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A microfossil and sedimentation study of the Late Precambrian formation of Hailuoto, Finland.

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A MICROFOSSIL AND SEDIMENTATION STUDY OF THE LATE PRECAMBRIAN FORMATION OF HAILUOTO, FINLAND

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with 4 figures in the text and 8 plates

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In fine-grained grayish portions of the sedimentary rock of Hailuoto, there occur in places acritarch forms and filamentous blue-green algae typical of the Late Precambrian. To some extent, new forms occur among them, such as, for example, the large *Cymatiosphaera precambrica* and the c. 80—100 μ wide *Oscillatoriopsis magna.* The filamentous blue-green algae belong to six genera, of which *Volyniella* is cylindrical in shape; spiral in the beginning, it developed into this shape when the sides of the algal filament grew together.

The lowest part of the sedimentary rock of Hailuoto is composed of a conglomerate overlain by a reddish, rather coarse arkosic sandstone. They probably correspond to the lower part of the Muhos Formation and were deposited before the upper stratum. The upper portion of the sedimentary sequence of Hailuoto, consisting of siltstone and shale, was deposited in a shallow sea. During sedimentation, fluctuations occurred in sea level, which is reflected in grain-size variations, but these variations, exhibiting a close rhythmic pattern, were primarily caused by changes in river flow.

The upper stratum contains, among other constituents, glauconite, the dating of which supports the microfossil evidence about 600 m.y.

Key words: paleontology, microfossils, acritarchs, algae, Cyanophyta, sedimentation, Muhos Formation, Late Precambrian, Riphean, Vendian, Eocambrian, Bothnian Bay, Gulf of Bothnia, Hailuoto, Finland.

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INTRODUCTION

The island of Hailuoto (Fig. 1) is located about 42 km west of the city of Oulu on the eastern side of the Bothnian Bay, in the middle of the zone of maximum recent land uplift. There are no rock exposures on this low-lying island, which at present has an area of c. 192 sq. km and is covered with sand and forest-covered dunes. The island is geologically young, having risen out of the Bothnian Bay during the period of Quaternary postglacial land uplift. The sandy sediment of which the island is composed was deposited by streams of meltwater from the receding continental ice sheet and by local rivers.

When the so-called Muhos Formation was found (Brenner 1941, 1944) on the mainland to the east of Hailuoto and later became better known (Okko 1954, Simonen and Kouvo 1955), the bedrock underlying the Quaternary deposits of nearby Hailuoto was also investigated. The Geological Survey of Finland first undertook seismic investigations on the island under the supervision of Dr. V. Veltheim, after which three diamond drill-holes were put down. The results of the studies were published by Veltheim in 1969. It had been ascertained that the Quaternary deposits of Hailuoto were also underlain by Precambrian sedimentary rocks, the thickness of which, however, was substantially less than of the Muhos Formation on the mainland. As drilling carried out by the Otanmäki company out at sea in the area situated between Hailuoto and the mainland in the area of the Muhos Formation, had also led to the discovery under Quaternary deposits of sediment comparable to that in the concealed area of Muhos (Veltheim 1969, p. 6), it was a fair assumption that the Hailuoto sedimentary rocks are relates to the Muhos Formation. Their age need not, however, be the same, for the sediments of Hailuoto and the mainland area may correspond to different stages of the Jotnian or Postjotnian depositional succession.

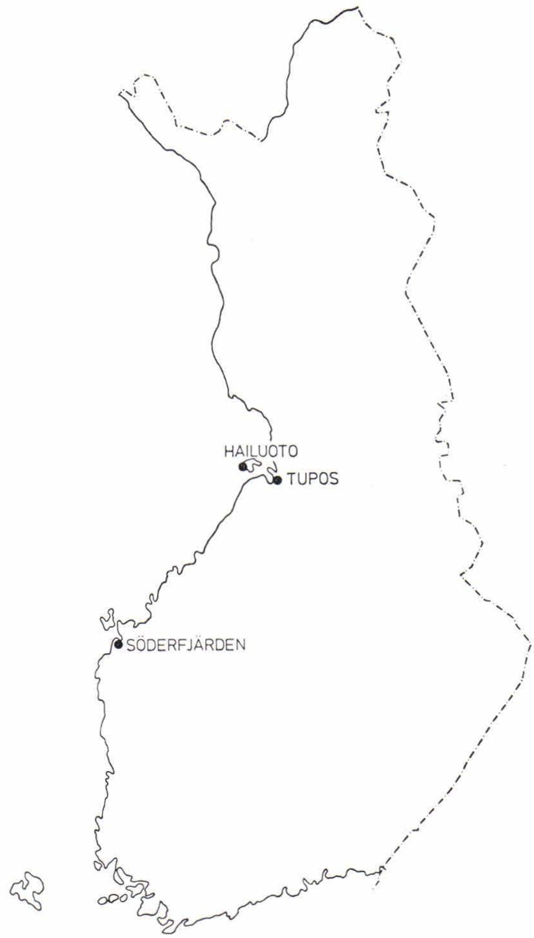

Fig. 1. Location of Hailuoto and the nearest comparable occurrences of sedimentary rocks.

In the preliminary microfossil examination made of a couple of drillcore samples, at Veltheim's request, no observations were made that might indicate an exception to the results obtained from the Tupos drill hole in the Muhos Formation (Tynni and Siivola 1966). The samples mentioned had an exceedingly sparse content of microfossils.

The microfossil investigation of the sedimentary rock of Hailuoto thus remained, for practical purposes, an open question. The present study deals with the microfossils of the sediments overlying the arkosic rocks as well as the sedimentation conditions of the series as a whole. Veltheim's description offers an answer to many questions, relating to, for example, the approximate grain size, the mineral composition of the sediments and the division of the strata sequence into two parts. The homogeneous sediments of the upper part are composed of semi-rounded grains averaging 0.2—0.4 mm in diameter. The grains are mostly quartz, feldspar being less than 10 % and the accessories extremely fine-grained quartzite lithoclasts and mica flakes. The color of the sedimentary package composing the upper part is light on the whole, whereas the arkose and shale intercalations in the lower part are either intensely red or brownish yellow. The granularity of the lower part averages between 1 and 3 mm, the main components being feldspar and quartz in a ratio of 1 : 2.

The Hailuoto siltstones contained in the upper sequence of layers resemble the gray and greenish siltstones of the Muhos Formation, which contains reddish siltstone as well in noticeable amounts. Its prevalence at Muhos has been interpreted as a sign of fluvial sedimentation (Simonen and Kouvo 1955). The Muhos sediment has also been interpreted as a Jotnian weathering sediment. The brown spots occurring in less colored places in the lower part of the sequence at Hailuoto are, according to Veltheim, post-depositional phenomena caused by the presence of iron. In general, the proportion of iron in the lower sequence of layers at Hailuoto is higher than in the upper part.

It is not known whether minerological differences exist between the reddish and the gray siltstone in the Muhos Formation, nor to what extent these color phenomena are of primary origin. The generally held view at present is that the formation of oxygen even before the Middle Riphean as a result of the photosynthesis of marine algae had caused the precipitation of red, banded iron oxides (BIF) * approximately 2000 —2100 million years ago, a short time before oxides formed on the continents (Cloud 1973). During the Middle Riphean, the formation of oxygen was greater in volume and the amount of it in the atmosphere about 1 300 million years ago was $< 1\ \%$, according to the graphic description presented by Cloud (1976). Under such conditions, iron oxide could have imparted color to sediments both on land and in the sea. However, the amount of oxygen was decisively less than at present; with rapid sedimentation reducing conditions could easily occur in the surface parts of the layers, especially if there was an abundance of decomposing algal vegetation. Under the prevailing conditions, it would have been natural for some of, for instance, the blue-green algae to remain in the deposits (Tynni 1978). This also presupposes anaerobic activity to a slight extent.

The sedimentary conditions were studied to interpret the environmental conditions for the period and a detailed granulometric study was also made.

The importance of microfossil studies of Precambrian formations has been enhanced steadily by the research done in recent years in various parts of the world. Schopf's survey (1975 a) of certain of the best known Precambrian microbiota, their dating and the conditions of their genesis reflects the current view of the evolution of Precambrian life.

* BIF = banded iron formation — sedimentary iron deposits consisting of alternating thin layers of siliceous iron-rich rock and nearly pure silica (Cloud 1973).

DIAMOND-DRILLING SERIES 1 AND 2, THE GENERAL NATURE OF MICROFOSSILS AND THE METHODS OF PREPARATION

Selected for investigation from the three Hailuoto drill cores were the two located farthest west, in which the thickness of the sedimentary rock is greater than in the third series, located farthest south. Series 1 is located on the NW shore of the island, about 1.5 km to the southwest from Keskiniemi. The main stratigraphic features can be seen in Veltheim's profile figure 10 (Veltheim 1969). According to this profile, there is a thickness of c. 35 m of loose sand, underlain by layers of sandstone, shale, siltstone, sandstone, shale, sandstone and siltstone to a combined thickness of c. 55 m. Underneath this sequence lie arkose, red shale and red arkose to a depth of 154.56 m, where the basement complex begins.

In the sequence of layers contained in the drill core, a significant part is played, from the standpoint of microfossil research, by the deposits overlying the arkoses and red shale. No microfossils are to be expected to occur in the arkoses because they represent sediments of the lifeless Precambrian mainland. Microfossils are not generally found in the red shale, either. The reddish Jotnian sediments have been regarded as having formed under oxidizing conditions (cf., Lokka 1950, Simonen and Kouvo 1955). In oxidizing conditions, the weak-structured blue-green algae, which represent the commonest Precambrian biotope, cannot be preserved from destruction. The red shale shown in Veltheim's figure 11 contains greenish gray splotches, which are probably diagenetic deoxidation areas or unoxidized fragments embedded in the sediment. This type of rock is the same as that found in the Tupos drill-core from the Muhos Formation.

