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Microfossils from the Precambrian Muhos formation in Western Finland

by Risto Tynni and Anneli Uutela

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with 9 figures, two tables
and 20 plates

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The majority of the microfossils of the Muhos formation comprise individual large chroococcaceaen forms ($\emptyset > 8\ \mu$), and globular clusters of spheroidal cells (Chroococcaceae colonies, Chamaeosiphoneae sporangia). The larger thin- and thick-crusted spheromorphs ($\emptyset\ 20 - >100\ \mu$) are scarce. The genera *Eosynechococcus, Palaeopleuracapsa, Gloecapsamorpha,* and *Floritheca* n. gen. are rare, as are some filamentous forms of the Hormogoneae group. Besides the above mentioned cyanobacteria the material also comprises forms which belong to the bacteria proper or Eubacteriales. Among the most conspicuous, although the most common are forms to be assigned to the acritarchs, and of unknown origin. Some of them probably belong to the green algae. In addition there are in the Muhos formation some other problematic forms, which are presented in the illustrations.

The microbiota corresponds to a near-shore plankton flora.

The cyanobacteria forms are largely the same which have been described from Proterozoic strata of different ages, and which resemble recent forms. Their significance for dating is small, but for the acritarchs there is a narrower biostratigraphic correspondence. The acritarch forms found are known from the end of the Proterozoic, and from the upper and middle Riphean (mainly the upper). The radiometric age of the Muhos formation is according to the K—Ar -method 1300—1400 Ma, but based on the biotype an age of about 1200 Ma would be more correct.

Key words: Microfossils, sedimentary rocks, Chroococcales, acritarch flora, problematic microfossils, biostratigraphy, paleoecology, Proterozoic, Finland, Muhos, Tyrnävä, Liminka

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INTRODUCTION

The first convincing finds of Precambrian well-preserved microfossils were made from the Gunflint chert in Ontario, Canada (Tyler & Barghoorn 1954). That study led to the rapid development of Precambrian paleobiology. The most well-known localities/objects were the cherty sedimentary rocks of North America and Australia, and within the area of the Soviet Union in addition argillaceous sedimentary rocks. In Finland attention had early turned to the signs of life found in Precambrian formations. Sederholm (1910) described from the schist of the Tampere region a carbon sack, *Corycium enigmaticum,* whose organic origin was proved by a carbon isotope study (Rankama 1948) and by a microfossil study showing poorly preserved algal cells of croococcaceae type (Matisto 1969, 1974).

The dating of Precambrian formations on micropaleontological grounds is still at the development stage. The monotone selection of microfossil types does not usually contain indicator species typical of a short period of time. The predominance of the forms frequently depends mainly on environmental factors (cf. Hofmann 1976, Knoll & Simonson 1981). During the Precambrian, mainly the Proterozoic, however, certain special types can be observed to have existed, and the filamentous and spheroidal forms had a tendency towards a bigger size. On the basis of these and more developed acritarch forms dating comparisons can be made.

The Muhos formation was not found until the late 1930s and the history of its study is short, but varying. Soon after the finding of the formation, which is covered by Quaternary deposits, Brenner (1941, 1944) suggested for it a Mesozoic age, based on a find of belemnite in the area of the formation. Later however Viluksela (1950, 1951) corrected the information on the origin of the belemnite.

In order to study the formation a number of deep drill-holes were made. The most important of them comprise: a sedimentary rock deposit 894.5 m thick within the area of the village of Tupos (Kalla 1960), a sedimentary rock deposit 452.4 m thick situated to the south of the church of Muhos which is about 27 km to the east of the first deposit, and a drill hole 186 m deep which does not perforate the sedimentary deposit, in the Tyrnävä area about 9 km to the W-SW from the previously mentioned site (Text-fig. 1). Samples from these drillings have been used in this study. No macroscopic biogenic structures were found in them, but Hyyppä (1940) claimed in connection with the Tyrnävä drill log that a little organic material and cells had been found, on which he based his estimation that the formation was younger than the Cambrian.

In 1955 Simonen and Kouvo stated that the rock of the Muhos formation shows the same properties as the Jotnian sandstone. The correspondence was later confirmed by the K-Ar dating of the Muhos formation (Simonen 1960) and by the Rb-Sr datings performed by Kouvo (1977). At present the age of the Muhos formation is estimated at 1300—1400 Ma on the basis of K-Ar and Rb-Sr datings (Simonen 1980b). This age falls into the Middle Proterozoic (1800— 1200 Ma, Schopf 1975). According to Bergström the Jotnian formations correspond to 1200—1300 Ma (Bergström *et al.* 1983, p. 32). Timofeev (1966) also suggested an age of about 1200 Ma based on the floratype.

The interest in the formation increased when Marmo (1959) assumed that it contained Pre-
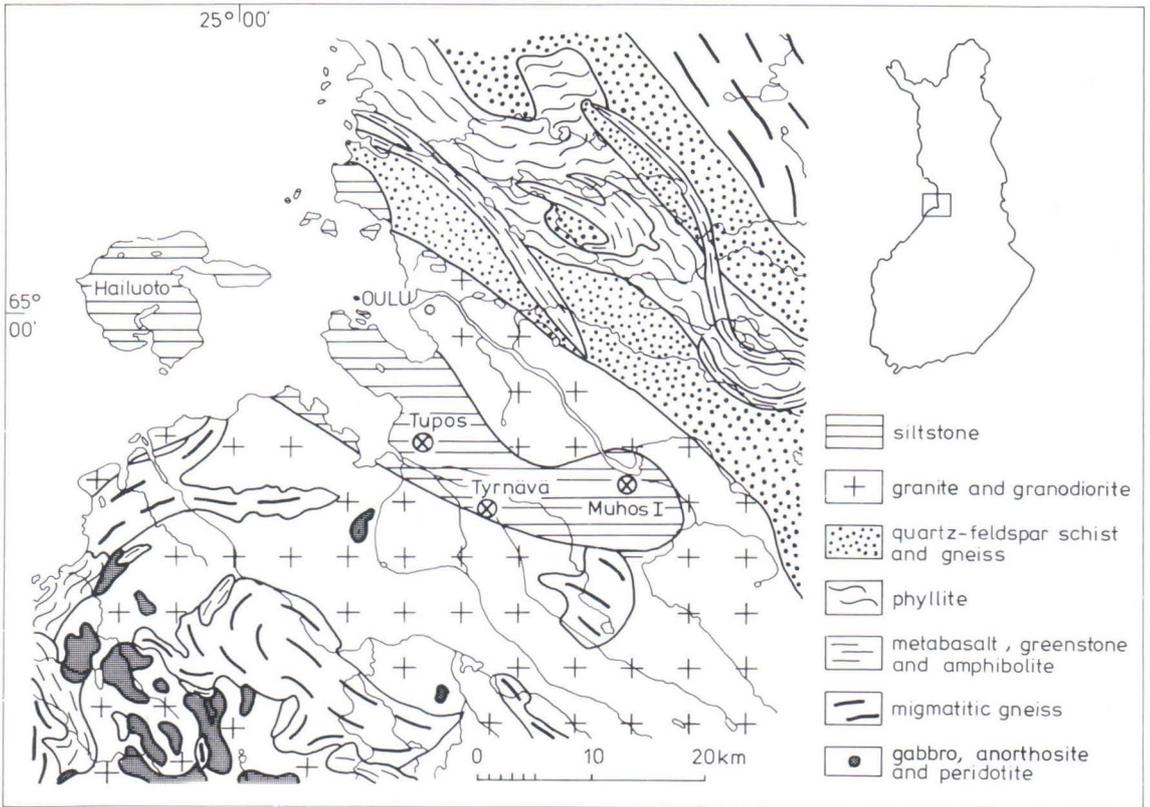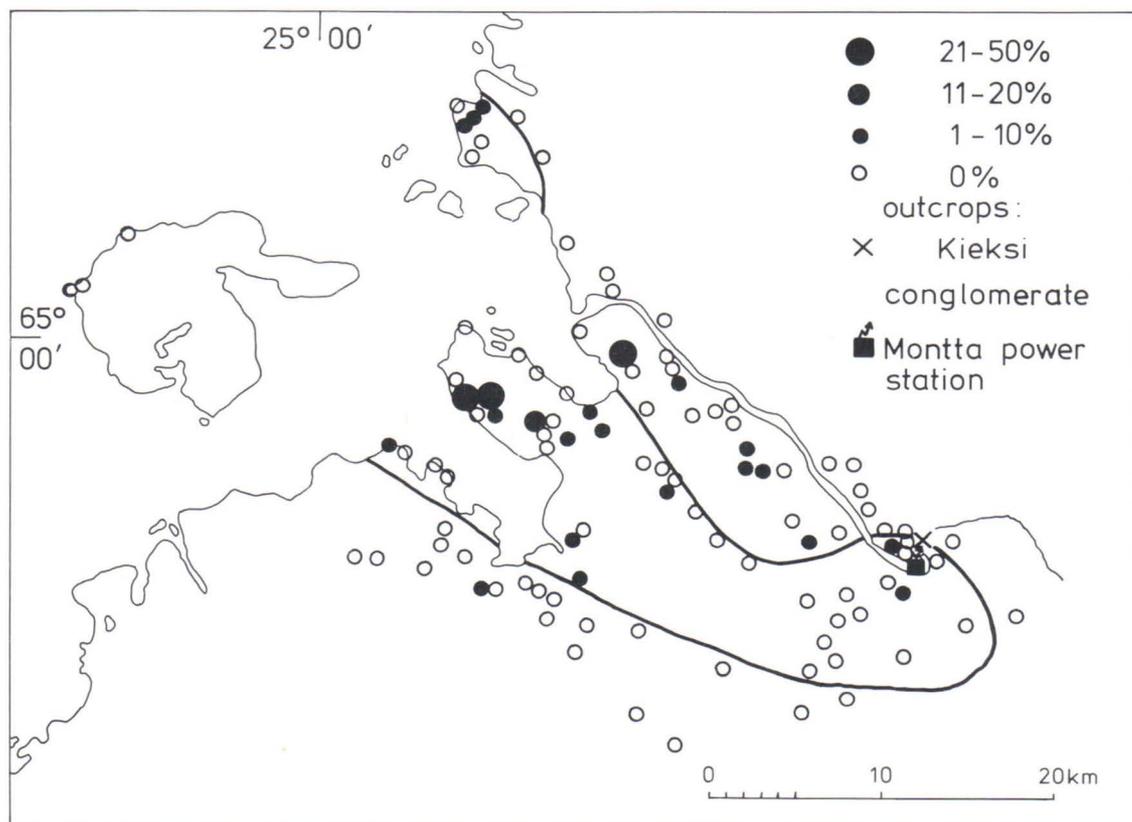
Text-fig. 1. The Muhos formation and the location of the drill cores studied.

cambrian microfossils similar to those described by Timofeev (1958) from the Soviet Union area. The study of the core samples from Tupos led to the finding of algal (and spheromorphous) microfossils, although very scare (Tynni & Siivola 1966), and the material did not very well lend itself to biostratigraphical correlation. The study material was then considerably less complete than today's, but a few additions to the previous study were made in 1978 (Tynni) in connection with the supplement based on the systematics created by Timofeev (1969). The microfossils of the Muhos formation were treated briefly in 1982 also (Alhonen & Tynni).

