposition of fine-detritus, an increased deposition of calcareous sediments, and a formation of fragment limestones. Consequently, the crinoidal limestones together with the majority of the Gotlandic coral reefs were possibly formed in connection with elevations of land but certainly not during depressions. That elevations have occurred is also confirmed by the appearance of sandstones and oolites, which in some cases are found in close connection with crinoidal limestones and reefs.

It might lead too far to continue here the analysis of the crinoidal limestones and the significance of the reefs for the interpretation of the formation of the Silurian series of Gotland; the author will return to this problem in his account of the rocks. He cannot forbear, however, already here to mention that Wedekind and Tripp (1930) expressed the opinion that the Gotlandic reefs were formed during periods of depression, during transgressions. In his discussion of the rocks, however, the author will return to their interesting paper also.

Crinoids occur as rock formers not only in the manner mentioned above but also in beds completely isolated from reefs. As a rule these crinoidal limestones are also relatively free from detritus and formed under similar conditions as those enclosing reefs. In other places, on the contrary, the crinoidal rocks are more marly, even if the stems and cups have disintegrated into their particles. On the formation of these rocks the change in the environmental conditions causing the vigorous growth of the crinoidal fauna in a certain place, has been of short duration and in many cases locally limited. The crinoidal beds at Bjersjölagård as well as some of the Gotlandic are of this type. In most cases the mud has been washed in between the crinoidal fragments after their enrichment, and we have thus no reason on account of the nature of these rocks to repudiate our opinion that the abundant occurrence of the crinoids has occurred in periods and places with minimal deposition of detritus.

Examples of a secondary embedding of crinoidal fragments in mud are also met with in the Leptaena limestone of Dalecarlia. Cracks in this reef limestone are sometimes filled by a black, highly bituminous, clayey rock, which can be replete with crinoidal fragments in the lower part of the cracks. The author had the opportunity of studying this rock in the reef at Kallholn as early as 1909 and afterwards on a renewed visit to the place (1912). After the deposition the crinoidal fragments were washed down into the cracks formed in the reef, and these have later on been further filled up with mud. The fragments can also have been washed down from the reefs into the mud deposited around them, and Isberg (1917, 227) has published a good description and reproduction of a muddy crinoidal rock formed in this manner. However, pure crinoidal limestones also occur in connection with the Leptaena limestone reefs, and these reefs as well as the surrounding stratified limestones are on the whole rich in crinoidal fragments.

All recent crinoids are marine. They occur in all seas, in cold as well as warm waters, and at all depths, from a few meters to more than 5000 m below the surface. The whole of the Swedish crinoidal limestones are formed at slight depth, and observations in other places have shown that the Paleozoic forms, as far as we know, have exclusively developed in shallow water.

Occurrence in societies is characteristic of the recent crinoids, especially of those attached to the sea-floor. As is evident from the preceding, the fossil forms have also occurred in this manner and for that reason given rise to locally developed crinoidal limestones.

The fossil crinoids thrived in pure water on a mudfree bottom, often together with and consequently in the same milieu as reef-forming animals. On account of their wider distribution the recent ones are probably less dependent on the milieu; the author does not, however, know of any direct statements on this.

Cystoidea.

Cystoidea are wholly limited to the Paleozoic: the first forms occur in the Cambrian, the last in the Carboniferous. They are found in many places in the Swedish series of strata but as rock formers in a proper sense only in the Middle and Upper Ordovician. In petrographic respect they are not of the same importance as the crinoids but in spite of that their occurrence is not less interesting.

Of the Swedish cystidean limestones none is more accessible to studies than the Oelandic sphaeronite bed. In the middle part of the Orthoceras limestone at the border between the upper and the lower Asaphus limestone (Moberg 1890, 13) are one or two limestone beds replete with the spheric cups of *Sphaeronis pomum* Gyllenh. (fig. 26). We can follow these strata for a distance of more than 70 km.

Besides the sphaeronite bed still another limestone replete with Cystoidea is found in Oeland. This rests on the youngest bed of the Orthoceras limestone and forms the bottom bed of the Chasmops limestone. In this bed the Cystoidea occur as abundantly at least as in the sphaeronite bed but in this younger part of the series of strata they are represented by another species, *Echinosphaerites aurantium* HIS.

In the Ordovician series in Oeland Cystoidea are also found in other beds than in those mentioned above but only in scattered specimens. The very abundant occurrence of these echinoderms in single layers shows that they have, like others for inst. certain modern echinoids, preferably lived in widely distributed societies. Their time of flourishing has been short and their development intense and rapid. That this has been favoured by certain environmental conditions may be considered

Fig. 26. Cystidean limestone. *Sphaeronis pomum* GYLLENH. Ordovician. Kinnekulle, Vestergötland. (Pl. 680.) — 1/1.

as a matter of course, and an examination of the rocks enables us in some degree to estimate them. Regardless of the fossil content the cystidean beds differ only slightly from the surrounding calcareous strata but in one respect, by their higher content of clay, they often contrast with the rock in the hanging and foot walls. The increased deposition of detritus is certainly not caused by a change in depth; but it may be connected with changes in the currents of the sedimentary region. At a slight depth and in relative proximity to a shore but in tranquil water was the argillaceous mud deposited, in which the above-mentioned species of Cystoidea developed. In places where the local conditions prevented the formation of a mud bed the Cystoidea did not thrive; in the sphaeronite bed the situation of these places is demonstrable, as the bed thins out there. In other places the currents have changed during or after the development of the Cystoidea; we then find these fossils at their normal place in the stratigraphic series but embedded in a limestone relatively free from detritus.

In many places outside Oeland we find cystidean limestones, containing the same species and formed in the same manner as the Oelandic. These rocks are particularly well developed in Vestergötland, Östergötland, and Dalecarlia. It is remarkable that, in spite of the enormous abundance of individuals, these limestones are poor in species. As a rule only one species is found. Moreover, the case is similar in other countries, as BATHER (1913, 362) among others points out in his monograph on Upper Ordovician Cystoidea from Scotland.

As mentioned above, scattered individuals of Cystoidea, representing a number of species however, are found in many places outside the said beds. As the Oelandic species mentioned before, some of them are forms thriving in mud,[1] while others have developed in a milieu more free from mud, for inst. in the Leptaena limestone reefs. These different forms are of little interest from a petrographical point of view but we shall perhaps be able to establish from the rocks the developmental environment of the different species and study the relation between this and the development of the species. An extreme milieu can give rise to extreme forms but, as BATHER (1913, 494) points out, one and the same genus can occur in widely different rocks. The Swedish Cystoidea, however, are not yet systematically investigated and, as long as we do not know the different species and genera, it is impossible to discuss the details of their varying milieu of development.

Echinoidea.

The fragments of *Palæechinidae* sparingly found in the Silurian of Sweden are of no petrographical consequence, and no echinoids in the Triassic-Jurassic strata of Scania are of such an interest that they deserve to be mentioned here. The Senonian-Danian strata, on the contrary, are relatively rich in Echinoids, both regular and irregular.

In the shell fragment limestone, particularly in the zone with *Actinocamax mammillatus,* an abundance of well preserved specimens of the genera *Salenia, Phymosoma,* a. o. are to be found (fig. 27). The majority of the echinoid tests, however, are broken. The large number of plates and spines in some parts of the limestone speaks for a periodically very large content of echinoids. As compared to the lamellibranchs, however, they play a less important part in the construction of the said limestones (cf. DE GEER 1881, 400 and 1887, 19).