The Hailuoto sequence No. 2 is located on the western side of the island about 5.5 km south of drilling site 1. At this point, the thickness of the sand deposits at the surface is 48.3 m. The combined thickness of the shales and sandstones overlying the arkoses is about 65 m. Here, as in layer sequence 1, microfossil analyses have been correspondingly performed. Microfossil analyses in the greatest density have been made on the greenish shale, at intervals of about 1—2 m. Microfossils are most frequent in the shales, although they are not present everywhere in sufficient numbers in the shales. At certain points, only an organic amorphous mass can be observed. In the yellowish-reddish portion of the sandstone, microfossils are present in extreme sparsity, and for this reason they have been studied at intervals of only 5—10 m.

Characteristic of the microfossils observed is their division, to be described more closely in the following chapters, into spherical forms and/or combination forms, as well as cell-chain filaments of the blue-green algae or cyanobacterial types or indivisible cellular filaments. The filamentous blue-green algae are on the average better preserved than the spherical forms. In this respect, the survival of the Hailuoto microfossil material is comparable to the situation noted by Burmann (1966) in the graywacke formation of Lausitz. Here are also to be found the best-preserved individual blue-green algal filaments.

In general coccoid species (acritarchs) are planktonic and filamentous species benthic, embedded in the deposits of a shallow sea.

For the microfossil analyses, samples of mechanically crushed sedimentary rock weighing c. 20—30 g were treated with an HCl and an HF solution to dissolve the silicate matter. The remaining solid residue was treated further by using a heavy $CHBr_3$ solution with a density of 2.2. The microfossil slides were made using Clophen-Harpix as a medium. Part of the concentrated microfossil material was studied and photographed with the scanning electron microscope of the Geological Survey.

ACRITARCH OBSERVATIONS

The existing acritarchs in each of the diamond-drill series represent a very limited number of species, consisting of about ten taxa. The prevailing type is closely akin to *Leiosphaeridia* Eisen. In many instances, the *Leiosphaeridia*-type sphere has been flattened on the surface, forming a surface structure resembling *Cymatiosphaera* (Wetzel 1933). In some cases, this structure may be the primary one, but in general it must be considered a secondary *Leiosphaeridia* structure.

Cymatiosphaera precambrica n. sp.

The surest evidence of the occurrence of *Cymatiosphaera* is a well-preserved fragment of a large form from diamond-drill series 2, taken from a depth of 52.6 m. On the basis of the fragment, the diameter of the form can be estimated to have been c. 250 μ. Diamond-drill series 1 yielded a large sphaeromorph c. 350 μ in diameter from a depth of 55.96 m; on its surface was dimly visible the same sort of reticulate membranous structure as on the aforementioned fragment. The probability is that the same rare form has been preserved. We have named the form *C. precambrica* on account of the exceptionally early period of its occurrence. One *Cymatiosphaera* sp., to be sure, had been found previously in the nearby Muhos Formation. It is conspicuously smaller than the Hailuoto form, from which it also differs with respect to its surface structure (cf., Tynni 1978).

Trachysphaeridium levis (Lopukhin 1971) Vidal 1974

Synonym: *Menneria Levis* Lopukhin. A sphaeromorph the surface of which is covered densely with small nodules. The diameter averages 70—90 μ. The acritarch form in question has been preserved best in the Hailuoto drill series 1 at a depth of 55.96 m, where it has been observed to be prevalent. *Trachysphaeridium levis* is mainly a late-Precambrian form, which has been met with in Vendian deposits (as, e.g., in Finnmark, Vidal) as well as in the Lower Cambrian of eastern Greenland (Vidal 1976).

Favosphaeridium sp. Timofeev (1956) 1959

The sphaeromorph is somewhat triangularly roundish and to some extent resembles the previously described *Muhosphora reticulata* (Tynni and Siivola 1966) but differs in that the surface structure is composed of irregular cells of varying size. The diameter is c. 140 μ. It is extremely rare, for only one individual distinctly distinguishable in structure has been met with in drill series 2, occurring at a depth of 52.6 m.

Podoliella prismatica n. sp.

Only one preserved acritarch, with a relatively complex structure, was found in Hailuoto drill hole 2, occurring at a depth of 48.4 m. Of the morphological species described by Timofeev in 1973, it bears the closest resemblance to *Podoliella*. The structure resembles *Symplassosphaeri-*

dium Tim., but the smaller spherical portions of the sphaeromorph do not cover the surface layer continuously. The structure also resembles that of *Polyedrosphaeridium bullatum* described by Timofeev in 1966, and it is uncertain whether these morphotypes should not be regarded as synonymous. Preference has been given to the younger *Podoliella* in distinction to *Polyedryxium* described by Deunff (1954, 1971).

Podoliella Tim. has been reported to occur in the Upper Vendian of the Ukrainian region (Timofeev 1973). *Polyedrosphaeridium bullatum*, again, has been found in the Riphean stratum of the region of the Maya river in Yakutia (Timofeev 1966, 1969) as well as in certain Vendian and Cambrian deposits of the U.S.S.R. (Timofeev 1966).

The diameter of the Hailuoto acritarch form measures c. 100 μ.

Symplassosphaeridium sp.

The morphotype described by Timofeev in 1959 has been observed to be rare at Hailuoto, the reason being probably that it has a delicate structure, not likely to be preserved. In layer series 1, this acritarch form occurs most prominently at a depth of 57.4 m. It consists of delicate, thin spherical cells, joined firmly together and not easily susceptible to disintegration like *Symplassosphaeridium*. The diameter of the spheres in the middle is c. 40 μ and that of the ones on the margin c. 35 μ and that of the complex as a whole c. 85 μ.

Morphologically, the Hailuoto type resembles the *Symplassosphaeridium parvum* individuals occurring at a depth of 234 m in Muhos but they are conspicuously smaller, c. 8—20 μ.

Trachyhystrichosphaera bothnica n. sp.

The morphotype described by Timofeev and German (1976) was found in the region of the Maya river in a deposit estimated to be about 890 million years old (Timofeev *et al.* 1976). A substantially larger form than the one occurring at Hailuoto is in question (200—500 μ), but the structure is of the same type in both cases. The surface of the spheres is rough, with small spines in rows. If a clearly defined opening could be detected on the spheres, a comparison could be made to the genus *Cymatiogalea* Deunff, 1961, but no opening has been found. The diameter of the Hailuoto form is c. 50 μ, which is probably uncommon.

Trachyhystrichosphaera sp.

The form in question has been poorly preserved, hence its identification is uncertain. Inferences can be made, however, from the rough surface of the sphaeromorph and the short spines distinguishable in spots. The form found in the Hailuoto drilling series 1 at a depth of 55.96 m is c. 150 μ in diameter, and it is noticeably larger than the foregoing form, approaching the dimensions of *T. aimika* as reported by German — 200—500 μ (Timofeev *et al.* 1976).

Kildinella cf. sinica Timofeev, 1966

The cluster of four individuals occurring at a depth of 57.4 m in Hailuoto 1 probably corresponds to the foregoing form. The diameter of the spheres is 35 μ, and the surface is rough as well as wrinkled.

The form is found in many places in Riphean and Vendian deposits (e.g., Timofeev 1969, Vidal 1976). The type found in the Muhos Formation is slightly smaller than the foregoing one (Ø 24—31 μ).

Kildinella sp.

The form in question came from a depth of 52.6 m in drilling series 2. It is noticeably larger than the foregoing type, being c. 140 μ in diameter. Its wrinkled surface is typical of *Kildinella*. In size it corresponds, again, to *K. jacutica* Timofeev, 1966, 1969. It is a form of the Riphean Miroediha beds. This form is also included in the large *Chuaria circularis* Walcott, 1899 morphological complex described by Vidal (1976) from the late Precambrian layer sequence of Visingö. The type reported from Hailuoto has been included in the *Kildinella* inasmuch as larger individuals clearly to be connected with *Chuaria* could not be observed to occur in the preparation in question. However, the *Chuaria* also probably belongs to the microflora of Hailuoto. Unfortunately, the individuals have been poorly preserved.

Chuaria circularis Walcott, 1899

Originally regarded as an animal microfossil, this form is now identified as a large phytoplankton closely related to *Leiosphaeridia* (Timofeev 1960, Eisenack 1966, Ford & Breed 1972, Ford 1975). Vidal (1974, 1976) has described a number of different forms from the Visingsö series that have been connected with the species mentioned. They vary between 100 and 1 000 μ in size, but certain fragments indicate a diameter of as much as 3 000 μ. Vidal further points to conspicuous variations in the surface structure of the species, which are attributed to pyrite. An interesting structural feature is the globular cavity inside the shell described by Vidal, 1974, Pl. 1 : 5. In the fragmentary *Chuaria* form found at a depth of 55.96 m in the Hailuoto layer series 1, there can be observed a sizable cavity c. 30 μ in diameter resembling a pylom. The original diameter of the sphere is estimated to have been c. 500 μ.

Chuaria circularis occurs according to Vidal, in the Upper Riphean and the Vendian (?).

Nucellosphaeridium bellum Timofeev, 1969, resembles the Hailuoto form closely if it is assumed that the black hole in the shell corresponds to the black spot of *Nucellosphaeridium*. The form has been found in a Riphean Miroediha deposit (Timofeev 1969) as well as in a Lahandin deposit in the Maya river region (Timofeev *et al.* 1976).

In the Hailuoto drilling series, the diversity of the acritarchs originally present in the sediment was considerably greater evidently than what would appear to be the case from the foregoing. In type, they are distinctly different from those in the Muhos Formation. In the sequences of Hailuoto, the size of the sphaeromorphs is larger and, for instance, the *Protosphaeridium* Timofeev genus, which is fairly common at Muhos, appears to be missing. At Muhos, there occur forms identified as *Protosphaeridium*, which are between about 10 and 20 μ in diameter with a folded surface. The forms exceeding 20 μ in diameter and with tiny knobs on the surface would more naturally fall into the *Trachysphaeridium* than the *Protosphaeridium* category.