From the Muhos formation geochemical studies have also been made. A small occurrence of methane is known in the Tyrnävä area. Its origin has been inferred to be in the organic

deposits of the Litorina stage of the history of the Baltic Sea (Hyyppä 1935, Heikkinen 1972). One question remains unanswered; whether there is in the same discharge of CH_4 also a small amount from a Proterozoic deposit or from still deeper in the mantle. It should be mentioned that Bergström (Bergström et al. 1983, p. 122) considers some Jotnian sandstone occurrences as possible reservoirs for hydrocarbons originating from the mantle (cf. Gold, in the publication Bergström et al. 1983). According to Hoering (1967) there is kerogen in the Tupos drill-hole at a depth of 234.3 m in the claystone. Heikkinen (1972) interpreted the hydrocarbons as secondary. The relatively high microfossil content of the horizon concerned supports Hoering's conclusion. On the other hand kerogen has been observed also in the

Text-fig. 2. The occurrence of claystone in the Quaternary deposit covering the Muhos formation and in the Hailuoto area.

Posio stinkstone, which is older than the foregoing one (Piispanen & Lähdesmäki 1983).

In the area of the Muhos formation field studies were made in connection with this study in order to get additional observations of the sedimentary rock sequence, especially from its eroded part, but no significant additional information was obtained. The proportion of sedimentary rock in esker material and till of the surface part of the Quaternary sequence, which is 50—80 m in thickness, varied strongly, 0—40 %, and in most instances there was less than 10 % of sedimentary rock (Text-figs. 2 and 3). In the uppermost part, 1.5 m, of the sequence the sedimentary rock fragments had in general vanished (Uutela 1983). Traces of the disintegrated reddish siltstone are instead to be seen in large areas south of the Muhos formation as a coloring of the late-glacial clay (cf. Purokoski 1958, Kukkonen 1978).

The pioneer works of Timofeev (1959, 1963, 1966, 1969) with their numerous detailed drawings have constituted acritarch objects of comparison related to this investigation. Precambrian acritarchs of the Soviet Union area are treated, with photographs, by Jankauskas (1979, 1982), among others. Also the investigation results of Vidal (1976) concerning the microfossils of the Visingsö formation are important for the comparison with the forms of the Muhos formation. The microfossil succession of the Hailuoto sedimentary rocks (Tynni & Donner 1980), presented during recent years, is a significant object of comparison as well.

According to the foregoing study the upper part of the Hailuoto sedimentary rocks corre-
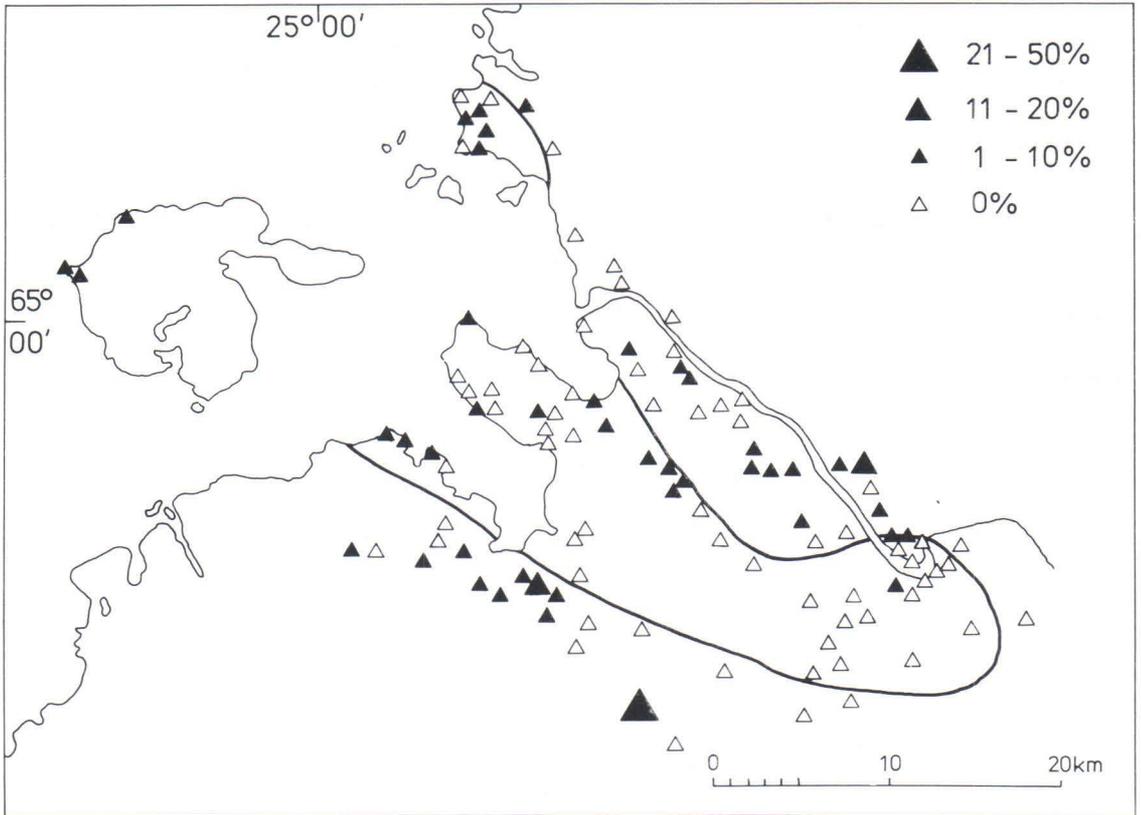
Text-fig. 3. The occurrence of arkosic sandstone in the Quaternary deposit covering the Muhos formation and in the Hai-luoto area.

sponds to the Vendian, i.e. it would be considerably younger than the radiometric age of the Muhos formation.

Microfossil-bearing deposits of the same age order as the Muhos formation have been presented from many places around the world. As an example there is the Roper Group in northern Australia, with a minimum age of 1300×10^6 yr. From it algal cells and filaments have been found (Peat *et al.* 1978), partly corresponding to those of the Muhos formation. The Californian Beck Spring dolomite is also of the same age order, $1.2—1.4 \times 10^9$ yr., and it contains among other things small spheromorphs with a reticulate surface (Cloud *et al.* 1969, Gutstadt & Schopf 1969, Pierce & Cloud 1979). The Abzanskaja formation in the Ural area (ca 1260 Ma) contains acritarchs (Jankauskas 1982),

part of which are of the same type as those of the Muhos formation. Greater similarities are, however, shown by the forms of the Tersk formation on the Kola Peninsula (ca 1080—1260 Ma) and those of the Muhos formation (Timofeev 1959, 1969). Closer in time to Muhos are, in addition, the Bushimay system of Zaire (Maithy 1975) and the Sokoma iron formation of northern Canada (Knoll & Simonson 1981). Exceptionally big megascopic algae have been presented from the Montana Belt supergroup as well (Walter *et al.* 1976, Horodyski & Bloeser 1978). An abundance of Precambrian formations containing microfossils older and younger than the Muhos formation are known and in them, as well, certain corresponding algal forms are found (as cited later).

Text-fig. 4. Kieksi conglomerate.

REGIONAL GEOLOGY

The conditions of the bedrock of the southern part of the area can be seen on the map compiled by Enkovaara *et al.* (1952, 1953) on a scale of 1 : 400 000, and on those compiled by Nykänen (1959) and Kesola (1983) on a scale of 1 : 100 000. The formation as a whole can be seen on the Simonen's map (1980a) on a scale of 1 : 1 000 000 and it is described in the explanation (1980b). In the more recent of these works attention is paid to the contacts of the forma-

tion, which is almost completely covered by Quaternary deposits (Gibbard 1979). The contacts have defined only in recent years (Lanne & Pernu 1974, Korhonen & Porkka 1975). The Muhos formation, e.g. the exposure of Kieksi conglomerate (Text-fig. 4), has been treated by Brenner (1941, 1944), Okko (1954), and Simonen & Kouvo (1955). Kesola (1981) has described clastic dykes from the surroundings of the Muhos formation, considering them to re-

flect the fissures and depressions of the depositional basement.

The Muhos formation belongs to the oldest unmetamorphic sediments in Finland, the so-called Jotnian sediments. According to Simonen (1980b) the Jotnian deposits are related to floodplain deposits in the piedmont facies of postgeosynclinal basins. Deposits of the same age are met with also in the areas of Satakunta (sandstone) and the Bothnian Bay (Veltheim 1969, Winterhalter et. al. 1981, Floden et. al. 1980). The preservation of the relatively large Muhos formation from glacial erosion is due to the sheltered position of the sedimentary rocks. The structure concerned is a rift valley, ca 1 km in maximum depth, 10 km wide on an average, and reaching ca 65 km into the present land. There is a system of fracture lines (Talvitie 1974), crossing the Muhos formation and continuing across the bottom of the Bothnian Bay according to the topography and seismic profiles (Tulkki 1977). The direction corresponds to the direction of the most common fracture lines in Finland (Tuominen et al. 1973).