In the arenaceous sediments, the Åhus sandstone and the Köpinge sandstone, the echinoids are more sparingly present, though they are represented by a number

[1] A greath part of the cystidean limestone in Dalecarlia is developed as highly argillaceous marlstone. Sometimes relatively pure shales, for inst. the Trinucleus shale, also contain Cystoidea.

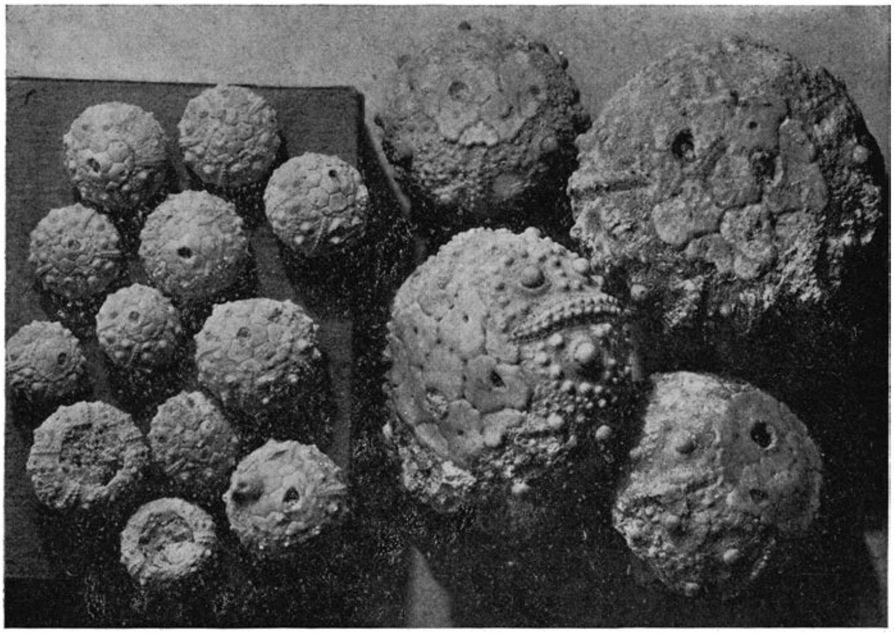

Fig. 27. Echinoids of the Senonian shell fragment limestone. (*Salenia areolata* WAHL., Barnakälla and *Trisalenia Lovéni* COTT., Ifö, Scania). (Pl. 683.) — 1/1

Fig. 28. Echinoids in Danian limestone. *Echinocorus* (*Ananchytes*) *sulcatus* GOLDF. Limhamn. (Pl. 638.) — 1/1.

of species. Particularly remarkable are the large forms of the genus *Micraster,* belonging to the more known fossils of the Köpinge sandstone.

Only a few echinoids occur in the Senonian chalk but in the Danian limestones they are sometimes so abundant that they form an essential part of a bed. The tests of *Echinocorus (Ananchytes) sulcatus* GOLDF. can form conglomerate-like beds (fig. 28), and loose spines and plates are spread in large numbers in the limestones. Sometimes the spines and plate fragments occur enriched to course-grained beds (fig. 29).

Fig. 29. Limestone with fragments of echinoids. Danian. Limhamn. (Pl. 639.) — $^1/_1$.

In order to form a correct opinion of the echinoids' importance as environmental documents, or vice versa to infer from the rocks the conditions under which the different fossil forms developed, a detailed knowledge of the occurrence and distribution of the different genera and species is required. As to the recent forms we have such a number of observations in this respect that we are able to form a fairly sure opinion from them. For natural reasons the circumstances are not as favourable in the case of the fossil species, and the author would specially wish that the Swedish Cretaceous echinoids had been monographically treated of in the same manner as the corresponding Danish forms (RAVN 1927 and 1928). The Swedish material is of greater petrographic interest than the Danish in so far as it is derived from rocks of very different character. The existent descriptions of or reports on the echinoids (as far as Sweden is concerned by HENNING, LUNDGREN, Schlüter, etc.) refer as a rule to the well preserved specimens and are seldom suited for a determination of the small fragments of which the rocks are more or less built up. Here and there in literature, certainly, reports on the micro-structure of the echinoids occur, and this has also been the object of special investigations (e. g. by Hesse 1900) but in many cases the specific determinations of the rockforming fragments are connected with great difficulties. However, even with our present slight knowledge of the distribution of the species it is possible to make inferences as to their milieu of development. Thus, the examined material shows that in the Swedish Cretaceous series members of the family *Spatangidae* are particularly abundant in the sediments rich in coarse detritus, while members of *Salenidae* and *Diadematidae* (fig. 27) are most common in the relatively detritus-free shell fragment limestones formed on shores of Archaean rocks. The coral, bryozoan, and dense coccolith and foraminiferal limestones, formed at somewhat greater depth and further from the shore, principally contain forms belonging to the family *Holasteridae*. Species of *Cidaris* and other *Cidaridae* are generally spread. All the forms belong to the shallow sea. As is known, the recent echinoids are very widely distributed: they occur in all seas at very varying depths down to 3000 meters or more below the sea-level. The majority of forms, however, have their principal development above the level of 200 m, and many of them are most abundant at slight depth below the low tide level.

The modern sea-urchins live in societies and especially at the time of the impregnation of the eggs they accumulate in large numbers at certain places, sometimes places where they are otherwise hardly found at all. The abundant occurrence of echinoids in some beds in the fossil series of strata shows that the forms long since extinct have lived in about the same manner as the modern ones.

On the study of the fossil Echinoidea and Cystoidea the attention is often attracted by the large crystals of calcite growing radially towards the centre from the inner side of the tests. Each of these crystals forms a crystallographic unit together with the calcareous plate on which it has grown. In the fossil forms the intrinsically thin and porous test is always crystallized in such a manner that each plate and each spine forms a crystal. During the crystallization the test has often thickened but has preserved all the details in the sculpture of the surface.

Vermes.

The worms do not play any greater rôles as limestone formers in the Swedish sediments. Certainly, different kinds of Serpula tubes are found in the Paleozoic as well as the Mesozoic series of strata but never in such quantities that they contribute essentially to the formation of limestones. No correspondence to the recent and fossil Serpula reefs in the Bermudas and other places occur in the Swedish sediments.

The Serpula tubes are most frequently found grown on to mollusc shells, corals, and bryozoans but also to echinoids, belemnites, or loose blocks. Sometimes, however, the tubes occur loose or grown together in fascicles or twisted masses. The author has observed the latter types best developed in the shell fragment limestones of the Senonian in north-eastern Scania (fig. 30).

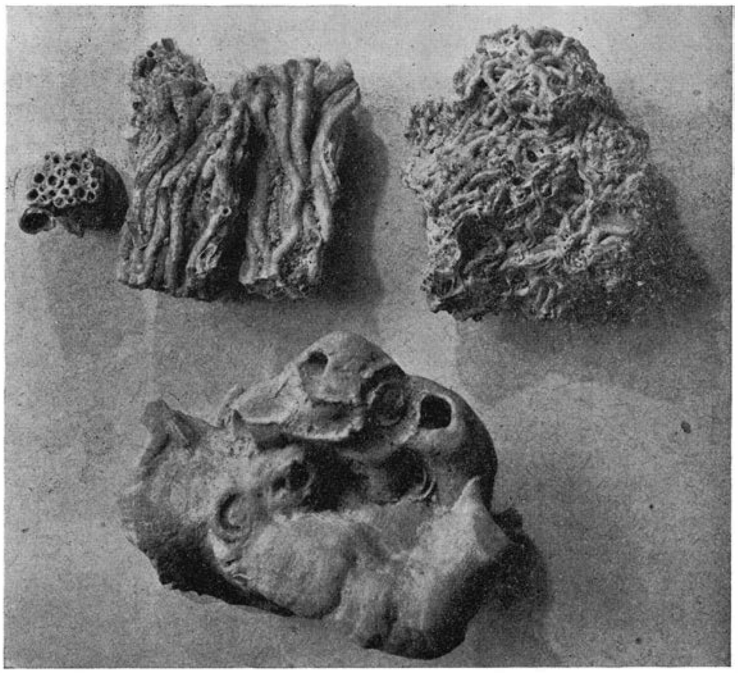

Fig. 30. Different forms of Serpula tubes from the Senonian shell fragment limestone. NE-Scania. (Pl. 687.) — $^1/_1$.