At Hailuoto, the genus *Synsphaeridium* Eisenack, 1965, is fairly common. Certain combinations resemble *Gloecapsomorpha* Zalessky, 1920. In layer series 1, at a depth of 55.96 m, some cells also occur in pairs, which are similar to some forms reported as occurring in the Miroediha deposit (Timofeev *et al.* 1976).

BLUE-GREEN ALGAE FILAMENTS

Filamentous forms are more important microfossils in many Hailuoto samples than are the spheres. Filamentous forms constitute a varied selection of types, which include either individual unbranched or branched, divided or undivided forms. The filaments may be either straight or twisted. Some of the filaments occur in globular clusters. Many of the forms resemble certain genera of blue-green algae.

Resemblances to previously described fossils in the Australian Bitter Springs formation (Schopf 1968, 1978) as well as to late-Precambrian filaments from the region of the Miroediha river can be observed. Resemblances also exist to types described from a Vendian deposit in the Ukrainian region (Timofeev 1973, Aseeva 1976).

The simplest forms, again, resemble many types reported to have been found in the oldest Precambrian deposits in, for example, North America. In the Hailuoto material, further, there are forms that have not been previously described in the literature. In the systematic representation of the forms, priority has been given to the descriptions of living forms, since no great changes have taken place in blue-green algae during the course of geological time. The classification of living forms is based in many instances only on slight structural differences. In dealing with the fossil material an effort has been made to place types resembling each other into certain genera and species with clear-cut distinguishing features.

Genus Paleolyngbya Schopf, 1968

Paleolyngbya lata n. sp.

There is a rare form that consists of a few fragmentary filaments surrounded by a clearly distinguishable sheathlike membrane. Situated one after another, the cells vary in shape and are approximately 30 μ broad and 8 μ high. They occur fairly separately and are dark in color.

Paleolyngbya was found only at a depth of 52.6 m in drillhole 1, where *Volyniella cylindrica* is the commoner form. The possibility of these forms representing different stages of development is not altogether ruled out.

Paleolyngbya resembles *Polysphaeroides filiformis* described by German from the Miroediha deposit (Timofeev *et al.* 1976, Pl. XIV : 1). The Miroediha deposit has been dated as being 700—960 million years old, and typical occurrences in it are, in particular, *Kildinella* and trichomes.

Genus Volyniella (Shepeleva 1973) Aseeva 1976

Volyniella valdaica has been described from Valdai (Shepeleva) and Podol, from the Upper Vendian (Aseeva op. cit.)

Volyniella cylindrica n. sp.

The filaments appear to be broad and tapering at the end, resembling hormogonia. The apparent width of the cells is c. 50 μ and the height c. 10 μ. The terminal cells are narrower and the outermost ones rounded. The longest cylinders measure roughly 150 μ, and are in many cases torn at one end. The cell filaments consist of monocellular rings about 10 μ wide, which have grown together at the sides to form a cylindrical structure closed at the ends (Fig. 2, Table 5).

In certain oblique filaments, the hollow cylindrical structure can be seen plainly. In addition, the walls of the cylinders are contracted at the point of division, suggesting tubular rings. In certain fragments, these rings appear to be com-

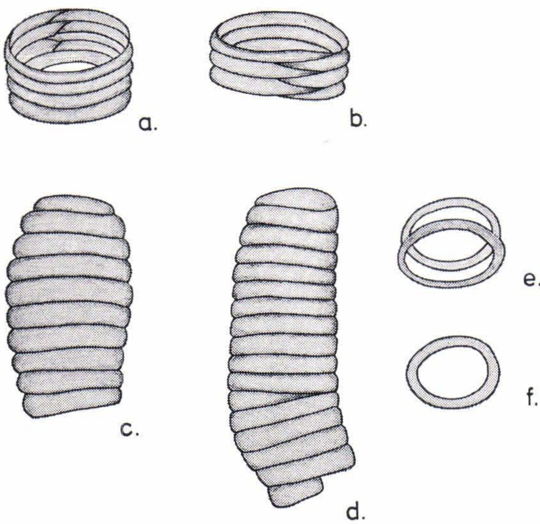

Fig. 2. Structural drawings of *Volyinella cylindrica* and its fragments. Measurements given in Plate V. The structure of the cell chains is shown in drawings a and b, corresponding to Figs. 55 and 57. The fragmentary cell rings (e, f) show that the joint forming the rings is firmer than the joint between rings forming cell tubes.

posed of cells as long as the perimeter, the ends of which are wedged into each other. The joint is situated on the longitudinal portion of the cylindrical complex (Fig. 2 a b).

The observations were made from a preparation investigated from a depth of 52.6 and 22.4 m in drill hole 2. In it there is one almost undamaged filament as well as twenty or so fairly large fragments.

The Hailuoto material also contains circular structures formed through the disintegration of complex blue-green algae. The center of each ring may be either open or covered with a membrane. In the latter case, the terminal portion of a chain of cells is probably the source. Flattened out, it resembles *Leiosphaeridia* types, just as do the detached short flattened cells presumed to be *Volyniella*. The ringlike cells probably correspond to the *Toromorpha* sp. form described by Timofeev (1973) from the Vendian deposit at Podolia. From the same site, larger fragments of blue-green algal filaments have also been described (e.g., Timofeev 1973; XIV: 6).

Discussion: *Volyniella* resembles to some extent *Paleolyngbya*. *Paleolyngbya Barghoorniana* Schopf is smaller than the Hailuoto form, and at the ends of the filaments are to be seen incompletely developed septa. The number of cells is rather small and the filaments have been regarded, with reservations, as hormogonia.

The form found at Hailuoto was well adapted to live in plankton on account of the hollow inner space presumed to have existed in the algal colony (fig. 3). Owing to its simple basic structure, it has been classified among the blue-green algae, but with respect to its reproductive capability and other forms of existence, no idea has been obtained from the material.

Genus Oscillatoriopsis Schopf, 1968

The type species *Oscillatoriopsis obtusa* Schopf resembles the Hailuoto form, with respect to its most important structural features as certain *Oscillatoria* Vaucher species of the pressent day resemble it even more.

Oscillatoriopsis magna n. sp.

The filaments are multicellular, unbranched, straight-edged, fairly even in width. The width of the filaments varies from 80 to 100 μ, the length of the longest fragments being c. 1.5 mm. The height of the cells is 15—18 μ. In size, the species resembles most closely *Oscillatoria princeps* f. *maxima*, the width of which varies between 45 and 70 μ. Besides the straight form of even thickness, in which the cells are all similar, there are also filaments in which the cells contract, forming a darkly differentiated zone. In these forms there does not occur the normal division. The dark zones seem to correspond to the formation of vacuoles. In some filaments, the outer walls of the cellular tissue contain oval or angular black rings, which probably correspond to pseudovacuoles. Terminal cells were not observed to occur in the material.

The occurrence is most abundant at a depth of 82.48 m in drill hole 2 at Hailuoto.

Similar ribbon-like broad filaments have been reported to occur in, for example, the Vendian stratum of Podolia (Timofeev, 1973, Pl. XII: 5, XXIII: 7).

Oscillatoriopsis bothnica n. sp.

Filaments multicellular and unbranched. Length of fragments 200 μ. Individual cells c. 12—15 μ broad and 5—7 μ high. Cells mostly clearly separate, but in certain cases the partition between successive cells is poorly distinguishable in part or is lacking, upon which the apparent height of the cell is c. 10 μ. Filaments of even thickness or slightly sinuous.

A few observations from 57.4 m of drill hole 1 and from 59.3 m of drill hole 2.

The Hailuoto form is larger than the *O. obtusa* Schopf described from Bitter Springs. The Hailuoto form bears a closer resemblance to German's (1974, Pl. VI: 5) *Paleolyngbya catenata*. The form has been seen in an Upper Riphean Miroediha deposit. In the Hailuoto instance, the species has been classified as *Oscillatoriopsis* in form, as no membranaceous sheath has been observed enclosing the chain of cells.

Oscillatoriopsis constricta n. sp.

The species resembles the foregoing in size and proportions. Width c. 12 μ, length c. 6 or 12 μ, depending on when the cells have split. On the whole, the walls dividing the cells are poorly visible. At intervals of approximately 40—70μ, the cell filament has darkened and contracted over a span of about 2/3 its width. Contraction seems to be a varying feature, and the likelihood is that *O. constricta* corresponds to a certain developmental stage of *O. bothnica*. The form has been described as a separate species because it has been observed to be present elsewhere than *O. bothnica*.

Observations made especially at a depth of 82.48 m in drill hole 2.

Genus Caudiculophycus Schopf, 1968

The type *C. rivularioides* Schopf reveals certain similarities with the *Rivulariaceae* family. Characteristically, it has a multicellular hair at the end of the filament. The end of the filament tapers down, however, more sharply than in the *Rivularia* genus, and no mucilagenous sheath has been observed to envelope the filament in the *Caudiculophycus* genus.

Caudiculophycus curvata n. sp.

Characteristic of this species is the twisted shape of one end of the filament and the curving of the other end, which thins down to a hair. Only a few individuals was met with, occurring at a depth of 82.48 m in drill hole 2. Length of form c. 200 μ, breadth c. 12 μ. The cellular walls are only visible close to the tip at intervals of c. 2—4 μ.

Genus Anabaenidium Schopf, 1968

Typical of the Hailuoto form are the thicker-shelled spherical ends of the curving multicellular filament, which evidently correspond to the heterocrysts of blue-green algae. The type is comparable to the present-day *Anabaena* Bory genus. In the Hailuoto type, the width of the filament is c. 10 μ. The walls between the cells are faintly distinguishable.

Anabaenidium hailuotoensis n. sp.

The form just described has been met with at a depth of 82.4 m in drill hole 2 at Hailuoto. The length of the form is c. 40—200 μ.

It resembles *Anabaenidium barghoornii* Edhorn, 1973 more closely than the type species reported from Bitter Springs. The Gunflint formation is considerably older than the Hailuoto and Bitter Springs formations (Animikie Group c. 2 Gyr). The *Anabaenidium* found at Hailuoto differs from the foregoing ones especially with respect to its larger filament breadth — c. 13 μ.