According to radiometric datings performed on the Jotnian sedimentary rocks and on the diabase dykes cutting across them (Simonen 1960, 1980b) the formation is of Middle Proterozoic.

MATERIAL, OCCURRENCE OF MICROFOSSILS, AND METHODS OF STUDY

The samples studied are from drill cores, which have been drilled at Tyrnävä in 1938, Muhos in 1939, and Tupos in 1954. From the Tyrnävä drill core 20 samples were studied, from Muhos 37 and from Tupos 161. The sediment profiles and microfossil-rich sampling points are shown in Text-fig. 5. In places the samples are spaced far apart, which is due to the frequency of oxidized sediment portions. In the oxidized reddish portions the microfossils have not been preserved (cf. Lipman & Timofeev 1957). This shows in all test preparations from reddish portions of the Tupos sequence. It is natural that the thin-walled microbiota was destroyed in oxidizing conditions. The sedimentary rock sequence is oxidized mainly in its middle and lower parts. In the upper part the microfossil content is in general very low, but in connection with the dark graded clayey structures occurring in places (Pl. I: B, C, D) microfossils are abundant. In these places the sampling frequency is exceptionally high. In the Muhos I drilling there were more microfossil-rich levels than in the other places. In addition 15 boulder samples from the gravel pits of the area of the Muhos formation were studied, including one sample from the rock surface of the Montta power station. Microfossils were mainly studied in preparations made by using the acid maceration method.

Material used in the microfossil study was also studied in thin sections. The material consists of homogeneous siltstone and thinly varved dark-banded claystone. In the siltstone the sorting and roundness of the grains are extremely poor. The strength of the rock is also poor and it disintegrates readily when handled in water. In the dark, clay-rich varves of the varved claystone, where only the biggest mineral grains can be discerned, sepia-colored humus membranes, partly covered with pyrite grains, are conspicuous. A graphite dissemination is common. The light-colored interbeds mainly consist of recrystallized carbonate. In a horizontal section there is in places an even-grained hexagonal pattern ($\emptyset \sim 15\mu$). The pyrite and CuS grains are in the recrystallized parts usually larger than elsewhere. The varved claystone is more resistant than the siltstone. Pl. II shows the structures of the sedimentary rocks.
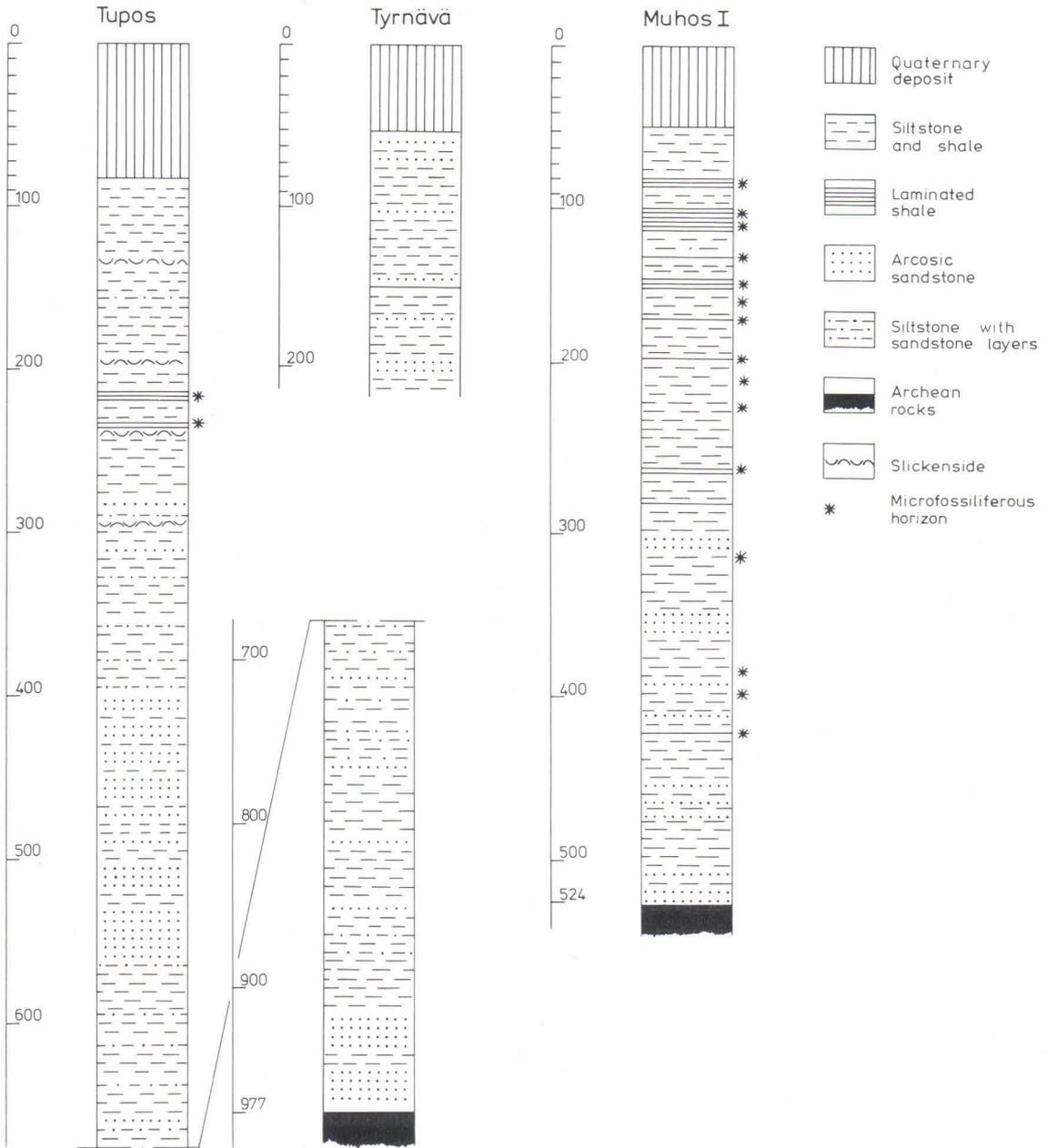
Text-fig. 5. The drill core sequences studied from the Muhos formation.

The best preserved microfossils usually occur in connection with the fine-grained clay minerals. The carbonate-rich varves have probably crystallized rapidly.

By the comparison of the thin sections and the preparations made by acid maceration from the Muhos formation we attempted to cast light on the proportion of original and pseudo-struc-

tures in the acritarchs. We came to the conclusion that the pyrite crystals and their combinations as well as carbonate crystals have in places deformed original organic structures. Deformation marks such as those of compression and faulting of internal sedimentary surfaces are also common. At the deeper microfossil-bearing sites the heating of the stratum has blackened the microfossils beyond recognition.

The amount of sample to be used, 10—20 g, was crushed into pieces ca 10 mm in diameter, since this size proved to be the best in order to keep the acritarchs whole. After removing the carbonates from the sedimentary rock with 10 % HCl we used 40—45 % cold HF for the maceration of the silicate minerals.

Treatment with strong hydrofluoric acid proved to be the best method for separation of acritarchs from the rock material. The treatment does not, however, destroy or wear the acritarchs significantly. This fact became apparent e.g. when some microfossils were kept in dilute HF solution for over half a year. The HF treatment was continued for 1 to 3 days or until the sample had disintegrated completely into a sludge, whereafter the colloidal compounds were dissolved by a number of consecutive treatments with hot HCl (10 %). As a heavy liquid a mixture of bromoform and isopropanol was used. The acritarchs are concentrated into this mixture during centrifugation due to their specific gravity of ca 2. Lopuchin (1976) states that the microfossils *Menneria-Hymenophacoides* are characterized by a low specific gravity, and that they are concentrated into distilled water. In connection with the present study we

also tried concentration into distilled water, but no positive results were obtained by this method. In the microfossils of the Muhos formation there are impregnations of pyrite, chalcopyrite or chalcosite (Tynni & Siivola 1966), which have increased their specific gravity. As a fixing agent for the preparations Clopenharpix was used. The specimens are numbered and kept in the collections of the Geological Survey of Finland.

The clay- and siltstones of the Muhos formation have undergone density determinations. The results are shown in Table 1.

Table 1. Determinations of specific gravity of silt- and claystones of the Muhos formation (Tupos drill core). The correction factor 0.99780 (22°C) has been used in the determinations.

