Investigations of the Lower Ordovician of the Siljan District, Sweden

IV.

Lithogenesis and changes of level in the Siljan District during a period of the Lower Ordovician

With a special discussion on the formation of chamositic ooids

By

Ivar Hessland

Introduction and acknowledgements.

In previous papers of the present series dealing with separate groups of organisms occurring in a section of the Lower Ordovician of the Siljan District (the province of Dalarna, Sweden), mention has been made of the lithogenesis and the changes of level which occurred in the district during this period.

These questions are more thoroughly elucidated in the present paper.

In a special chapter the ooids present are described and an interpretation of their genesis is given.

Since the stratal sequence is partly iron-bearing to a considerable degree, a special discussion is devoted to the origin of this iron. It seems to have been derived, at least to a great extent, from volcanic ashes ejaculated in the Siljan District during that time.

This volcanicity may also have caused the changes of level.

In presenting the results of this investigation I wish in the first place to express my deep gratitude to the late Prof. G. SÄVE-SÖDERBERGH who drew my attention to the interesting stratal sequence investigated, and who facilitated my work in several respects.

I am also greatly indebted to Prof. H. G. BACKLUND for his interest in the investigation.

For valuable discussions I cordially thank Mr V. JAANUSSON.

The chemical and granulometrical analyses were performed by Mr J. LUKINS, Dipl. Ing., and Mrs E. LUKINA. The spectral analyses were made by Dr P. H. LUNDEGÅRDH. Dr O. MELLIS had the kindness to perform some petrological analyses.

The thin slides were prepared by Mr G. ANDERSSON. The diagrams were drawn by Mrs I. THOMASSON and Mr A. NILSSON.

My wife has assisted me both during the field work and in the laboratory research.

To these collaborators I am very pleased to express my sincere obligation.

Finally, I thank Mr C. JACKSON, M. A., for the linguistic revision.

Institute of Palaeontology, Uppsala, Sept. 1948.

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1. Material and methods of investigation.

The methods used in geological investigations are of course adapted to the purpose of each separate investigation. As a matter of fact, however, investigations which aim to elucidate the genesis of a formation must necessarily be based on as many ways of investigation and as much comprehensive indicative data as possible. Interpretations of the lithogenesis are favoured if, besides the minerogene sedimentary phase, the formation considered also includes a biogene.

The present lithogenetic investigation is based on material including both a minerogene and a biogene phase.

Material.

Vertical sequences of samples throughout stratum *G* and the adjacent parts of *R I* and *R II* (cf. the chapter on the stratigraphy, p. 449) were taken in 5 localities. In 4 additional localities parts of this stratal sequence were available. These 9 localities were more closely investigated; they are situated in the following parts of the mainly circular Ordovician-Gotlandian Siljan District (Fig. 1):

Southern part: Rävanäs (*R I*, *G*, *R II*)
Röjeråsvägen (*R I*, *G*, *R II*)
Granmor (*R I*, *G*, *R II*)
Eastern part: Silverberg (part of *G*)
Silverberg II (upper part of *G*, *R II*)
Born-Dådran (upper part of *G*, *R II*)
Gulleråsen (*R I*, *G*, *R II*)
Northern part: Leskusänget (*R I*, *G*, *R II*)
Western part: Stenberg (*R I*, lower part of *G*)

Furthermore, material was secured from 10 additional localities:
Southern part: Amtjärn (*R I*, *G*, *R II*)
Eastern part: Blecket (*R I*, *G*)
Nedre Gärdsjö (drifts; *G*)
Born (drifts; *G*)
Fjäckan (*R I*, *G*, *R II*)

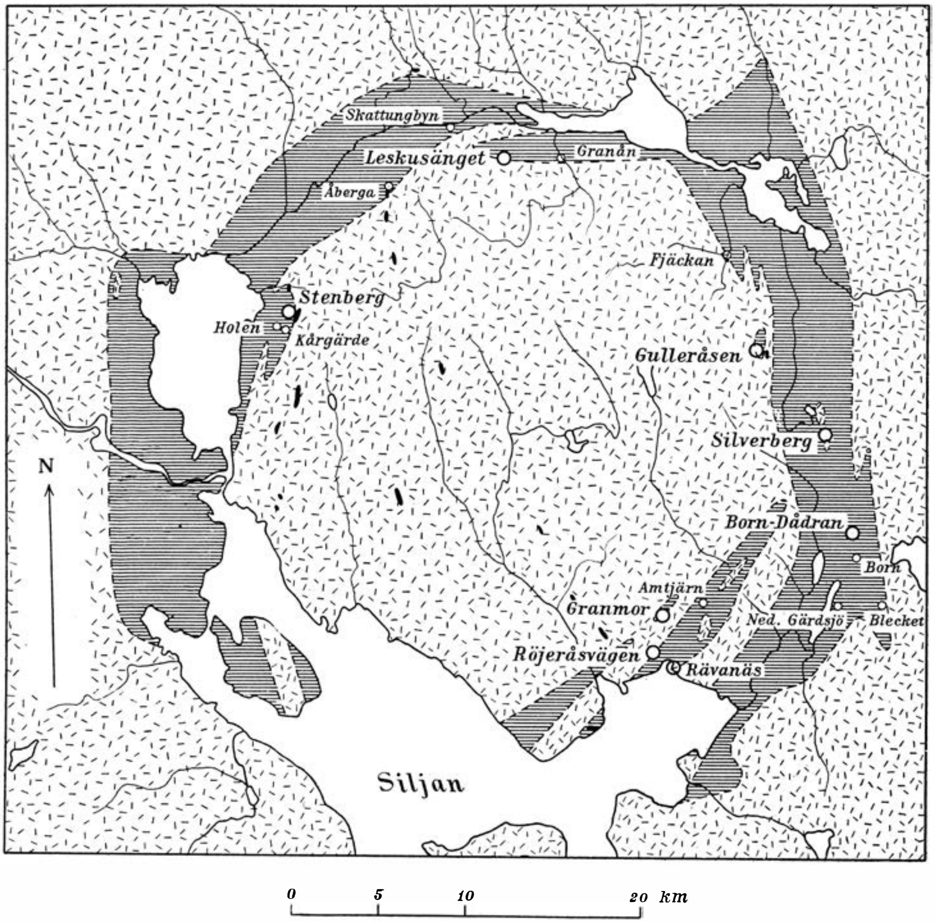

Fig. 1. Map of the Siljan District, showing the circular Ordovician and Gotlandian formation. Black surfaces indicate basaltic dikes. The localities described in this paper are printed in fat-faced types. Compiled from TÖRNQUIST 1883 and THORSLUND 1936; some northern boundaries of the formation corrected.

Northern part: Granån (*R I*, *G*, *R II*)
Skattungbyn (*R I*, *G*, *R II*)
Western part: Holen (*G*)
Kårgärde (*G*)
Åberga (*R I*, *G*, *R II*)

The vertical distance between two consecutive samples in a sequence is not uniform. In sections of obvious interest the samples lie close to each other, but in other sections the distance varies, according to the circumstances. Samples were, as a rule, taken from both sides of lithological discontinuities.

In the diagrams drawn in this paper the midheight of the samples is marked. On the average, the distance between these levels is 18 cm (min. 5 cm, max. 50 cm), exclusive of Rävanäs and Röjeråsvägen where the corresponding data are 53 cm (min. 15 cm, max. 1.6 m).

The samples are of different weights: in most cases about 1—3 kg, but sometimes much more. A great deal of the samples was used up in the fossil analyses.

Laboratory research.

Polished sections and thin slides.

Lithological structures were studied in polished sections at a low magnification and in thin slides at a high magnification.

Sequences of thin slides are absolutely necessary for lithogenetical investigations of fossiliferous deposits. They are not least necessary for the investigation of the biogene phase in showing not only the faunistic composition of the organic debris, but also its state of preservation, which may be very elucidative of the palæohydrology; (inorganic corrosion and activity of penetrative algae are, for instance, indications of special hydrological conditions). Furthermore, they are necessary in order to show the mode of precipitation of iron and phosphorus colloids especially, which, likewise, is of great importance for the elucidation of the palæohydrology and consequently also of the lithogenesis and the changes of level.

Granulometry.

Minerogene particles.

The residuum which remains after the components soluble in acids have been dissolved consists of mineral particles, amorphous silica particles, and silicified organic tissues. In the present case the amount of such tissues is negligible.

Before discussing the genetic significance of the granulometric distribution of the insoluble residues it is necessary to examine to what extent they represent the original distribution of the particles. The size of particles can have been influenced by diagenetic processes and by the treatment with the dissolving agent.

Diagenetic changes of the insoluble residue. The total frequency of the minerogene phase can be proportionally increased by a more or less far-reaching chemical destruction of the biogene phase. The mutual distribution of the particles within the minerogene phase can also be changed, especially by colloidal agglomeration of particles during the consolidation of the sediment, by formation of new minerals during tectonic pressures, and by disintegration during weathering.

Colloidal agglomeration is of great importance in slates but may play a minor role in limestones.

In the present case, the rock samples have not been exposed to weathering in any noteworthy degree, and the tectonic processes which have occurred in the Siljan District have only to a relatively small extent affected the stratal sequence investigated. In connection with the tectonic raising of the strata (which was different in the particular localities) only minor slides took place.

The original granulometric composition of the minerogene phase has thus scarcely been changed to any larger extent in the present case.

Changes of the insoluble residue by means of acids. Mineral particles are, to a certain extent, soluble by the acids used for their liberation. As a rule of general application, the solubility of the particles is due to their size: the smallest are the most soluble. But minerals have different solubility. Quartz seems to be practically insoluble both in dilute hydrochloric and in sulphuric acid; feldspar, clay minerals, and mica are partially dissolved. They are also influenced by organic acids but not in so high a degree. In the present case boiling hydrochloric acid was used, in order to dissolve the iron ooids and the fossil fragments encrusted with hydrous iron oxide. Glauconite and chamosite were also dissolved by this method.

The minerogene particles were certainly influenced by this procedure of liberation, but to what extent is difficult to ascertain. The changes may scarcely have been of such an order that the general appearance of the distribution curves was changed very much, judging from the fact that the size changes of clay minerals were fairly moderate when the minerals were treated with 18 % HCl (evaporation to dryness), as stated by THIÉBAULT (1925). In the present case it happens that the small-sized fractions are much more frequent than the next large-sized sequence which scarcely should be expected if considerable dissolution took place, which, in the first place, should have occurred just in the small-sized fractions.

Considering the rounded amorphous silica particles, they were observed to occur mainly in the larger residual fractions after the samples had been treated with hydrochloric acid. The question is whether they are original or whether they were newly formed by the activity of the hydrochloric acid.

Particles of this kind do not appear after treatment of the samples with acetic acid. In this case, there are also silicious particles but they have a different appearance; some of them are internal moulds or have been encrusting fossils. Such structures do not occur in the residuum left after treatment with hydrochloric acid. Very likely, the particles appearing after treatment with hydrochloric acid are transformed silicious compounds. During the hydrochloric acid process jelly-like substances are visible in the solution.

Presentation of results. The granulometry of the residuum was examined partly by sieving (fractions $>$ 0.06 mm) and partly by the so-called pipette analytic method (fractions $<$ 0.06 mm).

The fractions are chosen so that the value of the upper limit of each fraction is twice as large as that of the lower limit (thus the fractions are in mm: 1 — 0.5; 0.5 — 0.25; 0.25 — 0.125, and so on). The graphical presentation, which is made by means of histograms, is facilitated in this way. When the limits of fractions are chosen just as was said, the bases of the bars will be equal (the logarithmic scale of the x-axis becomes in this case equal to an arithmetical).

From the above discussions it may appear that the curves scarcely reproduce the original frequency and distribution of the minerogene particles, but also that diagenetic processes and the dissolution by acids are hardly of such an order that the general appearance of the curves has been considerably changed.

The granulometry of the amorphous silica particles is most likely caused by the treatment with hydrochloric acid, and their present size distribution is thus of no importance for the illustration of the original granulometry. The amount of such particles has been determined in the sieve fractions ($>$ 0.06 mm) but not in the fractions inferior to 0.06 mm. Irregularities in the curves of the fractions $<$ 0.06 mm may partly be due to such substances.

As already mentioned, the curves may give an idea of the original size distribution of the minerogene particles. But there is reason for only moderate conclusions as regards the transporting agencies and the conditions of deposition, on the basis of the frequency. Total curves of the distribution of the minerogene phase are also, for another reason, sometimes unsuitable for such discussions. For that purpose the frequency curve of one group of particles which are difficult to transport should be put in relation to that of another group of particles which are easily transportable; if the distance between the maxima of the curves along the x-axis is great, one may conclude that the sediment had been deposited in an area traversed by currents. On the other hand, if their maxima appear at particles of about the same size there is reason to believe that, carried there by different agencies, the particles were deposited in stagnant water.

Since the present material offers other indications for an interpretation of the palæohydrology I have, as regards the granulometry of the minerogene phase, only established its total distribution, which, as said, may be sufficient to give an idea of the supply of mineral particles during the genesis of the stratal sequence.

Ooids and encrusted fossil fragments.

The ooids occurring are described on p. 477 f. They consist mainly of limonite and chamosite.

The rock also includes non-ooidic fragments of hard organic tissues encrusted with limonite (occasionally encrusted with chamosite).

The ooids and the non-ooidic fragments encrusted with iron components were freed and studied as regards frequency and shape. An analysis of trace elements in the limonitic ooids was also performed.

The particles now mentioned were freed from the matrix by means of acetic acid, except for the ooids which were analysed chemically; these latter were separated mechanically.

Dilute hydrochloric acid is not suitable for freeing limonitic particles since the particles themselves are somewhat dissolvable. Dilute acetic acid is also a solvent, but it acts much more slowly. In the present case, the rock samples were exposed to the action of the acid for two-hour periods until the whole sample was dissolved. The encrusted particles freed during each period were detached and washed. Iron was not discernible, or occurred only as traces in the acetic acid after such a two-hour period.

The encrusted particles set free were sieved and the fractions weighed. The frequency data thus obtained are presented as histograms.

By this same method of liberation phosphoritic and amorphous silicious particles were also set free. Their total frequency is plotted separately in the histograms.

Chemistry.

Elements analysed.

In the present case it is of minor interest to know the total chemical composition of the sediment. It is of greater importance, however, to establish the frequency of some special elements which may indicate the palæohydrology and the lithogenesis.

Some of those elements are either of organic origin or their mode of occurence has been influenced by the vital processes of organisms.

During their life-time, organisms act upon the sediment in several respects: mechanically by creeping and dragging themselves through the surface layers, and chemically by other activities.

Many elements are supplied to the sediment in the excretory products of the animals, above all phosphorus and nitrogen (phosphorus may also be derived from shells of certain groups of organisms, especially inarticulate brachiopods but also other groups, such as Conularia).

The frequency curves of phosphorus and nitrogen may, however, not without consideration of certain conditions be suggested to illustrate the frequency of animal life during the sedimentation of the strata concerned. Since they are easily soluble from newly formed faeces, surroundings traversed by currents continuing to the ocean are not favourable for their preservation; but stagnant waters are conducive to such preservation. Furthermore, since both phosphorus and nitrogen are very important nutritious elements for plants, the course of their frequency curves can have been influenced by algal resorption.

Waste gases, carbon dioxide produced by respiration (also produced by decomposition), and oxygen from plants, influenced the composition of the sediment in various ways. Carbon dioxide favoured plant life, and oxygen animal life. The CO_2-pressure in the water was of great importance for the solubility of the iron bicarbonate: at a high pressure great quantities would be in solution, but at a diminished pressure (inter alia caused by algæ), and in the presence of oxygen (partly produced by algæ), it was precipitated as hydrous iron oxide.

Many elements become incorporated in the sediment when animals and plants are embedded postmortally. Such important elements are carbon and sulphur.

For these elements the same fact is applicable as was just stated about phosphorus and nitrogen; they are best preserved in stagnant surroundings. Also, in this case their frequency curves may have been influenced by plants, viz. in that these elements are oxidized by the oxygen produced by algæ.

Potassium and magnesium occur both in plants and animals. Potassium is especially distinguishing for plants; in non-calcareous plants it takes first position among the metals. Magnesium comes third, after calcium; inter alia, it is included in the chlorophyll. In marine algæ encrusted with calcium carbonate, the content of magnesium is regularly high. In marine invertebrates, on the other hand, magnesium, as a rule, occurs in small quantities.

The sediment, however, may be supplied with potassium and magnesium derived not only from organisms (especially plants), but also from inorganic sources, especially basaltic and trachytic effusives and ashes.

In the present analyses of magnesium, both the quantity confined to silicates and that which is not confined to silicates has been examined. The former may be mainly inorganic, indicating the quantities of volcanogene compounds in the minerogene sedimentary phase; the latter may be of organic (mainly phytal) origin. As for potassium, only the quantity not confined to silicates was analysed, which may thus be mainly phytogene.

However, this investigation has indicated that these potassium and magnesium components are less elucidative of the phytal activity than might be expected (cf. p. 461).

The most important component of organic origin is calcium carbonate. Besides occurring in the form of shells and other calcified hard tissues it is also precipitated in an amorphous or granular state.

As a matter of fact, calcium and carbonate ions can be supplied to the water and also precipitated as calcium carbonate by means of inorganic agencies. However, amorphous and granulose layers of calcium carbonate can also be formed organically. It is a well-known fact that easily soluble Ca-salts of the sea are converted into $CaCO_3$ by the vital processes of inferior plants, especially denitrifying bacteria. Furthermore, calcium ions are released from calcareous substances by the activity of boring organisms (not least penetrative algæ) and supplied to the water; they may finally be precipitated as $CaCO_3$, either inorganically or on account of the carbon dioxide assimilation by plants.

Interpretation of the genesis of amorphous calcium carbonate in sedimentary rocks is a difficult problem. It is impossible to decide to what extent it has been formed in an inorganic way or by the activity of organisms. However, by studying certain microscopical structures one may arrive at some idea in this respect. If shells are bored by algæ to a great extent there is reason to believe that this algal activity has been conducive to the formation of amorphous calcium carbonate. Corrosive activity by acids (formed as vital waste products, or at decomposition) can also have released $Ca^{\cdot\cdot}$ ions which were later precipitated as $CaCO_3$.

Changes in the original chemical frequency due to diagenesis.

In the above discussion of chemical elements elucidative of the type and the intensity of the ancient biocoenoses, and the palæohydrology, some remarks were made concerning the fact that the frequency of certain elements may have already been changed before they were embedded in the sediment — (phosphorus and nitrogen may have been used up by algæ; carbon and sulphur may have been oxidized, and calcium carbonate may have been dissolved by different agencies).

Changes in the frequency of chemical elements may also have appeared because of diagenetic processes.

There are thus reasons to be most careful in the interpretation of the frequency curves of the elements.

Changes in the concentrations of chemical elements after the sediment has been consolidated can have been caused by different agencies.

The circulation of pore water is one such factor; the circulation is proportional to the porosity.

In fine-sediments the circulation is very restricted; clays (diameter of particles $< 2\,\mu$) are impenetrable for water. In sediments of greater porosity both solution and precipitative activity may take place by means of circulating pore water, thus changing the original concentration of certain elements. Also, the possibility may not be excluded that ions carried away have been replaced by other ions. Calcium ions may thus be replaced by magnesium ions.

Volcanogene and tectonic processes can also cause changes in the proportions of many elements. Hydrothermal and pneumatolytic activities, which occur in the vicinity of lava masses, are of great importance in this respect, not least in adding juvenile and resurgent elements to the sediment. Increase of temperature and pressure caused by vulcanogene and tectonic processes is also of great importance for changes in proportions, and for recombinations of many chemical elements. Diffusion is increased, which may result that certain elements (for instance carbon) are expelled from the sediment. By means of the catalytic effect of volcanicity and tectonic processes, elements of biogene origin (for instance phytogene potassium) may be included into newly formed minerals and thus transferred into the insoluble residue, the main part of which is abiogene.

Considering the strata here investigated, they are more or less raised, but slides occur only in parts of the sections and are of subordinate importance. No magmatogene influence is traceable in the localities examined. The sediments are very fine-grained, and redeposition and replacement of chemical elements by means of circulating pore water must have been very restricted. A far-reaching recrystallization has not occurred.

As a matter of fact, diagenetic processes do not seem to have influenced in any noteworthy degree the original composition of the chemical elements investigated here.

Methods of analyses.

Iron. The iron, occurring mainly as hydrous oxides, was dissolved by boiling (4—6 hours) in dilute hydrochloric acid. The ferric ions dissolved were reduced to ferrous state by means of stannous chloride, the excess of which was destroyed by mercuric chloride. Titration by means of permanganate.

Sulphur. Oxidation in the wet way by means of aqua regia. Evaporation to dryness with some hydrochloric acid. Immersion of the sample in hot water to which was added 1 cc concentrated hydrochloric acid. Filtration. Iron and aluminum precipitated with ammonium hydroxide and filtered off. Sulphur determined as barium sulphate.

Phosphorus. Oxidation in the wet way by means of aqua regia for one hour, followed by two further evaporations to dryness; some nitric acid was added each time. The molybdate method was used in the analyses.

Potassium. Only the content of potassium not bound to silicates was analysed.

Samples were heated to 400—500° C, then added to cold water. Possible occurrence of sodium established. After filtration, iron and aluminum were precipitated by means of ammonium hydroxide, and calcium by means of oxalic acid. Filtrate acidified with hydrochloric acid and evaporated to dryness. Potassium determined as potassium chloride after heating to a temperature of 200—300° C.

Magnesium, total amount. Fusion with sodium carbonate or solution in concentrated hydrochloric acid. Iron and aluminum precipitated with ammonium hydroxide and filtered off. Calcium precipitated with oxalic acid, and magnesium with diammonium phosphate. Magnesium determined as pyrophosphate.

Magnesium, not bound to silicates. After ignition and treatment with ammonium hydroxide the continuation of the analyses was performed as just described.

Nitrogen. Analyses according to KJELDAHL's method in PARNAS' and WAGNER's modification. A KJELDAHL macro apparatus was used. Digestion according to ARNOLD and WEDEMEYER (potassium sulphate, mercury sulphate, copper sulphate, and sulphuric acid). Nitrates reduced by means of powdered iron.

Carbon and carbonate. Organic carbon substances and carbon bound as carbonate were determined according to the direct method.

First, the content of the carbonate was determined. The carbon dioxide was expelled with dilute sulphuric acid (1:5); short boiling. The gas was cleaned of possibly occurring hydrogen sulphide in a tube containing copper sulphate and pumice, dried in two other tubes (concentrated sulphuric acid and quartz, and silica gel resp.), and absorbed in two tubes with natron asbestos and silica gel.

Before entering the system the traversing air had been cleaned and dried in concentrated sulphuric acid and in a natron asbestos tube. An absorption tube with natron asbestos and silica gel prevented air to enter the system from the suction side.

The organic carbon was then determined. It was oxidized with chromium trioxide and concentrated sulphuric acid during 10 minutes of boiling; further treatment identical to that just mentioned.

2. Stratigraphy of the layers investigated.

A stratigraphic survey is given in part I of the present series of papers (ostracods).

It appears from this one that, for the time being, it is scarcely possible to make complete stratigraphic correlations to the Lower Ordovician strata of Estonia and the Island of Öland which are the areas where the prevailing Lower Ordovician stratigraphy of the Scando-Estonian Region has been founded. Judging by the macrofossils it appears, however, that the Lower Grey *Orthoceras* Limestone which later was called *Expansus* Limestone, includes the *Expansus* and almost certainly the *Raniceps* zones of Ingermanland and Estonia (B III α and B III β resp.).

The Estonian strata next subjacent to the *Expansus* Zone, i. e. the *Lepidurus* and *Bröggeri* zones (B II β and B II γ resp.) do not seem to occur in the Siljan District. Neither macrofossils nor the characteristic ostracodal fauna of the *Lepidurus* Zone have been found here.

Whether the Estonian stratum next superjacent to the *Raniceps* Zone, i. e. the *Eichwaldi* Zone (B III γ), is represented in the Siljan District has not been ascertained.

The mainly grey layer which includes the *Expansus* and *Raniceps* Zones is here provisionally called stratum *G*. The subjacent red stratum (the *Limbata* Limestone) is mentioned as *R I*. The superjacent stratum is called *R II*. Its lower part is generally called *Gigas* Limestone which may be an unsuitable denomination for this stratum which is practically non-fossiliferous up to about 5 m above the boundary *G/R II* where *Megalaspis gigas* ANGELIN is represented with large quantities in a thin layer.