Molluscoidea.

As rock formers Molluscoidea are of great importance and, as will be seen from the following account of their occurrence in the Swedish sediments, this holds good of *Bryozoa* as well as *Brachiopoda.* These two classes, however, occur in quite different manners as rock formers.

Bryozoa.

The corals and bryozoans, biologically so very different, show many conformities as limestone formers. Both groups of animals live in colonies and build up calcareous bodies of the most varying forms: — compact, ramified, netlike, etc. Though the bryozoans are not reef formers, they nevertheless can, in the same manner as corals and stromatoporoids, form the bulk of thick limestones. The reason why the bryozoans do not form reefs is partly the slender and fragile structure of the ramified forms, and partly the small size of the compact forms. The bryozoan limestones are mainly built up of horizontally lying fragments of branches (fig. 31). Together with them we find varying amounts of fossil remains of other organisms, for inst. shells of lamellibranchs and gastropods, fragments of echinoderms, etc.

Fig. 31. Bryozoan limestone. Silurian. Gotland. (Pl. 636.) — $^1/_1$.

Numerous members of all the limestone-forming bryozoan orders are found in the Swedish series of strata. *Cryptostomata* and *Trepostomata* occur already in Ordovician strata and have their principal distribution (in Sweden) in the Silurian. *Cyclostomata* are met with both in the Ordovician-Silurian and in the Cretaceous deposits, while in Sweden *Cheilostomata* are limited to the Cretaceous beds.[1]

Trepostomata are well represented in the Silurian of Gotland partly by compact, spherical or tabular types, particularly species belonging to the families *Monticuliporidae* and *Trematoporidae*, partly by finely branched forms, for inst.

[1] As regards descriptions of bryozoans occurring in Sweden the author refers to the works of int. al. HENNIG, VOIGT, LEVINSEN included in his bibliography.

species of the family *Batostomellidae*. As far as the author knows, these different forms are nowhere rock formers in a proper sense.

On the study of the series of strata in Gotland characteristic forms of *Cryptostomata* are met with almost everywhere. It is sufficient to call attention to the netlike species of *Fenestella* and the still more scattered, foliate species of *Ptilodictya*. Nor can these species be called rock formers in spite of their general occurrence.

Fig. 32. Bryozoan limestone with *Coenitis repens* WAHL. Marly. Silurian. Halla limestone. Möllebos, Gotland. (Pl. 647.) — 1/1.

Although *Cyclostomata* have their proper flourishment during the Mesozoic, they show a number of species already during the Silurian. They are found developed in varying forms, mostly ramified however, sometimes adherent, slender-branched as *Stomatopora*, and sometimes freely developed with thicker branches, for inst. the species of *Coenites*. The latter, particularly *C. repens* WAHL., sometimes occur in such abundance that they form the bulk of certain limestone beds. The author has found no more typical bryozoan limestones in the Gotlandic strata than those essentially built up of different forms of *Coenites*. These rocks are sometimes relatively detritusfree fragment limestones containing, besides branches of bryozoa, crinoidal fragments, shells of molluscs, a. o. (fig. 31), but in other cases the rock is developed as detritus-rich (marly) limestone with very well preserved bryozoans laid bare on weathering (fig. 32).

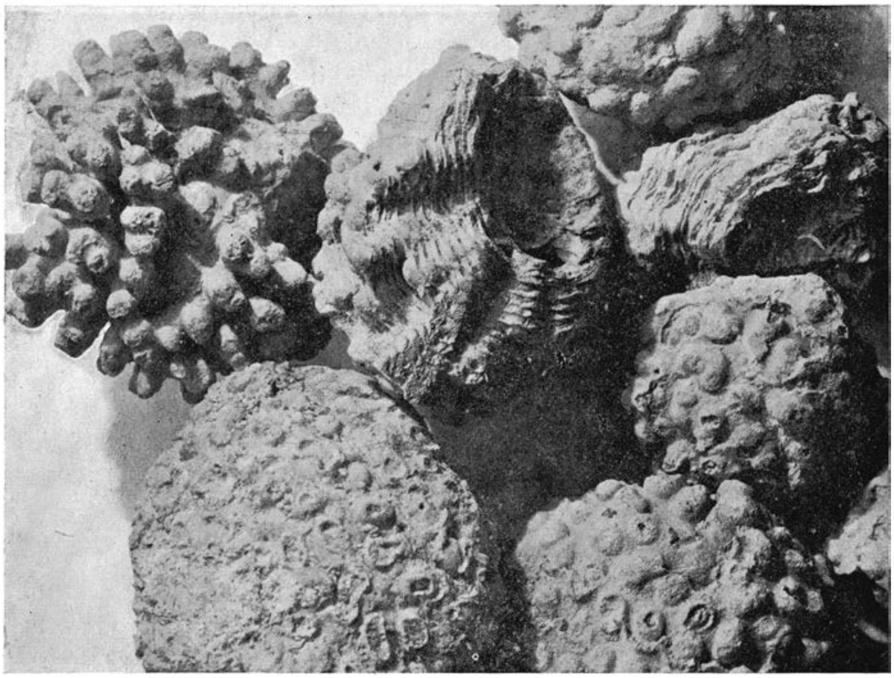

Fig. 33. Globular Cyclostomata from the Senonian shell fragment limestone. *Lichenopora* (upper left ball) and *Ceriopora*. Balsberg, Scania. (Pl. 697.) — 1/1.

Fig. 34. Fragments of ramified Cyclostomata. *Heteropora crassa* v. HAG. Senonian Balsberg. (Pl. 690.) — 1/1.

In the Swedish Senonian and Danian sediments the *Cyclostomata* are still more abundant than in the Silurian and also more varying in form. Compact, more or less spherical zoaria of the genera *Ceriopora, Lichenopora,* a. o. occur in the Senonian shell fragment limestones as well as in the different Danian limestones (fig. 33). Ramified or foliate forms, essentially belonging to *Cheilostomata,* however, are still more spread and it is principally among them the rock formers proper are found.

In the bryozoan limestones, for inst. in the Danian series of strata at Limhamn, we find the majority of types represented by numerous individuals. On a closer examination of the rock we also find that it is by no means wholly built up by bryozoans, as we might believe on a more cursory inspection. In a sample examined by the author an abundance of Hexacoralla, Octocoralla, Hydrocoralla, echinoidal spines, Serpula tubes and a smaller amount of brachiopod and mollusc shells were found. The bulk of the rock, however, consisted of fragments of bryozoa, and most individuals identified belonged to the genera *Membranipora, Onychocella, Rhagasostoma,* and *Porina.*

Fig. 35- Bryozoan limestone. Danian. Limhamn, Scania. (Pl. 644.) — 1/1.