Depth	Specific gravity	Rock type
155.75	2.563	green varved claystone
163.70	2.500	green/red claystone
165.00	2.479	—»— —»—
166.40	2.479	—»— —»—
184.00	2.498	—»— —»—
267.20	2.536	—»— —»—
305.00	2.572	green varved claystone
316.90	2.387	gypsum, thin claystone intercalation
317.00	2.547	green/red siltstone
330.40	2.546	green varved claystone
370.25	2.556	green/red claystone
394.65	2.591	—»— varved claystone
406.05	2.570	greenish grey siltstone, gypsum lens
492.75	2.572	greenish grey siltstone
510.00	2.664	red coarse sandstone, carbonate(?)
554.35	2.600	reddish grey siltstone

MICROFOSSILS

The microfossils of the Muhos formation can be divided into the following types: (1) solitary spheroidal cells or spheromorphs with a diameter of < 30 μ, and which possibly belong to the order Chroococcales of the phylum Cyano-

phyta. They mainly correspond to big single chroococcae forms (cf. Mendelson & Schopf 1982, p. 70). The portion of small forms (< 8 μ) is minor. The vegetative (2) and globular (4) clusters occur as colonies. The bigger globular
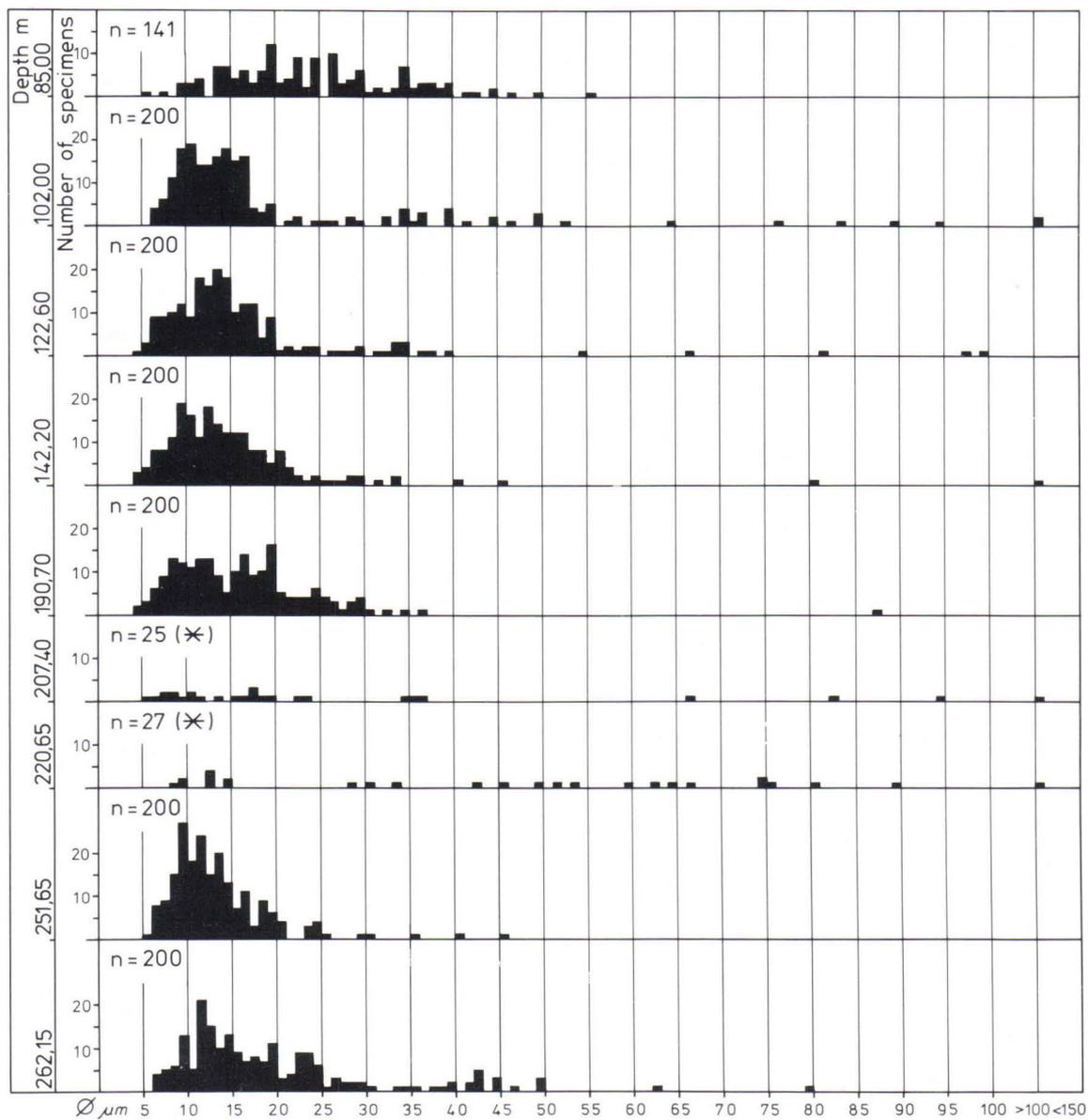
Text-fig. 6. Size distribution of spheromorphs of Coccoid/Leiosphaeridia type at 9 different levels in the Muhos I drill core.

forms (> 30 μ) with smooth or divergent surface structure are grouped with (5) the acritarchs (Evitt 1963). The deposits of cells with a dicho- tetrachoton cell division pattern are grouped with (3) the order Pleurocapsales. The filamentous forms comprise unbranched types of the order Oscillatoriales (6), possibly also of the order Nostocales. The problematic forms (7) include spool-shaped forms, possibly belonging to the order Eubacteriales, and unidentified forms which diverge from the foregoing ones.
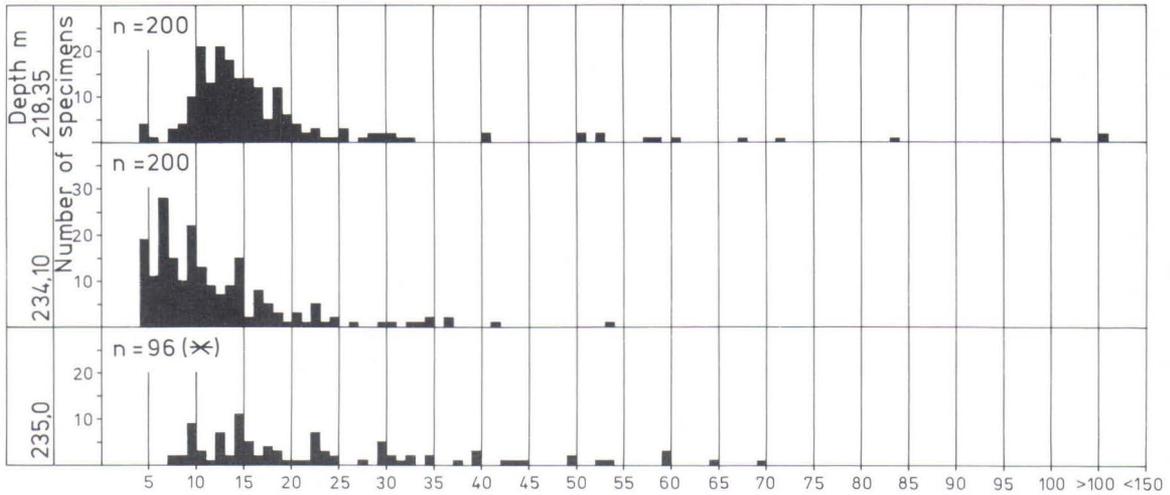
Text-fig. 7. Size distribution of spheromorphs of Coccoid/Leiosphaeridia type at 3 different levels in the Tupos drill core.

Of the foregoing types the small sphero-morphs (1) constitute the most common type (70—95 %) in all well-preserved samples. In the Muhos I drill core it occurs in a clear-cut man-ner on six levels (Text-fig. 6), but in the Tupos drill core on three levels (Text-fig. 7). The globular clusters of spheromorphs constitute the second most common type. Their portion is largest, ca 46 %, at a depth of 102.5 m in the

Muhos drill core (Text-fig. 8). The majority of the spheromorphs can be compared to the ac-ritarchs, of which the genus *Leiosphaeridia* is the most common, followed by *Turuchanica* and *Trachyspheridium*. Structurally further specialized types, as *Granomarginata* and *Ptero-spermella* are extremely rare, and one cannot be completely sure of the primarity of their deposi-tion. Filamentous forms were scarce in the
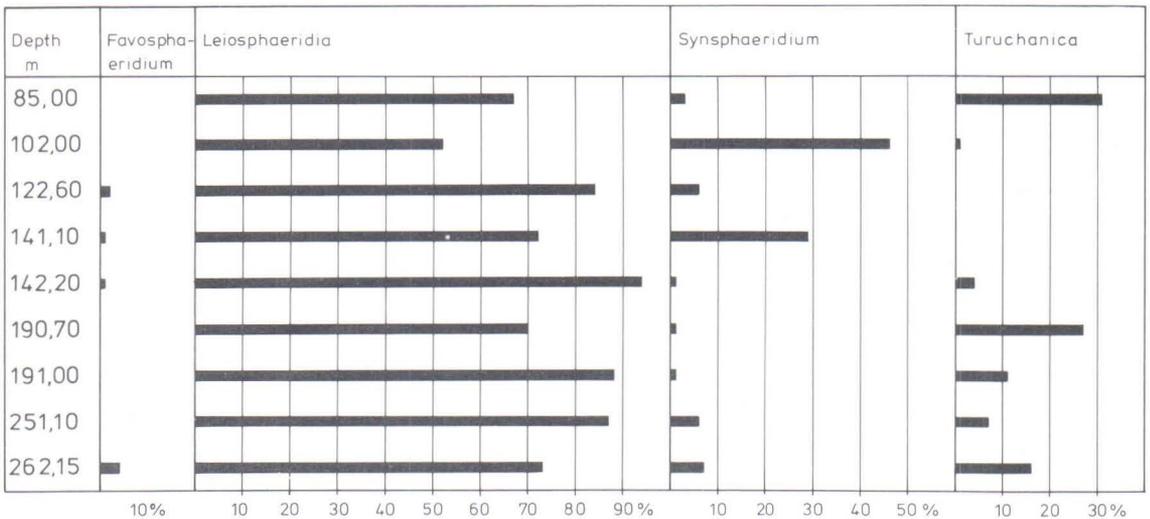
Text-fig. 8. Percentual shares of most common microfossil types in the Muhos drill core.

maceration samples, but in a thin section from a depth of 218.70 m in the Tupos drill core an abundance of worn filamentous forms was found. In the preparation made by the macera-tion method from the same depth no such forms were found, wherefore worn filamentous forms probably do not withstand the acid maceration method.

Spheroidal cells or spheromorphs ($\emptyset \leq 30 \ \mu$) possibly of the order Chroococcales

In all places with a more abundant content of microfossils spheromorphs with a diameter of $\leq 30 \ \mu$ constitute the maximum. The most common size is 10—20 μ, but in the drill core of Tupos at a depth of 234.10 m it is exceptionally 5—10 μ (Text-figs. 6 and 7). The size ranges presented pertain to thin-walled light-colored spheromorphs. The dark types characteristic of the genera *Kildinella* and *Turuchanica* are ex-cepted from these ranges. Part of the small spheromorphs may be disintegrated colonies. On the other hand the forms presented belong to the rather small *Leiosphaeridia* forms, be-cause they also fulfill the definition of this genus of acritarchs. In the systematics we have instead as far as possible observed the algal sys-tematics, and thus the genus *Leiosphaeridia* is treated in detail later, in connection with the acritarchs.