The boundaries between *R I* and *G* (*R I/G*) and between *G* and *R II* (*G/R II*) are mainly synchronous in the whole Siljan District according to reasons presented in the above-mentioned stratigraphic survey.

The following macro-fossils were found:
In the *Limbata* Limestone: *Megalaspis limbata* (BOECK)

In the *Expansus* Zone:
Asaphus expansus (L) WAHLENBERG
Ptychopyge angustifrons (DALMAN)
Niobe frontalis (DALMAN)
Megalaspis acuticauda SCHMIDT
Illaenus esmarkii (SCHLOTHEIM)
Illaenus centrotus DALMAN
Ampyx nasutus DALMAN
Agnostus sp.
Pterygometopus sp.
Lingula aff. *longissima* PANDER
Orthis callactis DALMAN
Lycophoria nucella (DALMAN)
Pseudoconularia dalecarliæ HESSLAND

In the *Raniceps* Zone:
Megalaspis heros (DALMAN)
Megalaspis rudis ANGELIN
Cyrtometopus affinis (ANGELIN)
Nieszkowskia tumidus (ANGELIN)
Clitambonites (*Iru?*) *zonata* (DALMAN) (Acc. to Mr V. JAANUSSON)
Ahtiella dalecarlica HESSLAND
Lycophoria nucella (DALMAN)
Group of *Orthambonites calligramma* (DALMAN)

In the stratum *G* there also occur specimens of the group of *Porambonites intercedens* PANDER, of the groups of *Sowerbyella quinquecostata* (M' COY) and *S. undulata* (SALTER), and *Inversella* sp. Further investigations of the macroscopical brachiopod fauna will show that it is much richer in species than appears from the data presented above.

3. Biogene and minerogene components of the sedimentary rock.

General appearance.

The three sections of the stratal sequence investigated (the strata *R I*, *G*, and *R II*) are lithologically different. However, the similarity between *R I* and *R II* is greater than that between any of these strata and stratum *G*.

More definite information concerning the distribution of abiogene and biogene components in the stratal sequence appears from descriptions given later in this paper, and from the diagrams.

In the present connection a brief account is given of the general appearance of the sediment and of special structures.

Stratum *R I* and the boundary *R I/G*. The main colour of stratum *R I* is reddish maroon, but minute grey-greenish spots may occur. Very distinctive for this stratum are thin, irregularly undulating microbeds of yellowish colour conforming mainly to the mean bedding. The microbeds, which are situated a few centimetres from each other, are only a few millimetres thick.

The reddish maroon colour is mainly due to iron oxides (especially limonite, but also goethite or hematite); the colour is also influenced by a phosphorous compound (most likely an iron phosphate) and possibly by a very small content of manganese oxides. The colour substances coat the microscopical crystals of calcium carbonate and other particles with a thin film. Small grains of glauconite occur now and then.

The yellowish microbeds appear brownish in thin slides. They are concentrates of hydrous iron oxides and the phosphorous compound mentioned. The concentration of these substances increases upwards in the microbeds but they end abruptly (Pl. I, Fig. 1). At the lower limit of the microbeds there are, as a rule, rather many grains of uncoated glauconite. Glauconitic grains appear only occasionally in the upper, more concentrated part of the microbeds; in this case the grains are generally coated by limonite. Glauconite also occurs as fillings in canals of organic hard tissues. In the upper part of the microbeds especially trilobite shells are distinctly corroded by acidic substances. Sulphuric components (pyritic nodules) may occur in the interior of relatively greater fossil fragments (especially crinoids). Small quantities of minute pyrite nodules may also occur in the substance between the microbeds.

Just at the transition to stratum *G*, the concentrations of the iron and phosphorous compounds are very distinct, so that discontinuity surfaces may be formed (Pl. I, Fig. 2). These surfaces are covered with a phosphoritic film. At Blecket, the very boundary *R I/G* is constituted by a distinct such surface. The discontinuity surfaces are, in turn, often covered with a stratum of somewhat impure glauconite (Pl. I, Fig. 3; Pl. II, Fig. 1).

It is a characteristic fact that the calcium carbonate is often recrystallized to a rather great extent just above the discontinuity surfaces. Phosphorite (partly from the discontinuity surface) was squeezed out among the calcite crystals at the recrystallisation.

The surfaces are crowded for the most part with small irregular pits. Some of the pits continue in narrow canals (2—3 mm diameter), filled with the same sediment as occurs just above the surface (Pl. II, Fig. 1). Their walls are covered with black phosphorite just as is the discontinuity surface. The canals from one surface do not penetrate the next subjacent, but deviate and run parallel to it. This means that animals digging canals from the actual sea bottom could not penetrate the next subjacent surface which had thus hardened at that time.

Stratum *R I* is crowded with fossils (for the greater part crinoids, ostracods, small orthoids, and fragments of trilobites). Perforative algae are, as a rule, scarce, but girvanelloid algae encrusted with calcium carbonate occur sometimes. In the substance between the yellow microbeds the fossils are not encrusted for the most part, but in the microbeds they are often filled whith limonite and phosphorite (in a few cases with glauconite also).

Stratum G and the boundary *G/R II.* The thickness of stratum *G* varies between 1.8 and 4 m. The colour is somewhat varying in the lowermost part, but generally light grey or greenish grey. In the middle part the colour, as a rule, is dark grey, and in the uppermost part light grey. Small red spots may occur, and a reddish zone may be developed in the upper part.

In the lowermost part there are two distinct discontinuity surfaces.

The stratum is, above all, characterized by being partly oolitic (Pl. III, Fig. 1); one oolite in the *Expansus* Zone and another in the *Raniceps* Zone. The ooids (which are more precisely described later in this paper) are mainly limonitic, but a few are chamositic, especially in the *Raniceps* Zone. The content of iron is high in the *Expansus* oolitic zone.

Some special structures in stratum *G* shall now be mentioned.

Somewhat below the *Expansus* oolite there occur invariably some characteristic substances consisting mainly of limonite and covered with black phosphorite. They give the unmistakable impression of having been semifluid (Pl. II, Fig. 3). A great many fossil fragments are generally included. Phosphoritic ooids are sometimes developed. The substances often form irregular lumps (lengthened or rounded), or a kind of "canals" (about 1 cm thick) mainly parallel to the bedding. In other cases, however, they form regular layers, obviously correspondent to the discontinuity surfaces just around *R I/G* and to the yellowish microbeds in *R I.* The irregular lumps and "canals" have certainly been precipitated as such layers, but have been slid somewhat during subsequent slight movements of the water. Such movements have also been registered in the sediment surrounding the aforesaid substances (Pl. II, Fig. 4).

In the *Expansus* oolite there are sometimes flattened horizontal canals filled with clay substance, as observed at Leskusänget. The ooids occur more or less irregularly in the matrix, but they are sometimes concentrated in agglomerations, one or a few centimetres in diameter.

In the stratum next above the *Expansus* oolite the rock has generally a somewhat cracked structure owing to the presence of irregularly undulating cleavages, which are slightly oblique to the bedding. Minute cleavages of this kind are discernible in thin slides; they are covered with greyish-brown iron and phosphorous substances. These structures are reminiscent of a very slight criss-cross bedding.

The light grey uppermost part of stratum *G* constitutes a fairly dense rock without any special structures.

The transition to stratum *RII* is marked as a colour change which is clearly discernible in unweathered rocks.

Stratum *G* is in part richly fossiliferous; fossil fragments are penetrated and enveloped by algae to a very great extent. The distribution of the organisms is accounted for in the next chapter and on Pl. IX.

Stratum *RII* (Pl. III, Figs. 2 and 3). The colour is maroon with greenish spots. A characteristic feature is that the abundant cephalopods are generally coated with a bluish layer of hematite.

The maroon colour is mainly due to limonite and sometimes hematite. The minute calcite crystals are coated with a film of these substances. As observable in thin slides, they are irregularly concentrated, partly into microbeds running in different directions. In these microbeds the abundant fossil fragments are encrusted with the substances mentioned. The fragments are bored by algae only to an inconsiderable extent. On the other hand, they are in part fairly corroded by acidic substances.

Biogene components.

Distribution of animal groups.

Cf. Pl. IX.

The macrofossils which have been determined are enumerated on p. 450. However, the greater part of the macrofauna consists of still undescribed species. For this reason, only a short survey of the vertical distribution of the groups of organisms is given in this paper.

Acrotretids. This group includes several species, the ventral valves of which are specifically fairly characteristic and which have a restricted vertical distribution. They will probably appear to be of stratigraphic importance when described after having been studied internally (cf. BELL 1941).

On the whole, the group is not abundant, but represented through the greatest part of the stratal sequence investigated. A few specimens may be observed in the uppermost part of *R I*, but in the lower part of stratum *G* the group is fairly abundant, especially somewhat below the *Expansus* oolite. Above this zone, acrotretids are absent or occasionally occurring, but towards *G/R II* they reappear in small numbers. In *R II* they occur invariably.

Atremate brachiopods. This group of brachiopods is represented by some fairly well preserved specimens (lingulids and obolids), but most of them are fragmentary. Fragments are rather often observed in thin slides.

Thin sections of these brachiopods are somewhat reminiscent of those of conulariae (Pl. IV, Fig. 4; cf. part III of the present series Pl. I, Fig. 2). They are different in the brachiopod shells being more distinctly stratified, and lacking the longitudinal ridges and canals which distinguish the conularia shells.

The group is represented all through the stratal sequence, but it has its greatest frequency in the lower half of stratum *G* and the uppermost part of *R I*. Obolids occur mainly in this part of the stratal sequence.

Small orthoids. In this group are included dalmanellids which externally are very similar to real orthids.

Small orthoids are abundant in the uppermost part of *R I* and the lowermost part of stratum *G*. Thereafter, the frequency is low (shell fragments observed only in thin slides), but the group increases for the most part towards *G/R II* and occurs generally in *R II*, though by far not as abundantly as in the uppermost part of *R I* and the lower part of *G*. Judging from the series of thin slides, dalmanellids occur especially in the lower part of stratum *G*.

Large brachiopods. Brachiopods of larger size appear fairly regularly in two sections of stratum *G*: one around the *Expansus* oolite and a second around the corresponding part of the *Raniceps* zone. Some of these brachiopods are enumerated on p. 450.

Crinoids. Fragments of small species (Pl. V) occur abundantly all through the stratal sequence. Sometimes they are less frequent, such as in the section just above the *Expansus* oolite.

Gastropods. The majority of the gastropods are small-sized; only a few somewhat larger specimens were observed. The gastropods have a characteristic distribution: they are fairly abundant in the uppermost part of *R I* and the lowermost part of stratum *G*, but they disappear generally almost completely in the *Expansus* oolite. For the most part they reappear towards *G/R II* (they are often abundant somewhat below this boundary). In *R II*, they soon seem to diminish in frequency again.

Cephalopods. They are frequent in the uppermost part of stratum *G* and just above *G/R II* but occur occasionally also in other parts of the stratal sequence. However, as a rule, they were not found below the *Expansus* oolite.

Trilobites. Fragments of trilobites (Pl. IV, Fig. 6) occur all through the stratal sequence. For the most part they consist of asaphids and megalaspids. They are very numerous and partly well preserved in two sections of stratum *G*, viz. in the *Expansus* and *Raniceps* oolites; the species determined are mentioned above, p. 450.

It may be added that larval hypostomas, most likely of megalaspids (according to a statement by Prof. L. STØRMER), appear in some localities in fairly great quantities just above *G/R II* (Leskusänget, Born-Dådran, Silverberg II, and Rävanäs).

Ostracods. They occur in great quantites in the lower part of stratum *G*, but disappear almost completely in connection with the important precipitation of hydrous iron oxide during the *Expansus* period. Only isolated specimens occur thereafter, but towards *G/R II* further species appear in increasing numbers. A sudden culmination in this migration was reached just after the development of *G/RII.* A detailed description of the ostracodal fauna is given in part I of the present series of papers.

Bryozoa. Fragments (Pl. IV, Fig. 5) occur occasionally in different parts of the stratal sequence.

Graptolites. Scattered fragments have been observed in the *Expansus* section of stratum *G* (Leskusänget and Stenberg).

Conodonts. Only a few conodonts were observed, mainly in the *Expansus* zone.

Polychaeta. A few jaws were seen in stratum *G*.

Conularia. Small, indeterminable fragments of conulariae were seen, especially in the *Expansus* zone, but also in the uppermost part of stratum *G*. A special paper is given on a new species of *Pseudoconularia* (part III of the present series).

Other chitinous organisms. Minute black globules, sometimes observed to be provided with a pore, occur in all localities, partly rather abundantly (Pl. IV, Fig. 1). They are found in all divisions of the stratal sequence investigated.

The nature of these globules is unknown. Most likely, they were eggs. The fact that their frequency is very similar to that of the trilobites may indicate that they were eggs of trilobites.

Also a few chitinous tubes, swollen in the shut end, were observed in the upper part of the *Expansus* Zone. Other lengthened chitinous tubes occur occasionally in this zone. In the uppermost part of *R I* a single specimen of an organism reminiscent of *Lepidocoleus* was observed.

Microorganisms. In thin slides and in the insoluble residues hystricomorph bladders and radiolarians were seen, but these fossils have not been studied.

Summary. Some groups occur fairly constantly all through the stratal sequence, especially the atremate brachiopods, the crinoids, and the minute chitinous globules. However, the latter ones are generally more frequent in the oolite section of stratum *G* than elsewhere.

The other groups constitute three divisions.

One of them consists of those groups which occur mainly around *R I/G* (especially just above this boundary) and around *G/R II*, but are absent or infrequent in the main part of stratum *G*. To this division are referable the small orthoids, the small gastropods, and possibly the acrotretids, which, however, also may be fairly numerous in the middle part of stratum *G*.

A second division is formed by those groups which are represented only in stratum *G* or are by far most abundant there. Larger brachiopods were found only in this stratum; they have the greatest frequency in the oolitic horizons. The trilobites are also most abundant in these two zones.

The third division is represented by the cephalopods which may occur in the middle and lower part of stratum *G*, but are much more numerous in the upper part of this stratum and in the lower part of stratum *R II*.

Animal frequency compared to that of the minerogene substance and the chemical elements.

Cf. Pl. X, XI, XIII, and XIV.

As regards the ostracods the calculation of the frequency was based upon counting of the individuals (part I of this series; special ostracodal frequency curves). The frequency of the other groups has only been valued in accordance with a scale 1—5. The ostracods are here included in the total animal frequency curve, and for this reason the ostracodal frequency was transformed in accordance with the scale.

It is evident that such a valuation is of restricted reliability for the elucidation of the total biological effect of the fauna, since the animals of the different taxonomic groups are of partly very different size and were partly ecologically different.

The following comparisons may only give an idea of the relations of the necrocoenoses to the insoluble residue and some chemical elements.

Minerogene substance. In most of the localities there are distinct contrarieties between the animal frequency and the minerogene substance as regards maxima and minima. Only occasionally can some few vague similarities be traced, and exceptionally single maxima are contemporary. It also happens that the great animal maxima are not corresponded by any changes in the curves of the minerogene substance, which is especially elucidated by the ostracodal curves.

Regarding the question whether there are special affinities between particular animal groups and the minerogene substance, one may say that, in some cases, correspondences exist (e. g. abundance of trilobites may correspond to a high content of minerogene particles), but regularities are not apparent. Further, the ostracods seem to show slight affinities to fine sediments, but nor are regularities ascertainable in this case.

Considering the sieve fraction particles, a slight tendency of increase of the fauna seems to occur when these particles are few, but there are exceptions. No regular correspondence is ascertainable.

Calcium carbonate. With the exception of Stenberg, there is a fairly far-reaching correspondence in the main course of the curves, and to a very great extent also as regards details in their fluctuation. (However, there is no regular commensurability for the most part as regards the magnitude of the fluctuations.) In Silverberg II there is a complete correspondence all through the stratal sequences.

The incomplete correspondence observable in several cases in parts of the stratal sequence where the content of calcium carbonate is low may not be as much referable to a low frequency in animal life as to high contents of the insoluble residue and iron. Small discrepances for the rest may mainly be due to different frequencies of minute shell fragments or amorphous calcium carbonate the amount of which has not been calculated. However, particles of this kind are not of such range in the present case that they conceal the fact as indicated by the curves, viz. that there existed a close connection between the density of animal life and the content of calcium carbonate of the sediment.

Considering ostracods especially, there is a main difference between their frequency and the amount of calcium carbonate. Ostracods are abundant in the lower half of stratum *G* where the content of calcium carbonate is low, but the low ostracod frequency in the upper part is not corresponded by a decrease in the calcium carbonate curve. In most cases, however, similarities as regards details occur, especially in the lower half but also in the upper. A remarkable divergence appears in the Röjeråsvägen curves.

In spite of the fact that the main frequencies of ostracods and calcium carbonate are different, there are several similarities between the curves which indicate that a real correspondence exists.

Iron. A regular correspondence seems to exist between these components. Maxima are contemporary in a few cases, but generally they alternate.

As regards the ostracods, it is very characteristic that their maxima do not correspond to the maxima of iron, but that the iron maxima in a most regular way generally follow those of the ostracods (in Röjeråsvägen both maxima appear contemporarily).

Phosphorus. In stratum *G* the phosphorus curves are often high where the fossils are abundant, but there is a general tendency for the phosphorus curves to diminish or disappear in *R I* and especially in *R II* in spite of the fact that the animal curve is still high, which may be due to the fact that the soluble phosphorus compounds were probably transported to the ocean during these ventilated periods.

As regards details of the curves the maxima of the phosphorus curve, as a rule, are not contemporary with the maxima of the animal frequency. Phosphorus and fauna exclude each other.

Considering ostracods, the fluctuations of the curve alternate for the most part. In some cases the maxima appear contemporarily. It also happens that one curve is indifferent when the other forms a maximum.

Carbon. In a few cases, great maxima are contemporary (Leskusänget, Granmor, and Silverberg II), but, as a rule, the curves are irregular to each other, or the fluctuations alternate. Regular correspondence is not ascertainable. This is also referable to the ostracods.

Sulphur. Owing to the fact that the sulphur curve is very low and little fluctuating, comparisons are scarcely reliable. Single similarities can be observed; some maxima are mainly contemporary, but maxima are often alternating.

Potassium. Maxima are sometimes contemporary, but alternations are more common. Regular correspondence between the ostracodal curves and the potassium curves are scarcely ascertainable.

Nitrogen. The nitrogen curves are low and so insignificantly fluctuating that comparisons are of small reliability. In many cases the fluctuations are contemporary with the animal frequency curves, but for the most part the curves are alternating. These remarks are also true as regards a comparison with the ostracodal curves.

Org. magnesium. Maxima of these components are occasionally contemporary, but, as a rule, they alternate. Similar conditions prevail as regards ostracods.

Inorg. magnesium. The relation between the curves is reminiscent of that between the animal and the organic magnesium curves. Concerning the ostracods, there is no regular correspondence as regards the course of the curves.

Summary. In most cases there is no regular correspondence between animal life and the minerogene substance and the chemical elements. However, the calcium carbonate curve seems to reproduce the density of animal life. Furthermore, precipitation of iron seems to have been influenced by animals or their waste products, judging by the fairly regular alternation of their maxima. Irregularities as regards the density of the animal life and the phosphorus content of the sediment may be partly due to the fact that the phosphorus acid was carried away during the ventilated periods.

Distribution of plants.

Cf. Pl. X.

The penetrative and enveloping algae of the present sequence of strata are described, and their lithogenetic significance is discussed in part II of this series of papers.

Here it may be recapitulated briefly that penetrative algae are very abundant in stratum *G*, especially in and around the *Expansus* oolite. They also occur in the adjacent parts of *R I* and *R II* but disappear in some distance from *R I/G* and *G/R II.* Enveloping algae are restricted to stratum *G*.

Calcareous, girvanelloid algae (Pl. IV, Fig. 2) have about the same vertical distribution as the penetrative algae.

Plant frequency compared to that of animal groups.

Cf. Pl. X and IX.

Total amount of animals. Regular correspondences between the frequency of algal and animal life are not ascertainable.

Ostracods. The beginning of the high algal frequency in the *Expansus* Zone is corresponded by a catastrophic decrease of the ostracods.

Acrotretids. No correspondence. Acrotretids occur both in the most algae-bearing horizons and in non-algal strata.

Atremate brachiopods. No correspondence.

Small orthoids. This group and algae mainly exclude each other.

Larger brachiopods. There is a fairly good correspondence between the distribution of algae and this group.

Gastropods. Gastropods do not occur in sections with high algal frequencies.

Trilobites. Regular correspondence does not seem to exist. Highest frequencies of trilobites occur, however, often in those zones where algae are abundant. Trilobites also occur where no algae were observed.

Cephalopods. No correspondence.

Crinoids. There are several examples of the fact that a high frequency of algae is corresponded by a low frequency of crinoids, but also vice versa. Examples are also given of the fact that the crinoid frequency is not diminished during high algal frequency. Crinoids are thus indifferent in relation to algae.

Summary. The similarities and dissimilarities which are indicated above may chiefly be results of accidents. For instance, it is difficult to understand why gastropods should be absent where algae occur. However, the catastrophic decrease of ostracodal frequency may be connected with precipitation of hydrous iron oxide on account of algal activity (cf. p. 478).

Plant frequency compared to that of the minerogene substance and the chemical elements.

Cf. Pl. X, XI, XIII, and XIV.

Minerogene substance. Considering first the group of localities characterized by an invariably low content of minerogene particles (Rävanäs.

Röjeråsvägen, and Granmor), penetrative algae occur all through the stratal sequence, save for Röjeråsvägen, where algae are absent in *R I* and the lowermost part of *G*, and in the middle and most of the upper part of *G*. The penetrative algae are abundant, except generally in *R I*, *R II*, and adjacent parts of *G*. The distribution of enveloping algae is more restricted; these algae occur mainly around the midheight of stratum *G*. The greatest frequency of these algae is generally immediately followed by a slight increase in the content of the minerogene particles. From this one may conclude that the transparency was decreased and the algae consequently diminished in frequency.

Regarding now the group of localities distinguished by a high content of minerogene particles in the lower half of stratum *G* (Leskusänget, Stenberg, and Gulleråsen); penetrative algae occur throughout the stratal sequence, except generally the lowermost part of *R I* and the uppermost part of *R II*. The frequency is high, save for the uppermost and lowermost sections of the algae-bearing sequence of strata.

There is one example of the fact that the frequency of both penetrative and enveloping algae was increased after the greatest maximum of minerogene particles (Stenberg), and another (Gulleråsen) of the fact that an increase of the minerogene particles caused a decrease of an abundant vegetation of enveloping algae which had arisen somewhat earlier during a period of low intensity in the supply of minerogene particles. On the other hand, as illustrated in Leskusänget, an abundant vegetation of penetrative algae existed during the very rich supply of minerogene particles, and the enveloping algae began to form a frequent vegetation just during the greatest supply of these particles.

This must mean that the water was very shallow at Leskusänget at this time.

In relation to the supply of minerogene sieve fraction particles there is no regular correspondence of the algae.

Calcium carbonate. The content of calcium carbonate is generally lowest when the great algal frequency begins (exception Granmor), but increases thereafter. However, real correspondence may not occur since the low values of the calcium carbonate curve are caused by the high values of iron and minerogene particles.

Iron. It is distinctive that the greatest maximum of iron is corresponded by the beginning of a very high algal frequency in most cases, and that the iron content is steadily decreased during the continuous abundance of algae. Thus, in the greater part of the upper section of stratum *G* a high frequency of algae is not invariably corresponded by a high content of iron. It is shown in this paper (p. 478) that algae are conducive to precipitation of hydrous iron oxide, but a rich supply of iron seems to be the most important reason for a high content of iron in the sediment. In other words favourable conditions for precipitation of iron are not sufficient to cause a high content of iron in the sediment if the supply of iron to the water is scanty.

Phosphorus. The curves indicate that, in stratum *G*, a high frequency of algae is corresponded by a low content of phosphorus. But, on the contrary, where algae are absent the content of phosphorus is high (cf. for instance Röjeråsvägen).

As regards *R I* and *R II*, there are no regularities in the relations between algae and phosphorus.