The bryozoan limestones in the Danian of Scania are often remarkably pure fragment limestones free from calcareous mud and fine detritus (fig. 35). They generally have no greater amount of secondarily deposited calcitic cement either. Both in consideration of the diagenetic processes and of the conditions prevalent on the formation the bryozoan limestones thus differ from the other limestones, the coral and Saltholm limestones, included in the series of strata. The author will return to these problems in his account of the rocks and his discussion of their formation.

An estimation of the forming conditions of the fossil bryozoan limestones is hardly possible from their content of bryozoans. We must instead try to form an opinion of the conditions under which the fossil forms of bryozoans lived, from the nature of the rocks.

The recent bryozoans are found in all seas and at different depths, though most abundant in the warm seas and at slight depth (less than 300 m). Several forms, however, occur in brackish or fresh water. The wide distribution of the separate genera and species is characteristic of the recent forms.

All bryozoans occurring in the Paleozoic and Mesozoic series of strata of Sweden are found in marine sediments formed at slight depth [1] and no doubt also in relatively warm water. Several forms could obviously have developed in regions with moderate deposition of fine detritus, others have preferred a purer water. In places where the bryozoans occur as rock formers they have in some cases, though not always, been subjected to a secondary enrichment.

Brachiopoda.

Shells of brachiopods are generally found in the Swedish Paleozoic and Mesozoic sediments. They are very often found enriched at some bedding surfaces, more infrequently they occur in equal abundance through whole beds. Terms as »Brachiopod shale», »Pentamerus limestone», etc. refer to stratigraphic units of which brachiopods of one or more genera form a noticeable part, without necessarily playing any greater petrographical rôle. Locally, however, the brachiopod shells are sometimes so abundantly enriched that, even if they do not form the bulk of the rock, they nevertheless constitute an essential part of it. This for inst. is the case in certain parts of the Leptaena limestone, in which members of the families *Orthidae* and *Strophomenidae* can be found in pure populations. Limited portions in scattered beds of the Oelandic Ceratopyge limestone are in the same manner mostly built up by *Eoorthis Christianiae* Kjerulf more or less mingled with *Eoorthis Wimani* Walc. and *Lingulella lepis* Salter.

The large and thick shells of *Conchidium conchidium* L. (fig. 36), *C. tenuistriatum* Walmst., *Pentamerus gotlandicus* Leb., *Stricklandinia lirata* Sow., a. o. occur in the Gotlandic series of strata not only as fossils characteristic of certain zones but sometimes also as an important ingredient of calcium carbonate in the rocks. In the last-mentioned respect the small and thin shells of a number of species are by no means less important. In the Silurian series of Gotland the author has

[1] The Danian bryozoan limestone at Limhamn was according to Hennig (1899 c, 166) formed at a depth of 100—150 fathoms.

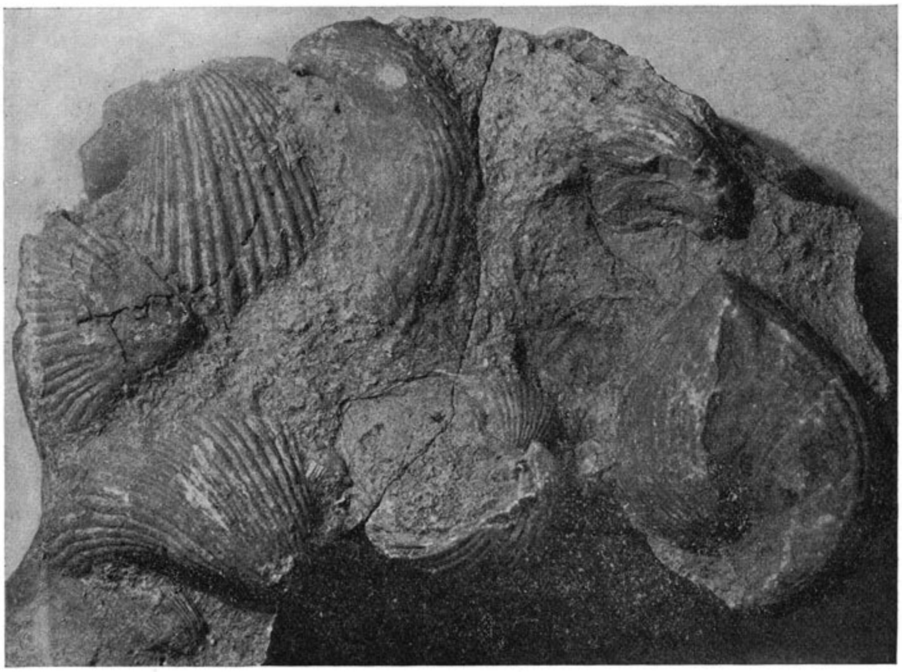

Fig. 36. Limestone with large brachiopods. *Conchidium conchidium* L. Silurian. Klinteberg, Gotland. (Pl. 691.) — 1/1.

Fig. 37. Brachiopod limestone. *Camarotoechia nucula* Sow. Silurian. Djupvik, Gotland. (Pl. 692.) — 1/1.

observed separate beds replete with shells of *Dalmanella canaliculata* LINDSTR., *Camarotoechia nucula* Sow. (fig. 37), *Atrypa reticularis* L., *A. Angelini* LINDSTR., *Dayia navicula* Sow., or other forms. Sometimes these brachiopod beds constitute good index layers in the series, whereas in other cases the species show a large vertical or a small horizontal distribution and then as a rule a local and strongly varying development.

The brachiopods are not confined to the beds in which they occur in the above-mentioned manner. Shells of brachiopods are also found as fragments interspersed in limestones of different kinds, and it is questionable whether this occurrence is not petrographically of the same importance as that described above. In the Paleozoic strata brachiopods are principally found together with fragments of trilobites, ostracods, and echinoderms and in the Mesozoic strata mainly together with lamellibranchs, bryozoans, hydrocorals, and corals. In the Ordovician series of strata in Oeland, the Silurian in Gotland, and the Senonian in Scania the author has met with numerous samples of brachiopod-bearing fragment limestones of this type. Owing to a great resistance to wear and breaking as well as to decomposition the fragments of brachiopods are relatively well preserved and easily identified both macroscopically and microscopically.

Whether the fossil brachiopods have been as widely distributed vertically as the modern ones is not evident from their occurrence in the Swedish sediments. This shows, however, that they also attained a strong development in the shallowest parts of the sedimentary regions immediately adjacent to the shore. We find them abundantly present in conglomerates and sandstones as well as in shales, marls, and limestones. In all these rocks the brachiopod shells are sometimes also found secondarily enriched. That they are most abundant in the limestones must of course not be regarded as if the brachiopods had been strongest developed in regions where calcareous mud was deposited. The dense rocks built up by calcareous mud, for inst. the chalk, the Saltholm limestone, and certain Ordovician and Silurian limestones are in reality remarkably poor in brachiopods. These have preferably lived on a bottom of solid rock, coarse detritus, or fragments of shells. In places where the deposition of detritus has progressed without interruption, the shells have become scattered in the formed sandstone or clayey rock. Occasional variations in the sedimentation may have given rise to beds rich in shells or, more exactly, local accumulations of shells at one place and sediments poor in shells at another.

The brachiopod shells embedded in sandstones and other coarse sediments have naturally undergone a stronger dissolution through water circulating in the sediments than those included in marls and limestones. In this connection attention should be called to the fact that together with shells of calcite we also find shells of chitin and calcium phosphate which are more resistant than the calcareous shells to dissolution. The author will here only mention the family *Obolidae*, represented in Sweden also by forms of rock-forming importance, for inst. in the Obolus limestone of Dalecarlia.