The small spheromorphs ($\emptyset \leq 30 \ \mu$) have a smooth surface. They are, on an average, better preserved than the larger spheromorphs or the dark forms of the same size. In the present study we have not attempted to divide the fore-going simple spheromorphs into different ge-nera, since the structural details of the walls do not give sufficient grounds for a division. *Huro-niospora* Barghoorn, small according to the size classification, is considered to be a coccoid cyanobacterium, and is of rare occurrence in the Muhos formation.

As an example of the chroococcacean cyano-bacteria Mendelson and Schopf (1982) mention a form resembling *Glenobotrydion majorium,* with a diameter of ca 30 μ. This form is shown in Pl. I:14 (*op. cit.*).

As a difficulty in the classification of the chroococcales/*Leiosphaeridia* forms there are the diagenetic effects appearing in the wall tex-ture. E.g. in connection with *Gloeodiniopsis lamellosa* Schopf the granulated texture is ap-parently interpreted as being diagenetic (Men-delson & Schopf 1982).

Vegetative chroococcae colonies

Order Chroococcales Wettstein, 1924
Family Chroococcaceae Nägeli, 1849
Genus *Eosynechococcus* Hofmann, 1976
Eosynechococcus moorei Hofmann-type (in-cludes also *E. medius* Hofmann)
Pl. VI, Figs 59, 61, 62, 63, 64
DESCRIPTION: Oval or bean-shaped cells, length 5—9 μ, width ca 3 μ, form large colonies: length 70—100 μ. Cells are grouped in various ways, partly forming short, arcuate cell chains, mainly irregular aggregates or parallel cell clus-ters. At the edge of the colony (Fig. 62) there are small combinations of four cells, divided cells. *Synechococcus* divides transversely by splitting, for which reason the Muhos form is different, and possibly the small combinations of four cells correspond to nannocyte forma-tion.
OCCURRENCE: In the preparation from a depth of 218.35 m in the Tupos drill core there are at least three colonies in prep. 519:1. Similar forms have been described by Hofmann (1976)

from the Kasegalik formation, Belcher Islands, whose age is ca 1900 Ma. The same form *(Eosynechococcus medius)* occurs in the upper portion of the Sukhaya Tungusta formation with an age of ca 1000 Ma (Mendelson & Schopf 1982). The same algal type has also been found in the Late-Precambrian Draken conglomerate of Spitsbergen (Knoll 1979).

REMARKS: The ellipsoidal colonial form, Ø ~ 3 µ (Pl. 6), from a depth of 218.35 m in the Tupos drill core resembles the form of Diver (1974), Fig. 1e. They possibly correspond to *Eosynechococcus. Eosynechococcus* differs from the oval *Chlamydomopsis* Edhorn 1973 cells by its smaller size, among other things. According to Edhorn (1973) the latter is a Precambrian green alga.

Genus *Floritheca* n. gen.

Cells 2—4 µ long, ellipsoidal and radially grouped inside globular vesicles. The number of ellipsoidal cells in a vesicle is generally six, the diameter of the vesicle being 6—10 µ. The vesicles are attached to one another, forming globular colonies with a diameter of 12—18 µ. In some vesicles, in addition to small ellipsoids, closely spaced spherules can be distinguished, ca 0.5 µ in diameter (Text-fig. 9 and Pl. V, Figs. 36 and 37). These spherules probably correspond to the nannocyte formation met with in certain pseudo-vacuoles or Chroococcales forms, or they correspond to pyrite microcrystals. The form described structurally resembles certain species of *Gomphosphaeria,* whose egg-shaped cells are situated radially in a globular vesicle.

TYPE SPECIES: *Floritheca muhosensis* n. sp.

DIAGNOSIS: As for genus.

TYPE SPECIMEN: Full-grown form in Text-fig. 9a and Pl. V, Fig. 37, nannocyte form in Fig. 36 (paratype), Muhos formation, Muhos I drill core, depth 251.65 m, GSF (Geological Survey of Finland) prep. 490.

Genus *Gloecapsamorpha* Zalessky 1917

Gloecapsamorpha sp.

Pl. V, Fig. 38.

Cells are ca 3 µ in diameter, and form cystoid part-colonies, 7—15 µ in diameter, which in turn are irregularly grouped into larger colonies. Tupos drill core, depth 235.00 m, GSF prep. 578:1.

Timofeev (1966) has presented observations of this genus mainly from Ordovician deposits, rarely occurring in Vendian deposits. Jankauskas (1982) has described this genus from the Riphean deposits of southern Ural.

Genus *Palaeoanacystis* Schopf 1968 p. 647

Cells spheroidal — elliptical, thick-walled, occasionally polygonal and angular due to compression. Generally clustered into more or less globular colonies, number of cells may exceed 300. Size of cells 4.3—7.3 µ. Cells of colonies not geometrically arranged in respect to the form of the colony.

Palaeoanacystis sp.

Pl. V, Fig. 42

DESCRIPTION: Size of cells 3—4 µ, or somewhat smaller than the species *P. vulgaris,* described by Schopf (1968). Cells are arranged into part-colonies in the form of tetrahedrons, which combine into a cylinder-like whole, diameter, ca 20 µ.

OCCURRENCE: Rare form in the Muhos formation, Tupos drill core, depth 218.35 m.

Genus *Sphaerophycus* Schopf, 1968

Sphaerophycus aff. *parvum* Schopf

Pl. VI, Figs. 60, 65, 66, 74

DESCRIPTION: Spherical or ellipsoidal cells are on an average 2 µ in diameter. They form colonies, in which parallel, winding cell lines can be distinguished. The structure corresponds to that which Schopf (1968) describes as irregular masses and pseudofilamentous aggregates.

OCCURRENCE: Rare in the Muhos I drill core, depth 102.0 m. Earlier observations from Bitter Springs (Schopf 1968), Belcher Islands chert (Hofmann 1976), Dismal Lakes Group (Horodyski & Donaldson 1980).

Order Pleurocapsales
Family Pleurocapsaceae
Genus *Palaeopleurocapsa* Knoll, Barghoorn &
Golubić 1975 Pl. V, Figs. 53, 54, 55
Palaeopleurocapsa sp.
Small spheroidal cells (Ø ca 2 μ) are grouped
into small Chroococcus-type subcolonies and
further into hemispherical or broadened depo-
sits. Subcolonies can be distinguished, but no
surrounding cystoid membrane. In this respect
the form differs from the types *Gloecapsa* and
Entophysalis, where the subcolonies are inside
cystoid, bulging membranes.

The form occurring in the Muhos formation
resembles one described by Knoll *et al.* (1975)
from the Skillogalee dolomite formation,
southern Australia, and ca 1000 Ma old, one
described by Hofmann (1976) from Belcher
Island, and on the other hand, certain recent
Pleurocapsa forms. In the Muhos formation no
successive pseudoparenchymic cell chains ap-
peared. The form in question may be a *status
adultus* form of the blue alga mentioned, or a
sporangia form of fairly unregulated cell ar-
rangement.

Globular colonies

Regular globular colonies have been pre-
sumed to be endospore formations (Downie
1973, Moorman 1974, Golubić 1976). The colo-
nies of the Muhos formation resemble the endo-
spore clusters of the orders Chamaeosiphonales
and Pleurocapsales, but also the spheroidal
colonies of the genus *Microcystis* Kützing or the
order Pleurocapsales, both of them vegetative.
The polygonal patterns (Pl. V, Figs. 33, 34)
occurring in some cells resemble the beginning
endospore formation of the species *Chroococ-
copsis gigantea,* described by Geitler (1925).
The colonies also resemble volvocacean algae
(Kazmierczak 1976, Peat *et al.* 1978).

The cell size of the most frequently occurring
colonies is 7—10 μ. Their surface may be granu-
lated, but no traces of pyrenoids or nucleus can
be discerned. It is a common form in the Muhos
I drill core at a depth of 110.0 m.
REMARKS: The form resembles most closely the
globular colony type IV described from the Bri-
overian chert by Chauvel & Schopf (1978). Ac-
cording to them the form is Vendian in age, but
Timofeev *et al.* (1980) correlate the deposit in
question with the Middle Riphean. The same
type has been described from the USSR Pre-
cambrian deposits, e.g. from the Mai area (Ti-
mofeev 1966, Pl. 61:9), *Synsphaeridium soredi-
forme,* and from the upper portion of the

Riphean in Ukraina (Jankauskas 1982).

In the Muhos formation there are also colo-
nies with smaller cells, resembling the form
Myxococcoides staphylidion, cell size on an
average 5.5 μ, described by Lo (1980) from
Lower Yudoma Suite.

The smallest cell sizes in the colonies are com-
parable to the endospore form of the species
Sphaerocongregus variabilis (Moorman 1974).
Vidal (1976) compares it to *Bavlinella faveolata*
Schepeleva. This form, which is most frequently
described from the Upper Proterozoic, is of
rare occurrence in the Muhos formation.

In the Muhos formation there are also rhom-
bically arranged cell colonies (Pl. IV, Fig. 21).
The cell size is at its largest ca 16 μ. The surface
is granulated, the shape of the cells spheroidal
to slightly polygonal.

Pl. IV, Figs. 22, 23, 24 and 27 show hemispheri-
cal colonies, the interior of which seem to be
devoid of cell tissue of the same type. The form
in Fig. 22 seems to surround a short cylindrical
darker filament. In Fig. 23 the cell colony forms
a ring, and in Figs. 24 and 27 the resemblance
of cell tissue shows in the globular colonies. The
size of cells is ca 8 μ, and the colonial growth
does not fill the central part tightly. When com-
paring these structures with those of recent blue
algae one possibility in question is a freely

floating chroococcales-type colony (Geitler 1925, p. 52). The form may, however, correspond to an unknown type with regard to recent ones. Fig. 22 indicates that the form may be a part of an epiphytical growth. Similar types are some sporangia of forms of the recent class

Phycomycetes (Harder 1931).