Genus Tortunema German, 1976

A typical feature of the form is the sinuous shape of its filaments. The filaments are 10—25 μ in width and the length of the cells is 25—30 % of their width. The walls between the cells are only faintly visible, most clearly in the proximity of the tapering ends of the trichome.

On account of its spiral form, the genus resembles the *Contortothrix* Schopf, 1968 form, which is different, however, owing to its smaller size and its easily distinguishable dividing walls. *Palaeospirulina* Edhorn, 1973 is likewise a smaller form, which has similarities to *Spirulina* Turp. insofar as the trichome is twisted and turned in two different directions.

Tortunema bothnica n. sp.

The relatively long trichome forms a spherical skein. The diameter of the firmer spheres is c. 70 μ, the widht of the trichome being c. 8—12 μ. The cells walls could only occasionally be distinguished, as there is an indistinct secondary (?) reticular structure on the surface. No separate mucilaginous sheath could be observed.

A few observations were made at the depths of 52.6 and 82.48 m in drill hole 2.

The species closely resembles *Tortunema eniseica* as described by German, having been found in an Upper Riphean deposit of Miroediha (Timofeev *et al.* 1976).

BLUE-GREEN ALGAE FILAMENT CLUSTERS

Blue-green algae filaments also occur in clusters in the Hailuoto material and can be distinguished by a certain regularity of occurrence. The main types are accumulations composed of filaments running parallel to each other and accumulations composed of spiral filaments.

The parallel filaments are unbranched and straight-walled, the septa of which are very hard to distinguish. The width of the filaments is c. 10 μ. The algal form probably corresponds to the present-day Nostocalean type. Similar filament accumulations have been found at a depth of 82.48 m in drill hole 2. The form resembles quite closely the type of algal filament described from the Podolian Vendian (Timofeev 1973, Pl. XXVIII).

The clusters composed of spiral filaments evidently contain unbranched filaments c. 8—10 μ broad twined together. The diameter of the accumulation found at a depth of 82.48 m is c. 500 μ. It resembles *Leiothrichoides tipicus* described by German (1974) from the Miroediha deposit, although these forms also have differences.

EPIPHYTIC BLUE-GREEN ALGAL FORM?

Of the previously described algal types, *Oscillatoriopsis constricta* possibly grow epiphytically on top of a *Laminarites*-type cell membrane. This, however, requires further confirmation.

BRANCHED FIBERS

In the Hailuoto material, there occurs as a rarity a membranaceous filament without separating walls from which extend thinner short, branched appendages. These are likely to have smaller extensions. The diameter of the filament varies between 10 and 45 μ. The surface of the membrane is covered with small nodules. The form was found at a depth of 79.55 m in drill hole 2. The same type also occurs in the Tupos drill series at the 165.47 m level.

This may be a bacterial or fungal form.

ORGANIC MEMBRANES

A fossil type of cellular tissue compared to the present-day brown seaweed genus *Laminaria* has been reported to be commonly present in late-Precambrian deposits, especially in the U.S.S.R. Laminarites clay has been described, for instance, from Krasnoye Selo (*Laminarites antiquissimus* Eichwald) (Timofeev, 1959). The *Laminarites* observations are confined to Vendian deposits (Timofeev, 1966, 1973).

The same type has been described from the Upper Vendian of Kotl as *Vendotaenia antiqua* by Gnilovskaya (1971). A related type, *Tyrassotaenia podolica*, was described by Gnilovskaya from the Lub series.

Since the *Laminarites* cell tissue appears to have stratigraphic significance, efforts have been made to detect its possible occurrence in the Hailuoto deposits. This is made difficult by the indefiniteness of the cell-tissue type. The stem of the alga in question is described by Timofeev (1959) as lamellar and gradually tapering. The width of the nervures is 2—3 mm and the color a dark brown. The actual algal fragments in the deposits of Vologda and Krasnoye Selo are several centimeters across.

The presence of *Laminarites* or *Vendotaenia* could not be established for sure in the Hailuoto material, but in a number of samples there are fragments of brownish cell membrane with a rough surface. Their origin cannot be determined for lack of any clearly defined structure. The fragments is question exceed 0.5 mm across.

The greatest abundance of membranaceous cellular tissue was found at a depth of 82.48 m in drill hole 2. Filmy brownish membranes could be clearly distinguished with a stereoscopic microscope. The membranes measure c. 2—3 mm across. They aıe even-surfaced, run parallel to the layer surface, are exceedingly thin but hold together when the membranes are prepared with a brush from between thin sedimentary layers.

Microscopic study under greater enlargement reveals the presence in association with the membranes of both algal filaments and black, evidently framboidal pyrite crystals or round spheres as well as the *Bavlinella* type. The concentration of lower organic forms, such as blue-green algal filaments in organic membranes probably points to a heterotrophic biotope in which the organisms had existed. The lack of distinct cellular features from the membranes also leaves open the possibility that the membranes had formed from organisms that had dissolved chemically in connection with precipitation.

PYRITOSPHAERA BARBARIA—BAVLINELLA FAVEOLATA

Bavlinella faveolata (Shepeleva 1962) has been reported from many late-Precambrian deposits in the U.S.S.R. as well as in the Vendian of Visingsö, Sweden. Vidal (1976) regards the form as belonging mainly to the Vendian acritarch community. Since the same biogenetic pyrite structure occurs in the shale of Hailuoto, special attention will be paid in the present connection to this biogenetic type.

Muir (1977) states that *Pyritosphaera* Love 1962 (should be 1958) signifies the same as *Bavlinella* Shepeleva. Further, corresponding to these was *Sphaerocongregus* Moorman (cf., Kalliokoski 1973). Also *Favorsphaera conglobata* Burmann, 1972 is a synonym, according to Vidal, for *Bavlinella*. According to Muir, *Bavlinella* is not a microfossil but probably a structure composed of sulphate-reducing bacteria. It would appear, however, that the morphology of pyrite crystallizations adheres to the same features as certain bacteria or blue-green algae forming spherical colonies.

Lonka and Papunen (1968) have described certain Cambrian sandstone boulders which were transported by ice during the Quaternary glaciations from the region of the Bothnian Bay to western Finland and which contain pyrite as a cement or as veins. The Pomarkku boulder contains framboidal pyrite spheres, which are of the same type as *Pyritosphaera*, but larger. The authors compare them to the framboidal pyrite spheres described by Papunen (1968) from postglacial sulphide-bearing sediments in the Gulf of Bothnia. The same structure has been reported by Papunen (1966) to occur in a bog deposit in southwestern Finland as well as by Ignatius *et al.* (1968) to occur in an postglacial Ancylus deposit in the Bothnian Bay.

The genesis of the framboidal pyrite spheres was, according to Papunen, as follows: Iron hydroxide has been absorbed in water into colloidal humus. As the acidity in the water increases, the humus and the iron hydroxide form larger spherical humus coacervate drops. If there is an oxygen deficiency in the water, an abundance of hydrogen sulphide is likely to form. This reacts with the iron hydroxide of humus particles to form framboidal pyrite spheres as crystallization products. The humus particles would be the organic beginning of this structural model of the pyrite spheres, but the formation of framboidal pyrite spheres in the guise of microfossils is likewise apparent, as Love (1958) has pointed out. The form in question, *Pyritosphaera barbaria*, is in its main features similar to *Bavlinella*, but with regard to their surface structure they differ, for only the former possesses a density of small radially sit uated spines.

The pyrite aggregates reported to occur in the Ancylus stratum in the Bothnian Bay contain framboidal pyrite spheres, which have been interpreted to be sulphur bacteria colonies (cf. Love and Amstutz 1966). They had functioned as crystallization centers for inorganic radially grown pyrite and markasite rings (Ignatius *et al.* 1968).

In the organic membranes found at a depth of 82.48 m in drill hole 2 at Hailuoto, globular framboidal pyrite bodies are present in abundance, resembling the ones described by Vidal (1976). In exceptional instances, pyrite spheres also occur as inner structures of algal filaments (Plate I: 4, 7, 8). Whether an endospore form of pyritized blue-green algal (cf., Moorman 1974) or sulphur-bacterial growth within algae will have to remain an open question in this connection. In the light of studies carried out up to the present, the *Bavlinella*-type formations would appear to be associated generally with Vendian deposits and younger sediments.

SEDIMENTATION CONDITIONS

The biogenetic structures observed suggest late-Precambrian or Vendian sedimentation in the upper part of the series of strata. The lower deposit consists at the bottom of a conglomerate overlain by arkosic sandstone, indicating the proximity of land. The sediments in question were possibly deposited in a shallow sea. Colored reddish by iron compounds, the sediment indicates the presence of oxygen. Possible microfossils could not have been preserved in