Mollusca.

Rock-forming molluscs are principally lamellibranchs but gastropods and cephalopods can also constitute a petrographically important part of the calcareous sediments. The different forms often show a very restricted vertical distribution in the series of strata at the same time as they can be spread over relatively large regions. As they are also abundantly present, easy to observe, and often positively identifiable, they have become exceedingly important as index fossils. On that account they have been of great interest to the paleontologists and stratigraphers, and we now know innumerable genera and species and also relatively well their occurrence in the series of strata. However, we shall not here give an account or even a summary of our knowledge as to the stratigraphic or geographic occurrence of the different forms, genera, families, etc. The author only intends to throw light on the mode of occurrence of the different classes and on their importance as limestone formers.

Lamellibranchiata.

The post-glacial shell beds on the west coast of Sweden give us the best examples and proofs of the lamellibranchs' occurrence as rock formers and of their important rôle as such. In the fossil series of strata other, still more important sediments of lamellibranchs are to be found but the shells are there as a rule broken, and generally they do not, as a shell bed in Bohuslän, give us the impression that the rock is built up of shells.

In many places in the fossil series of strata of Sweden we find limestones and other calcareous sediments in which the most important organic ingredient consists of lamellibranchs. The shells are often so generally present that they cover the greater part of a bedding surface but in spite of that only relatively few parts of the series contain a sequence of strata in which the lamellibranchs occupy so much of the mass that they may be said to be important as rock formers.

In the Ordovician and Silurian strata scattered shells of lamellibranchs are often found, but in the sediments poor in calcium carbonate and rich in detritus the shells are seldom preserved. In some places in the Upper Silurian and where limestone facies prevails, the shells can form an essential part of the rock. The Megalomus beds in Gotland (fig. 38), are illustrative examples of this. Even if the shells in these rocks are transformed or wholly dissolved, their casts and moulds nevertheless give us a clear idea of their importance for the construction of the limestone.

The shells of lamellibranchs play a similar rôle in certain calcareous beds in the youngest Silurian of Scania (the Öved-Ramsåsa-Klinta series) and also in a number of Tertiary blocks in Scania (see HADDING 1929, p. 259, fig. 137 and 138).

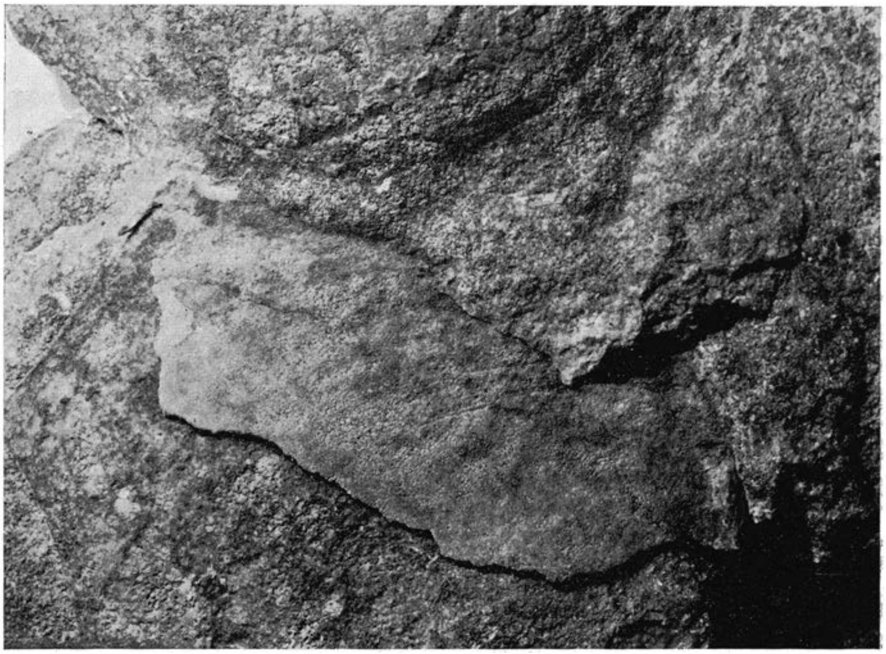

Fig. 38. Megalomus limestone. Shell fragments of *M. gotlandicus* LINDSTR. Petsarve klint, Gotland. (Pl. 699.) — 1/1.

Fig. 39. Lamellibranch limestone with orthoceratite. Silurian. Ramsåsa, Scania. (Pl. 700.) — 1/1.

Fig. 40. Fine grained fragment limestone with large shells of lamellibranchs. *Spondylus* and *Ostrea*. Senonian. V. Olinge, Scania. (Pl. 702.) — $^1/_1$.

Fig. 41. Lamellibranchs from Senonian shell fragment limestone. *Ostrea haliotoidea* Sow. and *O. cornu arietis* NILSS. Kjuge, Scania. (Pl. 698.) — $^1/_1$.

Fig. 42. Large Ostrea shells from Senonian shell fragment limestone. *Ostrea diluviana* L. Karlshamn, Blekinge. (Pl. 701) — 1/1.

Fig. 43. Shell fragment limestone with lamellibranchs, brachiopods, bryozoans, echinoderms, corals, a. o. Senonian. Balsberg, Scania. (Pl. 645.) — 1/1.

The shells are never as large as in the above-mentioned strata of Gotland but they certainly occupy an equally large part of the rock (fig. 39).

The largest accumulation of shells or fragments of lamellibranchs occurring in the Swedish series of strata is found in the Senonian shell fragment limestone in north-eastern Scania and in adjacent parts of Blekinge and Halland. The shells are here accumulated in thick layers directly on the Archaean rock surface or on the weathering products covering it. The accumulation of shells has taken place in the neighbourhood of the shore line and at slight depth. Conglomerates occur both at the base of the series of strata and in the interior of it. The content of fine detritus in the shell gravel is often very low. The enormous development of the lamellibranchs and the accumulation of their shells have occurred in a relatively mud-free, agitated water. A great part of the shells have been broken and ground by wave action (fig. 40), and the fragments have been sorted before the deposition. In some places the fragment limestones are therefore built up of relatively large fragments of shells, in others of smaller fragments or calcareous mud. However, other variations in the nature of the rock often occur, showing that the environmental conditions have changed. The percentage of lime and detritus, the coarseness of detritus, etc. vary not only from place to place but also from bed to bed (see the numerous reports on this published by Grönwall 1915). The size and thickness of the shells also show great variations.

The shell fragment limestone is mainly built up of shells of lamellibranchs but it also contains a varying amount of fragment of other organisms: echinoderms, bryozoans, brachiopods, corals, etc. (fig. 43). The more fine-grained forms sometimes contain fairly abundant foraminifera. The shells and fragments are sometimes relatively free, sometimes embedded in calcareous mud, and sometimes cemented into a solid rock. In some cases this diverse petrographic character stands in a definite relation to the conditions of deposition but it does not show any clear changes in the lamellibranchs' milieu of development.

The recent lamellibranchs are, as the fossil ones, principally marine. They occur at very different depths but their strongest development takes place close to the shores and at less than 100 m. As a rule the forms living at greater depths have thinner shells than the shallow water forms, but variations in salinity, temperature, and food supply of the water influence the development of the different forms. For the study of the environmental conditions under which the fossil series of strata were formed it is therefore of consequence that attention is also paid to the lamellibranchs enclosed in them.

Gastropoda.