In the material there are in addition globular vesicles with densely or sparsely spaced smaller cells inside. They resemble sporangia forms of blue algae and they are treated in connection with *Favosphaeridium* (acritarchs).

Acritarchs

A group of microfossils, the taxonomy of which is based on morphography and which is not bound to the natural plant systematics (Evitt 1963) probably comprises both pro- and eucaryotic forms. Generally such spheromorphs have been interpreted as eucaryotic, which exceed 50 μ in diameter, and which have dense organic bodies interpreted by many workers as possible remnants of organelles (Schopf 1975). It has been estimated that spheromorphs over 60 μ in diameter appeared during the Middle Proterozoic ca 1400 Ma ago (Schopf 1978). According to Horodyski & Bloeser (1978) the larger spheroids are not comparable to the coccoidal cyanophyte forms, but to the encystment stage of eucaryotic algae.

The Proterozoic acritarchs mainly belong to the plankton of seas and lakes, since they occur in claystone but generally not in cherts of the shallow littoral zone, where different blue algae of the benthos are prevalent. In connection with the Muhos formation, the growth environment has corresponded to a near-shore open sea.

Genus *Eomicrhystridium* Deflandre 1968

Precambrian organic microfossils, of very small size, generally less than 20 microns, spherical or more or less polyhedral, ornamented with horns or simple spines which are variable in number and may be very reduced.

Eomicrhystridium sp. 1

Pl. XVI, SEM-fig. 230

DESCRIPTION: Vesicle ellipsoidal, slightly polyhedral. Length ca 5 μ. On the surface small nodules, 5 in the line of 1 μ, they tend to form lines. Opening or depression in the apical end.

OCCURRENCE. Only one observation in the Muhos I drill core at a depth of 262.15 m.

Eomicrhystridium sp. 2

Pl. VII, Figs. 94, 95, 99

DESCRIPTION: Vesicle small, rounded oval, diameter 3—5 μ. Small spines are concentrated to the ring-like part of the apical end of the ellipsoid (Figs. 94, 95), where the rupture opening of the vesicle is situated.

OCCURRENCE: Observations from the Tupos drill core, depth 218.75 m and from the Muhos I drill core, depth 142.20 m.

REMARKS: Form resembles the form *Eomarginata striata*, diameter 5—10 μ, presented by Jankauskas (1979, 1982). It has been described from the Lower Riphean deposits of southern Ural.

Genus *Eosphaera* Barghoorn 1965

Eosphaera sp.

Pl. XII, Figs. 169, 170

The polygonally patterned form resembles *Eosphaera* sp., described by Barghoorn and Tyler (1965) from the Gunflint formation, and a larger form described by Lo (1980) from the Yudoma formation, eastern Siberia. The form from the Muhos formation, however, exceeds these in size, the length of the vesicle complex being 25—30 μ.

Genus *Favosphaeridium* Timofeev (1959) 1966

The genus determination is controversial. Apparently the name is derived from the Latin word *favus*, honeycomb, which denotes a cellular structure. According to the diagnose (Timofeev 1966) the vesicle is 25—100-150 μ in diameter, it is spherical, stout, surface reticulate.

Meshes frequently closed, of the same or different size, angularly rounded to rounded in general view. Type species *F. scandicum* (Timofeev 1966, Pl. 8:3).

REMARKS: Relatively clear-cut species of this genus have been described by Burmann (1972, *Favosphaera*). According to Timofeev *et al.* (1980) there are in the Vern-sur-Seiche algal limestone of northern Brittany, age Upper Brioverian (Middle Riphean), occurrences of *Favosphaera conglobata* Burmann, *F. aequabilis* Burmann, *F. sola* Burmann, and *F. grandifavosa* Burmann.

The forms counted as *Favosphaeridium* in the Muhos formation can be divided into at least two groups: 1. spheromorphs which contain small spheroidal or ellipsoidal vesicles which are separate from one another, and 2. spheromorphs in which small spheroidal vesicles are grouped without gaps at least under the

Text-fig. 9. a, b. *Floritheca muhosensis,* a. vegetative colony with oval cells, b. small spheres in colonies possibly nannocytes; c—h. complex spheromorph types of the Muhos formation. c. *Favosphaeridium* type 1, d. *Favosphaeridium* type 2, e. *Symplassosphaeridium parvum,* f. ringlike sporangium form, h. spherical *Synsphaeridium* sp. Figures not to same scale.

wall of the spheromorph in the surface part. Examples of the forms are shown in Text-fig. 9 and in Pls. V and VIII.

Favosphaeridium sp. type 1
Pl. V, Figs. 43—49, 51, 52

DESCRIPTION: Spheromorph flattened, circumference relatively circular, diameter 23—65 μ, interior vesicles 3—10 μ. Surface of spheromorph rough, central part concentrically depressed or with a large opening (Figs. 43, 46). When the number of cells is small, the form resembles the subspherical colonies of the form *Eoentophysalis dismallakensis,* described by Horodyski & Donaldson (1980).

OCCURRENCE: Solitary occurrences in the Tupos drill core at depths 218.35 and 218.75 m, and in the Muhos I drill core at depths 122.60, 141.10, and 191.00 m.
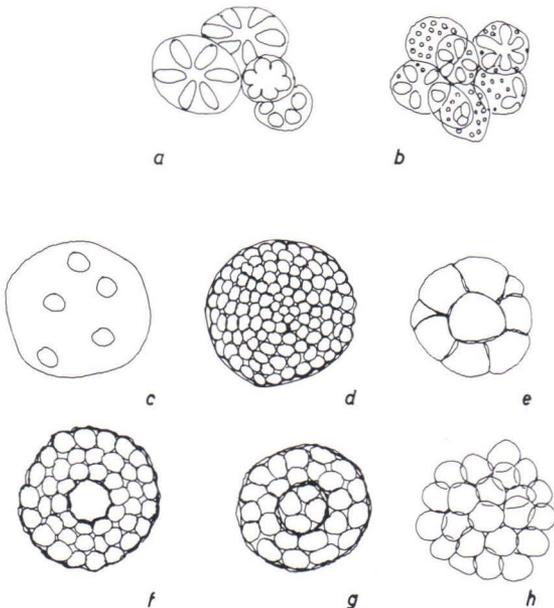
Favosphaeridium sp. type 2
Pl. VIII, Figs. 105—111, 113—121

DESCRIPTION: Spheromorph. *Leiosphaeridia*-type, thin-walled, generally 25—50 μ in diameter, diameter of interior, densely spaced vesicles ca 3 μ, rarely ca 2 μ. Vesicles may be missing in the central part (Fig. 105, in the center possibly precipitate of cell fluid).

OCCURRENCE: Of relatively rare occurrence in the Tupos and Muhos I drill cores.

REMARKS: The cellular structure which occurs regularly inside the wall has not been interpreted as diagenetic, but it can be considered an endosporangium form of the Cyanobacteria, larger than the one described by Moorman (1974). Examples of diagenetic pseudostructures caused by pyrite crystals are Figs. 118 and 121, in which the cellular patterns are irregular in form and size.

In a comparison of types 1 and 2, features in common are the spheromorph proper and the small vesicle type inside it. Differences are in the density of vesicles and, to some extent, in their size. The spheromorph with its separate small vesicles is probably comparable to an already opened endosporangium or mother cell (Fig. 46), from which the majority of former

spores have separated and turned into cocci.

Genus *Granomarginata* Naumova 1960

Spheroidal or ellipsoidal wall, thickened edges. Surface of exine granulated, folded or devoid of wrinkled folds. Diameter $10—15\mu$. Type species *G. prima* Naumova 1960. Larger forms have later been added to the genus.

Granomarginata sp.

Pl. XI, Figs. 142, 147

DESCRIPTION: Central vesicle spheroidal or ellipsoidal, surface granulated. Diameter $20—28 \mu$. In the equatorial area a thin, continuous border, ca 3 μ wide.

OCCURRENCE: Of very rare occurrence in the Tupos drill core, depth 218.75 m, and in the Muhos I drill core, depth 191.00 m.

Genus *Leiosphaeridia* Eisenack 1958, emended by Downie & Sarjeant 1963

Spherical to ellipsoidal bodies without procecces, often collapsed or folded, with or without pylomes. Walls granular, punctate or unornamented; thin. Without division into fields and without transverse or longitudinal furrows or gridles.

SYNONYMS: *Leiosphaeridium* Timofeev, *Leiopsosphaera* Naumova, *Protoleiosphaeridium* Timofeev, *Kildinella* Timofeev.

REMARKS: With respect to size, a very variable genus of acritarchs. Small forms have been classified as cyanobacteria. In the present study the separation of forms is based on size determination. The most common size classes in the Muhos mudstone are $10—20 \mu$ and $20—30 \mu$, but in the upper portions of the drill cores there are also smaller and larger thin-walled types of *Leiosphaeridia* (Pl. III, Figs. 1—18). The largest *Leiosphaeridia* sp. is 140 μ in diameter. It was found in the Tupos drill core at a depth of 218.35 m.

In the larger ($> 30 \mu$) spheromorphs of the Muhos formation, e.g. in *Leiosphaeridia,* large deformation structures occur, owing to pyrite crystals or crystal aggregates, which have formed the walls according to the form of the crystals (Pl. XV, Figs. 211—220). In some in-

stances the reticulate surface structure can be interpreted as diagenetically formed (Pl. XIV, Figs. 201, 205).

Deformation forms, more common than the foregoing ones, are the compression structures formed before the lithification of the deposits. As an example the fold patterns characteristic of the genus *Kildinella* may be mentioned (Pl. III, Fig. 11). Vidal (1974) also mentions concerning *Kildinella* cf. *vesljanica* that the folds are postsedimentary. Horodyski (1980) also considers *Kildinella* a deformation phenomenon. Folded forms have already earlier been assigned to the genus *Leiosphaeridia,* by e.g. Eisenack (1958), Volkova (1968), and Volkova *et al.* (1979). An exceptional property with respect to *Leiosphaeridia* is, however, the mostly dark sepia color of the *Kildinella* type. An important property of the spheromorphs is probably also the color of the wall, since it varies and it is assumed to be due to compositional differences in the walls. In the same samples from the Muhos formation both very light-colored and dark sepia-colored spheromorphs are found.