Carbon. A high frequency of algae is very often corresponded by an increase of carbon. However, the content of carbon may soon decrease, in spite of the fact that algae are still abundant. On the other hand, it also happens that the content of carbon is high, though algae are few or absent.

Sulphur. There is possibly a regular correspondence between sulphur and algae so much that they seem to exclude each other. However, the content of sulphur is so insignificant that definite statements cannot be made.

Potassium. Regular relations between algae and potassium cannot be ascertained. It happens that the potassium curve increases at the same time as the algal frequency, but there are equally as many examples of the contrary. The potassium curves form maxima independent of algal frequency.

Nitrogen. No regular relation was discernible.

Organic magnesium. A high frequency of algae seems fairly invariably to be corresponded by a diminution in the content of organic magnesium.

Inorganic magnesium. There is no regularity in the relations between this component and algae.

Summary. A rich supply of minerogene particles (which diminished the transparency of the water) decreased the algal frequency, except in the locality which is interpreted to have been situated closest to the shore (cf. p. 462).

The beginning of the high algal frequency may possibly have induced the lively precipitation of hydrous iron oxide.

Abundance of algae seem often to have caused a diminution of phosphorus and sulphur and possibly an increase of carbon.

It is astonishing that real correspondence was not observed between algal frequency and that of potassium and the magnesium which is not bound as silicates. These substances were suggested to be phytogene, but they may also be partly of another origin. The value of these analyses is thus restricted.

Residue insoluble in dilute hydrochloric acid.

Cf. Pl. XI.

As pointed out in the discussion of the influence upon the granulometry by treatment of the samples with hydrochloric acid (p. 443 f.), the size distribution of the particles has certainly been altered but probably not to such an extent that the general appearance of the curves was considerably changed. The curves may thus give an idea of the supply of minerogene particles during the periods concerned.

The localities constitute two main types of granulometric distribution.

One type is distinguished by the fact that the content of the insoluble residue is invariably low, save for the uppermost and lowermost parts of the stratal sequence where the amount of fine-particles is somewhat higher. The content of large particles (i. e. those of the sieve fractions) is low all through the stratal sequence. Localities characterized by this type of the insoluble residue are Rävanäs, Röjeråsvägen, Granmor, and possibly Silverberg. The three former localities are situated in the southern part of the Siljan District, and Silverberg in the eastern part.

The second type is constituted by Leskusänget, Gulleråsen and Stenberg, which are situated mainly in the northern part of the district. This type is characterized by the fact that the total amount of insoluble particles fluctuates greatly in stratum *G*; the content is generally high in the lower half of this stratum. The amount of large particles is higher than in the first type of localities, and their changes in frequency are more considerable. Especially in Leskusänget large particles are abundant in some sections, and the changes in frequency are very pronounced. These changes are partly contemporary with those of the total amount of the insoluble residue, but many divergencies occur. Examples of such divergencies are given in Leskusänget (samples 13—14), Gulleråsen (samples 8—9), and Stenberg (sample 8). As far as *R I* is concerned there is a slight correspondence between the fluctuations of the total amount of the insoluble residue and the large particles. In *R II*, on the other hand, the increase in the total amount of the insoluble residue is not corresponded by an increase of the large particles. In this respect there is similarity with the first group of localities.

The different size and frequency distribution of the insoluble particles as represented by the two types mentioned must have been caused by the fact that the sedimentation took place at different distances from the shore.

The localities belonging to the first type must have been situated at a greater distance from the shore than those belonging to the latter type, i. e. the shore line must have been situated in the north, certainly not far from Leskusänget, and the southern part of the area must have been situated towards the open sea.

Frequency of the insoluble residue compared to that of the chemical elements.

Cf. Pl. XI, XIII, and XIV.

Calcium carbonate. The great minima of the calcium carbonate curves generally correspond to the maxima of minerogene particles. Regular correspondence to the frequency of the sieve fraction particles is not ascertainable.

Iron. As pointed out at the description of the curves of the minerogene particles, two types of curves occur: one with infrequent variability and one with high values in the lower half of *G*.

Considering the first-mentioned type of curve, the great iron maximum in the *Expansus* Zone is not corresponded by an increase in the content of minerogene particles (in Granmor an insignificant maximum corresponds to it). In the upper part of stratum *G* the iron curve grows invariably inferior to that of the minerogene particles. A certain amount of conformity is discernible in *R I*.

Regarding the second type of curve of minerogene particles, the greatest values, as mentioned, occur in the lower half of *G*. This is also true of the iron curve, but it is distinctive that the maxima of the curves are not quite contemporary. In the upper part of *G* both iron and minerogene particles are less frequent than in the lower half. The small *Raniceps* maximum of iron is corresponded by a decrease of the curve of minerogene particles. The uppermost part of the iron curve (mainly in *R II*) is invariably inferior to the minerogene curve (just as in the first-mentioned type of curve).

The content of minerogene sieve fraction particles is indifferent to the iron maxima in the localities where the content of these particles is invariably low and little fluctuating (the southern localities).

In the group of localities where the content of large particles is great and their frequency is very fluctuating in the lower half of stratum *G* there are both correspondences and divergences (the northern group of localites). The greatest iron maximum is invariably corresponded by a lower content of large particles than in the nearest sub- and superjacent samples. As regards the smaller iron maxima, opposite conditions occur for the most part.

Phosphorus. Regular correlations between the phosphorus and the total curve of minerogene particles do not seem to exist.

Concerning the sieve fraction minerogene particles: when the content is high the phosphorus content is often low; a striking example of this is Leskusänget 5, where an occasional increase in the curve of the sieve fraction particles is corresponded by a complete absence of phosphorus. However, regularities do not occur; a high content of phosphorus may also be corresponded by fairly great quantities of sieve fraction particles.

As regards the group of localities where the sieve fraction particles are invariably few, the phosphorus curves run quite irregularly in relation to the frequency of these particles.

Carbon. Regular correspondence to the curve of the total minerogene particles and to the sieve fraction particles does not seem to exist.

In some cases, an increase in the content of the sieve fraction particles may be corresponded by a decrease in the content of carbon, but an increase can also be without effect upon the carbon curve. In many cases, a direct correspondence is discernible, but in others there is no regularity.

Sulphur, potassium, nitrogen, and organic magnesium. Regular correlation not ascertainable.

Inorganic magnesium. In those localities where the content of minerogene particles is high in the lower part of *G* there is a good correspondence with the inorganic magnesium curve in the lower part of the stratum but not in the upper. Correspondence may be re-established to some extent in *R II.* However, the magnesium curve often diminishes or disappears below *G/R II.*

In those localities where the content of minerogene particles is invariably low there is no correspondence between the curve of the total minerogene particles and the inorganic magnesium curve (except Granmor which in this respect is reminiscent of the above-mentioned group).

As regards minerogene sieve fraction particles there is no regular correspondence to the inorganic magnesium curve.

Summary. Regular correlations between total amount of minerogene particles and chemical elements do not seem to occur as regards most of the elements. A certain amount of correlation occurs with iron and inorganic magnesium, viz. in the lower part of stratum *G* in the northern group of localities which are interpreted to have been situated relatively close to the shore. The greater iron maxima are here invariably corresponded by a decrease of the minerogene sieve fraction particles.

The calcium carbonate curve is contrary to the curve of the total minerogene particles with regard to the greater maxima.

Residue insoluble in acetic acid.

Cf. Pl. XII.

By the treatment of rock samples with acetic acid as described on p. 445, particles consisting of limonite, glauconite, chamosite, undetermined amorphous silicious compounds, and phosphorite were released.

The total distribution of these components is reproduced in Pl. XII.

The black fields in the histograms show the total frequency of ooids. Since, in many cases, concentrically structured limonitic ooids cannot be distinguished externally from those non-concentrically structured, and since the chamositic ooids are too few to be reproduced separately, these different types of ooids are accounted for as one group. The main part are concentrically structured limonitic ooids. (It happens that, in Pl. X, a few samples are indicated to contain ooids, but this does not appear from Pl. XII which, however, is due to the fact that the frequency is too inferior to be reproducible in the histograms.)

The hatched areas illustrate the frequency of the non-ooidic limonitic particles. The total frequency of the remaining insoluble particles (mainly phosphorites and undetermined amorphous silicates) is reproduced by open fields. The frequency of each separate component of this group was not illustrated, partly on account of the fact that the frequency is sometimes low and partly since the particles often consist of more than one of the components.

The components released by means of acetic acid are briefly accounted for below.

Limonitic particles.

These particles are partly ooidic, partly non-ooidic. Two horizons with a larger content of ooids are generally discernible: one in the *Expansus* Zone and another in the *Raniceps* Zone. The former is the richest ooid-bearing. The horizons are for the most part separated by a non-ooidic layer. In Rävanäs and Röjeråsvägen the *Raniceps* oolite is less distinctly developed.

Leskusänget takes a special position on account of its great richness in ooids. In Rävanäs, on the other hand, the content of ooids is remarkably low.

As far as the size of the ooids is concerned, most of them belong to the fraction of 0.25—1.0 mm. Also fairly common are ooids of the size 0.125—0.25 mm. There are, moreover, samples including rather numerous ooids of the 0.06—0.125 mm fraction (*Raniceps* oolite of Gulleråsen). On the other hand, 1—2 mm ooids occur in some localities, especially in the most ooid-bearing part of the *Expansus* Zone.

As a rule, the size of the ooids in the *Expansus* Zone is increased upwards. Comparing the size of the ooids in this zone of the different localities, one finds that the ooids are larger in the mainly northern localities (Leskusänget, Gulleråsen, and Stenberg; chiefly 0.25—1.0 mm) than in the southern localities (Rävanäs, Röjeråsvägen, and Granmor; mainly 0.125—0.5 mm). The former were situated nearer the shore than the latter group (cf. p. 462). The Silverberg ooids are, on the whole, very small (for the most part 0.125—0.25 mm).

Concerning the size of the *Raniceps* ooids, they are, in Leskusänget, equally large as in the *Expansus* Zone, but in the other localities where the *Raniceps* Zone is represented in reproducible quantities (Gulleråsen and Stenberg) they have diminished in size in relation to the *Expansus* ooids.

The non-ooidic limonitic particles occur partly in layers without ooids and partly in the ooid-bearing horizons. From the histograms it appears that, in the northern localities, the amount of non-ooidic particles is large below the ooidic maximum of the *Expansus* Zone, but that it has decreased considerably in this zone. The content remains low in the continuation. Thus, during the heavy precipitation of hydrous iron oxide in the *Expansus* period there occurred a change towards an increased formation of ooids. This corresponds to the fact that enveloping algae increased in number contemporarily.

In the southern localities (which seem to have been situated in a greater depth, cf. p. 462) the content of non-ooidic particles is highest in the most ooidic samples. This may be due to the fact that enveloping algae were not as abundant as in the northern localities situated closer to the shore.

As regards the size of the non-ooidic particles in the *Expansus* Zone, they occur, in the northern localities, for the greater part in more small-sized fractions than the main part of the ooids. Exceptions may appear occasionally, such as in Leskusänget sample 11. In the southern localities, they are for the most part of mainly the same size distribution as the ooids.

In the *Raniceps* Zone the size distribution of the non-ooidic limonite particles is mostly similar to that of the *Expansus* Zone.

The occurrence of limonitic ooids is compared below to minerogene particles and chemical elements.

Minerogene particles. The content of minerogene particles is invariably high before the appearance of the ooids. In the very oolite the frequency of minerogene particles is decreased, and partly very low (for instance Gulleråsen). In Leskusänget it occurs that a high frequency of ooids is accompanied by a high content of minerogene particles (samples 11 and 13).

As far as the sieve fraction particles are concerned, it is characteristic that they increased in number at the end of the formation of ooids and in the next following non-ooidic period. It may also be observed that the content of large particles is high at the beginning of the formation of the ooids (cf. Leskusänget). During the culmination of the formation of ooids the supply of such particles, as a rule, decreased.

Calcium carbonate. The content of calcium carbonate is generally low in the ooidic layers.

Iron. Correspondence evident.

Phosphorus. The ooidic horizons are rich in phosphorus, but the highest phosphorus values often appear just below the ooidic horizons. Phosphorus content is often high after the end of the formation of ooids (sometimes absolute phosphorus maximum in this horizon, as in Gulleråsen).

Carbon. The ooidic layers are generally corresponded by a high content of carbon; maxima of ooids and carbon often contemporary. Examples of the fact that the content of carbon is low during the formation of ooids also occur (e. g. Rävanäs 5, and Stenberg 9); on the other hand, a high content of carbon (also the absolute maximum) can occur without formation of ooids.

Sulphur. The content of sulphur seems generally to be low during the formation of the ooids.

Potassium. The content of potassium is often high in the ooidic layers, such as in Leskusänget, but high values appear in many cases both below and above; sometimes the potassium values are low in the oolite and higher on both sides. Regular correspondence not ascertainable.

Nitrogen. The content of nitrogen is often low in the ooidic layers but also somewhat higher than above and below. Regular correspondence not established.

Magnesium. Regular correspondence not discernible. Occasional correspondence may appear, such as is the case regarding inorganic magnesium in Leskusänget and Gulleråsen.

Summary. The most favourable conditions for formation of limonitic ooids seem to have been near the shore when the supply of minerogene particles had diminished, especially those of larger size. At the end of the formation of ooids, large-particles were supplied in increased numbers. The content of phosphorus and carbon in the sediment is high, indicating, like the above-mentioned distribution of minerogene particles, that the water was stagnant during the most intensive formation of ooids. The increase of minerogene large-particles during the end of this period and the following one indicates that the water had begun to be less stagnant.

Chamosite and chamositic ooids.

Chamositic substances occur mainly in the *Raniceps* Zone, where they form ooids to a great extent. Chamositic ooids occur occasionally also in the *Expansus* Zone.

The occurrence of the chamositic substances is referable to minerogene particles and the chemical elements in the following way:

Minerogene particles. Greatest frequency of chamosite occurs during a mainly low supply of insoluble particles; the content of sieve fraction particles is not very low, however.

Calcium carbonate. Regular correspondence scarcely discernible.

Iron. Occurrence of chamosite corresponded, more or less perfectly, with an increase in the curve of iron. However, the increase of iron is caused also by limonite.

Phosphorus. Occurrence of chamosite corresponded by a relatively high content of phosphorus.

Carbon. As a rule, equal to phosphorus.

Sulphur. Insignificance of sulphur excludes comparison.

Potassium. In several cases, chamosite was formed during a period of potassium decrease, and finished just as potassium increased again. But, there are also examples of the fact that formation of chamosite took place both during maxima and minima of potassium and also at a complete absence of potassium. High contents of potassium may, on the contrary, occur without formation of chamosite. Thus, the appearance of chamosite is independent of potassium.

Nitrogen. Regular correspondence not discernible.

Magnesium. Equal to nitrogen.

Summary. The occurrence of chamosite substances corresponds with a high content of iron, phosphorus, and carbon, and a low content of minerogene particles, all of which indicates stagnancy.

Phosphoritic and undefined silicious remains.

The frequency of these compounds is highest in the northern group of localities. They are proportionally most abundant before the formation of the *Expansus* ooids. During the actual formation of these ooids they generally decreased in frequency. In the *Raniceps* Zone they seem to have increased proportionally again, as observed in Leskusänget.

In the southern group of localities these compounds have a low frequency (Rävanäs, Röjeråsvägen, and Granmor).

Glauconite.

Glauconitic grains appear especially around *R I/G* though not in larger quantities. They are more frequent in the southern localities. In a few localities they may occur fairly invariably in very small quantities rather high up in stratum *G* (such as in Leskusänget and Stenberg).

The more richly glauconite-bearing strata have a rather high content of minerogene particles, and the content of potassium is invariably rather high. In relation to other elements no regular correspondences are discernible.

A slight temporary increase of the iron content around *R I/G* seems to be caused by the glauconite.

Glauconite and chamosite mainly exclude each other, but it may happen that some glauconitic grains occur in chamositic strata. Occurrence of chamosite in mainly glauconitic layers was not observed, however.

Analyses of chemical elements.

Chemical analyses.

Cf. Pl. XIII and XIV.

Calcium carbonate. The content of carbonate was determined by dispelling the carbon dioxide. The carbonate is presented as calcium carbonate.

Only a small part may occur as magnesium carbonate judging by the fact that the content of magnesium is low. Some small quantities may also be present as iron carbonate. Thus, the curves practically reproduce the content of calcium carbonate.

The content of calcium carbonate is about 80—90 % of the sedimentary rock, except in the lower half of stratum *G*, where it often decreases to 60—70 %. It may decrease even more; the minimum content of calcium carbonate observed is 27.20 %.

The curves show invariably one or more pronounced minima in the lower half of stratum *G*. For the rest the curves fluctuate only a little. The transitions at *R I/G* and *G/R II* take place without break.

Iron. The iron substances are mainly oxides and are presented here as Fe_2O_3. Iron occurs in smaller quantities as pyrite and possibly in carbonates and phosphates. The quantities of glauconite and chamosite are also of subordinate importance.

From the curves it appears that the frequency of iron is considerable in the lower half of stratum *G* where the content of Fe_2O_3 can amount to 30—45 % of the sedimentary rock. In some localities, only one maximum was observed (the localities of the southern part of the Siljan District: Rävanäs, Röjeråsvägen, and Granmor), but in others, three maxima may be discerned (the localities of the northern, north-western and north-eastern parts: Leskusänget, Stenberg and Gulleråsen).

The content of Fe_2O_3 is low in the remaining parts of the stratal sequence investigated. In a few localities one may discern a small maximum in the *Raniceps* Zone. The iron content is low in the reddish strata *R I* and *R II* (in *R I* mostly 2—3 % [min. about 2 %, max. about 5 %], in *R II* mostly 2—3 % [min. about 2 %, max. about 5 %]).

Phosphorus. This element is presented as P_2O_5.

In *R I* and *R II* the content of phosphorus is very low, or phosphorus is sometimes completely absent.

In stratum *G*, on the other hand, the content of phosphorus is fairly high in certain sections (maxima for the most part 0.7—1.4 % P_2O_5). In the lower half of the stratum (with the exception of Rävanäs) two maxima are discernible, the greater of which corresponds mainly to the most oolitic part of the *Expansus* Zone. The second maximum appears just above *R I/G*.

In the upper part of the stratum there is for the most part a distinct maximum in the *Raniceps* Zone; sometimes it is followed by a small second maximum, such as in Leskusänget, Gulleråsen and possibly Born-Dådran. A third distinct maximum may appear just below *G/R II* as stated in Gulleråsen and Silverberg II, where samples were taken immediately below this boundary.

Some few analyses were made in order to determine whether phosphorus is concentrated in the limonitic ooids. It was found that the phosphorus content is slightly higher than in corresponding samples consisting of ooids and the matrix. In Leskusänget sample 13, for instance, the content of phosphorus in the ooids is 0.43, but in the ooids plus the matrix 0.30 %.

Carbon. The content of non-carbonatic carbon ("organic" carbon) is, as a rule, fairly low (most often < 0.2—0.3 % C). In stratum *G* the content sometimes is higher; a maximum of about 0.8 % is reached in Leskusänget. For the most part, one maximum appears in the *Expansus* section and another in the *Raniceps* section of stratum *G*.

Sulphur. The content is low, or sulphur is completely absent. It does not exceed 0.1 %; for the most part it is inferior to 0.05 %.

Potassium. Only the potassium which is not bound to silicates is considered here. It is presented as K_2O. The content is low; for the most part, the curves vary between 0.01 and 0.05 % K_2O; the absolute maximum is about 0.08 %. The highest values most often appear in the *Expansus* part, but high values may also occur in the *Raniceps* part.

Nitrogen. The content of nitrogen is low in all samples. In most cases it does not exceed 0.02 % N; maximum amounts to about 0.04 %.

Magnesium. The content of magnesium is fairly low. In most cases it amounts to about 0.2—0.5 % MgO. In two localities (Röjeråsvägen and Stenberg) it is extremely low (maximum about 0.01 %).

The distribution of the magnesium occurring as silicates and that occurring as other compounds are presented in separate curves.

In the uppermost part of *R I*, sometimes one of these curves is more frequent, sometimes the other, but in stratum *G* the curve of the magnesium which is bound to components other than silicates dominates, especially in the lower half. This curve can be superior practically to *G/R II*, but, as a rule, it is exceeded by the curve of the magnesium bound as silicate somewhat below *G/R II.* In some cases it may also have disappeared below this boundary. If continuing in *R II*, the curve forms a minor maximum just below *G/R II.*

Spectral analyses.

Some spectral analyses have been made to establish the frequency of some elements in the limonitic ooids (Leskusänget samples 5 and 14, and Röjeråsvägen sample 4) and in the originally semifluid limonitic substances which occur in the lower part of stratum *G* (Gulleråsen sample 5).

The elements were chosen partly with the intention to examine whether there exists any correspondence between the oolite and some sulphide ores in the Siljan District.

The table shall not be commented upon in its entirety; only some remarks shall be made.

It may first be mentioned that the content of potassium and magnesium is considerable which may be due to phytal concentration (the ooids include both penetrative and enveloping algae, and shell fragments bored by algae are also included in the limonitic Gulleråsen substance analysed). The frequency of these elements is higher in the lower of those Leskusänget samples investigated.

The relatively high content of manganese in the Gulleråsen limonitic substance may derive from manganese components in its black, mainly phosphoritic, discontinuity surface. The content of manganese in the ooids has diminished in the uppermost sample investigated (Leskusänget 14).

The partly high content of titanium in the ooids is remarkable. This element, which is generally abundant in volcanogene products, may have been incorporated in the ooids as a colloid. The highest content was found in the lower Leskusänget sample.

The reason for the decrease upwards in stratum *G* of the elements now mentioned, (K, Mg, Mn and Ti) which are frequent in basic volcanic

Elements	Röjeråsvägen 4	Leskusänget 5	Leskusänget 14	Limonitic substance
Ag	< 0.00005	< 0.00005	0	Traces
Al	c. 4	c. 8	—	1.5
As	0	0	—	0
Au	0	0	—	0
B	0.01	0.01	0.002	—
Ba	0.1	0.1	0	0.2—0.5
Be	—	—	0	0.2
Ca	3.25	2.35	1.0	25.5
Ce	0	0	—	—
Cd	Traces	Traces	—	Traces
Co	< 0.00005	< 0.00005	0	Slight traces
Cr	0.0003	0.00025	0.003	0.0002
Cu	0	0	Traces	Slight traces
Fe	38.0	24.0	37.3	14.0
In	0	0	—	Traces
K	1.10	1.45	0.82	0.91
Li	0.005	0.005	0.006	< 0.05
Mg	2.57	1.66	0.65	1.55
Mn	0.030	0.024	0.06	0.134
Mo	Traces ?	Traces ?	0	0
Na	< 0.10	< 0.10	< 0.01	< 0.1
Ni	< 0.00003	< 0.00003	0.001	0.0005
Pb	0	0	0	Traces
Pt	0	0	—	Traces
Sn	Traces	Slight traces	—	0
Sr	0.09	0.20	Traces	0.2—0.4
Ti	1.0	2.0	0.1	> 0.5—(3)
V	0.03	0.015	0.02	0.01
W	< 0.001	< 0.001	—	—
Zn	0.01	0.008	0	0.05

products, is not known. The different contents may be the result of an accident, but real causes may also be suggested. However, the scattered data as given above are not sufficient for definite conclusions in this respect.

The content of boron and sodium seems also to be somewhat higher in the earlier part of the *G* stage which may indicate that the salinity had decreased.

Chemical elements compared to each other.

Cf. Pl. XIII and XIV.

The following comparisons between the distribution of the chemical elements is only a brief accompanying text to the curves. Thereby, not only have the elements been compared which show similarities to each other, but, for the sake of completeness, also those where no relations occur or can be expected to occur.

Calcium carbonate — iron. The most pronounced minimum of calcium carbonate generally corresponds to the greatest maximum of iron. The smaller minima are often corresponded by smaller maxima of the iron curve.

Calcium carbonate — phosphorus. In a few cases, occasional similarities occur, but often the curves run contrarily. Real correspondence is not ascertainable.

Calcium carbonate — carbon. Some occasional similarities occur, especially in the upper part of the curves, but generally they are contrary to each other or otherwise mutually irregular. Real correspondence may not exist.

Calcium carbonate — sulphur. Real correspondence is not discernible.

Calcium carbonate — potassium. In some localities there is a certain similarity in the main course of the curves or in details (cf. Gulleråsen), but in others the curves are contrary or mutually irregular. Correspondence is hardly discernible.