The Swedish pre-Quaternary sediments are nowhere essentially built up of gastropod shells, and only seldom are these shells accumulated in such quantities that they dominate over other fossils present in the rock. Some of the Tertiary rocks found on the south coast of Scania are relatively rich in gastropods (fig. 45). In the Paleozoic and Mesozoic limestones and marlstones members of several different genera and species are found; thus for inst. Lindström (1884) described no less than 174 gastropod species solely from the Silurian beds of Gotland. The shells occur, however, only in scattered specimens in the reef limestones as well as in the stratified limestone and marly shales. In the Cretaceous limestones shells of considerable size (fig. 44) are present both in the Senonian shell fragment limestone and in the Danian limestones but do not play any greater rôle in these rocks either.

In the same manner as the lamellibranchs the gastropods also occur in the seas as well as in brackish and fresh water. The marine forms occur at varying depths, though most abundant in shallow water adjacent to the shores. For the estimation of the conditions of formation of the fossil sediments several genera are of interest.

The family *Hyolithidae*, represented in the Swedish Cambro-Silurian strata by a number of species (see int. al. Holm 1893), probably belongs to the gastropods, more exactly to the *Pteropoda*. Their conical or pyramidal calcareous shells occur scattered in different parts of the series of strata, most numerous, however, in its lowest part, the Olenellus and Paradoxides stages. Only in one place, the upper part of the Middle Cambrian, are the shells enriched to such an extent that they form an essential part of the rock. This rock, however, the Hyolithes limestone, is not very thick and has probably a fairly inconsiderable horizontal distribution.

The small but thick-shelled tubes of *Tentaculites* are abundantly present in the Swedish Silurian strata, sometimes enriched in a bed or on bedding planes. Their place in the system is not quite plain. Petrographically they are of no importance but a more detailed study of their distribution would be of great interest, not least from the point of view that it would enable us to form a more reliable idea of the life at these animals. As *Styliola* and other recent pteropods, they probably occurred in the manner of plankton. They ought to be valuable as index fossils.

Cephalopoda.

The cephalopods are of an enormous geologic significance, particularly from a stratigraphic point of view. It suffices to mention the three most important sub-orders of the class: — the nautiloids, ammonites, and belemnites. As rock formers they are only of little consequence, but in the following a short account of their occurrence in the Swedish sediments will be given.

Fig. 44. Gastropods (moulds) from Senonian shell fragment limestone. *Cerithium.* Ifö, Scania. (Pl. 704.) — 1/1.

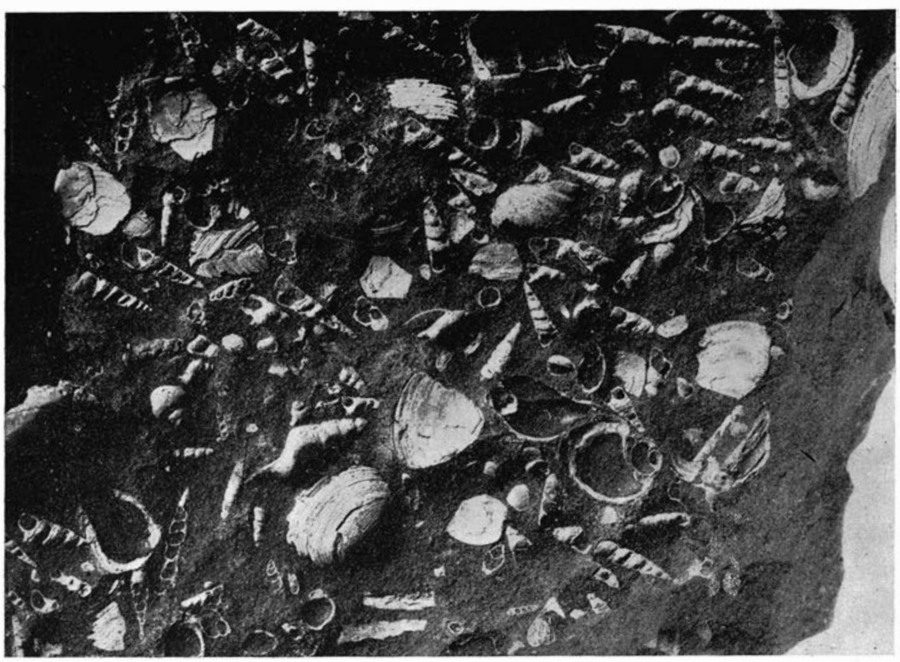

Fig. 45. Gastropods and lamellibranchs. Tertiary sandstone. Erratic block. Glumslöv, Scania (Pl. 703.) — 1/1.

Nautiloidea.

In the Ordovician limestones a number of species belonging to the genera *Endoceras, Orthoceras, Lituites,* a. o. occur. The thick and widely spread limestone series in the Middle Ordovician, the Orthoceras limestone, is in a certain degree characterized by these fossils, which never occur in such quantities that they essentially contribute to the building up of the rock. In the Silurian beds the nautiloids also play a similar rôle (fig. 46). The author will only call attention to the genera *Ascoceras* and *Phragmoceras,* described in detail from

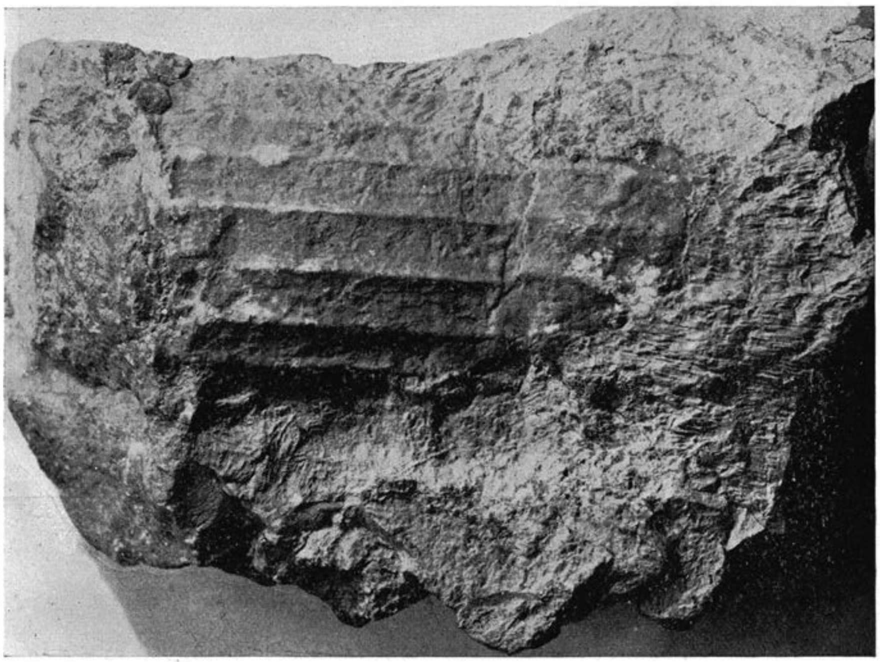

Fig. 46. Fragment of orthoceratite in Silurian limestone. Gotland. (Pl. 706.) — 1/1.

Gotland (Lindström 1890, Hedström 1917) and often found in certain parts of the Gotlandic series of strata together with orthoceratites.

In the Danian limestones, especially the coral limestone, we find a few species of *Nautilus,* one of which, *N. danicus* Schloth., also shows a great number of individuals scattered in the reef lumps. The shells are never preserved, only the moulds of compact, hard limestone.

Ammonoidea.