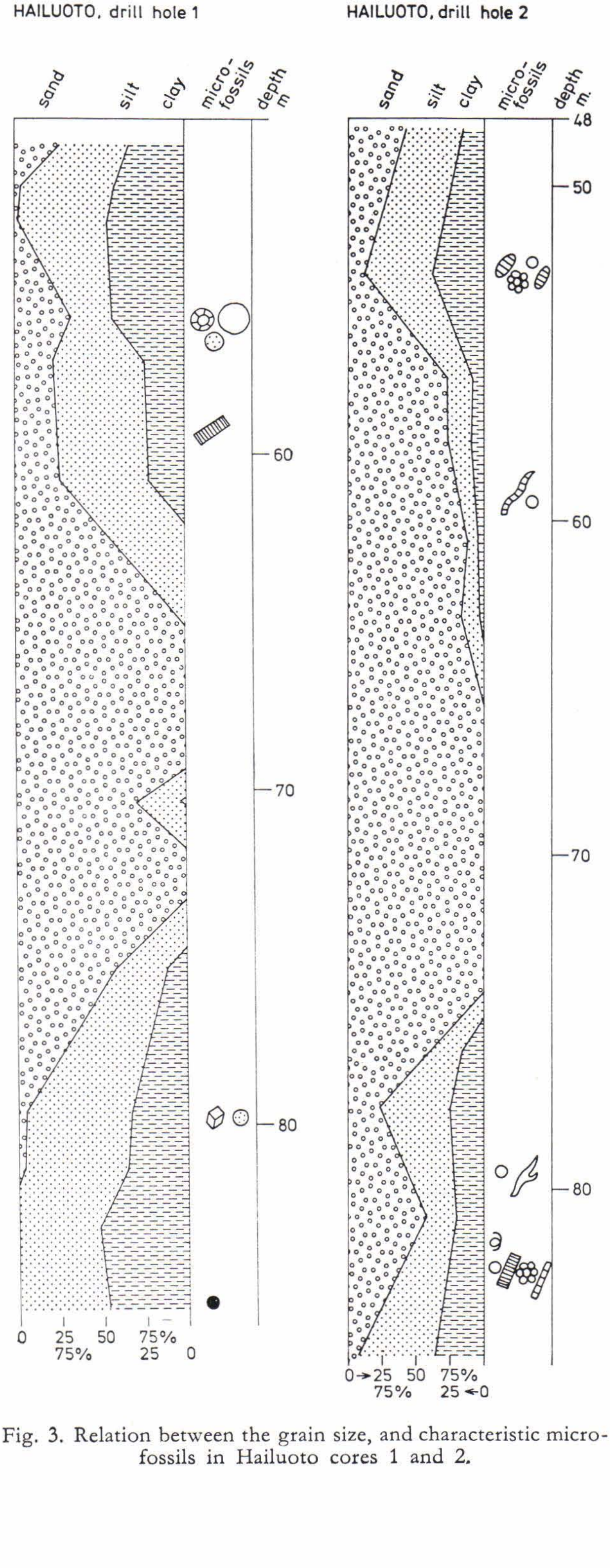

Fig. 3. Relation between the grain size, and characteristic micro-fossils in Hailuoto cores 1 and 2.

the coarse-grained sedimentary deposit. The phenomenon can be observed also in the upper portion of the deposits, where microfossils and the grain size of the sediments are compared (Fig. 3). In drill hole 2, microfossils were found only in the horizons where the proportions of clay and silt are relatively large.

Upon the deposition of the upper, finer-grained silt — and even clay — sediment, a transgression was taking place, during which the depth of the water increased. It was at this time that the water layer close to the bottom became deoxidized, which enabled the preservation of weak-structured blue-green algae in reducing conditions where the activity of anaerobic bacteria evidently was considerably less than at present.

The prevailing type of blue-green algae is very modest as regards its vital requirements. As regards the oxygen situation and temperature, among other things, it is adaptable. However, some blue-green algae depend on H_2S to hold the oxygen level down (Cloud 1974, p. 59). Blue-green algae are met with in cold waters as well as in hot springs (with temperatures above 80° C) and in both saline and fresh water. The circumstance of their prevalence, in combination with the absence of forms of life with more exacting requirements points to conditions inhibiting the existence of forms on a higher level of development. Among the most important limiting factors were probably the low oxygen content of the atmosphere and the water as well as the high temperature of the sea water. Presumably, the water in the seas and oceans before the Eocambrian glaciation was considerably warmer than it is at the present day.

Evidence of a fairly warm climate before the sedimentation of the shale is the high kaolin content that has been noted by Veltheim (1969, p. 32). The present-day formation of kaolin is associated only with a warm climate. The existing kaolin probably formed on the mainland with the weathering of potash-feldspar-bearing bedrock (older arkosic sandstone). In finegrained sedimentary rock, the stratification varies in thickness from less than a millimeter to a couple of centimeters. Although the sedimentary rock of Hailuoto resemble glacial clay in outward appearance, they are not glaciogenetic.

The Precambrian glaciations were important to climatic and hydrographic evolution. The information on glaciation is still contradictory. It was generally accepted earlier that the Huronian Ice Age took place about 2 000 million years ago and that it was followed by a younger, Eocambrian Ice Age, of which evidence exists in, for instance, southern Norway (Nystuen 1976). Schermerhorn (1976) draws attention to the poor compatability of Eocambrian mixtites and formations requiring warm conditions. Huronian-age tillites in a Hurley-type continental grouping are generally succeeded by aluminous quartzites (paleobauxites) and BIF deposits (Cloud 1971) — a view supported by Horwitz and others. The successiveness of the deposits is of slight significance from the standpoint of Ice Age interpretation if between these different types of formations there is a substantial time span, which appears to be probable. Possibly, the Precambrian glaciation had a considerable bearing on the emergence of temperature conditions favoring the development of organisms.

Nearly synchronous with the upper part of the Hailuoto sequence is probably the sediment of the upper part of the Visingö formation dating from the Vendian and containing stromatolites. It is noteworthy that Vidal interprets as possibly glaciogenetic the late-Riphean portion of the deposits in the northern and eastern parts of Visingö. No convincing signs indicative of the Ice Age came to light in connection with the conglomerate of the Hailuoto sequence of layers. The faint striations to be seen on the surface of a few stones might conceivably have been caused by the sliding of sedimentary deposits.

It has been endeavored to reconstruct structural models of the early evolutionary stages in the history of the Earth, such as, for example, of the formation of the oxygen envelope (Cloud

& Gibor 1970) and of its effect on the biogeochemical processes of the hydrosphere and the atmosphere (Cloud 1972, 1976). Attempts have been made to investigate the earliest conditions of the Earth's history by means of these structural models. The genesis of the Hailuoto series of strata corresponds in Cloud's (1972) structural model to the Eucaryotic stage and the beginning of Metazoa of life, which was characterized by an increase in the amount of oxygen, an abundance of calcium-carbonates and dolomites and the prevalence of red beds. In Cloud's structural model, the second glaciation took place slightly before the turn of the Phanerozoic and Cryptozoic ecosystems, 680 million years ago. At that time, the oxygen content of the atmosphere is estimated to have still been low, less than 2 % (Cloud 1976), or less than 0.4 % (Neruchev 1979).

At the end of the Precambrian, the atmosphere was still composed to a considerable extent of CH_4—NH_3 gases, released in connection with volcanic activity, and this naturally led to the generation of nitrogen compounds also in the hydrosphere. Nitrogen compounds promoted the production of blue-green algae. According to Neruchev (1979) CO_2 concentration in the late Precambrian atmosphere was 97—98 %, and atmospheric-pressure very high.

The arkose sand of the lower deposits at Hailuoto was probably deposited by flowing water close to the mainland. To judge by the only partial roundedness and rather poor sorting of the grains, the material had not been transported very far from the weathering area.

The observations reported by Veltheim (1969) from the Piehinki area seem to provide additional clues to the conditions prevailing during the time of sedimentation. Sandstones containing a fair abundance of, among other things, pyrite concretions have been found in the Piehinki area, which is located about 45 km S—SW of Hailuoto. Mixed among the sandstones are also ventifacts and sandstones from which the finer grains have been removed by wind erosion. Ventifacts have also been found among erratic boulders still farther to the southeast, at Vihanti, where, according to Väyrynen (1954), they occur in large numbers. The phenomenon points to a Jotnian desert environment. Further at Pyhäjoki in a phyllite pebble covered with graphite, there are filaments that very closely resemble a large blue-green algal filament found at a depth of 82.48 m in drill hole 2 at Hailuoto. However, according to Veltheim, the rock type of the phyllite pebble may be classified as Karelian.

The sedimentary rock of Hailuoto contains in drill hole 1 at a depth of 75.34 m hexahydrite $(Mg, \ldots) SO_4 \cdot 6 H_2O$, which is gypsumlike and occurs in salt-lake deposits (Winchell & Winchell 1951). The formation of hexahydrite presupposed a marine connection and a succeeding stage of hypersalinity. No microfossils have been found in this horizon.

Higher in the series of strata, at a depth of 55.96 m, glauconite is present, which likewise indicates sedimentation in sea water. Glauconite is known only from the late Precambrian and Phanerozoic deposits younger than 1 000 million years (Rutten 1971). Glauconite forms at the bottom of warm, shallow seas during the sedimentation of limestone (Rutten op. cit.). In the same horizon in which glauconite occurs, microfossils are also present, being late-Precambrian and Vendian in type.

Sedimentary rock contains pyrite also in other connections besides microfossils. At the depth of 51.98 m, the greenish siltstone contains thin concretions measuring about 2 mm in diameter, which evidently formed around pyrite crystals. As a rarer mineral, malachite is also found, at a depth of 59.36 m.

Microfossil research supports the view that the silt- and clay-bearing sedimentation dates back to the Upper Riphean, possibly the Vendian. Mineralogical and biological circumstances point to shallow seawater conditions. Öpik (1956) has previously concluded that there was a marine connection to the Baltic, including the Gulf of Bothnia during the Lower Cambrian. This conclusion was supported by investigations of the Söderfjärden sedimentary basin, in conjunction with which a Lower Cambrian series of strata was propounded (Laurén *et al.* 1978). The series of strata at Hailuoto indicate that a marine connection had prevailed in nearby areas earlier. The grain-size variations exhibited by the sequence, with the shales, siltstones and sandstones alternating, indicate changes in the shore-line of corresponding periods.

Comparative summary:

MICROFOSSILS OF THE SEDIMENTARY ROCKS AT HAILUOTO AND CERTAIN SEDIMENTARY ROCKS INTERPRETED AS OF LATE-PRECAMBRIAN ORIGIN

At Hailuoto, the microfossils are in places sufficiently abundant to give an idea of the prevailing organic community. In each of the drill holes, microfossils could be seen to be present over a stretch of about 30 meters in rocks containing clay and silt. The majority of the strata, however, proved to be nearly sterile as regards microfossils. Although the drilling sites are located only 5.5 km apart, drawing parallels between them on the basis of the occurrence of microfossils does not appear to be easy. The reason for the difference in age between adjacent deposits of the same type is probably the intensity of the tectonic processes that had been at work in the region (Veltheim 1969). The upper portion of drilling site 2 is probably younger than the upper portion of drilling site 1. The 82-m level at site 2 probably corresponds to the 59-m level at site 1 (Fig. 3), because at these levels there occurs a flat-celled blue-green algal filament, *Oscillatoriopsis magna* n. sp.