Calcium carbonate — nitrogen. In some localities there are slight similarities, but for the most part the curves are contrary or mutually irregular. Correspondence is scarcely ascertainable.

Calcium carbonate — organic magnesium. The most pronounced minima of calcium carbonate are for the most part corresponded by maxima of organic magnesium. In those parts where the content of carbonate is higher, similarities in the course of the curves may occur.

Calcium carbonate — inorganic magnesium. In a few localities, there is some similarity in parts of the curves, but mostly no similarities appear. General correspondence may not occur.

Iron — calcium carbonate. Cf. above.

Iron — phosphorus. The great iron content in the *Expansus* Zone is generally corresponded by a high content of phosphorus. However, maxima are practically never contemporary. In this part of the stratal sequence the phosphorus maxima precede the iron maxima, but in the *Raniceps* section the contrary appears for the most part. In some cases phosphorus is abundant but the iron content is low.

Iron — carbon. The course of these curves is similar in some localities even as regards details, viz. in the lower half of stratum *G* (Leskusänget, Gulleråsen, and Stenberg). However, the carbon curve is high in the upper half of stratum *G* of these localities, but the iron curve is low.

In other localities the curves are often dissimilar. It may happen that a high content of iron in the lower part of stratum *G* is not corresponded by abundance of carbon. The curves may also be contrary to each other in the upper part of this stratum and in *R II* (Silverberg II and Born-Dådran); the content of carbon is low in this case.

Iron — sulphur. In most cases there is opposition between the concentrations of these elements; the sulphur curve is low, however, and a comparison is of minor reliability.

Iron — potassium. The great maxima of these curves in the lower half of stratum *G* are generally not perfectly correspondent. In the majority of those localities where the closest sequences of samples were examined, it could be observed that the absolute maximum of the potassium curve appears somewhat earlier than that of the iron curve, such as in Leskusänget and Stenberg. In other localities, the maxima may be contemporary (Röjeråsvägen, maximum of potassium low), or the absolute iron maximum may preceed the potassium maximum (Rävanäs and Gulleråsen), but in the latter cases there is also a potassium maximum below the iron maximum, though at somewhat greater distance.

In relation to that of iron, the potassium curve runs proportionally high in the upper part of stratum *G* in most of the localities (sometimes it runs higher than in the lower half of this stratum; Röjeråsvägen, Gulleråsen, and Granmor).

Iron — nitrogen. Both in the upper and lower sections of the stratal sequence there are important correspondences, especially in the lower half of stratum *G*.

The great iron maximum of the *Expansus* Zone is corresponded by high contents of nitrogen in the localities with the closest samples. Also similarities in details as regards the course of the curves are often observed. In the localities with larger interspaces between the samples, correspondences between the curves as now mentioned were not observed.

The smaller iron maximum in the *Raniceps* Zone may also be corresponded by a small nitrogen maximum (Leskusänget, Gulleråsen, and Born-Dådran). In Röjeråsvägen there is a fairly great nitrogen maximum which is not corresponded by a similar increase of the iron content. Contrarieties between the curves were observed in one locality, viz. Silverberg II.

In fact, there are many indications of a correspondence between iron and nitrogen.

Iron — organic magnesium. These elements are, as a rule, more abundant in the lower part of *G* than in the upper. A small enrichment of both in the upper part is often seen. However, general correspondence as regards the details of the curves does not occur.

Iron — inorganic magnesium. Both elements have generally the highest frequency in the lower part of stratum *G.* The main course of the curves is often correspondent, as in Leskusänget, and in many cases one may trace a far-reaching similarity as regards details, for instance Gulleråsen.

Phosphorus — calcium carbonate. Cf. p. 472.

Phosphorus — iron. Cf. p. 472.

Phosphorus — carbon. The main distribution of the elements is fairly similar, but there are differences in the details. It may be discernible that the carbon maxima are most often preceded by phosphorus maxima.

Phosphorus — sulphur. In many cases a maximum of one curve is corresponded by a minimum of the other. Only occasionally, some conformity may occur.

Phosphorus — potassium. In the lower half of stratum *G* there is mostly correspondence between the great maxima of the curves. As regards the small maxima there are, however, irregularities for the most part.

In the upper part of stratum *G*, there are mostly similarities.

In *R II* the phosphorus curve decreases in most cases but that of potassium is increased. Maxima of the two curves are entirely correspondent in one locality (Röjeråsvägen).

There seems to exist some correspondence between the distribution of phosphorus and potassium.

Phosphorus — nitrogen. A few accidental coincidences between the curves may appear.

Phosphorus — organic magnesium. In Rävanäs and Born-Dådran there are distinct correspondences. As regards Leskusänget and Granmor, many similarities occur, but also divergences. Far-reaching or complete dissimilarities, on the other hand, exist in Gulleråsen, Silverberg, and Silverberg II.

Regular correspondence may not occur.

Phosphorus — inorganic magnesium. Correspondences are discernible, even as regards details, between the curves of these elements. However, some striking differences also occur, viz. in Gulleråsen (lower part of stratum *G*), Silverberg II (middle part of *G*), and Silverberg.

Carbon — calcium carbonate. Cf. p. 472.

Carbon — iron. Cf. p. 473.

Carbon — phosphorus. Cf. above.

Carbon — sulphur. Regular correspondence is not ascertainable.

Carbon — potassium. There is a good correspondence between the curves in several localities: Rävanäs, Granmor, Silverberg, and Silverberg II. In the remaining localities, there is partly a far-reaching correspondence but also distinct differences. The differences appear mostly in the upper part of stratum *G*.

Carbon — nitrogen. A good correspondence occurs in Silverberg and Silverberg II. In most of the other localities the curves are indifferent or divergent, but also mainly similar (somewhat higher frequencies in the *Expansus* and *Raniceps* Zones separated by a minimum; Leskusänget, Gulleråsen, and Granmor).

Some correspondence between carbon and nitrogen may possibly exist, but it is not more definitely established.

Carbon — organic magnesium. These curves are somewhat more correspondent than those of carbon and inorganic magnesium, but there are also dissimilarities (especially Röjeråsvägen and Silverberg II), and it is difficult to ascertain whether any regular correspondence occurs.

Carbon — inorganic magnesium. Similarities may occur (especially Rävanäs and Born-Dådran), but for the most part the curves are indifferent or contrary. Regular correspondence does not seem to exist.

Sulphur — calcium carbonate. Cf. p. 472.

Sulphur — iron. Cf. p. 473.

Sulphur — phosphorus. Cf. p. 474.

Sulphur — carbon Cf. p. 474.

Sulphur — potassium. A few occasional correspondences occur, but, as a rule, there is no regular correspondence between the curves.

Sulphur — nitrogen. Reliable comparisons are scarcely performable on account of insignificant concentrations of these elements.

A few correspondences occur, but for the most part the curves are fairly indifferent. Whether regular relations exist is not decidable.

Sulphur — organic magnesium. Most of the curves do not show any similarities. Only a few occasional coincidences appear. Regular correspondence is not ascertained.

Sulphur — inorganic magnesium. Occasional coincidences occur, but in most cases there are no similarities, and regular correspondence is not proved.

Potassium — calcium carbonate. Cf. p. 472.

Potassium — iron. Cf. p. 473.

Potassium — phosphorus. Cf. p. 474.

Potassium — carbon. Cf. p. 474.

Potassium — sulphur. Cf. above.

Potassium — nitrogen. A far-reaching correspondence occurs in most of the localities as regards the lower half of the curves. However, the curves may also be indifferent (Rävanäs) or slightly contrary (Röjeråsvägen).

The curves are in most cases contrary in the uppermost part (except Röjeråsvägen and Silverberg II).

Potassium — organic magnesium. The main frequencies of the elements are, for the most part, fairly correspondent (generally a high frequency in the lower part of stratum *G* and somewhat below *G/R II*, but a lower frequency in the intervening section).

As regards details in the courses of the curves there is a certain amount of correspondence in the lowermost part of stratum *G*, but for the rest there are no regular detail similarities.

Potassium — inorganic magnesium. Certain similarities occur in the lower part of stratum *G*, but regular correspondences are not discernible for the rest.

Nitrogen — calcium carbonate. Cf. p. 472.
Nitrogen — iron. Cf. p. 473.
Nitrogen — phosphorus. Cf. p. 474.
Nitrogen — carbon. Cf. p. 475.
Nitrogen — sulphur. Cf. p. 475.
Nitrogen — potassium. Cf. p. 475.
Nitrogen — organic magnesium. No regular correspondence.

Nitrogen — inorganic magnesium. A practically perfect correspondence was observed in one locality (Gulleråsen), but in the other localities there is a great variability as regards the relations between the two curves. Some accidental coincidences occur, but for the most part the curves are indifferent, and in Granmor they may be said to be contrary.

Org. magnesium — calcium carbonate. Cf. p. 472.
Org. magnesium — iron. Cf. p. 474.
Org. magnesium — phosphorus. Cf. p. 474.
Org. magnesium — carbon. Cf. p. 475.
Org. magnesium — sulphur. Cf. p. 475.
Org. magnesium — potassium. Cf. p. 475.
Org. magnesium — nitrogen. Cf. above.
Organic magnesium — inorganic magnesium. Cf. p. 470.
Inorg. magnesium — calcium carbonate. Cf. p. 472.
Inorg. magnesium — iron. Cf. p. 474.
Inorg. magnesium — phosphorus. Cf. p. 474.
Inorg. magnesium — carbon. Cf. p. 475.
Inorg. magnesium — sulphur. Cf. p. 475.
Inorg. magnesium — potassium. Cf. above.
Inorg. magnesium — nitrogen. Cf. above.
Inorg. magnesium — org. magnesium. Cf. p. 470.

Summary. The sulphur curves are indifferent to the other curves to a great extent. Sulphur is, however, weakly concentrated and the curves fluctuate very little so that comparisons with other elements are scarcely reliable.

The curves of the magnesium which is considered to be organogene are indifferent to most of the curves of the other elements. However, similarities occur with iron and phosphorus.

The curves of calcium carbonate are indifferent to most of the other curves. They are contrary to the curves of iron and organic magnesium.

A partly far-reaching correspondence seems to exist between the distribution of the following elements: iron — phosphorus — carbon — potassium — nitrogen — magnesium.

4. Genesis of the present types of ooids.

There are 5 main types of ooids present:

1. Chamositic real ooids.
2. Limonitic ooids with concentric structures.
3. Limonitic ooids without concentric structures.
4. Calcitic concretionary ooids.
5. Phosphoritic concretionary ooids.

Since iron ooids are the most frequent of these ooids, some data and considerations will be given as regards the mode of occurrence of iron in the sea before discussing the formation of the ooids.

The occurrence of iron in the sea.

Hydrous iron oxide.

In the present sea, iron occurs only in inconsiderable quantities as real solutions, viz. as ferric fluoride (COOPER 1937), which is a very little dissociable compound. Easily dissociable iron compounds, released for instance by the decomposition of organisms, cannot exist in these surroundings but are hydrolysed into hydrous ferric oxide. In those parts of the sea where the content of strong electrolytes is high the colloids thus formed are flocculated. The content of iron in such waters will thus be low. Also in waters where the amount of electrolytes is low only negligible quantities of hydrous iron oxide can be dissolved owing to the fact that its solubility is very small at the pH prevailing in the sea (about 8). No larger quantities of sols covered with coating colloids can exist in a ventilated water, since the coating colloids are readily oxidized so that the sols become released and precipitated.

Thus it appears that iron compounds are generally not accumulated in sea water: as they arrive they are successively precipitated and incorporated in the sediment.

However, the water's content of iron can be raised during certain circumstances, viz. if the CO_2-pressure in the water is high. Such conditions are created in closed areas where great quantities of organogene detritus are accumulated and the content of oxygen is low, thus in shallow and enclosed coastal areas. In this case the iron occurs as a solution of $Fe(HCO_3)_2$.

This unstable compound is, however, easily transformed into hydrous ferric oxide when the CO_2-pressure is lowered in the presence of oxygen.

This transformation can be caused by a mechanical stirring up of the water. But it may also occur in a constantly stagnant water, mainly because of the process of carbon dioxide assimilation by plants and by the decomposition of organic substances with an excess of oxygen.

The importance of plants for the precipitation of hydrous iron oxide is discussed in part II of the present series of papers (cf. also below).

A few words shall be mentioned here on the importance of the process of decomposition for the precipitation of hydrous iron oxide.

Carbon dioxide is released at decomposition, and in stagnant water the CO_2-pressure may be increased considerably in spheres around decaying bodies. Large quantities of $Fe(HCO_3)_2$ may be accumulated in such spheres, especially if simultaneously the O_2-pressure is low, which is often the case in such surroundings.

However, iron and sulphur are also released, but at the high CO_2-pressure the iron is converted into $Fe(HCO_3)_2$:

$FeS + 2H_2O + 2CO_2 \rightarrow Fe(HCO_3)_2 + H_2S$

Thus, at the same time as the concentration of the bicarbonate is increased, the solubility of this compound is decreased because of the lowered CO_2-pressure.

If oxygen is absent, the $Fe(HCO_3)_2$ is transformed into the neutral $FeCO_3$ which is precipitated as a colloid:

$Fe(HCO_3)_2 \rightarrow FeCO_3 + H_2O + CO_2$

As a matter of fact, a partial re-solution of $FeCO_3$ may take place as the CO_2-pressure increases when CO_2 is continuously produced at the decomposition, and when $Fe(HCO_3)_2$ is converted into $FeCO_3$. But iron and sulphur are continuously released (production of $Fe(HCO_3)_2$ and decrease of CO_2-pressure); further, CO_2 is diffused, and the quantities of CO_2 consumed at the formation of $Fe(HCO_3)_2$ are, moreover, larger than those released at the formation of $FeCO_3$. Thus, the final result will be that $FeCO_3$ is formed as long as iron and sulphur are released.

If, on the other hand, oxygen is present at the decomposition, hydrous iron oxide will be the final product. This will happen if plants are present in accordance with the following scheme:

$Fe(HCO_3)_2 \rightarrow FeO + H_2O + 2\ CO_2$ (consumed by plants)

$2FeO + \frac{1}{2}O_2$ (produced by plants) $\rightarrow Fe_2O_3$

$Fe_2O_3 + n\ H_2O \rightarrow Fe_2O_3 \cdot n\ H_2O$

The decomposition will not change the pH in any higher degree if calcium carbonate is present. The calcium carbonate and the waste carbonic acid will create a buffer solution of pH about 8 (in physiological laboratories buffer solutions of pH 8 are made by the action of H_2CO_3 upon $CaCO_3$; verbal communication by Prof. P. E. LINDAHL). The solubility of the hydrous iron oxide is thus quite negligible, and the precipitation will take place at once.

The consistence of the precipitate is dependent on the amount and type of electrolytes in the water. If the flocculation value is exeeded, precipitates of greater concentration are formed; but if this value is not reached, less concentrated colloids may be deposited. In addition to that, the electrolytes have a dehydrating effect (SPRING 1899). Thus, very subtle structures can be expected (for instance fillings of minute canals in organic hard tissues) if the electrolytic effect is low. On the other hand, if the electrolytic effect is high, one may expect that the colloids are generally precipitated as irregular masses and coatings.

Iron silicates.

The iron of the sea is precipitated not only as hydrous oxides but to a large extent as colloidal silicates. However, very little is known about their present formation.

A necessary condition for their formation is that silica is present to which iron ions can be fixed. Silica is supplied by so-called peptization of silicious skeletons, but the greatest quantities are terrigenous, carried to the sea by streams. Very great quantities are supplied when a deeply weathered land surface is invaded by the sea. The fact, for instance, that the land surface of NE Scania was deeply kaolinized when the Senonian sea invaded this area is certainly the reason for the circumstance that great masses of green iron silicates were formed during this transgression.

If a period characterized by a precipitation of iron silicates is followed by a precipitation of hydrous iron oxides, this must be due to the circumstance that the supply of silica has ceased. The silicates do not exclude the hydrous oxides. As a matter of fact, the presence of both is favourable for their precipitation since they have different electric charges.

A precipitate of a positively charged hydrous oxide induces a precipitation of the negatively charged silicate around the oxide. The silicate stratum induces, in turn, a precipitation of hydrous oxide, and so on. Such alternating precipitation is often seen in the present material (cf. for instance Pl. VI, Fig. 1).

Just as in the case of the hydrous oxides, the water's content of electrolytes is of great importance for the consistence of the silicates precipitated. The most subtle structures may be formed at a low content of electrolytes, and concretions at a high content.

Chamositic real ooids.

Pl. VI, Figs. 3—6 and Pl. VIII.

In the present case these ooids occur together with limonitic ooids. They may occur sparsely in the *Expansus* oolite, but they are distinctive for the *Raniceps* oolite; however they are not very abundant.

The ooids are often distinctly stratified. A nucleus is observable in many cases. This one may be a shell fragment encrusted with limonite. A fine intercalation between limonitic and chamositic strata may be observed in the stratified part of the ooids. The surface layer is often dark green or black. The black colour is mainly because of the presence of phosphorous and sulphurous compounds. In the interior the ooids are greyish green or whitish and often of a somewhat mealy appearance; this whitish substance seems to be identical with myeline (= nacrite), which is interpreted by SLAVIKOVÁ and SLAVIK (1918) as a secondary product of chamosite. Sometimes the ooids may include layers of originally colloidal calcium carbonate. Enclosures of phosphorite and pyrite are common. In the ooids there are generally fine radiating cracks, which are certainly original.

Chamositic ooids occur in differrent parts of the Palaeozoic region of Scando-Estonia. They have partly also been described, but their chamositic character has not been recognized.

ORVIKU (1940) has most thoroughly described such ooids from the Aseri stage of Estonia. The ooids are mentioned by him as "white ooids" and their substance is considered to be mainly calcite (p. 107). Calcitic ooids occur, as a matter of fact, in his material (cf. Pl. XXIV, Figs. 4—7) but the majority of the "white ooids" are chamositic. This appears from his description (p. 113), and from his very elucidating photographs. I have myself had the opportunity to study so-called white ooids from the Aseri stage both macro- and microscopically. There is no doubt as to their chamositic nature. It may be added that they coincide perfectly with the present ones.

Chamositic ooids (partly including originally colloidal calcium carbonate) occur also in the Island of Öland. Especially at Byerum this stratum is well developed. According to oral communication by Dr B. BOHLIN and Mr H. MUTVEI, this horizon is referable to the *Raniceps* Zone, i. e. the same horizon as that of the Siljan District where the chamositic ooids are most common.

Lower Ordovician layers of chamosite ooids are known from other countries. The ore fields at Nučice and some other places in Bohemia contain chamositic oolites to a large extent. The well-known ores of Thuringia and Wales are also chamosite-bearing. Chamositic ooids form an important part of the ores in the Armorican schists and sandstones ("bavalite et variétés", according to CAYEUX 1909, p. 271). In the iron ores of Wabana, Newfoundland, chamositic ooids constitute an essential part.

Younger iron ores partly consist of chamositic oolites, such as the Jurassic ores of Cleveland and Lorraine. Oolitic iron ores of the same age consisting to a large extent of chamosite also occur in Scania, Sweden (HADDING 1933).

Returning to the Scando-Estonian Lower Ordovician chamositic ooids, they attain their highest frequency after the greatest abundance of the limonitic oolite has occurred. In the Siljan District the frequency of the chamositic ooids in the *Raniceps* Zone is still inferior to the frequency of the limonitic ooids, but in the Island of Öland the *Raniceps* chamositic oolite forms a fairly considerable layer, whereas limonitic ooids are quite sparse. The limonitic oolite in the *Expansus* Zone is, on the contrary, less comprehensive in Öland than in the Siljan District. ORVIKU (1940, p. 65) mentions that the "white ooids" replace the limonitic ooids in the uppermost part of the Aseri stage.

These alternations must mean that the water's content of silica had increased, according to the facts mentioned in the general discussion above of hydrous iron silicates (p. 479). This increase is possibly due to the fact that sediments rich in fairly mobile silica were exposed and the silica transferred to the sea after a covering layer of richly ferrugineous sediments had been consumed.

In the following, some facts shall be mentioned which are elucidative of the formation of the chamositic ooids in the Siljan District.

It was mentioned above that the negatively charged chamosite was deposited around a nucleus which in many cases could be observed to be a grain of hydrous ferric oxide or an object covered by this substance (thus positive charge). In the continuation, chamosite and limonite were precipitated alternately in partly extremely thin layers. This indicates that the precipitation which may have been caused by opposite electric charges of both substances could proceed quietly. A condition for this was that interference of other electrically charged particles was small, i. e. that the water's content of strong electrolytes was low. The fact that the layers are partly so very thin indicates, furthermore, that both substances were very dilute precipitates, possibly sols. The low concentration and the weak superficial tension is shown by the circumstance that the appearance of some ooids has been influenced by gentle movements in the water. Colloidal precipitates of such a low concentration may have been formed only if the amount of electrolytes in the water was inferior to the flocculation value. One additional fact favours the idea that the content of electrolytes was low, viz. that indications of dehydrative activity by electrolytes are not discernible. Such an activity is manifested by V-shaped cracks in the margins. The substances which are characterized by such cracks have also another appearance. They are homogeneous and concretionary, and give the unmistakable impression of having been deposited as gels, i. e. in a water with a high content of electrolytes. Glauconitic concretions are of this type. The fine, radiating cracks which occur frequently in the chamositic ooids are certainly partly due to cracking during the normal aging of the colloids, but partly also to tensions due to recrystallization induced by certain enclosures, especially particles of limonite or phosphorite.

Thus, there are many indications favouring the idea that the ooids were formed in a water with a relatively low amount of electrolytes. There are also reasons which favour the idea that the water was fairly stagnant.

Such a reason is that the ooids often include particles of phosphorus and sulphur compounds, or are surrounded more or less completely by such substances. The phosphorus curve especially shows a maximum in the part of the stratal sequence where the chamositic ooids occur. Both phosphorus and sulphur occurring in larger quantities indicate a stagnancy of the water.

The carbon curve is mostly high in the chamosite-bearing part of the stratal sequence. This also indicates stagnancy. The fact that the supply of mineral particles was low at that time points in this direction too.

The hydrological conditions during the formation of the Estonian strata containing chamositic ooids have not been studied along the same lines as in the present case. But judging from the appearance of the ooids, the hydrology seems to have been very similar to that of the Siljan District. The ooids are so equal that they are not distinguishable from each other. They are accompanied by phosphorus and sulphur compounds just as in the present case.

The chamositic ooids from the *Raniceps* Zone of Öland have not been described. I have only studied them in a few thin slides. They are similar to those from the Siljan District and Estonia.

Chamosite and glauconite precipitation.

None of these substances is homogeneous in chemical respect. They are chemically closely related, but they show some differences.

They are different in chemical respect mainly as regards the proportions of SiO_2, Al_2O_3, iron, and potassium. Chamosites have lower content of SiO_2, but a higher content of Al_2O_3 and iron. The iron is essentially ferrous silicate, whereas that of glauconite is ferric silicate to a larger extent. Furthermore, the chamosites are completely devoid of potassium, the very distinguishing element of glauconite.

Glauconite has not the ability of forming ooids, which is a characteristic feature of chamosite. Glauconite is concretionary for the most part. But it may be pointed out that chamosite and glauconite can be structurally similar. Chamosite may occasionally be concretionary as the glauconite, but both can also occur as impregnations in structures of organic hard tissues. Such structures are generally very narrow, for instance the fine canals in sponges and crinoids. In these cases the silicate substances have certainly been precipitated as weak concentrations, i. e. in a water where the flocculating effect was relatively low. As regards both the present chamositic and glauconitic precipitates of this type it can be stated that the water was stagnant. The chamositic precipitates were formed in the surroundings just described in the discussion of the chamositic ooids. As far as the glauconitic precipitates of this type are concerned, they were observed in the yellowish microbeds in the upper part of stratum *R I*. These microbeds certainly indicate periods of stagnation judging by the fact that the content of iron and phosphorous compounds is high.