The ammonites observed in the Mesozoic sediments of Sweden are never abundant; they are not even so common that they could advantageously be used as index fossils. For the estimation of the age of the beds, however, certain species are of interest, for inst. *Ammonites Bucklandi* a. o. in the upper part of the Liassic beds at Dompäng in north-western Scania and *Ammonites Jamesoni* in the lower part of the Jurassic series at Kurremölla in south-eastern Scania. The ammonites in the Senonian (fig. 47) are also stratigraphically interesting but without importance as rock formers.[1]

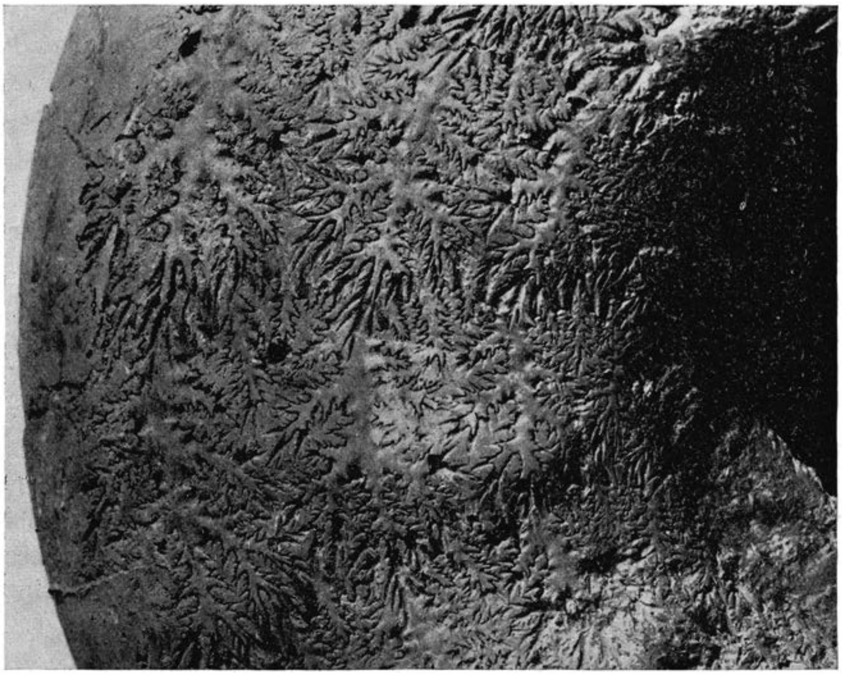

Fig. 47. Fragment of an ammonite from Senonian shell fragment limestone. *Am. Stobaei* NILSS. Ifö, Scania. (Pl. 712.) — 1/1.

Belemnoidea.

Of the dibranchiates only *Belemnoidea* or more exactly the family *Belemnitidae* is represented in the Swedish sediments. Belemnites have been found in the Jurassic strata of Scania but they are tolerably numerous only in the Senonian limestone and marls. It is, however, an exception that the rostra are accumulated in such quantities and occupy an essential part of the rock. As a rule they lie well scattered in the shell gravel, or in the calcareous or marly mud. In places where, as at Ugnsmunnarna in Ifö, they are accumulated in certain beds, they are secondarily enriched by the action of the waves on a shore.

As the ammonites, the belemnites are of a great stratigraphic but slight petrographic interest. They are of little use in the interpretation of the developmental

[1] Some of the forms are of large dimensions; *Ammonites Stobaei* NILSSON can reach 1/2 m in diameter.

milieu of the rocks, in spite of the fact that we can to a certain degree infer the mode of living of the belemnites from the investigations of Abel (1916). In this connection the author wishes further to emphasize what he has so often had reason to point out, viz. that it cannot be inferred from fossils or minerals in a sedimentary rock that this was formed in the milieu in which the fossilified organism lived or the mineral was formed. In the discussion of the mode of living of the fossil dibranchiates Abel (1916, 203) expresses the same opinion when he sais that the animals can have lived, died, and been buried in quite different places.

Arthropoda.

Of arthropods numerous members of the class *Crustacea* occur in the Swedish sedimentary rocks, but only exceedingly seldom species belonging to *Merostomata* (for inst. *Eurypterus*) or *Arachnoidea* (for inst. *Paleophonus*) are found. As limestone formers only crustaceans are of importance.

Crustacea.

Crustaceans are fairly common in the marine sediments of all the formations represented in Sweden. In the Paleozoic strata ostracods and trilobites, thus *Entomostraca,* in the Mesozoic, on the contrary, *Malacostraca,* more exactly decapods, dominate. Cirripids and phyllocarides are only very sparingly found and may be quite left out of account here.

Ostracoda.

The ostracods are characteristic fossils in some parts of the Cambro-Silurian series of strata. They occur not only in limestones but also in shales and sandstones. Thus they are found in large quantities for inst. in the Middle Ordovician black shales above the zone with *Nemagraptus gracilis* at Fågelsång in Scania as well as in certain sandstone beds of the Upper Silurian at Ramsåsa-Klinta. From natural causes, however, the shells are best preserved in the highly calcareous rocks, and among them beds are also found that can essentially be built up of ostracod shells (fig. 48 and 49). Terms as »ostracod limestone», »Leperditia shale», and »Beyrichia limestone» used of Silurian rocks may be inappropriate in so far as they refer to stratigraphic units but in many cases they are suitable as sediment-petrographic notions.

The recent ostracods occur in saline as well as brackish and fresh water, and they are pronounced shallow water organisms. In the Swedish pre-Quaternary sediments we know them only from marine beds which, however, as a rule are of a marked shallow water type. Stratigraphic series which, judging from the nature of the sediments, were formed at varying depths, also show an obvious

Fig. 48. Ostracod limestone with brachiopods and lamellibranchs. See also fig. 49. Silurian. Bjersjölagård. (Pl. 710.) — 1/1.

Fig. 49. Ostracod limestone, rich in *Beyrichia*. The same bedding plane as in fig. 48. — 4 ×.

Fig. 50. Trilobites in stinkstone. *Agnostus laevigatus* DALM. and *Liostracus costatus* ANG. Upper Cambrian. Ulunda, Vestergötland. (Pl. 708.) — 1/1.

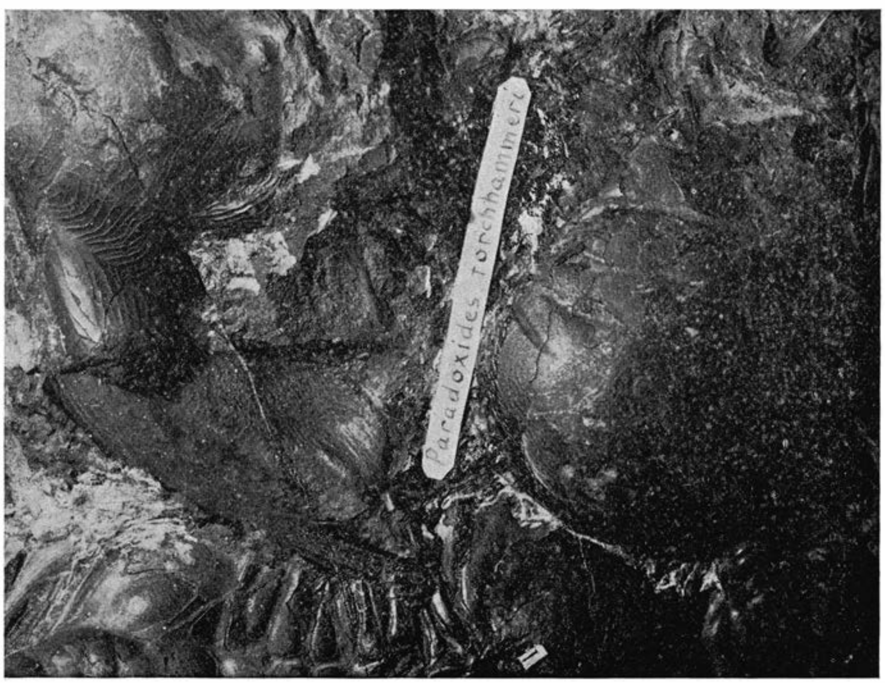

Fig. 51. Trilobite limestone with *Paradoxides Forchhammeri* ANG. and *Centropleura Lovéni* ANG. Andrarum limestone. Andrarum, Scania. (Pl. 707.) — 1/1.