Genus *Leiovalia* Eisenack 1965

Oval vesicle, smooth, consisting of an organic substance similar to that of the Hystrichospheres.

Leiovalia sp.

Pl. VII, Fig. 75

DESCRIPTION: Form with rounded apices, ca 45 μ long and 11 μ wide. Surface smooth, except small longitudinal furrows.

OCCURRENCE: Only one observation from the Tyrnävä drill core from a depth of 142.0 m. Generally the form occurs in younger formations but e.g. from the Upper Precambrian of Africa Puchova has described *Leiovalia* (Bozhko *et al.* 1974).

Genus *Lunulidia* Eisenack 1958, redefined by Eisenack *et al.* 1976 p. 433

Vesicle semicircular, wall simple, smooth. Several species have an elongated pylome fissure at the equatorial belt. Holotype *Lunulidia* (ex-*Leiofusa) lunula* (Eisenack 1951).

Lunulidia nana n. sp.

Pl. VII, Figs. 96, 97, 100

DESCRIPTION: Arcuate form with rounded apices, length 8—13 μ, width 3—5 μ, in the largest individual the apices are of different width. Wall thin, simple and smooth. In the ventral edge there may be a longitudinal fold or a rupture.

REMARKS: *Archaeoellipsoides grandis* Horodyski & Donaldson (1980) from the Dismal Lakes Group represents the same sausage-shape as that one presented in the foregoing from Muhos. *A. grandis* is 9—92 μ in size.

OCCURRENCE: Very rare in the Tupos drill core at a depth of 218.75 m.

HOLOTYPE: Specimen (Pl. VII, Fig. 96) in GSF preparation No. 497:1.

Microvalia n. genus

DISCUSSION: The new genus name is meant to characterize a *Leiovalia*-type small form with spines or nodes on its surface. The form resembles in some respects the genus *Rhachosoarium* Tappan & Loeblich 1971 and on the other hand also the genus *Lophodiacrodium* Timofeev 1958, but there are differences in respect to both genera; the spines of *Microvalia* are sparse and they are not clearly concentrated to the apices.

TYPE SPECIES: *Microvalia spinosa* n. sp.

DESCRIPTION: The ellipsoidal wall tapers from the middle towards rounded apices. Its length is 6—10 μ, width 3—5 μ. On the surface relatively sparsely spaced small spines and still smaller nodes. Wall single-layered, fairly dark, generally sepia in color, brittle. Fissures usually transverse.

Microvalia spinosa n. sp.

Pl. VII, Figs. 76—83, 88

DESCRIPTION: As for genus, type specimen.

TYPE SPECIMEN: Pl. VII, Fig. 76, from the Muhos I drill core, depth 142.20 m, specimen in GSF prep. No. 487:1 (38.7/115.0).

OCCURRENCE: Rare in the Muhos I drill core at depths of 142.20 and 251.65 m in fine-grained graphite-bearing detrital maceration residue. The same type, but larger than the foregoing,

11—14 μ, occurs at a depth of 102.0 m.

REMARKS: The form resembles certain resting spores of the genus *Nostoc* and on the other hand spores of fungi. In the Tupos drill core at a depth of 218.75 m there are skittle- or egg-shaped sepia-colored forms, occasionally with dentate edges (Pl. VII, Figs. 89—93), resembling the pseudovaginata walls of the recent *Chamaeosiphon fuscus* exospore. These forms are not readily preserved in the maceration preparations, and we have not been able to preserve the type species.

Genus *Nucellosphaeridium* Timofeev 1963

Nucellosphaeridium sp.

Pl. XIV, Figs. 196, 197

DESCRIPTION: *Leiosphaeridia*-type wall, 50—70 μ in diameter. Wall folded in same manner as *Kildinella*. Dark precipitate is seen in the interior, ca 15 μ in diameter.

OCCURRENCE: Extremely rare in the Tupos drill core at depths of 218.75 and 234.10 m.

Genera *Octaedryxium* and *Polyedryxium*, pseudoforms in Muhos. The broken form shown in Pl. XV, Fig. 215 resembles certain species of the genus *Polyedryxium* Deunff (1954) 1971. The forms in Figs. 211—213 resemble simpler spheromorphs of the type *Octaedryxium* Rudavskaja 1973, which however in the Muhos formation belong to the pseudoforms shaped by inward crystal growth. In principle the angular algal types may have been represented as early as the Precambrian, but due to the possibility of deformation and lack of unequivocal evidence it was necessary to treat them with reservation. Cf. Vidal 1974: *Polyedrospheridium* is comparable to a strongly deformed *Kildinella hyperboreica*.

Genus *Pterospermella* Eisenack 1972

Circular central body, in side view generally oblong. The central body is equatorically and concentrically bordered by a ring-formed smooth or lobule-edged flange. It may be smooth or radially folded.

REMARKS: *Pterospermella* is intended to replace the genus *Pterospermopsis* W. Wetzel 1952 ex-

cept for *Pt. danica* W. W. (Eisenack *et al.* 1973). Also *Granomarginata* Naumova 1960 is a similar genus, as it has been applied to forms with wider rims, e.g. *G. squamacea* Volkova 1968. The forms with flanges, met with in connection with the Muhos form, are assigned to *Pterospermella,* if the flanges have lobules. Forms with a narrower rim, entire and tightly joined to the equator, are assigned to *Granomarginata.*

Pterospermella simica Jankauskas (1980) 1982
SYNONYM: *Pterospermopsis simica* Jankauskas 1980
Pl. XI, Figs. 143, 144, 145
DESCRIPTION: Central body fairly thick-walled, diameter 20—27 μ. Equatorially placed flange 5—10 μ wide with undulating rim. Total diameter 25—35 μ.
OCCURRENCE: Rare in the Tupos drill core at depth of 234.10 m (two observations) and in the Muhos I drill core, depth of 165.8 m (thin section). Observations by Jankauskas from the Upper Riphean deposit of southern Ural (Jankauskas 1980, 1982).

Genus *Pterospermopsimorpha* Timofeev (1962) 1966

Vesicle spherical to ellipsoidal with diameter from 30—40 to 80—90 μ; stout, thick and large. Entirely surrounded by a densely reticulate membrane.

Pterospermopsimorpha ornata n. sp.
Pl. XI, Figs. 138—141
DESCRIPTION: Flattened spherical central body 70—105 μ in diameter. 5—10 μ farther out surrounded by a thin membrane with cellular structure. It may be either diagenetically formed or primary. On the surface of the central body a reticulate structure, generally along with a delicate punctuation, is dimly visible. In a smaller, better preserved individual (Fig. 139) the surface texture is leatherlike and faintly reticulate.
OCCURRENCE: Fairly rare, preserved only in the Muhos I drill core at a depth of 262.15 m.
HOLOTYPE: Pl. XI, Fig. 138. The Muhos I drill core, at a depth of 262.15 m, same as the para-

type Fig. 139. GSF prep. No. 433.
DERIVATION OF NAME: With reference to the wall texture.
REMARKS: The form is attributed to the genus *Pterospermopsimorpha* on account of its main structural feature, the membrane entirely covering the central body. The deviations from the definitions of Timofeev may be due to diagenetic changes, except for the size, which gives reason to enlarge the size scale of the genus.

The form may correspond in type to the smaller species *Globophycus rugosum* (Schopf 1968), presented from the Bitter Springs formation. It has been compared to either of the classes *Chlorophyceae* or *Rhodophyceae* (Schopf & Blacic 1971), or to the class *Chroococcaeae* (Hofmann 1976).

However the form most closely related to that in the Muhos formation is probably a large dispheromorph type described from the Roper formation, which has further been compared to the pteromorphs (Peat *et al.* 1978). A typical feature of the dispheromorphs of the Roper formation is a thin outer wall with a median split, through which the richly folded, sepia spheromorph can separate. There are also solitary split thin walls. According to the illustrations the diameter of the spheromorphs is 30—135 μ, or the type from the Muhos formation would fit into this size range. In case the same type is in question, it would mean that the areole structure of the outer membrane is a secondary feature.

Genus *Symplassosphaeridium* Timofeev 1959

Spherical clusters of small, spherical, smooth vesicles, diameter 10—60 μ. The outline of the vesicles is undulating.
REMARKS: Structurally this form is closely related to the *Favosphaeridium* type 2. The undulating outline of the spheromorph is due to the distending effect of the small central vesicles.

Symplassosphaeridium parvum Tynni (1978)
Figs. 13—16 Tynni & Uutela 1984, Text-fig. 9e.

Diameter of spheromorph 8—20 μ, diameter of small vesicles 3—5 μ. Ca 10 observations from the Tupos drill core from a depth of 234.00 m. Holotype Fig. 13 (Tynni 1978).

REMARKS: The species has been compared to the similar genus *Microconcentrica* Naumova 1960. Jankauskas (1982) has presented a similar type, *Symplassosphaeridium undosum* Jankauskas 1979, from the Lower and Middle Riphean deposits of Ural.

Symplassosphaeridium sp.

Pl. VIII, Figs. 104, 112

DESCRIPTION: Diameter of spheromorph 30—40 μ, length of wavy line at outline of spheromorph ca 5 μ.

OCCURRENCE: Rare in the Muhos I drill core, e.g. at a depth of 85 m.

Genus *Synsphaeridium* Eisenack 1965, sensu lato

According to Eisenack the interconnected vesicles do not form spherical aggregations, but Timofeev (1966) has described spherical complexes, too. Some other authors have followed this practice. Spherical complexes have also been attributed to the genus *Symplassosphaeridium*. The manner of joining of the spherical parts is however a more important characteristic than the complex form of *Synsphaeridium* and *Symplassosphaeridium*. In the latter the joining of the cells is tighter than in the former, at whose outline the height of the wavy line is ~ 1/3 of the diameter of the cell. The genus *Synsphaeridium* occurs in the Muhos formation both as irregular and as spherical colonies. In the description of the latter we have primarily followed the practice of algal systematics.