Stagnation in itself does not, as a matter of fact, mean that the amount of electrolytes was low. The fact that rounded concretions of glauconite with V-shaped superficial dehydration cracks occur in the yellowish microbeds (Pl. VI, Fig. 2) also indicates that this was not the case. But in stagnant water, the efficiency of the electrolytes can be diminished locally, viz. if the solubility of the silicate is increased in this area. This takes place if the pH is increased. Such a local increase in the pH occurs around decaying bodies in stagnant water. But, when the pH successively decreased as the decomposition ceased and the basic substances diffused into the surroundings, a gentle precipitation could occur. The precipitate was of small concentration and could thus be adsorbed capillarily into minute structures in the resistant tissues of the decaying body. If hydrous iron oxides with a contrary electric charge were present, an alternation between silicatic and oxidic strata could be realized. The present material affords several examples of this sequence of development. Pl. VI, Fig. 1 shows an alternating precipitation of hydrous iron oxide and glauconite in a crinoid skeleton; a concretionary glauconite with dehydration cracks is deposited at the side, which indicates that the flocculating effect was higher in the surroundings.

For the precipitation of glauconite in the weakly concentrated form as described here special conditions are thus required. Nor is this type of glauconite the most common, but, as mentioned, concretionary types (which must be postulated to have been precipitated as gels) are those which generally occur.

The chamosites, on the contrary, must, as a rule, have been precipitated in a weakly concentrated form: they occur as diffuse impregnations in sediments, as fillings in minute structures of hard tissues, or as finely laminated ooids.

Now the question arises: why does not the glauconite form ooids in most cases rather than concretions, and what is the reason for the fact that chamositic substances have a special ability of forming ooids?

Such an intricate debate must be preceded by a brief discussion of the surroundings in which chamosite and glauconite are generally formed.

These substances can occur together, though with a great predominance for one of them. But in a broad sense it may be said that glauconite and chamosite exclude each other.

HADDING (1932, p. 162) rightly pointed out that "the structural as well as the chemical differences show that the chamosite was formed under quite different milieu conditions than the glauconite". He postulated that chamosites "were formed in an oxygen-free and probably strongly reducing environment" owing to the fact that they are "typical ferrous minerals".

To this argumentation some further facts may be added.

Considering first glauconite, it may be recapitulated that its content of iron and aluminum is relatively low. As pointed out earlier in this paper, only fairly small quantities of iron can be accumulated in the open sea, where the water is ventilated and the pH and the content of electrolytes are high. Aluminum is very similar to iron in this respect. Silica, on the other hand, is fairly easily soluble at the pH in the sea (about 8), and it is furthermore hydrophile, i. e. considerably less influenced by the electrolytes than are the hydrous iron and aluminum oxides which are hydrophobic. Thus, high concentrations of silica can be reached, especially in coastal regions, since silica for the most part is transferred from the land. When a precipitation takes place, substances rich in silica can be formed. As glauconite is rich in silica, surroundings of this type are likely to be favourable for its formation. Finally, the glauconitic iron is ferric for the most part which is to be expected in a ventilated sea.

These features as regards the chemical composition of glauconite favour the idea that glauconite is formed in the open sea relatively near the shore. As was mentioned above, a high content of electrolytes may have been present as appears from superficial dehydration cracks in concretionary glauconite.

As the water's content of silica was high, fairly large lumps could be precipitated when they were acted upon by a large amount of strong electrolytes. The dehydrating effect of strong electrolytes caused an exsiccation and consequently a constriction of the surface layer of the lumps, which rendered them rounded in appearance. Sometimes glauconitic lumps are covered with a stratum of hydrous iron oxide; this stratum was certainly attached on account of the different electric charges of the silicate and the hydrous oxide. But often there is no coating of hydrous iron oxide. This may be due to absence of such compounds in the water, but also to an effect of the immediate dehydration, viz. that the surface stratum was concentrated so much that it was de-electrified.

Surroundings of the type now considered were obviously suited for formation of concretionary glauconite, but very unsuited for formation of iron silicate ooids.

Considering, secondly, chamosites, their content of silica is inferior to that of glauconite but their content of aluminum and iron is superior; moreover, the iron is mainly in a ferrous state. Great amounts of iron (and aluminum) and a low oxidizing stage of the iron can be expected in coastal basins with a high content of carbon dioxide; the high contents of iron thus occurring as $Fe(HCO_3)_2$ is transformed into ferrous oxide when the CO_2-pressure is lowered. This and other oxides are adsorbed by the silica which can occur in fairly great quantities in these stagnant surroundings where the pH is at least 7.

The principal distribution of the main chemical elements in closed coastal areas may thus be suitable for the formation of chamosites. The green sediments which are today precipitated in such areas of lower latitudes may possibly be chamositic; their chemical composition is not known to me, however (cf. MÜNSTER-STRØM 1936, p. 72).

In such closed areas the amount of electrolytes may be lower than in the open sea and this must be favourable for the development of the chamositic structures, which in the present case, as mentioned, are diffuse impregnations in the sediment, fillings in structures of organic hard tissues, and not least, ooids. This mode of occurrence indicates a very fluid consistency of the precipitates which must be due to a low amount of electrolytes in the water. Especially the development of the ooidic structures required to be undisturbed by charges of electrolytes in the surroundings; furthermore, a quiet water was necessary (p. 481).

From this argument it may appear that the formation of glauconite is favoured in surroundings different from those which are suitable for the formation of chamosite. The former surroundings are not favourable for the formation of ooids which, on the contrary, is the case as regards the latter. This may be the real reason for the inability of glauconite to form ooids, and, on the other hand, the ability of chamosites as regards this process.

A question which is of great interest in this connection is why glauconite is rich in potassium, whereas chamosite is devoid of this element. One might conceive that both substances have about the same ability to adsorb potassium, but that the available amount of potassium was higher during the formation of glauconite than during the formation of chamosite. Another alternative is that the two substances have different ability to adsorb potassium.

The second alternative is obviously correct. In the present case the supply of potassium was about the same during the formation of chamosite as during the formation of glauconite. Their different abilities to adsorb potassium must be referable to a difference as regards their lattice structure. The lattice of glauconite which is akin to that of the mica group must be suitable for fixation of potassium with its great ion radius, but that of chamosite which is akin to kaolinite does not seem to be suited for this purpose.

Limonitic ooids with concentric structures.

Ooids of this type have not been formed in the same way as the chamositic ooids. The latter, which are interpreted to have been formed in such a manner that colloidal substances with a different electric charge were precipitated alternately around a nucleus just on account of the different charges of the colloids, are considered real ooids. The limonitic ooids, on the other hand, are not considered real ooids in spite of the fact that they are concentrically stratified. The reason for this is that these structures were already existing when the precipitation of the hydrous iron oxide took place. These existing structures were merely filled with hydrous oxide.

As described in part II of the present series of papers the structures consisted of enveloping algae. In this paper was also described how the hydrous oxides were precipitated on account of the process of carbon dioxide assimilation by algae.

Obviously the hydrous iron oxides were precipitated in a dilute consistence. The fine algal filaments would otherwise not have been entirely filled. This mode of precipitation indicates a low content of electrolytes in the water. Furthermore, the precipitation must have taken place in a stagnant water, which was necessary for the local decrease in the CO_2-pressure and the increase of the O_2-pressure requisite for the precipitation.

Limonitic ooids without concentric structures.

These ooids have been formed in different ways. They usually consist of rounded shell fragments.

As described in part II of the present series of papers, the roundness has been realized by the activity of perforative algae. Precipitation of hydrous iron oxide was also caused by the algae (the process of carbon dioxide assimilation; cf. above as regards laminated limonitic ooids). As in the laminated limonitic ooids, the hydrous iron oxide must have been precipitated in a dilute consistence and consequently formed in similar surroundings.

False limonitic ooids are also formed of entire, smooth ostracod carapaces, the interior of which was filled with hydrous iron oxide and possibly some iron carbonate, and the surface of which was covered with hydrous iron oxide. Now and then one of the valves in such false ooids belongs to one species and the opposite valve to another (cf. part I of the present series, Pl. XVIII, Fig. 3). It also happens that false ooids referable to the group now concerned include only one valve, whereas the opposite side is formed of a rounded hydrous iron oxide lump which fills up the concave part of the valve (part I of the present series, Pl. XVI, Fig. 4).

The precipitation may have been caused in this case by decomposition processes as described above, p. 478. The oxygen required for the formation of the hydrous iron oxide was derived from algae living in the immediate vicinity (sometimes in the ostracodal valves). For this precipitation stagnant water was required.

Phosphoritic-limonitic and calcitic false ooids.

In the present material there occur blackish false ooids, consisting of phosphorite and limonite (Pl. VIII). They are often ellipsoidal in shape. Sometimes they are connected by narrow bands of the same material (Pl. VIII, Fig. 1). Ooids of this type are not very common. They were formed during the most stagnant part of the *G* stage.

These false ooids are most likely coprolites. The formation mentioned, which is reminiscent of a string of pearls, is very similar to the faeces of certain gastropods, for instance *Hydrobia*.

The reason for the fact that the coprolites have been preserved may be that hydrous iron oxide was adsorbed and that the stagnant surrounding prevented the phosphorous compounds from being dissolved and carried away.

These ooids, as well as those which include chamositic, limonitic, and phosphoritic substances, are often surrounded by calcite crystals, arranged radially (Pl. VII, Fig. 5 and Pl. VIII). Limonitic substances of the ooids are often squeezed out between the calcite crystals thus giving prominence to the radial arrangement of these crystals. Calcite crystals can have been formed in such quantities that the aggregates consist of calcite for the greater part. They become ellipsoidal in shape and are properly characterized as false calcite ooids.

The limonitic and phosphoritic substances seem to induce the formation of calcitic crystals. They are partly used up during this process, so that they may occur as irregularly shrunken lumps within the calcitic ooids.

Pure calcitic concretionary ooids are rare in the present material.

Ooidic particles consisting of smooth ostracods filled with calcite may possibly also be called calcitic false ooids.

ORVIKU (1940) has described ooidic particles consisting of a dark opaque substance which is often coated with a layer of radially arranged calcite crystals. The dark substance is said to be iron hydrate. They are very similar to the above-mentioned false ooids which are interpreted as coprolites. ORVIKU also figured false calcite ooids.

5. The origin of the iron.

As appears from the descriptive part of this paper, the content of iron in the stratal sequence is partly very high, viz. somewhat below the mid-height of stratum *G*. As a matter of fact, it is of great interest to know the reason for this high content of iron.

Theoretically one may think of several reasons for the high iron content. One such reason is that the supply of iron was fairly constant during the whole period concerned, but that conditions for the fixation of iron were especially favourable when the stratum with the very high iron content was formed. Another is that conditions for the fixation of iron were fairly similar during the whole period concerned, but that the supply of iron ions was very increased during the formation of the stratum with the high content of iron. A third possibility is that the genesis of this stratum is due to the circumstance that the supply of iron was especially high at the same time as conditions for the fixation of the iron were particularly favourable.

In discussing this question it may first be recalled that the iron-bearing substances in the present case are limonite, chamosite, glauconite, and possibly iron phosphate and some iron carbonate. The substance which represents the greatest quantities of iron is limonite. Chamosite and glauconite are partly fairly abundant and may thus have a certain influence upon the content of iron in the sediment.

From the preceding chapter it has appeared that the content of iron in the open sea is low, but that the iron content can be higher in coastal basins with restricted communication with the sea. Thus it is theoretically impossible that any larger quantities of iron are precipitated in the former surroundings, but the latter type is favourable for fixation of iron in the form of limonite and chamositic substances (siderite in non-oxygenized water).

The vertical distribution of the iron in the present case is in coincidence with this fact: the amount of iron is low in the open sea stages *R I* and *R II* (cf. p. 469), but partly high in the enclosed stage *G*. However, the amount of iron is very different within the *G* section. It may also be noted that chamosite generally appears after the greatest limonite maximum. It is of decisive importance to establish whether the conditions for fixation of iron changed so much during the *G* stage that the very different contents of iron were realized on that account.

The stagnation did not change in any higher degree during the *G* stage; the water possibly became even somewhat more stagnant in parts of the district during the *Raniceps* period (when the iron precipitation was fairly small) than during the *Expansus* period (when the iron precipitation was very high). The fact that the stagnancy was still high is indicated by the circumstance that the amount of carbon and phosphorus is high and partly higher than in the *Expansus* Zone; also sulphur may be relatively abundant (Pl. XIV). That communication with the ocean was restricted during this period is indicated by the ostracodal fauna (part I of the present series of papers). However, there existed a certain amount of oxygen in the water, judging by the fact that plants were still present, though not so abundantly as during the preceding period (Pl. X). The presence of oxygen is also indicated by the fact that the iron to a great extent was precipitated as hydrous ferric oxide; only a small part was fixed as chamosite and pyrite.

Conditions for the accumulation of iron in the water were thus equally as favourable as during the formation of the subjacent highly iron-bearing stratum. In fact, the changes in the content of iron in the *G* stage reproduce mainly the changes in the supply of iron to the Siljan District during this period.

The origin of the iron shall now be discussed.

The circumstance that especially great quantities of iron were fixed at Leskusänget, which seems to have been situated near the shore (p. 462), indicates that the iron was supplied from the land to a great extent. The iron may thus be expected to have derived from an iron-bearing formation which was disintegrated and transported to the sea especially during the *Expansus* period.

Those rocks which occur around the present oolitic formation are the Digerberg Sandstone (large areas in the north; lacking in the southern part), gneiss and granite (to the south and east of the formation; granite also in the area enclosed by the formation — the central cupola), and porphyry (to the west and north).

The iron content in these rocks is low, and the rocks are not very easily disintegratable, so there is no reason to believe that greater quantities of iron were released from the fresh rocks.

From weathered rocks of the present types iron may have been more easily released, however.

A sample of Digerberg Sandstone from Vattnäs (W part of the Siljan District) had a Fe_2O_3 content of 2.57 %. Another sample of weathered granite from Alsarbyn (S part) showed 3.57 % Fe_2O_3.

As a matter of fact, the land surface in the Siljan District was weathered when the district was invaded by the Ordovician sea. Great quantities of iron were obviously also supplied to the sea during this time, as appears from the following.

The fact that the surface was fairly deeply weathered can often be observed. The rock, especially granites, are often disintegratable into a coarse gravel, and kaolinized small parts are sometimes observable. Great quantities of fine-grained weathering products in an original position have not been observed, however, so nothing can be specifically stated on the ancient extension of these products.

Judging from the fact that, as mentioned, traces of kaoline can be found the weathering was scarcely lateritic but of kaolinitic type. No greater desilication of the weathering products may thus have occurred which, however, would have appeared in case of a laterization. This means that both the silica (the hydrophile sols of which are relatively mobile) and the iron oxides (the hydrophobic sols of which are more easily flocculable and thus relatively little mobile) were retained in place until a transgression stirred about in the sediment. Provided that the silica was retained until then, great quantities could at once be released together with hydrous iron oxide, and thus a great amount of glauconite could be formed during the very transgression. The fact is that an intensive production of glauconite began at the same time as arkoses and conglomerates were formed (the *Obolus* Conglomerates and adjacent sediments). The precipitation was intensified during the formation of the following *Obolus* Gravel Limestone and the adjacent formation of glauconitic clays. An *Obolus* glauconite clay from Kårgärde (W part of the Siljan District) contains 13.60 % Fe_2O_3. During the succeeding *Ceratopyge* period the formation of glauconite diminished, and during the *Planilimbata* and *Limbata* periods the iron was precipitated as hydrous oxides to a great extent.

The total amount of iron precipitates had decreased, meanwhile, and it was also low during the first part of the stage succeeding the *Limbata* period, i. e. the *G* stage. It was previously alleged in this paper that conditions for the accumulation and fixation of iron in the Siljan District were not very different from those prevailing during the following very high iron precipitation (the *Expansus* oolite).

The reason for the decrease in the iron content of the stratal sequence must be that the iron-bearing formation had been consumed. The new intensive precipitation of iron must be explained in the way that another iron-bearing sediment had been incorporated with the sea. This might be explained by the circumstance that the sea, during a transgression, had reached new parts of the weathered land surface. But, as shown on p. 497 f. not a transgression but a regression is indicated to have taken place exactly during this time. The explanation mentioned is thus untenable. Most likely the explanation is that the iron derived from volcanic substances. Volcanic ashes rich in iron may have been carried partly direct and partly secondarily to the sea after having been deposited on land.

Like diabases and basalts volcanic ash is a good source of iron: the content of iron is high and the iron is easily dissoluble. According to 5 analyses, the amount of $Fe_2O_3 + FeO$ is on the average 14.58 % in Vatnajökull ash (BARTH 1938, p. 34). VON ECKERMANN states a content of up to 17.90 % iron oxides in the Swedish Gävle diabase (1925, p. 304). TRYGGVASON found 14.78 % in a basaltic boulder from the Bothnian Gulf (1940, p. 179). The average value of the iron oxides in the volcanic strata of the Swedish Lappland series of Mesket (KULLING 1933, p. 402) is 8,88 %. In the Lower Ordovician Stören Greenstone of Norway the iron oxide content is 10.82 % (VOGT 1945, p. 466). TRYGGVASON (1943, p. 313) made a survey of 352 analyses of basalts from different parts of the world; it appears from this that the mean is 12.51 % $Fe_2O_3 + FeO$. The greatest part of the iron of basaltic volcanic products is ferrous.

Four samples from diabase dikes in the Siljan District were tested. The following Fe_2O_3 contents were observed:

Dike from the vicinity of Leskusänget	11.85 %
» » » » » Gulleråsen	13.60 %
» » » » » Storstupet (N part of the Siljan District)	17.35 %

The occurrence of two elements in the stratal sequence may also be elucidative for the origin of the iron, viz. titanium and magnesium.

Basaltic substances are rich in titanium: the Vatnajökull ash 2.51—3.20 % TiO_2, the Gävle diabase 3.24 %, the above-mentioned basaltic boulder from Östhammar 2.70 %, for instance; diabases from the Siljan District do not contain so much titanium (Leskusänget 0.85 %, Gulleråsen 0.33 %, and Storstupet 0.66 %). The sediment from the *G* stage is, however, fairly rich in titanium. In the ooids it may have been concentrated up to 2 % titanium (p. 471) and in the bentonitic clay from Gulleråsen (p. 492) 0.82 % and 0.78 % TiO_2 were observed. For comparison, analyses were performed of the bentonitic clay reported by JAANUSSON and MARTNA (1948) from the Middle Ordovician of the Siljan District and another bentonitic clay of the same age from the Mount of Kinnekulle in Västergötland, Sweden. In the former case the content of TiO_2 was 0.30 %, in the latter 0.16 %. According to THORSLUND (1947) who published analyses from different Middle Ordovician bentonitic clays, the Kinnekulle clay contains 0.14 % TiO_2. A bentonitic clay from Bornholm, on the other hand, had a TiO_2 content very similar to that of the Gulleråsen clay, viz. 0.78 %.

The high content of titanium in the sediment from the lower part of the *G* stage and in ooids from the corresponding part of the stratum indicates that the great quantities of minerogene particles supplied at that time were of volcanic origin to a great extent. This supports the idea that the great quantities of iron which were precipitated contemporaneously also were derived from volcanic products. The surrounding pre-Ordovician rocks, as a matter of fact, did not yield such great quantities of titanium. The Digerberg Sandstone and the granite from Alsarbyn contain only slight traces. The glauconitic clay from Kårgärde mentioned above, which was certainly formed of derivative products of these pre-Ordovician rocks, contains only a small amount of titanium (0.04 % TiO_2).

Considering magnesium, the content is high in volcanogene layers (the Vatnajökull ash: 4.70—5.00 % MgO; average of the 352 analyses quoted by TRYGGVASON: 7.06 %). GOLDSCHMIDT (1926) has shown that the content of magnesium is much higher in volcanogene Norwegian sedimentary rocks than in non-volcanogene sediments. The diabase dikes in the Siljan District are fairly rich in magnesium: in the Leskusänget dike 2.55 %, in the Gulleråsen dike 3.00 %, and in the Storstupet dike 2.17 % MgO. On the other hand, the MgO content in the Digerberg Sandstone is 0.82 % and in the Alsarbyn granite only 0.37 %. The relatively high magnesium values which are observed in the most abundant ooidic zone may thus indicate a volcanic origin of this element.

A few words may be added on the bentonitic clay which occurs in

Gulleråsen and possibly a few other localities in the lower part of stratum *G*. This clay substance is partly stratified and shale-like. It swells in water and is split up along the stratification surfaces thus indicating that minerals of the montmorillonite group are present. In thin slides a foliaceous structure is visible. Furthermore, there are isotropic substances present (colourless to brown) which have a refractive index of 1.60, and particles showing aggregate polarization (analyses by Dr O. MELLIS). The isotropic substances may be organic substances or glass particles from basic ashes (the refractive index of the Vatnajökull glass is 1.61, according to BARTH 1938); the particles showing aggregate polarization may be derivative products of glass. Fresh glass particles were not observed, nor biotite.

It may be added that isotropic particles occur also in other parts of the *G* stage, as well as lumps of chalcedony in the oolites.

From the above-mentioned data it may appear that there are in the sediment many indications that volcanic products were transferred to the Siljan District especially during the first part of the *Expansus* period.

It is difficult to trace the origin of these sediments, since volcanicity is not known to have occurred in the vicinity during this period. But, as a matter of fact, there are a great many traces of volcanic activity in the Siljan District, and it is possible that this activity took place partly during the *Expansus* period.

As appears from the map (Fig. 1) there are several basaltic dikes in the area; a revised field investigation on that point would certainly yield many more. TÖRNQUIST (1872, p. 26) points out that the Digerberg Sandstone is practically invariably broken through by the dikes. This sandstone is considered to be sub-Jotnian (RAMSAY 1931, p. 274). On the other hand, TÖRNQUIST states that the Orsa Sandstone is not broken through by the dikes (loc. cit.). The Orsa Sandstone is considered as belonging to the uppermost Gotlandian. Thus, one may conclude that the volcanicity took place between the sub-Jotnian and the upper Gotlandian. There are, however, a few facts which may be indicative for a somewhat more exact dating of the volcanicity.

During later years it has been observed that bentonite-like clays occur in different parts of the Middle and Upper Ordovician of the Siljan District (JAANUSSON and MARTNA 1948). The origin of the bentonite has not been traced, but it may perhaps be suggested to originate from the local volcanic activity during which parts of the dikes mentioned were formed. Another part of the dikes may be somewhat older, as suggested by TÖRNQUIST (1883, p. 13): "the appearance of the dikes may at least partly fall within the time of the formation of the *Orthoceras* Limestone".

TÖRNQUIST had made observations on the relations between some dikes and the *Orthoceras* Limestone (1871, p. 97 and 125; 1872, p. 24). A detailed dating of these dikes, on the basis of the descriptions by TÖRNQUIST, is not possible, however, and I have not yet had the opportunity to make a thorough field investigation of this problem. The strata are partly covered with earth at Åberga, the locality which is perhaps the most elucidating. However, I could not observe that the *Macrourus* Limestone was broken through by this dike, nor the subjacent *Platyurus* and *Gigas* Limestone, so it is likely that the dike was formed during the Lower Ordovician. This question is intended to be studied during further field work.

ASKLUND (1936, p. 383) declared as regards the age of the Åberga dike that he had proved it to be "post-Cambrosilurian, possibly Permian". No proof was given, however.

Origin of the iron of limonitic oolites extraneous to the Siljan District.

The Estonian strata of iron oolite are well-known: the "untere Linsenschicht" in the *Raniceps* Zone and a sequence of oolitic horizons constituting the "obere Linsenschicht" of the Aseri stage. Both these "Linsenschichten" are reported to have been observed in a boring in Latvia at a depth of about 500 m (KRAUS 1937). The latter is also represented in the Island of Gotland, as observed in the File Haidar deep boring (THORSLUND and WESTERGÅRD 1938); (another oolite probably in *Schroeteri* Limestone; corresponding to the Lasnamäe stage of Estonia). In the submarine area of the Bothnian Gulf the *Schroeteri* Limestone also includes limonitic ooids. This stratum corresponds to Lasnamäe and the uppermost part of the *Aseri* stage (the *kowalewskii* stratum) according to Mr V. JAANUSSON (verbal communication); the *kowalewskii* stratum also is ooidic.

As a matter of fact, it is impossible to make definite statements on the origin of the ooidic iron in these regions without special investigations. Some considerations may be made, however.