Fig. 52. Silurian limestone rich in calcareous fossil fragments: corals, stromatoporoids, bryozoans, brachiopods, gastropods, cephalopods, ostracods, and trilobites. Gotland. (Pl. 705.) — $^{1}/_{1}$.

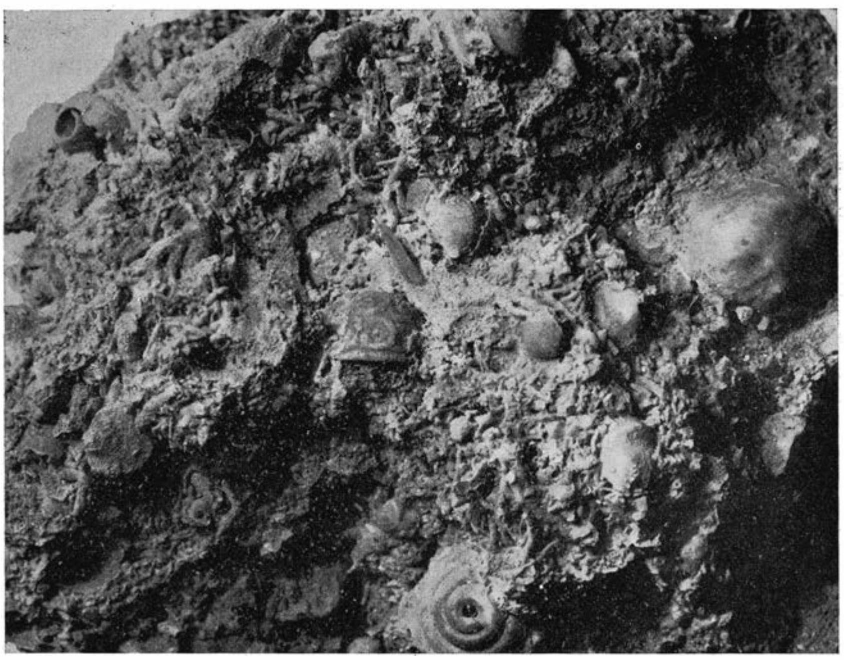

Fig. 53. Cretaceous limestone rich in calcareous fossil fragments: corals, hydrocorals, echinoids, serpula tubes, bryozoans, brachiopods, lamellibranchs, and gastropods. Danian; bryozoan limestone. Faxe. (Pl. 643.) — $^{1}/_{1}$.

shallow water facies, noticeable in the petrographic character as well as the fossil content of the rock, in places where they have partly been developed in ostracod facies. The great accumulation of ostracods in some sediments is no doubt caused by the fact that the animals lived in societies.

Trilobitae.

For the study of the Cambro-Silurian deposits the trilobites enclosed in them have been of the greatest importance. As index fossils they have played a perfectly dominating rôle in the stratigraphic scheme of the Cambrian sediments of Sweden and, together with the graptolites, also in zonal classifications of the Ordovician. Our knowledge of the different species and their stratigraphic occurrence is also relatively good.

As rock formers the trilobites are of little importance but in the said respect they nevertheless play a greater rôle than would, perhaps, be generally imagined. In the Cambrian and Ordovician series of strata bedding surfaces wholly covered by trilobites are often found, and sometimes the accumulation of shields continues through whole beds (fig. 51). Where the shield fragments are well preserved, for inst. in the interior of many stinkstones, they can occupy the bulk of the rock or of a lamination in it (fig. 50). In the limestone beds especially rich in trilobites the unbroken dorsal shields constitute only an inconsiderable part of the rock, whereas the larger and smaller fragments of broken cephalon and pygidium shields and of thoracic segments are by far more abundant. Consequently, several of the limestones rich in trilobites are typical fragment limestones (cf. HADDING 1927, p. 32, fig. 9).

Best preserved are the trilobites when they have been buried in clayey mud before or immediately after the death of the animal. They are found preserved in this manner for inst. in the Silurian marls of Gotland, though only in scattered specimens. Whole dorsal shields are only exceptionally accumulated in large numbers, as for inst. in a marly form of the orthoceras limestone at Vestanå in Östergötland.

All trilobites are marine and the majority of forms occur in typical shallow water sediments. To a large extent the trilobites have lived in and subsisted on the bottom mud rich in organic matters. It is therefore quite natural that the fossils remains of some forms are particularly abundant in rocks formed from this mud.

Trilobites often occur together with ostracods, cephalopods, lamellibranchs, brachiopods, and crinoids but also together with corals in reefs as well as in stratified rocks.

Decapoda.

In some parts of the Swedish Danian limestones we find scattered decapods, brachyurous forms somewhat more abundant than anomurous and macrurous (cf. SEGERBERG 1900 and SCHLÜTER 1874). Together with the other fossils of the limestones they constitute a faunistic population which indicates that these rocks were formed at relatively slight depth.

As the recent decapods, the fossil ones have also subsisted on other animals, the marine forms mainly on lamellibranchs. Their power of breaking shells as well as their voracity are extraordinary, and a large population of crabs and cray-fishes can, when appearing on shell banks, rapidly transform these into real deposits of shell fragments (cf. WALTHER 1910, 30 and 39).

Vertebrata.

Only few remains of vertebrates are known from the pre-Quaternary strata of Sweden; almost all of them have been found in limestones.

Well preserved fish remains are abundantly present in some beds of the Danian limestones. From the same rocks we also know fragments of reptiles, *int. al.* the skull of a long-snouted crocodile, as well as bones of birds. The Senonian shell fragment limestone of Scania, deposited close to the shore, contains fish teeth and saurian vertebrae. Quite recently the carapace of a turtle has been found in the Senonian limestone at Maltesholm.

Remains of vertebrates never occur enriched in the Swedish pre-Quaternary series of strata. The remains are of petrografic interest as environmental documents only.

Résumé.

The above survey of the lime-secreting organisms shows not only that they are of exceedingly great importance as rock formers, it also shows on a large scale to what extent the different groups of animals and plants are of such an importance.

As a rule a group of animals or plants does not alone form the material of which a limestone is built up. In his account of the present investigation the author has been obliged repeatedly to point out that the one or the other fossil group is not so abundantly present in the rocks as to form the bulk of them. On the study of the limestones it is a continous experience that it is not the individual forms but the populations of lime-secreting animals and plants that give rise to these rocks (fig. 52 and 53).

In the following parts of the series of which the present work forms a link, the author will give an account of the petrographic analysis of different types of limestone. The occurrence and distribution of the rocks, the structure and varying nature of the series of strata, their content of detritus and precipitates will of course be investigated. In this connection, however, the author will have reason to further illustrate the fossil content of the rocks. In his account of the forming conditions of the rocks the author will also discuss the environmental conditions under which the different fossil forms of animals and plants have developed.

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*Se the notes on the figures.