Typical of the Hailuoto formation are many blue-green algae of the filament type, which on the average are fairly broad. The afore-mentioned *Oscillatoriopsis magna* is the broadest of them, measuring between 80 and 100 μ, or broader than the *Oscillatoria* forms of the present day. Some paleontologists have had their attention drawn to the tendency of procaryotic filaments and cell diameters to grow broader during the time from the early Precambrian to the late Precambrian (among others, Schopf 1975 b, Pflug 1974, Cloud 1976).

Forms of the type characterized by broader, ribbonlike filaments were reported to have been present in the Vendian deposit of Podolia (Timofeev 1973). It seems likely, however that the Hailuoto sediment would have an age of 650—570 million years, although other comparisons indicate a greater age. Great similarities exist in comparison with the microfossils of the Upper Riphean of the Miroediha river (Timofeev *et al.* 1976). This series of layers has been estimated to be 700—960 million years old.

In a larger framework, the Hailuoto forms resemble certain filament and cell types described from a deposit c. 900 million years old at Bitter Springs, including *Caudiculophycus* (Schopf 1968, Schopf & Blacic 1971).

Important from the standpoint of comparisons is also the region of the Maya river in the U.S.S.R. The glauconite occurring there has been dated at 890 million years. Typical of the Maya river deposit are large spheromorph forms and so-called twin forms (Timofeev *et al.* 1976). Evidence of the presence of such forms has also been observed in the Hailuoto deposit.

The late-Precambrian dating is supported by a comparison of the acritarch forms of Hailuoto with the acritarchs of the Visingsö formation studied by Vidal, but filamentary forms have not been reported to be present at Visingsö. Forms in common are *Trachysphaeridium levis*, certain combination forms, a *Chuaria circularis* type (sensu lato) and a *Bavlinella* type. According to Vidal's observations, some of the afore-mentioned forms are Riphean and some Vendian in age.

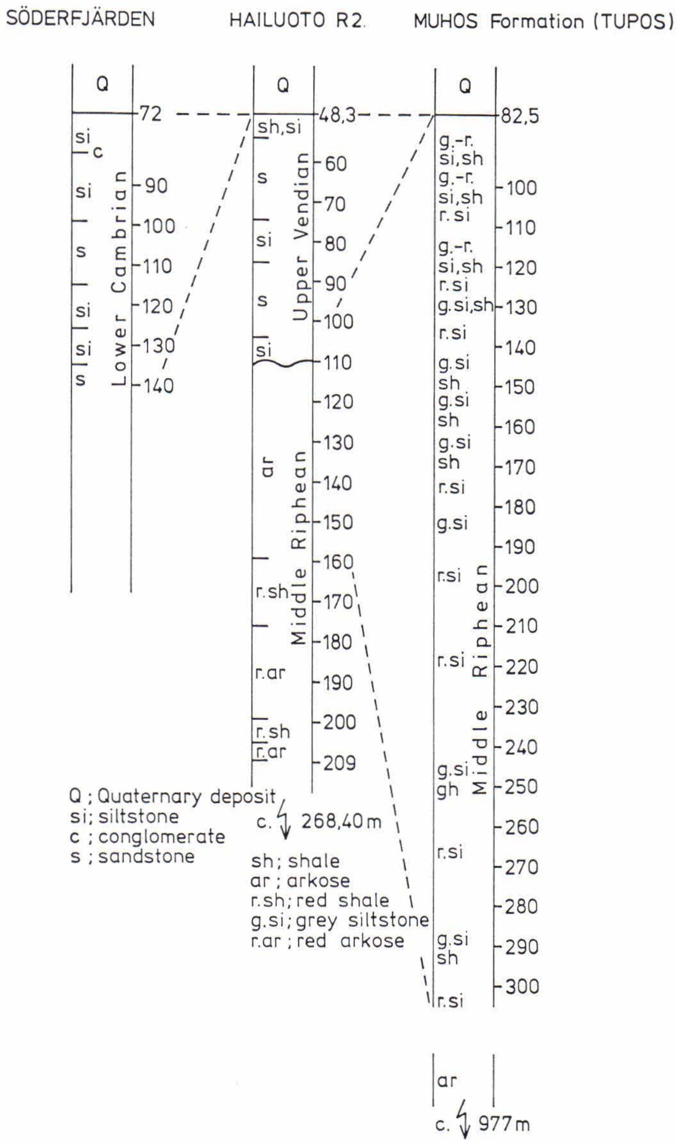

Fig. 4. Stratigraphic correlation of the Hailuoto Formation, the Muhos Formation and the Söderfjärden sedimentary rocks.

From the Biskopåsen formation in southern Norway, which dates from the late Precambrian, Spjeldnaes (1967) has described a number of microfossils, among them large spheromorphs (of the *Chuaria* type) as well as the singular *Papillomembra compta* Spj., which resembles morphologically the cylindrical *Volyniella cylindrica* T & D of Hailuoto. *Papillomembra compta* and *Volyniella cylindrica* represent exceptional types in comparison with other filamentary blue-green algae, types that taxonomically belong to a class different from *Hormogoneae* and other recent classes of blue-green algae.

The sparagmite formation of Norwegian Lapland is Eocambrian (Vendian) and Timofeev (1963) has reported the occurrence of microfossils there. These forms are fairly large spheromorphs, but in type they are not close to the Hailuoto forms.

Hailuoto is located near the Muhos Formation. The Tupos drill hole at Muhos is located about 45 km SE from the Hailuoto drill holes. In Fig. 4, a correlation has been made between the Hailuoto and Muhos (Tupos) formations on the basis of the microfossil and sediment types contained in them. The conglomerates and reddish arkose sediments of the lower part would appear in both series to correspond to each other. The fine-grained sedimentary rock of the Muhos Formation also contains microfossils, but not in such an abundance that any succession could be worked out. The forms described (Tynni and Siivola 1966, Timofeev 1969, Tynni 1978) differ to such an extent from the Hailuoto types now discussed that it is obvious that in Hailuoto there is missing the deposit brought to light in the Tupos drilling and interpreted as Middle Riphean (K-Ar determination c. 1 300 Ma, Simonen 1960). The possibility cannot, however, be entirely ruled out that also a late-Riphean or Vendian deposit might be found in the surface portion of the Muhos Formation.

The comparisons made do not justify any precise dating, but an indicative proposal could be a late-Precambrian age of about 600 million years.