Prior to the formation of the ooidic strata, great quantities of iron had been precipitated partly as glauconite (particularly in the B I and B II α stages), and partly as pyrite (in the *Dictyonema* shales). Iron was precipitated as glauconite in the beginning of B III α, i. e. the *Expansus* period, but only small quantities were precipitated during the remaining part of this stage. Somewhat up in the following stage (the *Raniceps* Zone) a concentration of iron in the form of the "untere Linsenschicht" took place. During the following period (B III γ) the iron precipitation seems to have been small. In the succeeding Aseri stage, iron was precipitated again, mainly as ooids; some glauconite was also precipitated, especially in the western part of the middle section, i. e. the *Echinosphaerites* Limestone. There are irregularities in the regional distribution of the ooids, but it is characteristic that the ooids are most abundant in the Cephalopod Limestone, i. e. in the uppermost section of the Aseri stage. The formation of ooids occurred repeatedly.

These data may indicate that the iron released from the weathering products had been used up before the oolitic strata were formed. The iron necessary for their formation may be suggested to be derived from intact weathering products reached by the sea during a transgression at that time, or from volcanic ash.

The former alternative is scarcely probable. The occurrence of ooids of exactly the same type as in the Siljan District indicates that the periods of formation of the oolites were periods of stagnancy. This is accentuated by the fact that many discontinuity surfaces covered with phosphorite occur in the Aseri stage. Furthermore, exactly during the richest formation of ooids (in the uppermost section of the Aseri stage) enveloping algae seem to have appeared (cf. ORVIKU 1940, p. 136) which may sooner indicate that a regression had taken place. During such circumstances it is scarcely probable that remaining layers of weathering products rich in iron could have been utilized.

For such reasons it seems more likely that the ooidic iron originates from volcanic ash. This idea is also favoured by the fact that the formation of ooids took place rhythmically and that the oolitic strata have a vast occurrence. As mentioned, they appear, more or less completely, in the submarine area of the Bothnian Gulf and in the subgrounds of Gotland and Latvia. Another reason which may favour the idea that volcanic sediments were carried to the sea during the periods concerned is the high content of magnesium in the corresponding strata of Estonia.

Evidences of volcanicity during the lower Ordovician in the region concerned do not seem to exist. The only traces of an activity which may be connected with volcanic eruptions are some cracks formed during the *Expansus* or the *Raniceps* periods in the Island of Odensholm, Estonia, which ÖPIK (1927, p. 58) most likely very correctly interpreted as seismic. A basaltic dike was found in a boring in Estonia, but this seems to have been formed in the upper Gotlandian or the middle Devonian (ÖPIK and THAMM 1933). The mere suggestion may be made, however, that parts of the volcanism which is represented by basaltic rocks and dikes in Ingermanland (Svir region) and in the Ladoga region of SE Finland took place in the Lower Ordovician. The formations now mentioned are considered post-Jotnian by RAMSAY (1931, p. 289). In the surroundings of the submarine area in the Bothnian Gulf there are volcanic rocks of post-Archaean but not more definitely determined age. Such rocks may also exist in the Bothnian Gulf itself judging from the fact that glacially drifted basaltic boulders occur in the coastal region of Uppland.

As a matter of fact, for the time being it is not possible to state whether a connection existed between any special volcanic activity as mentioned here and that or those postulated to have provided the ash from which the ooidic iron in the aforementioned areas may have been derived.

Some facts on Lower Ordovician volcanicity.

A very active volcanicity took place in other areas during the Lower Ordovician.

VOGT (1945) has shown that a mighty series of volcanic rocks was formed in the Trondheim region during this period. To the Skiddavian VOGT has referred the Stören series which consists of thick effusive greenstones with pyroclastic material. The thickness is about 2500 m. The Hölonda andesitic porphyrites are considered to have been formed during the Llandeilian. The thickness is estimated to be a few hundred meters. The volcanic activity continued during the Middle and Upper Ordovician, but seems to have been practically expired at the close of the Ordovician. The Stören Greenstones are characterized as being beyond comparison the most extensive of the volcanic rocks.

Volcanic activity occurred also in other Norwegian regions during the Lower Ordovician. The basic lavas from the Island of Smöla W of Trondheim and those in the Os and Stord districts of the Bergen region are correlated with the Stören Greenstones.

In Swedish Lappland volcanicity also took place during the Ordovician. KULLING (1933), discerned different series of volcanic layers. Especially the Mesket series forms a mighty sequence, which is considered by KULLING to be of Lower or Middle Ordovician age. VOGT is of the opinion that this series is contemporaneous with the Stören volcanism.

It is a well-known fact that a lively volcanic activity occurred in the British Isles during the Lower Ordovician. During the Skiddavian, volcanic rocks were formed in Scotland and Wales. The greatest outbursts took place in Llanvirnian with the formation of the ash series in the Arenig District and the Llanvirn ashes in Wales, the Stapely ashes of England, and the radiolarian cherts and tuffs of Scotland. During the Llandeilian, the mighty Borrowdale volcanic series were formed. In the Caradocian the volcanicity diminished, and it finished in the Ashgillian. Iron ooids occur in many volcanic series. Those of North Wales have attached great interest, since these oolites are workable. They are chamositic to a great extent. Most of them are of Llandeilian age.

Very close relations between tuffitic layers and iron oolites can be observed in the Bohemian and Thuringian oolitic fields. In these cases the idea has been proposed that the oolitic iron is derived from volcanic products (SLAVIKOVÁ and SLAVIK 1918; cf. also HAYES 1915, p. 87).

From this survey it appears that a lively Lower Ordovician volcanicity occurred in many regions. It is also evident that a close connection exists between certain iron oolites and contemporaneously formed surrounding volcanic rocks.

As regards the iron oolites of the Siljan District and the area in the

Bothnian Gulf as well as those of Estonia, Latvia, and Gotland, definite connections with particular volcanogene formations are not established, as mentioned above. However, the volcanogene products which are considered to have been the source of the ooidic iron do not seem to have derived from the volcanicity in the Scandinavian Mountain Chain. If this had been true, more iron-bearing horizons would have been expected in the more closely situated Siljan District than in Estonia, but the contrary is the case. As anticipated, the volcanic products which yielded iron to the oolites most likely were ejaculated within the particular areas or in adjacent regions.

For the rest, it is difficult to correlate exactly the periods of formation of oolite both in the Siljan District and in the other areas mentioned with any of the volcanic activities in the Mountain Chain. But this can be due to some erroneousness in VOGT's dating. As a matter of fact, this dating is a very difficult task.

The Stören group is petrographically of similar type as the Skiddavian volcanic products of the British Isles. The correlation of the Stören group with the British Skiddavian is not, however, made on account of this similarity, but is based on a palaeontological dating of the superjacent beds. VOGT referred these beds to "probably Lower Llanvirnian age, indicating a Skiddavian age of the Stören Greenstone" (1945, p. 512). However, Mr V. JAANUSSON, who has especially studied the brachiopod genera in question, points out that the beds cannot be older than the Llandeilian, provided that the genera are correctly determined (verbal communication). Thus VOGT may have referred them to an earlier period than is really indicated by the fossils. The Stören Greenstones may, in fact, possibly be Llanvirnian and thus contemporary with the greatest Lower Ordovician outbursts of the British Isles.

The occurrence of *Nileus* sp. and *Niobe ?* sp. which are considered by VOGT to be of great value as age indicators, are not very suitable in this respect, the former genus occurring both in the Llandeilian and Llanvirnian, and the latter being obviously so badly preserved as not to be determinable.

The volcanicity here postulated to have taken place in the separate oolite-bearing areas may also be correlatable with the Llanvirnian volcanism. *Tetragraptus* species do not, practically, seem to go above the *Limbata* Limestone (EKSTRÖM 1937) nor above the Skiddavian of the British Isles (STUBBLEFIELD and EVANS, p. 72 and ELLES and WOOD 1918, Table A). *Didymograptus murchisoni* (BECK) which appears in the Upper Llanvirnian corresponds mainly to the *Platyurus* Limestone and to the Aseri stage, which includes the "obere Linsenschicht" (cf. EKSTRÖM 1937, p. 28 and RAMSAY 1931, p. 327; the *Schroeteri* Limestone is correlated by THORSLUND 1940, p. 183, with the Lower Llandeilian *Glyptograptus teretiusculus* Zone). The intervening layers which include the "untere Linsenschicht" and the Siljan oolites may thus belong to the Lower Llanvirnian·

6. The changes of level.

The macroscopical appearance of the present stratal sequence does not indicate that any changes of level occurred during its formation. However, changes of level may have taken place.

An analysis of this problem is intimately connected with the study of the development of the hydrology. The most important indications of the hydrological changes are obtained by studying the mode of occurrence of certain chemical compounds precipitated as colloids, especially hydrous iron oxides, hydrous iron silicates, and hydrous phosphorous compounds. Of great importance are, furthermore, the changes of the amount of sulphur and carbon in the stratal sequence. The composition of the necrocoenoses as well as of the insoluble residue have also to be considered.

On the basis of such data (which are collected in the previous chapters of this paper) an analysis is given here of the hydrology and the changes of level during the formation of the stratal sequence investigated.

Stratum R I.

The depth of the water was fairly shallow during the *R I* stage, especially towards the very close of the period judging from the fact that penetrative algae began to appear at that time. A few encrusted girvanelloid algae were also found, but enveloping algae, which seem to indicate a very shallow water, did not occur.

On the whole, the water was fairly ventilated during this stage, judging from the fact that the content of carbon, phosphorus, and sulphur in the sediment is rather low. The amount of shell detritus is, however, high so that considerable quantities of sulphur and carbon may have been released at the decomposition of the soft tissues. Since algae were few during this stage no greater quantities of oxygen were produced by phytal activity, and the oxidation of sulphur and carbon compounds was thus certainly caused by oxygen brought there by the movements of the water. The fact that the iron was precipitated as glauconite to a rather great extent favours the idea that the water's content of oxygen was fairly high. The absence of chamositic substances points in the same direction (cf. p. 484). The phosphorus was leached out from the faecal pellets and partly carried away to the ocean.

There are some reasons which indicate salinity to have been rather high during the *R I* stage, viz. traces of the dehydrating activity of salt water. The limonite is sometimes partly dehydrated to a reddish oxide, and the glauconite grains are sometimes superficially cracked (cf. p. 481).

The yellowish microbeds of the *R I* limestone indicate that certain occasional changes in the hydrology had taken place. The circumstance that the microbeds are concentrations, besides hydrous iron oxides, also of phosphoritic substances indicates that a slight stagnation had appeared. In a ventilated water the phosphorus acid is extracted from the animals' excretive products (the most important source of phosphorus) and to a great extent carried away to the ocean, whereas, in a stagnant water, the phosphorous compounds are enriched (MÜNSTER-STRØM 1936, p. 53).

The hydrous iron oxides and the phosphorous compounds were continuously increased upwards in the yellowish microbeds, thus showing that the effect of the stagnation had increased. Phosphorus acid and acidic decomposition products could locally be so enriched that shell fragments were deeply corroded.

A special circumstance which supports the idea that the water was stagnant during the formation of the yellowish microbeds is that the small amounts of glauconite which were formed during these periods were partly precipitated in so dilute a state that fine canals in organic hard tissues could be filled (argumentation p. 483).

Salinity may not have changed in any higher degree during these short periods of stagnation. The amount of electrolytes must have been rather high since the hydrous iron oxides were partly precipitated in a fairly concentrated state judging from the fact that fine canals in organic hard tissues were sometimes not filled and some glauconites are superficially cracked.

The reserve of oxygen may not have been used up judging from the fact that iron was precipitated in a ferric state, and sulphur and carbon were oxidized to a great extent.

The changes back to ventilated conditions seem to have taken place rapidly, since the upper limit of the yellowish microbeds is rather distinct for the most part.

Towards *R I/G* the periods of stagnation grew more pronunced. The concentration of the phosphorous compounds had increased so that a thin but continuous layer of a blackish brown substance mainly consisting of phosphorite had been formed. The amount of electrolytes may still have been sufficient to flocculate the phosphorite and perhaps it also caused the dehydration of the phosphorus precipitate so that a hard surface was created. But the hard surface was more likely formed by the influence of the new set of electrolytes which were supplied just in the beginning of the ventilation.

Immediately after the formation of such surfaces fairly much glauconite was precipitated. This glauconite originates certainly to some extent from the iron which had been accumulated in the water as bicarbonate during the preceding period of stagnation (cf. Pl. I, Fig. 3).

The supply of minerogene particles had been proportionally high during the *R I* stage; in some cases the amount of these substances had increased towards *R I/G*.

Stratum G.

As mentioned above, the depth of water had obviously decreased during the *R I* stage. The decrease continued in the *G* stage. The amount of penetrative algae was rapidly increased, and enveloping algae appeared thereafter.

These algal groups are very abundant in the middle part of stratum *G*; the very maximum is generally reached somewhat below the midheight. This high algal frequency appeared in spite of the fact that the transparency of the water must have been low since minerogene fine-particles were supplied abundantly at the same time. The abundance of algae thus certainly indicates the water to have been very shallow.

During the latest part of the *G* stage, enveloping algae disappeared completely; they had diminished in frequency already about at the midheight or shortly afterwards. The amount of penetrative algae had decreased, but they continued even to the lowermost part of the stratum *R II*, where they, however, soon disappeared.

Let us now return to the development around *R I/G*.

This border is a colour border between a mainly red stratum (*R I*) and a mainly grey (*G*). The colour of the former (the ventilated parts) is due to the fact that the colour substance is dispersed in the sediment coating the separate particles with a thin film. In the latter stratum the said colour substance (hydrous iron oxide for the greater part) is concentrated to particles consisting of mainly limonite. The colour of the rock is thus caused chiefly by the colour peculiar to the matrix of the sediment.

The border *R I/G* evidently indicates a very important hydrological change, viz. that the Siljan District had been mainly permanently stagnant. In the previous discussion it is shown that the intermittent periods of stagnation during *R I* had been more and more pronounced towards *R I/G*. The *G* period is nothing but a stage in this progressive sequence of stagnations.

However, the *G* period was not perfectly uniform in hydrological respect. During its first part certain structures were developed which indicate that occasional communications with the ocean were established. Such structures are two distinct discontinuity surfaces occurring just above *R I/G*. They are covered with a phosphoritic crust upon which glauconitic grains occur. The phosphoritic stratum was very likely flocculated and dehydrated by invading salt water, and the iron, accumulated in the water during the previous stagnation, was precipitated to some extent as glauconite indicating that the invading water was rich in oxygen.

Thereafter, a few periods of salt water inflow may still have appeared, judging from some structures, viz. the irregularly formed limonitic masses described on p. 451. They also contain phosphorite which increases in frequency upwards and often culminates in a black film covering the surface. These substances were certainly formed during a high degree of stagnation, but the surface stratum may have been fixed by electrolytes transferred there with inflowing water. This inflow is also marked by superficial fluidal structures in the limonitic substances and sometimes by the arrangement of the particles just above the surface which indicates that turbulent movements in the mobile sediment occurred at that time (Pl. II, Fig. 4).

The assumption that water with a high content of electrolytes was brought into the Siljan District during the first part of the *G* stage is furthermore indicated by the circumstance that some of the precipitates of hydrous iron oxide somewhat above *R I/G* had been dehydrated into a reddish compound (goethit or hematite).

Thereafter, a period of fairly uniform stagnancy appeared, viz. when the *Expansus* oolite was formed. Periods of extreme stagnancy followed by periods of ventilation cannot be discerned to have occurred during this time. However, water with a higher salinity may have flowed in occasionally during the first part of this period judging by the fact that the ooids have sometimes been so dehydrated as to have become reddish in colour.

There are no structures in the sediment which indicate that movements in the water took place during this period of intensive formation of ooids. According to the theory on the formation of the limonitic ooids which was given in a preceding chapter and in part II of the present series of papers, a necessary condition for their formation was that the water was stagnant. Positive on that point is, furthermore, the fact that the content of phosphorus is invariably high in this part of the stratal sequence. The content of carbon is generally also high, in a few localities very high. The sulphur, which is a distinguishing element for stagnant waters, is invariably low and little fluctuating, but this is certainly due to oxidation by means of the oxygen produced by the algae.

After this pronounced stagnancy, a period with slight movements in the water seems to have appeared. Certain irregular bedding structures were formed (p. 452), and the hydrous iron oxide was somewhat diffusely precipitated. In a few cases hydrous oxide covers the calcite crystals with a film, thus giving the rock a slightly reddish appearance. Ooids were not formed, or only in a small number.

This period was in turn followed by another period of pronounced stagnation (the *Raniceps* period) when ooids were formed again, though not in quantities as great as in the *Expansus* period. In this part of stratum *G* are the majority of the chamositic ooids. They are interpreted to have been formed in very stagnant surroundings with a low content of oxygen (p. 484). The low oxygen content is in accordance with the fact that algae had decreased in number at that time and that the amount of carbon was considerable in several cases. The high content of phosphorus also indicates a distinct stagnancy.

In the narrow zone between the *Raniceps* oolite and *G/R II* (except just below this boundary) only small quantities of hydrous iron oxide were precipitated, mainly as fillings in canals and cavities of hard tissues. The matrix is practically free from limonite. Chamosite was still precipitated, though no longer as ooids but as fillings in organic hard tissues. The content of oxygen may still have been low, and the surroundings may continuously have been stagnant. The stagnancy is especially indicated by the fact that shell fragments are corroded to a great extent, most likely of phosphorus acid and acidic decomposition products.

Stratum R II.

The algae soon disappeared in this stratum in spite of the fact that there were great quantities of shells to be bored, so the disappearance was not caused by any deficiency of penetrable substances. The reason may be that the water had been too deep for algae to be able to live there. After the development of *G/R II* the hydrous iron oxide was partly precipitated as a diffuse substance constituting a thin covering of the calcareous particles. Fossil fragments were encrusted and in part filled with hydrous iron oxide. Glauconite was not formed. The phosphorus content is generally low, or phosphorus is absent. The content of carbon and sulphur is also mostly low.

This means that a second important change in the hydrological conditions had occurred, a change of equal importance to that which occurred at the transition from *R I* to *G*. The communication with the ocean had been reopened.

Ventilated sea water invaded the Siljan District and caused the iron bicarbonate to be precipitated. A slight occasional increase of the iron curve can be discerned just above *G/R II*. The water could no longer be charged with iron as had been the case during the enclosed *G* stage when the CO_2-pressure had been high.

This hydrological change was accompanied by a faunistic. Pelagic organisms, such as radiolarians and larvae of trilobites, occur abundantly just above *G/R II* in some localities. Cephalopods appear in great quantities.

The change is especially distinct as regards the ostracods. After the catastrophic decrease probably on account of the heavy precipitation of hydrous iron oxide during the *Expansus* period, the ostracodal fauna could not recover during the remaining part of the *G* stage, as the communication with the ocean was very restricted and the ecological conditions were obviously not favourable for oceanic types (cf. part I of the present series). But when the communication with the ocean had been opened and tolerable ecological conditions for oceanic species had been re-established in the Siljan District a very distinct and sudden increase of the ostracodal fauna took place.

However, ecological conditions permanently equal to those of an open ocean coast do not seem to have been created by the transgression. The animal life was not improved to such an extent as might be expected from the sudden increase just at the formation of *G/R II*. Instead, the frequency was soon diminished. The consideration may not be excluded that the communication with the ocean became somewhat more restricted again. The fact that shell fragments are corroded by acids to a rather great extent and that concentrations of phosphates may occur indicate that there was a certain amount of stagnancy.

The hydrology and the changes of level in *R II* and the next superjacent strata will be taken up for further discussion in a future paper.

Summary. See introduction of the following chapter.

7. On the nature of and reason for the changes of level.

In the preceding chapter it was shown that the height of water had changed during the genesis of the sequence *R I—G—R II;* it had diminished to about the *Expansus* period and increased thereafter.

The regression had been repeatedly interrupted by small transgressions represented by the ventilated stages in stratum *R I* and by the traces of inflowing water which are discernible in the lower part of stratum *G*. The periods of ventilation had grown continuously shorter, whereas the periods of stagnation had grown longer and more distinct. Correspondent intermittences are not certainly ascertainable from the post-*Expansus* transgressive phase of the *G* stage.

The changes of level are theoretically referable to vertical movements in the earth's crust, or to variations in the height of the level of the ocean, or to both of these fundamental factors of level changes.

In discussing this question the transgressive intermittences during the regression are of special interest.

These transgressions took place suddenly, judging by the fact that the stagnant periods were ended very abruptly. Such rapid changes may not occur in the height of the oceanic level.

Nor is there reason to suggest that the ventilation was caused by intramarine transgressions, i. e. transgressions of internal layers in the sea. By such an occasional transgression there were scarcely any larger quantities of oxygen supplied so as to cause the long periods of ventilation which occurred at least in the beginning of the sequence of events described here. To suggest series of intramarine transgressions during the ventilated periods would hardly be plausible.

The changes of level are thus certainly referable to vertical movements in the earth's crust. The general elevation of the Siljan District during the *R I* stage and the first part of the *G* stage was, however, not a uniform process of swelling, but it was interrupted by minor shock-like sinkings (represented by the above-mentioned sudden transitions from periods of stagnation to periods of ventilation and by discontinuity surfaces); as a matter of fact, these sinkings did not influence the final result of the elevation.

The most distinct traces of the shocks were formed during the latest part of the sea stage (*R I*) when the water was shallower than earlier, and during the very first part of the enclosed *G* stage. The following shocks are only slightly traceable, viz. in the form of certain iron and phosphorus precipitations caused by inflowing salt water (cf. p. 499). During the maxima enclosure no shocks seem to have been registered in the Siljan District. It is also not certain that such events occurred during this time which obviously marked a change in the vertical main movements of the earth's crust in so far that the regression was turned into the post-*Expansus* transgression. The abrupt transition from *G* to *R II* which at once caused a marine type of hydrous iron oxide precipitation to occur and also caused a new fauna instantly to invade the Siljan District, may have been realized on account of a shock-like sinking.

The discontinuities during an epeirogenetic main process, as indicated in the present case, are not unique, but may be the general mode of reaction of the earth's crust upon changes of its level. von Post (1947) found that such shocks were registered in Scandinavia during the restoration of the equilibrium of the geoid after the Quaternary glaciation.

The elevation of the earth's crust in the Siljan District during the *R I* stage and the first part of the *G* stage was certainly caused by the volcanism which is interpreted to have taken place contemporarily in this region.

The succeeding sinking of the earth's crust might be imagined to have been caused by the circumstance that the volcanic products depressed the crust after the volcanicity possibly had ceased in the *Expansus* period. But it is certainly more likely that this movement was brought about when the equilibrium had to be restored after the preceding volcanic disturbance.

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Explanation of plates.

Photographs taken by the author and Mr N. HJORT (Plate II). No retouch.

PANPHOT photographic equipment, filter light green (γ), GEVAERT REPLICA orthochromatic plates.

Plate I.

40 ×.

Fig. 1. Stratum *R I*. Section through upper part of yellowish microbed (period of stagnancy) and adjacent part of superimposed stratum (period of ventilation). Röjeråsvägen 1.

Fig. 2. Border between the strata *R I* and *G* with discontinuity surface (*R I/G*) covered with phosphorite. Blecket 2.

Fig. 3. The same discontinuity surface as in Fig. 2, in turn covered with glauconite.

Plate II.

Figs. 1—3: Nat. size. Fig. 4: 8 × (polished section).

Fig. 1. Rock sample showing uppermost part of stratum *R I* and lowermost part of stratum *G*. The boundary *R I/G* developed as a discontinuity surface crowded with small pits which partly continue in canals filled with the same sediment as in stratum *G*; surface covered with a thin layer of phosphorite which may in turn be overlain with glauconite (right half of the discontinuity surface). Another discontinuity surface seen from below in the lowermost part of the rock sample. Blecket.

Fig. 2. Discontinuity surface in stratum *G*. Below the surface is phosphorite (black), above are limonitic (appears light in the figure) and chamositic impregnations in the limestone. Black ooids consist of chamosite and phosphorite; those ooids which appear light are limonitic. Stenberg 4.

Fig. 3. Limonitic, originally semifluid substance below the *Expansus* oolite. Gulleråsen 5.

Fig. 4. Transverse, polished section through limonitic substance as shown in Fig. 3. The brown limonitic substance appears lightish in the figure. A thin covering of phosphorite visible. The particles above this surface arranged in accordance with turbulent movements in the water. Gulleråsen 5.

Plate III.

40 ×.

Fig. 1. *Expansus* oolite. Thin section showing limonitic ooids and fossil fragments encrusted with limonite. Matrix much recrystallized. Röjeråsvägen, sample taken by Prof. G. SÄVE-SÖDERBERGH.

Fig. 2. Stratum *R II*. Thin section of a sample from a locality situated at a relatively great distance from the shore (Röjeråsvägen 9). Matrix impregnated with hydrous iron oxide and crowded with fossil fragments; fragments of ostracods, gastropods, trilobites, and calcareous algae visible.

Fig. 3. Stratum *R II*. Thin section of a sample from a locality situated relatively near the shore (Leskusänget 25). The matrix is more richly impregnated with hydrous iron oxide than in the above sample from the locality situated at greater distance from the shore. (Among the fossil fragments are trilobites, ostracods, brachiopods, and a radiolarian.)

Plate IV.

Fig. 1: 265 ×. Figs. 2—6: 40 ×, except Fig. 4 (130 ×).

Fig. 1. Section through chitinous globule. Stenberg 8.
Fig. 2. Section through calcareous alga. Röjeråsvägen 1.
Fig. 3. Section through shell of orthid brachiopod. Leskusänget 2.
Fig. 4. Section through shell of inarticulate brachiopod. Leskusänget 21.
Fig. 5. Section through bryozoa. Born-Dådran 7.
Fig. 6. Section through corroded carapace fragments of trilobites. Gulleråsen 5.

Plate V.

40 ×, except Figs. 2 (76 ×) and 4 (130 ×).

Figs. 1—8. Different sections of crinoids, for the most part encrusted with hydrous iron oxide.

Fig. 1. Stenberg 13.
Fig. 2. Born-Dådran 5.
Fig. 3. Rävanäs 8.
Fig. 4. Gulleråsen 10.
Fig. 5. Gulleråsen 16.
Fig. 6. Gulleråsen 6.
Fig. 7. Leskusänget 22.
Fig. 8. Born-Dådran 2.

Plate VI.

Figs. 1, 2, and 6: 130 ×. Fig. 3: 76 ×. Fig. 4: 40 ×.

Fig. 1. Fragment of crinoid filled with alternating layers of limonite (black) and glauconite (light). To the right a concretionary glauconite grain. Leskusänget 2.

Fig. 2. Concretionary glauconite grain with superficial cracks, covered with a thin layer of hydrous iron oxide. Leskusänget 2.

Fig. 3. Ooid with alternating layers of deep green and whitish chamositic substances. Some thin layers of limonite also occur (black). Stenberg 9.

Fig. 4. Regenerated chamositic ooid, and ooids consisting of chamositic, limonitic, and phosphoritic substances surrounded by a layer of radiately arranged calcite crystals. Limonite squeezed out among the calcite crystals. Pyritic substances cover the upper part of the upper left ooid. Stenberg 9.

Fig. 5. Crinoid fragment surrounded by laminated chamositic substance. Gulleråsen 5.

Fig. 6. Regenerated chamositic ooid. Gulleråsen 8.

Plate VII.

40 ×, except Figs. 1 (130 ×) and 4 (76 ×).

Fig. 1. Distinctly laminated chamositic ooid with a dark green central zone surrounded by a whitish zone which is distinctly laminated (intercalating dark lines partly limonitic substances). Gulleråsen 8.

Fig. 2. Distinctly laminated chamositic wrapper around a calcitic nucleus. Dark intercalated bands partly limonitic substances. Stenberg 9.

Fig. 3. Indistinctly laminated chamositic ooid partly covered with calcite and pyrite (pyrite particles also included). Stenberg 9.

Fig. 4. Regenerated ooid including calcite (white) both in the primary and in the secondary ooid. Wrapper in both cases chamosite with intercalating minute layers of limonitic substances. Dark dots pyrite particles. Gulleråsen 3.

Fig. 5. Chamositic ooids in the upper half of the figure with a dark central part and a light outer. The central ooid partly surrounded by a thin limonitic stratum and a low stratum of radially arranged calcite crystals. Dark dots above and in the ooid are pyrites.

In the lower half of the figure chamositic, limonitic, and phosphoritic substances surrounded by radially arranged calcite crystals. Limonite squeezed out between the crystals. Stenberg 9.

Fig. 6. Partly irregularly stratified chamositic ooid enclosing calcite (white), and surrounded by radiately arranged calcite crystals and pyrites. The chamositic substance partly greenish, partly whitish. Limonitic strata intercalated. Several fine radiating cracks. Stenberg 9.

Plate VIII.

40 ×, except Figs. 2 and 7 (76 ×).

Fig. 1. False ooids consisting mainly of hydrous iron oxide and phosphorite. Very reminiscent of faecal pellets of gastropods. Leskusänget 16.

Figs. 2—6 and 8. False ooids (originally most likely faecal pellets) consisting of hydrous iron oxide and phosphorite, partly deformed at the formation of the covering calcitic stratum. Calcite crystals arranged radially, limonite squeezed out between the crystals.

Fig. 2. Leskusänget 16.
Fig. 3. Leskusänget 11.
Fig. 4. Stenberg 8.
Fig. 5. Stenberg 8.
Fig. 6. Stenberg 9.
Fig. 8. Leskusänget 17.

Fig. 7. Mainly calcitic ooids, including a nucleus consisting of chamositic and limonitic substances (partly also pyrite and phosphorite enclosed). Nucleus deformed when the calcitic layer was created; limonite squeezed out between the calcite crystals. In centrum a tangential section of a calcitic ooid. Stenberg 9.

Plate IX.

Vertical distribution of animal groups. The size of the signatures indicates the frequency. Distance *R I/G—G/R II* 4 m.

Plate X.

Total frequency of animals and plants. Frequency of animals in accordance with a scale 1—5 for each group, frequency of plants indicated by the breadth of the lines showing the vertical distribution.

Vertical distribution of ooids, and chamositic and glauconitic substances. Distance *R I/G—G/R II* 4 m.

Plate XI.

Distribution of residues insoluble in hydrochloric acid (mineral particles and amorphous silica). Hatched areas in sieve fractions indicate content of minerogene particles. Distance *R I/G—G/R II* 4 m.

Plate XII.

Distribution of residues insoluble in acetic acid. Results are reproduced only where the samples contain ooids in reproducible quantities. Distance *R I/G—G/R II* 4 m. Black areas = ooids (mainly limonitic); hatched areas = particles encrusted with limonite; white areas = remaining insoluble particles (mainly amorphous silicious compounds and phosphorites).

Plate XIII.

Upper suite:

Distribution of calcium carbonate, iron, and residues insoluble in hydrochloric acid.

Lower suite:

Distribution of nitrogen and potassium.

Distance *R I/G—G/R II* 4 m.

Plate XIV.

Upper suite:

Distribution of carbon, phosphorus, and sulphur.

Lower suite:

Distribution of organic and inorganic magnesium.

Distance *R I/G—G/R II* 4 m.

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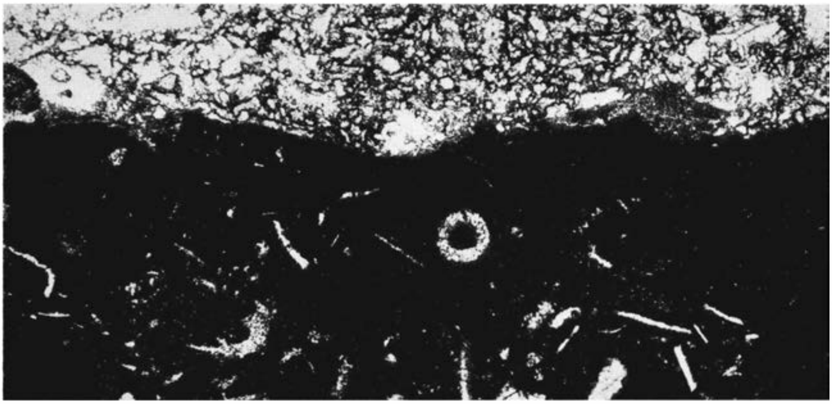

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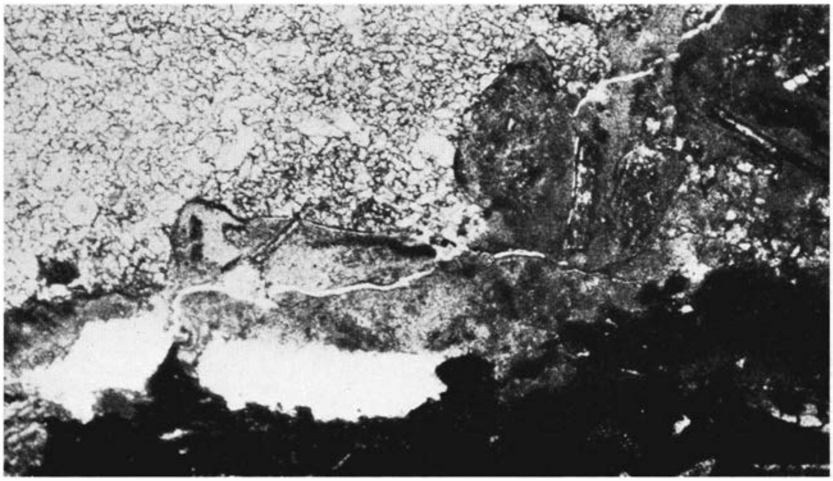

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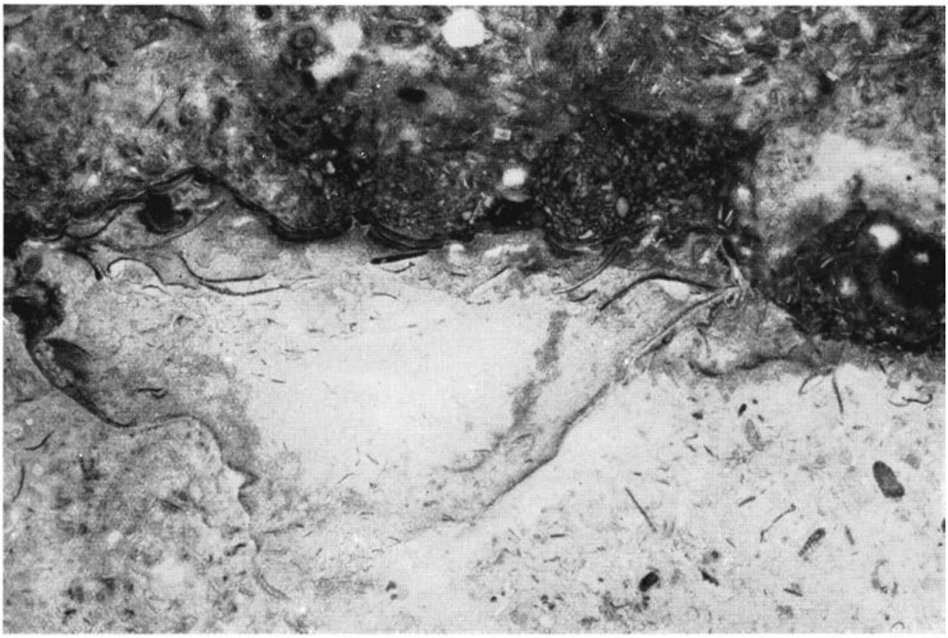

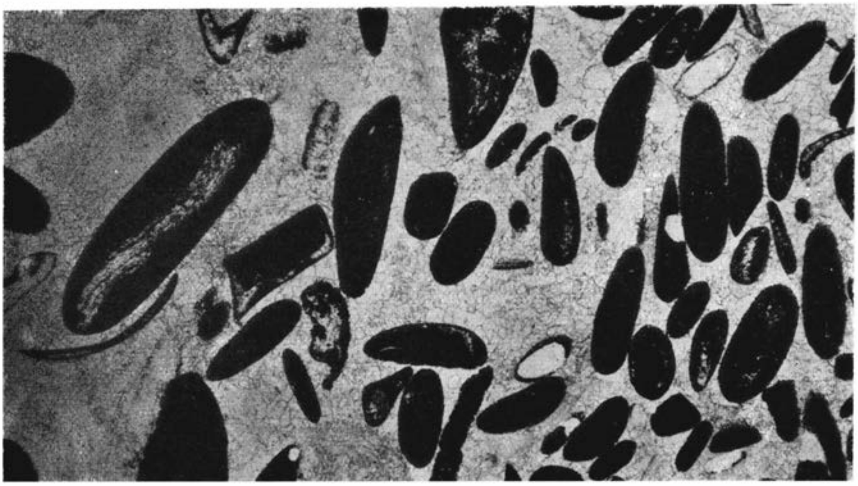

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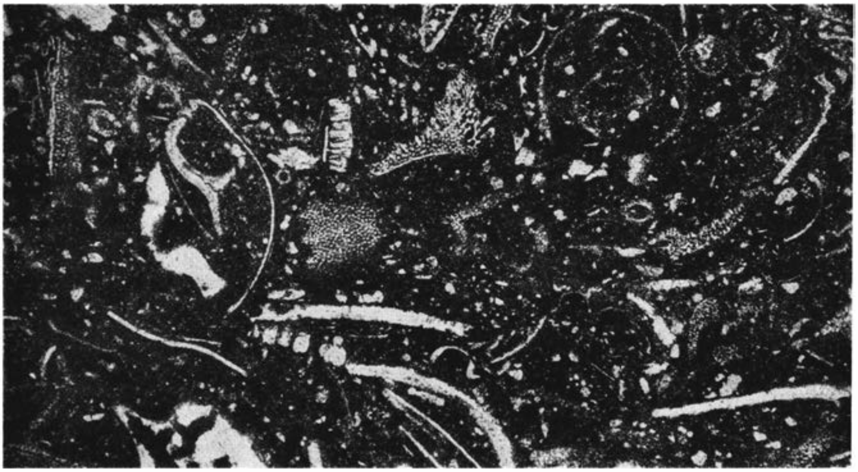

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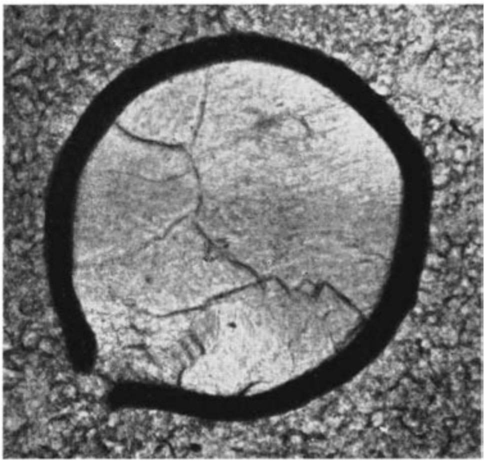

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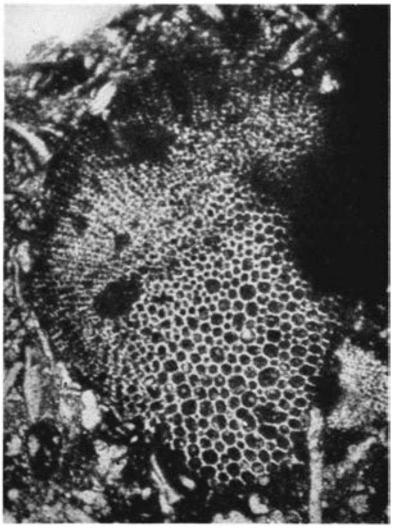

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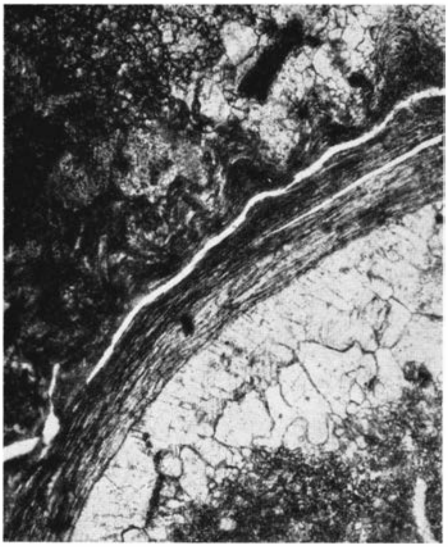

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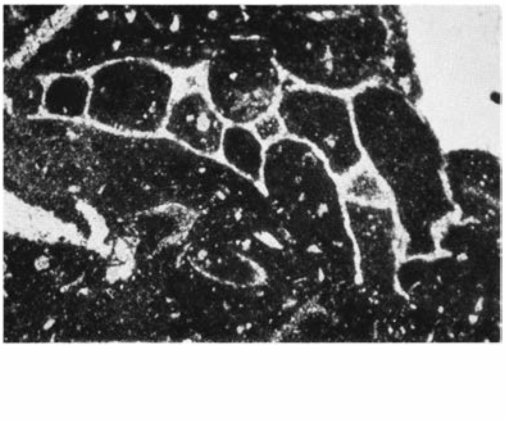

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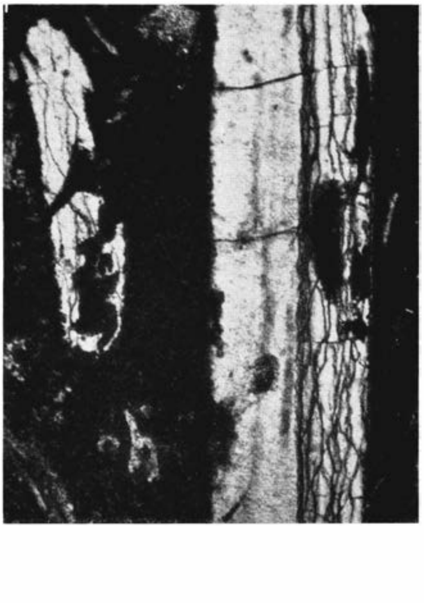

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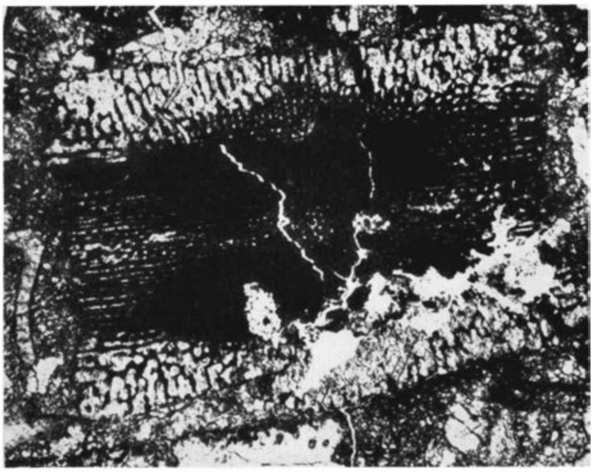

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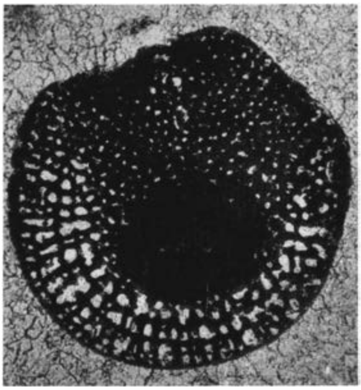

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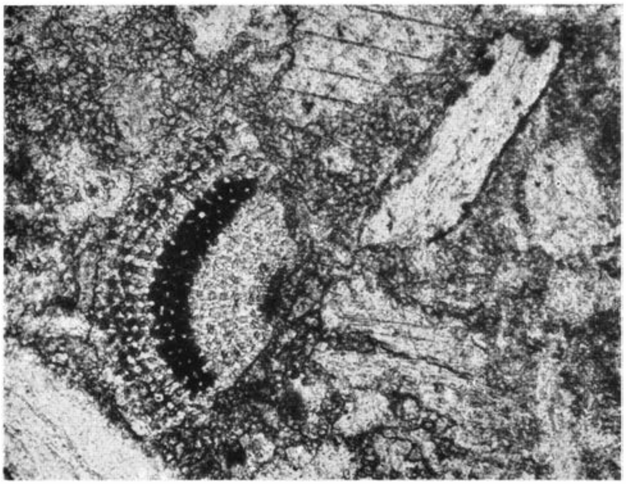

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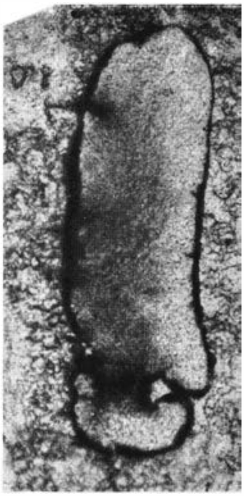

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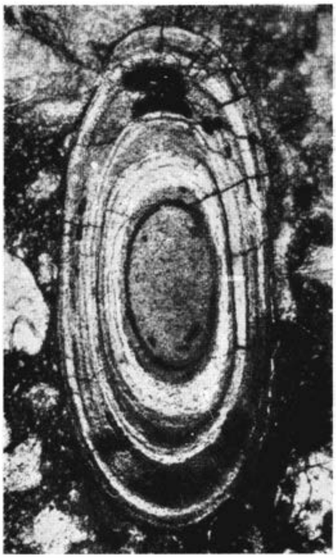

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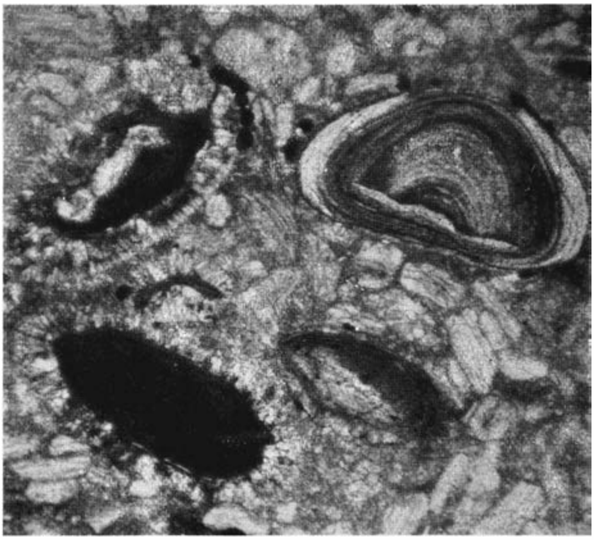

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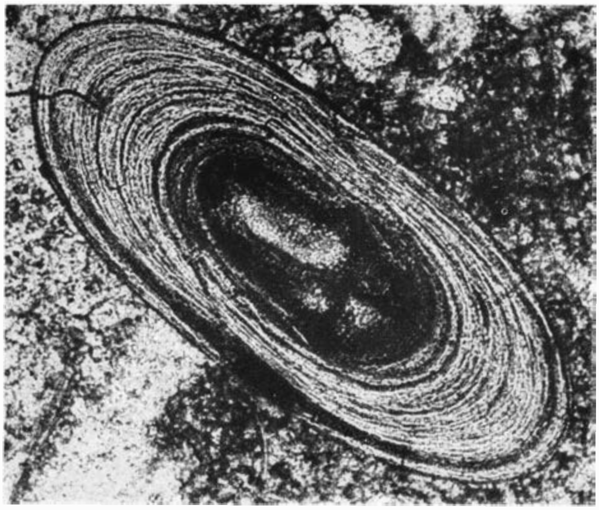
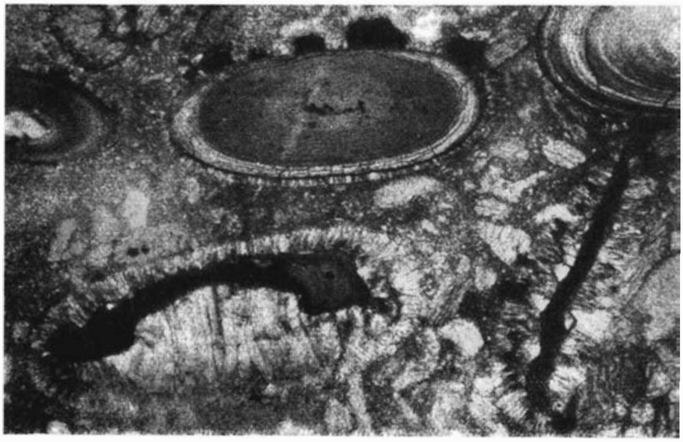