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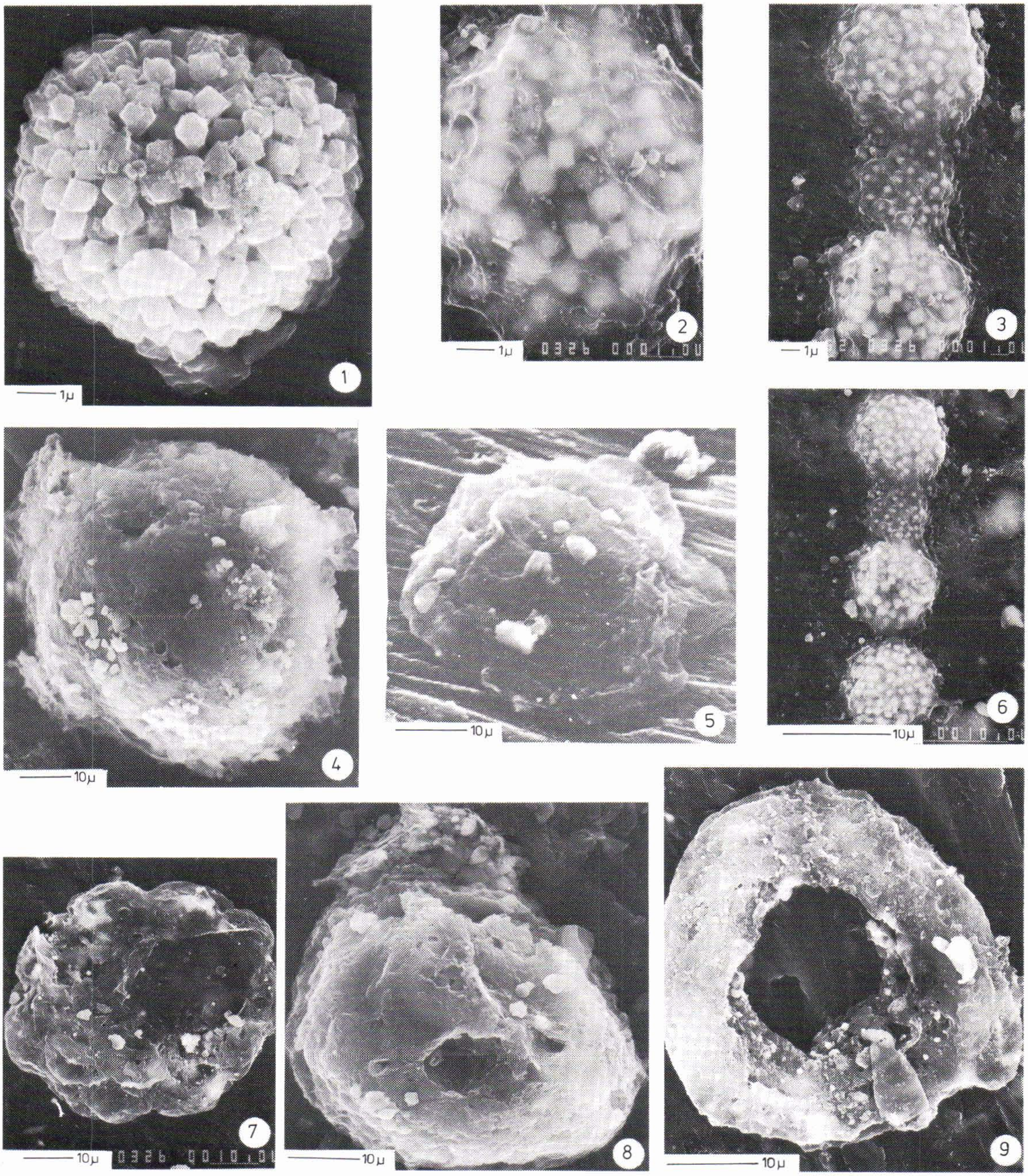
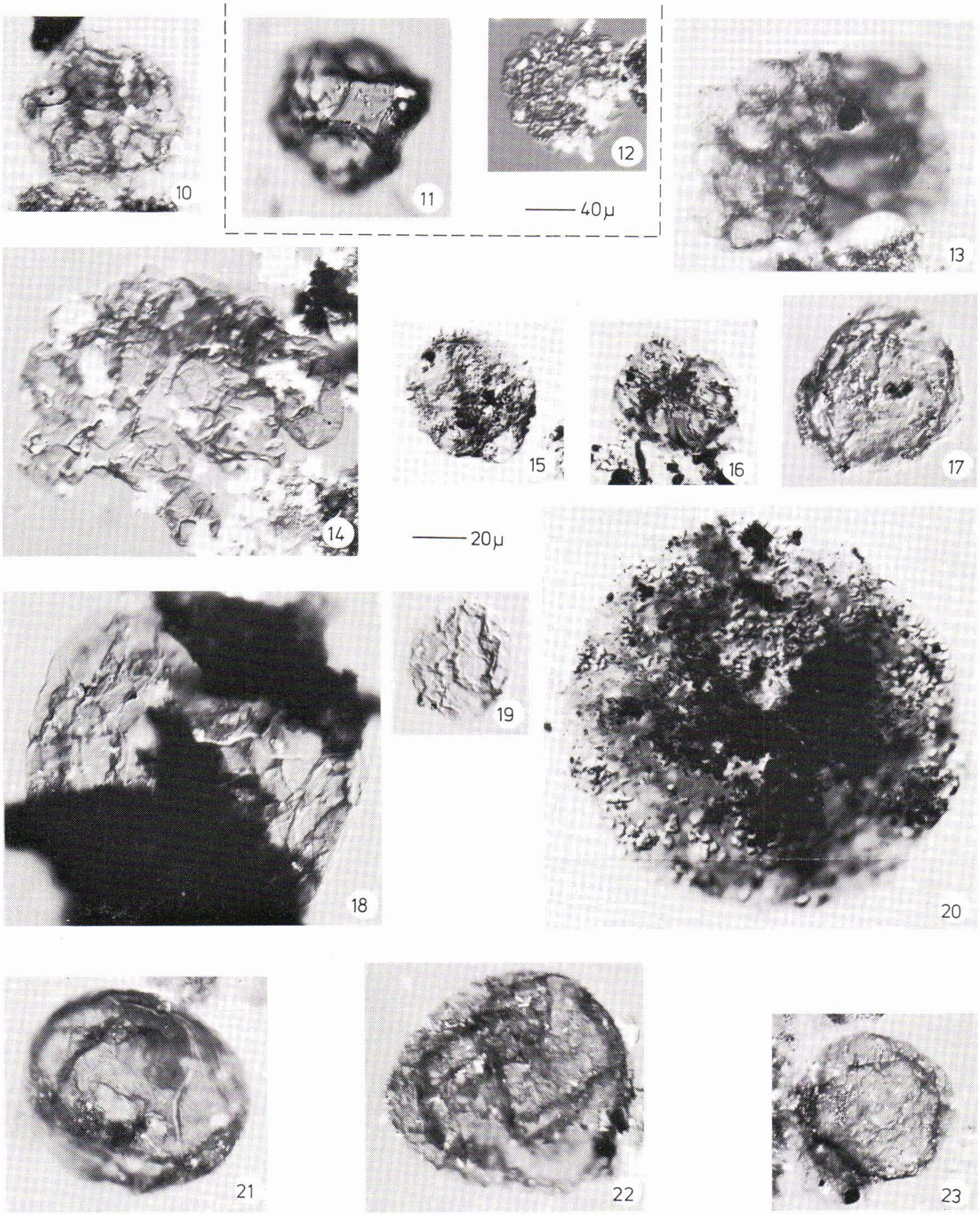


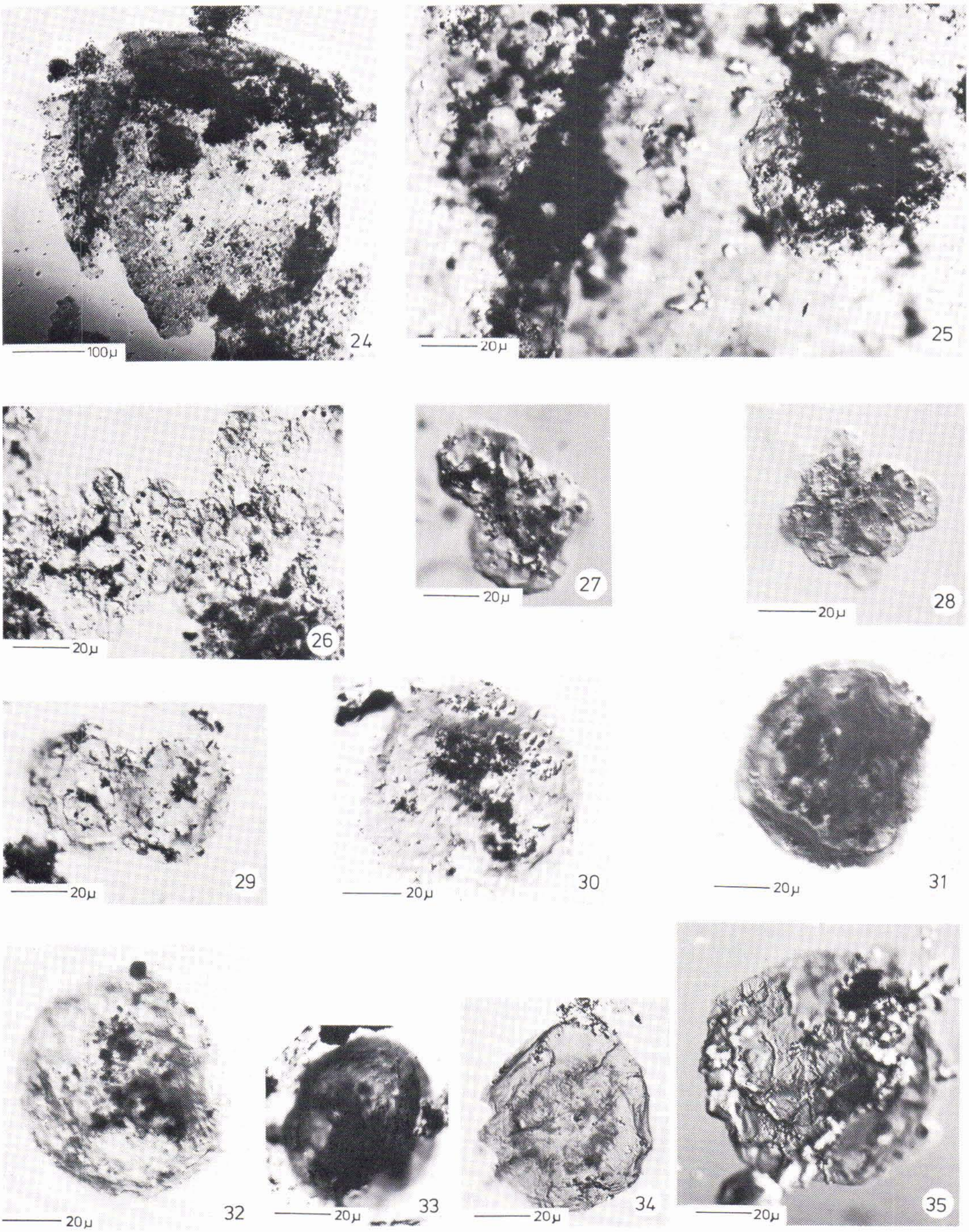
1, 2, 3, 6. Algal cells filled with pyrite crystals. In 3 and 6 the cells form filament. The separate clusters resemble *Bavlinella faveolata* and nannocytes of blue-gree algae (cf., Neves & Sullivan 1964, Moorman 1974) that have undergone pyritization.

4. A sphaeromorph with a thin membrane. 5, 7. *Synsphaeridium* sp. 8 and 9. a fragment of cylindrical algal filament (cf., Figs. 47—63).