1

2

3

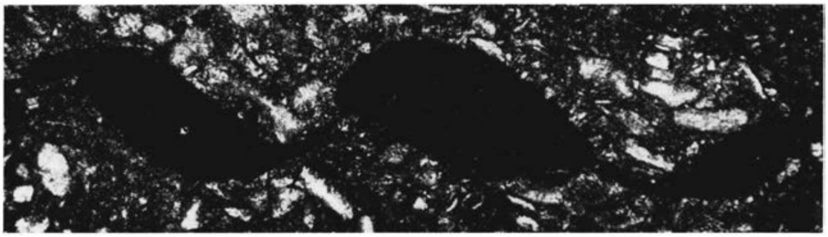
4



5

6

1



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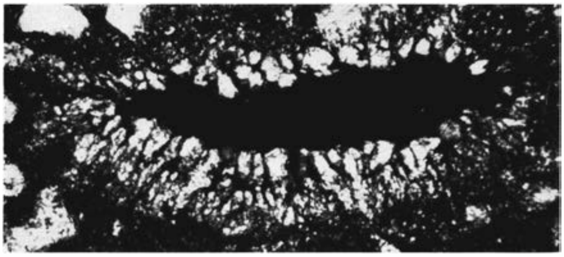

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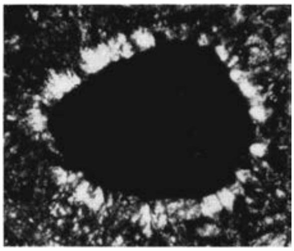

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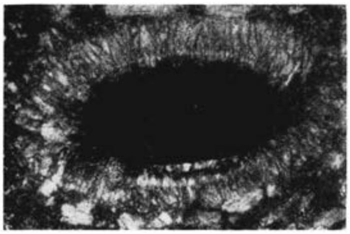

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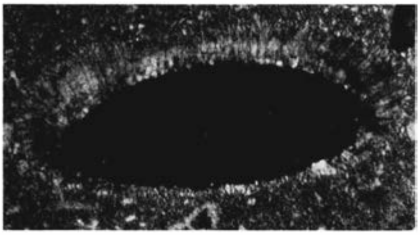

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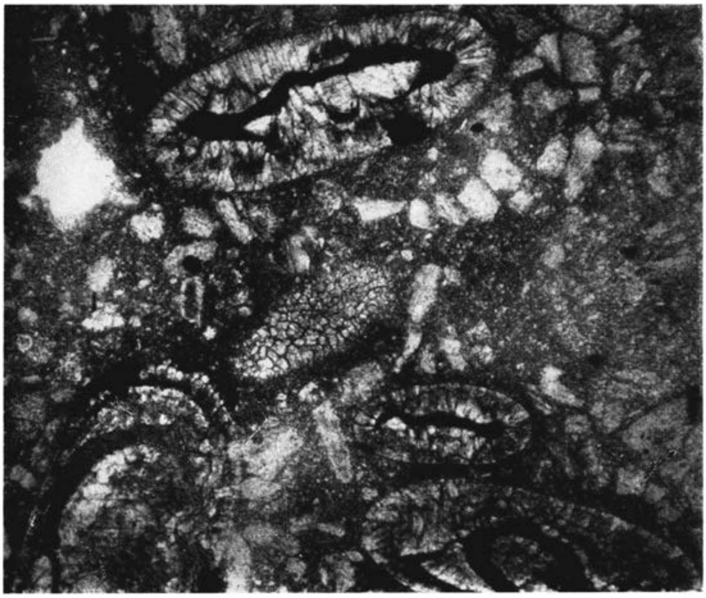

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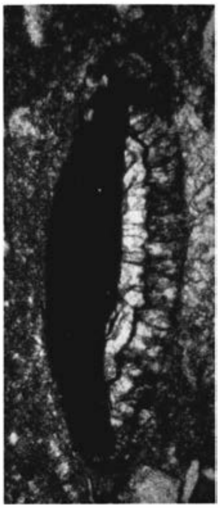
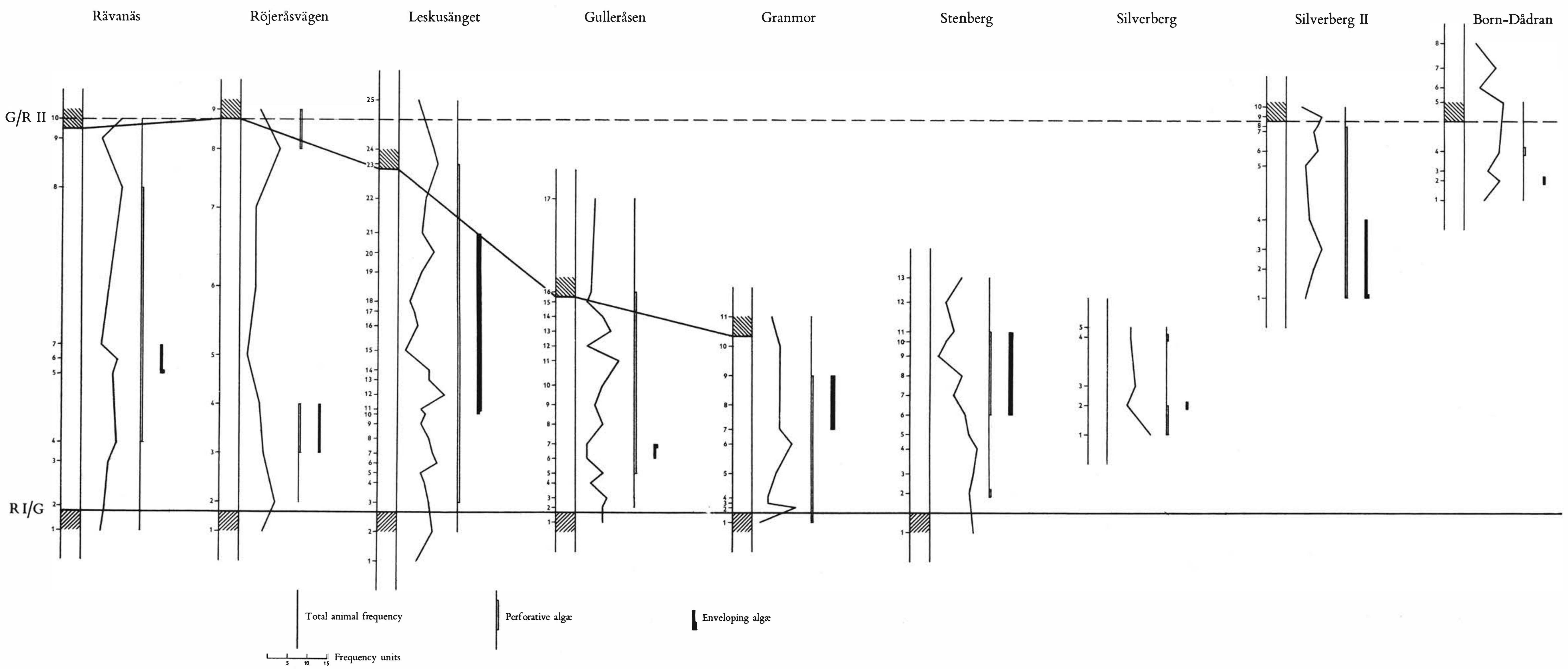
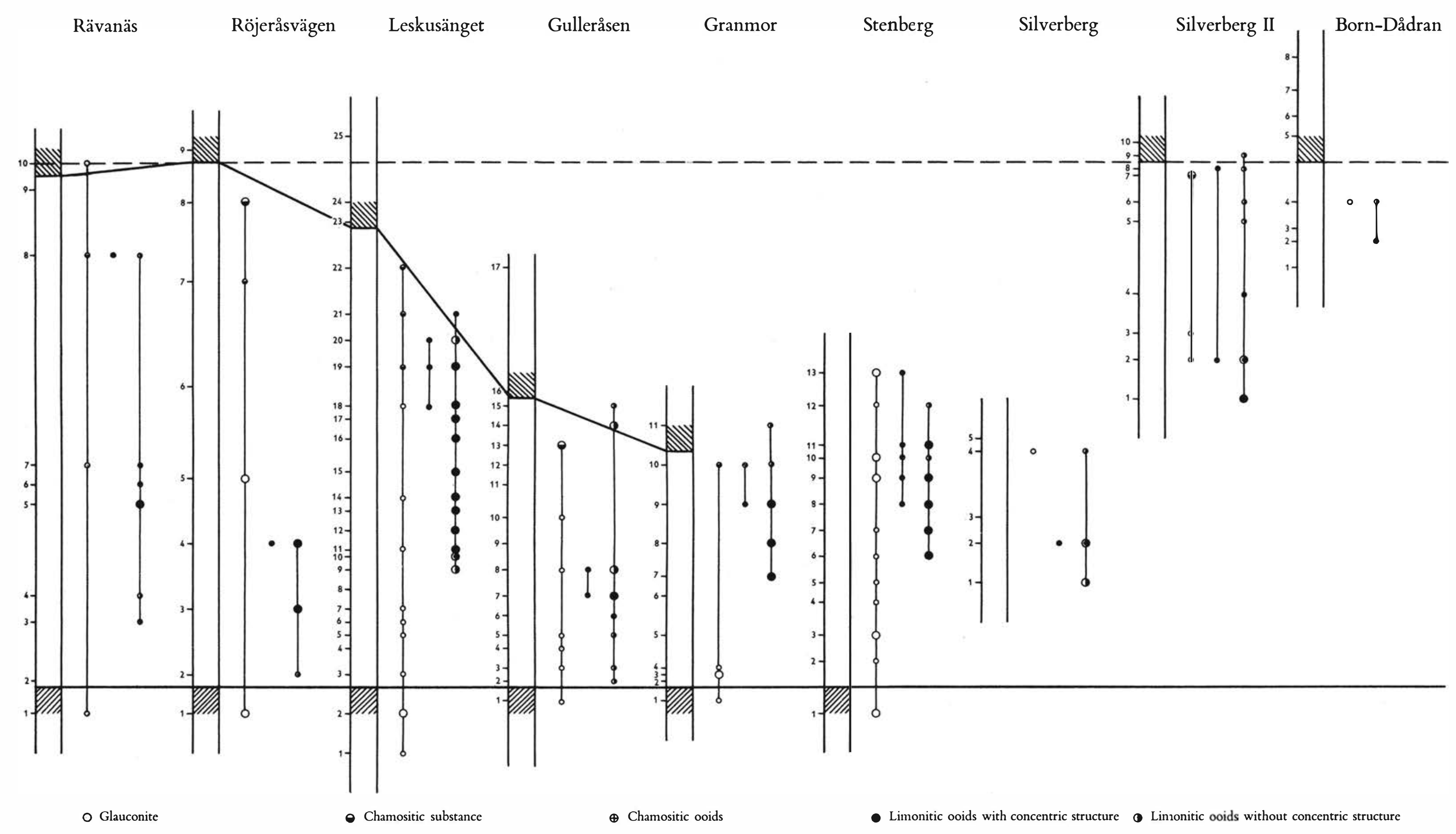
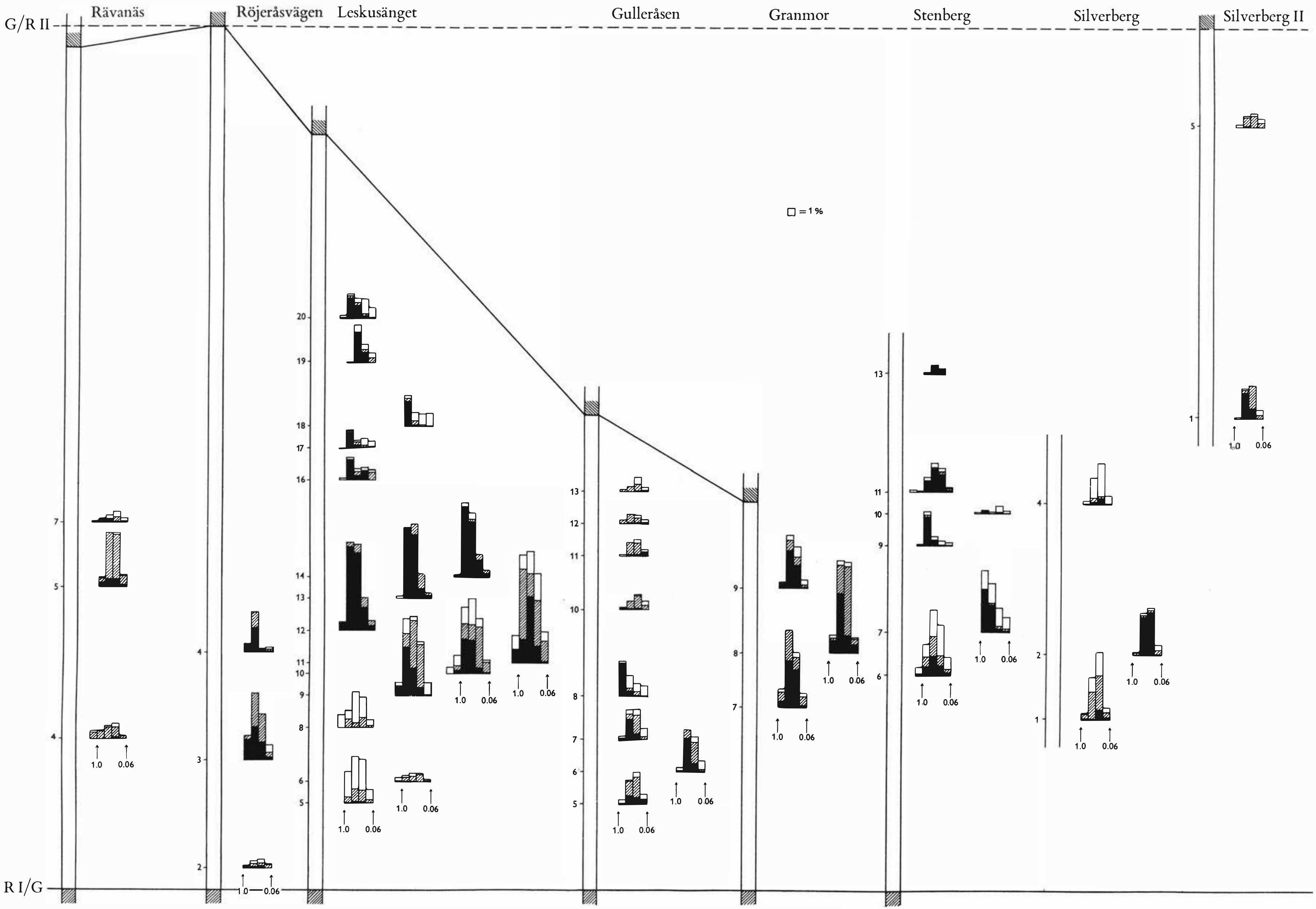


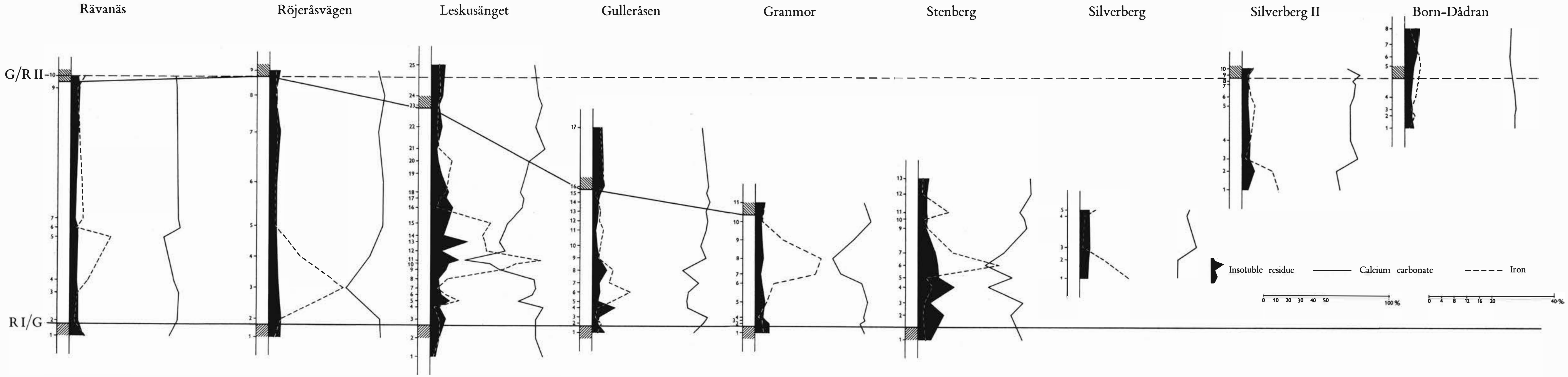

Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Trilobites
Cephalopods
Small orthoids
Crinoids
Larger brachiopods
Acrotretids
Atremate brachiopods
Gastropods
Chitinous globules

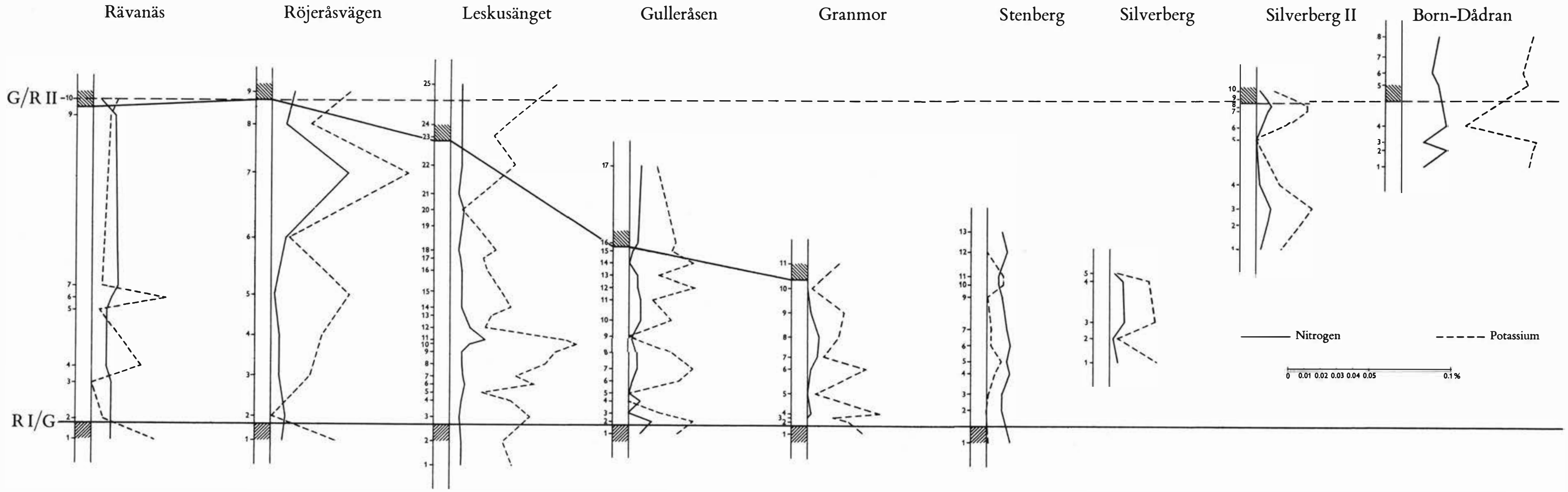

Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Total animal frequency
Perforative algæ
Enveloping algæ
5 10 15
Frequency units

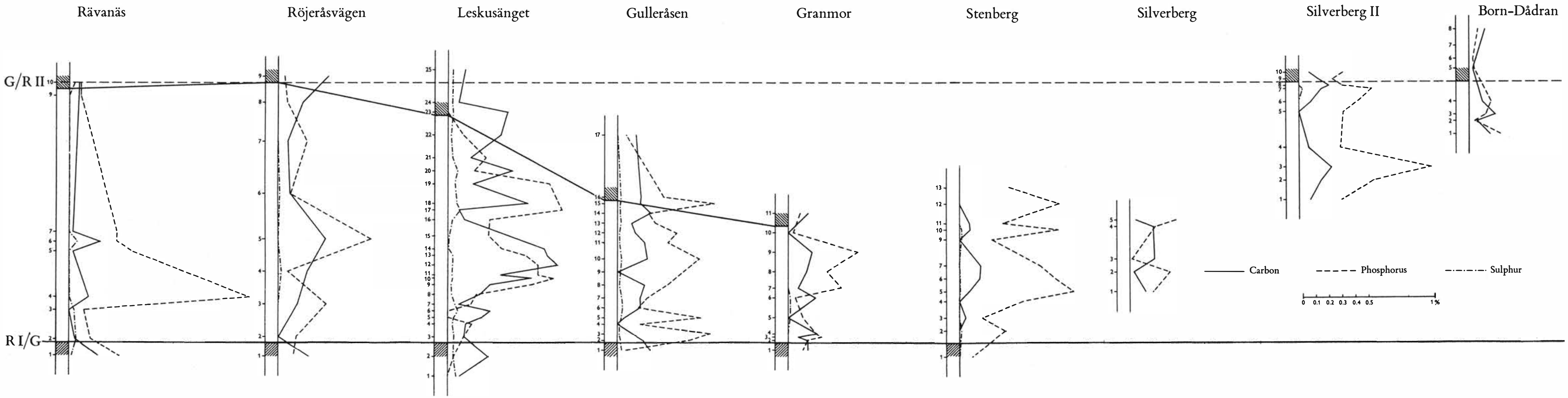

Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
○ Glauconite
Chamositic substance
⊕ Chamositic ooids
● Limonitic ooids with concentric structure
Limonitic ooids without concentric structure

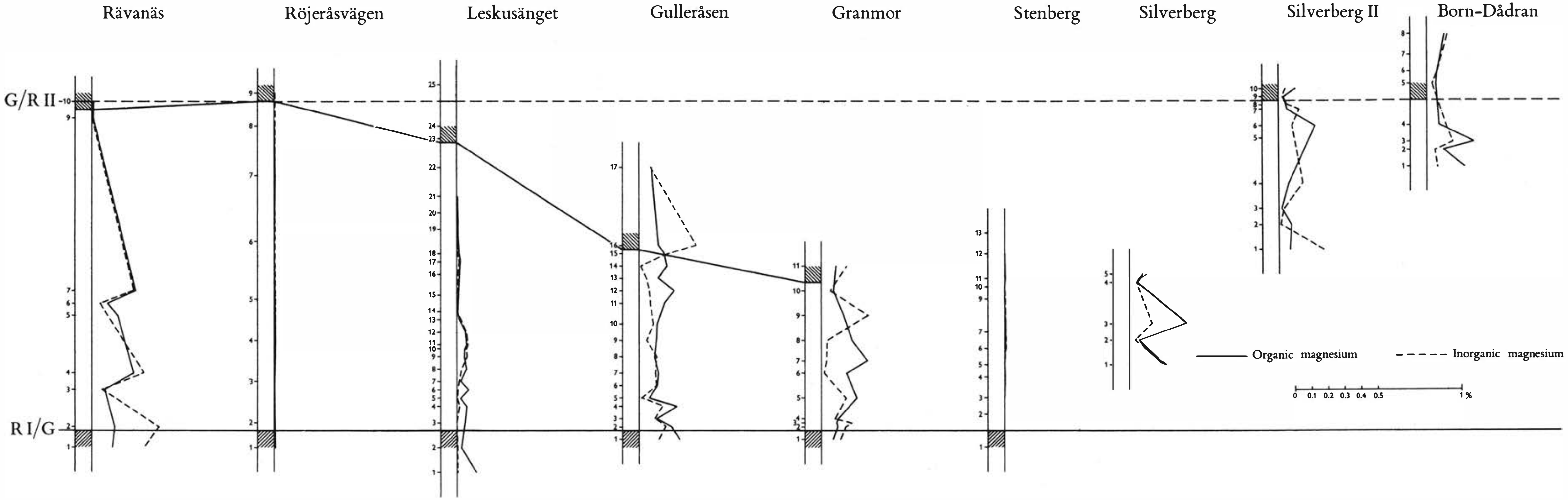

Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
RI/G
□ = 10 %
0.06 mm
0.5 μ
1 μ


G/R II
R I/G
Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
□ = 1 %
1.0
0.06


Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Insoluble residue
Calcium carbonate
Iron
0 10 20 30 40 50 100 %
0 4 8 12 16 20 40 %


Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Nitrogen
Potassium
0 0.01 0.02 0.03 0.04 0.05 0.1 %


Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Carbon
Phosphorus
Sulphur
0 0.1 0.2 0.3 0.4 0.5 1%


Rävanäs
Röjeråsvägen
Leskusänget
Gulleråsen
Granmor
Stenberg
Silverberg
Silverberg II
Born-Dådran
G/R II
R I/G
Organic magnesium
Inorganic magnesium
0 0.1 0.2 0.3 0.4 0.5 1%