PLATE II

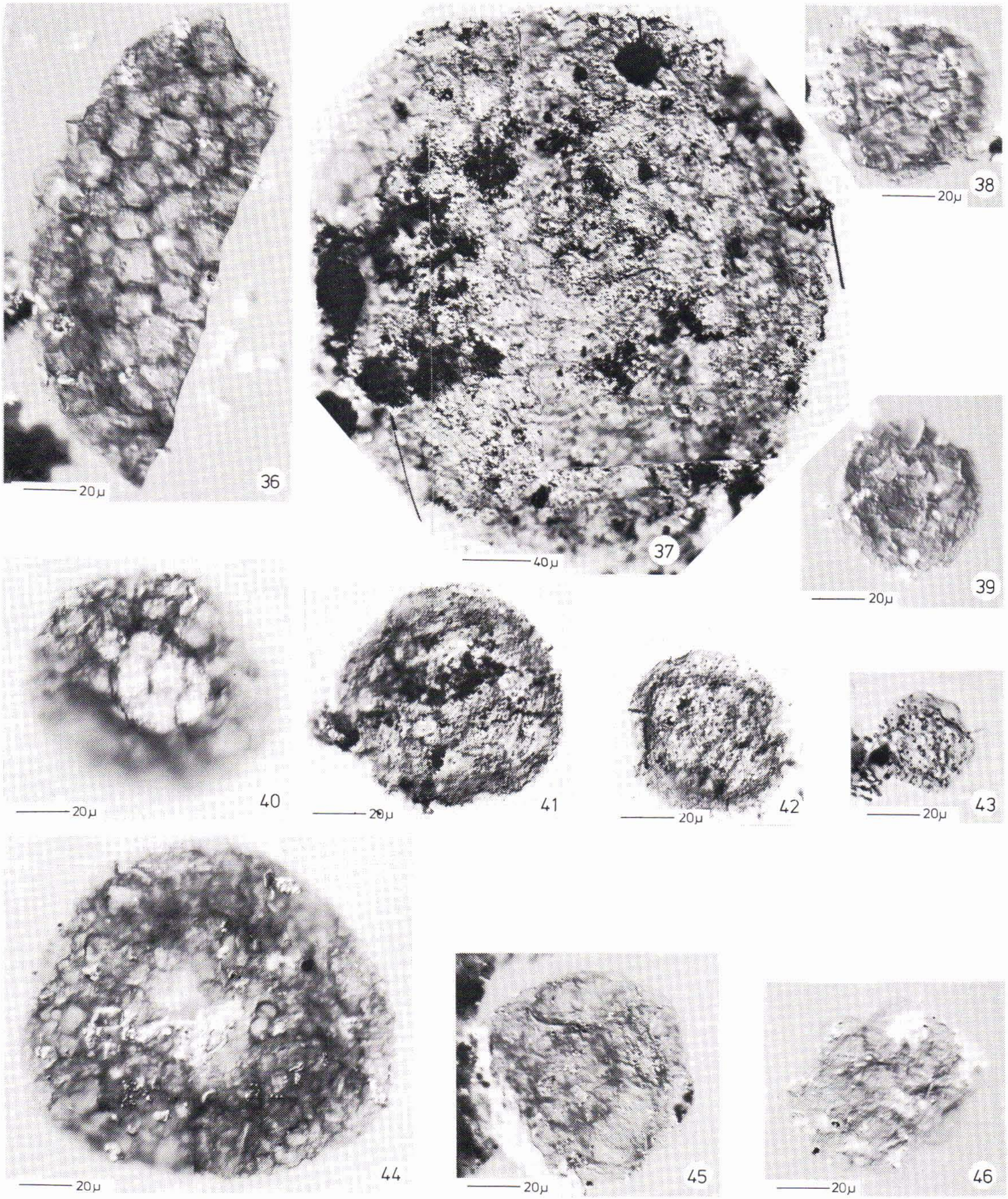


10. *Symplassosphaeridium* sp., 11. *Podoliella prismatica*, 12, 13, 14. *Synsphaeridium* sp., 15, 16, 17. *Trachyhystrichosphaera bottnica*, 18. *Kildinella* cf. *sinica*, 19. *Leiosphaeridia* sp., 20 ? *Trachyhystrichosphaera* sp., 21, 22, 23. *Leiosphaeridia* sp.



24, 25. *Chuaria circularis*, with pylom. 26, 27. *Gloecapsomorpha* sp. 28. *Synsphaeridium* sp. 29, 30. twinsphaeromorph. 31, 33. *Granomarginata* sp. ? 32. *Trachyhystrichosphaera* sp. ? 34, 35. *Leiosphaeridia* sp.

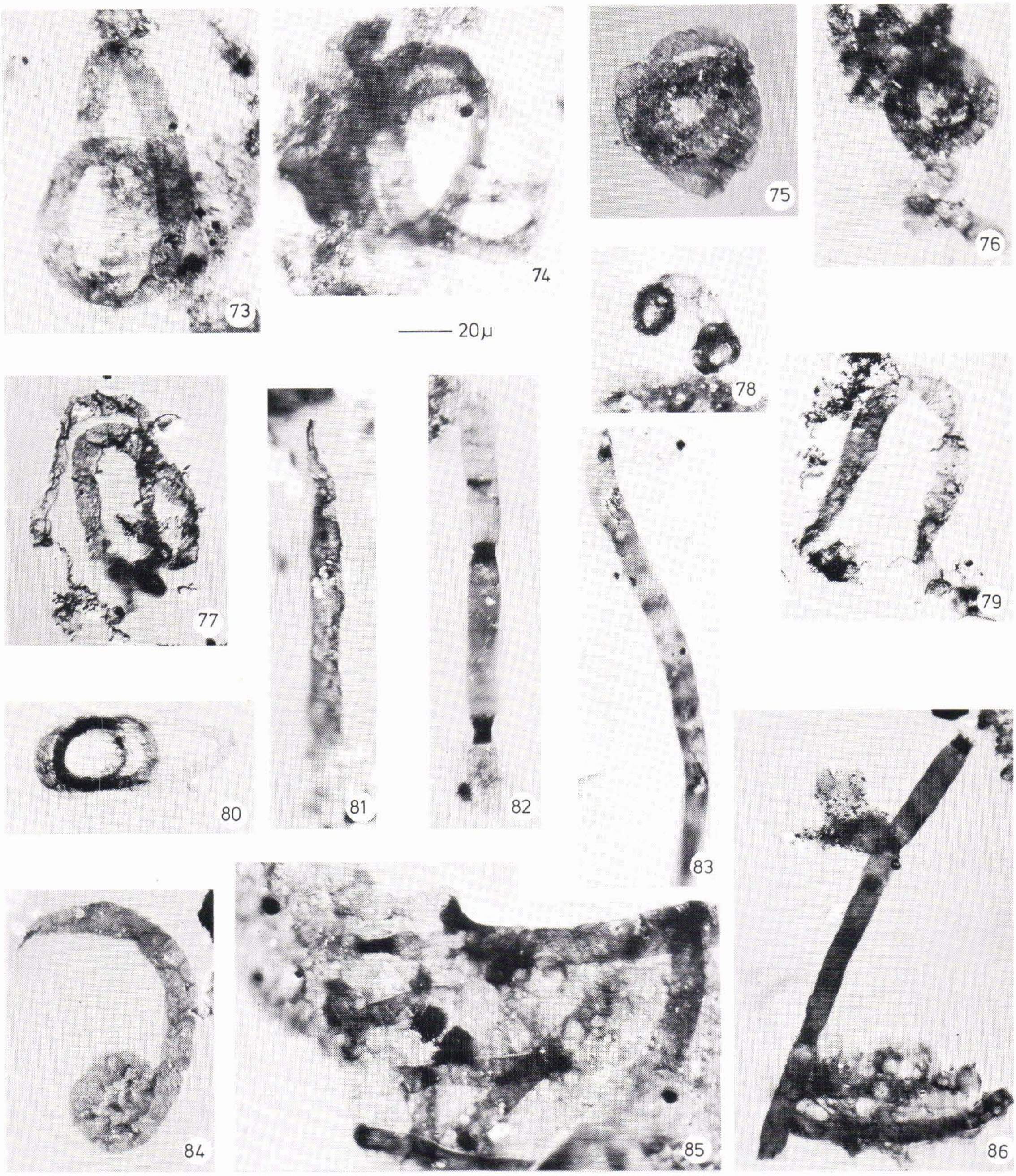
PLATE IV



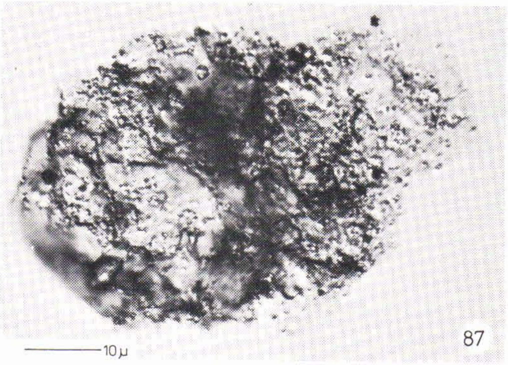
36, 37. *Cymatiosphaera precambrica*, 38. *Cymatiosphaera* sp., 39. *Leiosphaeridia* sp., 40. *Cymatiosphaera* sp., 41, 42. *Trachysphaeridium levis*, 43. *Trachysphaeridium* sp., 44. *Favosphaeridium* sp., 45, 46. *Symplassosphaeridium* sp.

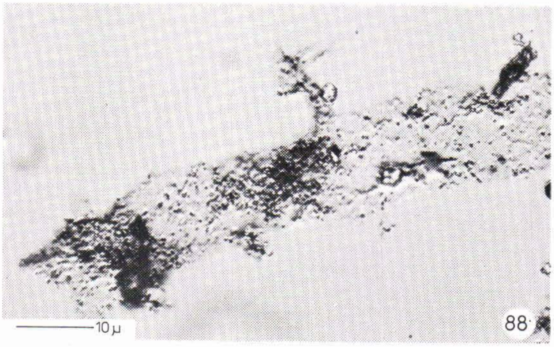
47—63. *Volyniella cylindrica*, large filaments and different fragments.

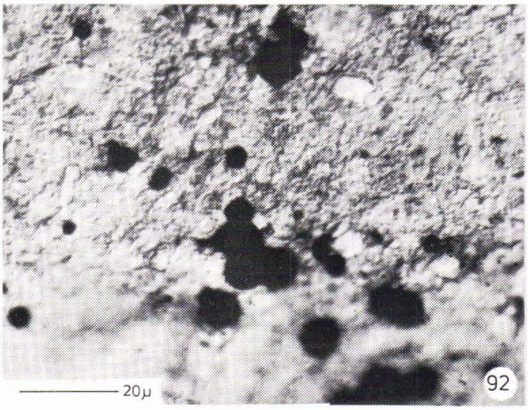
64—66. *Oscillatoriopsis magna.* 67. *Paleolyngbya lata.* 68—70. *Oscillatoriopsis magna*, different stages of development. 71, 72. ? *Paleolyngbya lata.*



73—76. *Tortunema bothnica*, 77, 81, 84. *Caudiculophycus curvata*, 78, 79. *Anabaenidium hailuotoensis*, 80. *Tortunema* sp., 82, 85, 86. *Oscillatoriopsis constricta*, 83. *Oscillatoriopsis bottnica*.







87. ? *Phycomycetes* sp. 88. branched filament. 89. Cluster of parallel filaments. 90. Cluster of spiral filaments. 91, 92. organic membrane with pyrite spheres. In Fig. 91, the pyrite spheres are concentrated to the algal filaments; in Fig. 92, the spheres are randomly distributed.

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