Genus *Trachysphaeridium* Timofeev (1966) 1969

In the determinations we have, in addition to Timofeev, followed mainly the systematics of Vidal (1974, 1976). The synonym list of Hofmann *et al.* (1979) is an example of the great diversity in the naming practice. In the Muhos formation the *Trachysphaeridium* is fairly well preserved, so that the relatively thick walls of the large to medium-size spheromorphs are visible with their shagrinate or slightly granulated surface texture. Their color is brownish or sepia. The folds typical of *Leiosphaeridia* and *Kildinella* are almost completely lacking. Examples of the forms are shown in Plate 9.

Protosphaeridium is probably the genus of the same type most closely related to this one.

Trachysphaeridium levis (Lopukin) Vidal

Pl. IX, Figs. 122—125

REMARKS: Typical features are the nodules on the surface, the folds encircling the outline, and the size of 45—60 μ, which corresponds to the smallish-medium size class in the approximate size classification given.

OCCURRENCE: Relatively rare in the Tupos drill core at a depth of 218.35 m, and in the Muhos I drill core at the depths of 110.00 m, 111.60 m, and 220.65 m. According to Vidal (1976) the species has been met with in Middle — Upper Riphean, Vendian, and Lower Cambrian deposits.

Trachysphaeridium laminaritum Timofeev 1966

Pl. IX, Figs. 126—129

REMARKS: The thick wall is a typical feature, which is full of cavities, giving rise to an undulating outline. The texture is formed by densely spaced small nodules. Due to the cavities the wall may be roughly reticulated. The diameter is 100—129 μ. It corresponds to the size range presented by Timofeev (1966), but according to Vidal (1974) the size range in the Visingsö formation is from 45 to 100 μ. Later Vidal (1976) gave the size range 41—57 μ, which is smaller than in Timofeev's original definition: 70—250 μ. Two different species may be concerned.

OCCURRENCE: Relatively rare in well preserved condition. Most of the observations are from the Muhos I drill core, from the depths of 207.40 m and 262.15 m. According to Timofeev (1966) the species has been found in Vendian and Lower Cambrian deposits.

Trachysphaeridium sp.

Pl. IX, Fig. 130

DESCRIPTION: Diameter of vesicle ca 50 μ.

Small nodules on surface, on the rim of the vesicle a fold in the direction of the periphery.

REMARKS: A form closely related to the species. *T. levis,* and should possibly be attributed to it as a form more poorly preserved than those in Figs. 122—125.

OCCURRENCE: In the Muhos I drill core at a depth of 262.15 m. As a rarity the *Trachysphaeridium* type was found joined to a sphere of a different type (Fig. 131) or of a similar type (Fig. 132). Cf. also Pl. XV, Figs. 220 and 221. It seems that twin forms of the smallish *Trachysphaeridium* forms possibly exist.

Genus *Turuchanica* Rudavskaya 1964

The wedgelike rupture marks on the flattened vesicle are typical of this form (Pl. XIII, Figs. 175—188). In part of the forms a distinct ribbon and punctate pattern appears light against the dark sepia-colored wall. This pattern does not consist of openings nor of nodules. Since the form may be of taxonomic significance it is described more in detail in the following.

Turuchanica maculata n. sp.

Pl. XIII, Figs. 175—186

DESCRIPTION: The lenticular or spherical vesicle has been flattened, which has caused wedgelike ruptures to form at the rim of the vesicle. On the sepia-colored surface the densely spaced ribbons patterns are discernible (Fig. 176). The diameter of the vesicle is 18—33 μ.

OCCURRENCE: Common in the Muhos I drill core, especially as fragments at a depth of 142.0 m. Rare in the Muhos I drill core at a depth of 190.70 m and in the Tupos drill core at a depth of 218.35 m.

TYPE LOCALITY: Muhos, south of Oulu.

HOLOTYPE: Specimen in GSF slide No. 467:3b, Pl. XIII, Fig. 175.

DERIVATION OF NAME: Maculata (lat.) = dotted

REMARKS: The differentiated wall structure possibly suggests an eucaryotic type. The surface structure resembles that of a spherotype described by Peat *et al.* (1978) from the Australian Roper formation, where the reticulate texture type I corresponds to the elongated cells.

Turuchanica aff. *kulgunica* (Jankauskas) n. comb.

SYNONYM: *Kildinella kulgunica* Jankauskas 1982.

Pl. XIII, Figs. 187, 188

OCCURRENCE: Rare in the Muhos drill core at a depth of 142.0 m. According to Jankauskas (1982) the form belongs to the Upper Riphean in South Ukraine. A similar form, *Leiosphaeridia pylomifera* has been found by Volkova *et al.* (1979) in the Lower Cambrian deposits of Latvia and Lithuania.

REMARKS: In the form of the Muhos formation the central pylome is relatively round and large, ca 5 μ in diameter, the total diameter being ca 25—30 μ. Still smaller forms lack pylome openings, but they have a small central circle. Surface granulated, diameter ca 20 μ. The rupturing typical of *Turuchanica* is probably a sign of a brittle wall structure. The fold encircling the central pylome as well as the rim of the opening are phenomena indicating pressure deformation of a vesicle wall originally extended in an equatorial direction.

Large spheromorph forms

The largest spheromorphs or fragments of them met with in the Muhos formation are more poorly preserved than the smaller forms. Plate X shows examples of the large forms (cf. Timofeev 1970). Fig. 137 shows a fragment of the largest spheromorph, which is ca 250 μ in diameter, worn, and has a feltlike surface.

The surface of the spheromorph in Fig. 136 is irregularly reticulate. On the other hand it resembles an irregular cellular structure. It is improbable that it has formed diagenetically from a thick-walled *Leiosphaeridia* type. The structure may correspond to the diagenetically areolated structure of a complicated wall complex,

ca 5 μ thick, or the original cellular structure of a wall complex. The diameter of the vesicle is ca 170 μ. The form is possibly of the genus *Protosphaeridium* Timofeev.

Filamentous forms

Genus *Contortothrix* Schopf 1968

Skeinlike trichome consists of small cask-shaped or cylindrical cells.

? Contortothrix sp.

Pl. XVIII, Fig. 245

DESCRIPTION: Diameter of trichome 2—3 μ, diameter of entangled group ca 25 μ. On account of poor preservation possible septa are not readily discernible in the maceration preparation.

OCCURRENCE: In the Tupos drill core at a depth of 218.75 m, prep. No. 497:1, extremely rare in a preserved state.

REMARKS: On account of the dimensions the form may be comparable to *Contortothrix vermiformis,* described by Schopf (1968) from the Bitter Springs formation.

Genus *Eomycetopsis* Schopf 1968

Eomycetopsis sp.

Pl. XVIII, Figs. 237—240, 242

DESCRIPTION: Poorly preserved ca 2—3 μ wide, more than 100 μ long trichomes in thin section.

OCCURRENCE: Fairly common in the Tupos drill core at a depth of 218.70 m. According to Mendelson & Schopf (1982) *Eomycetopsis* has been of abundant and cosmopolitan occurrence in the Proterozoic microbiota.

Genus *Heliconema* Schopf 1968

Tubular thallus nonseptate, unbranched and coiled at an angle of ca 45° into a regular helix. Of the modern Oscillatoricean genera it resembles *Spirulina* most closely.

Heliconema sp.

Pl. XVIII, Fig. 241

DESCRIPTION: Diameter of trichome ca 0.5 μ. Diameter of the coils 2—3 μ, distance between subsequent coils ca 2 μ. Length of single trichome without uncoiling ca 20 μ.

OCCURRENCE: Some observations in the Tupos drill core from a depth of 218.75 m in prep. No. 497:1.

Genus *Siphonophycus* Schopf 1968

Siphonophycus sp.

Pl. XIX, Figs. 250—253

DESCRIPTION: Width of trichomes vary between 8 and 13 μ. They have thin membranes and are relatively light-colored. They have been compared to sheaths of oscillatorealean algae (Hofmann & Aitken 1978).

OCCURRENCE: Rare in the Muhos I drill core. The genus has earlier been described from Bitter Springs, Little Dal, northern Canada and many other Precambrian sediments (Hofmann & Aitken 1978).

Giant filament

Pl. XIX, Fig. 246

DESCRIPTION: Large, filamentous and blackened form ca 180 μ wide and preserved part more than 600 μ long. A reticulate structure appears in the worn part, probably diagenetic.

OCCURRENCE: Only one observation in the Muhos I drill core from a depth of 190.70 m (prep. No. 476:1).

REMARKS: The giant filament ca 120 μ in diameter, described from the Roper Group, has been compared to the various species of *Lyngbya* (Peat *et al.* 1978). *Tawuia dalensis* Hofmann, which is significantly larger than that one described above, has been described from the Little Dal Group, Canada. It has also been assumed to be an algal form (Hofmann & Aitken 1978). *Vendotaenia antiqua* Gnilovskaya 1971, described from the Vendian formations of the Soviet Union, is also of larger dimensions than the type found in the Muhos formation. According to Sokolov (1973) *Sabellidites,* which is to be assigned to the pogonophorii, and the

form *Paleolina evenkiana* Sokolov, which re-
sembles it, exist in formations as old as the
Vendian. They are also of larger dimensions.
Proterotania montana Walter, Oehler and
Oehler 1976, described from the Belt Super-
group, Montana, is closest to the dimensions of
the type found in the Muhos formation; its
diameter is 0.13 mm.

Sheathlike tube
Pl. XIX, Figs. 247—249
DESCRIPTION: Problematic form. The most
clear-cut fragment (Fig. 195) is ca 100 μ long, at
its wider end 24 μ, at its narrower end 15 μ. The
wall is relatively well preserved and smooth, but
on the surface there are circular openings spaced
ca 10—20 μ apart, and in them a small swelling
is distinguishable. The diameter of the smaller
sheath is on an average 15 μ (Fig. 249). The
sheath is brown to grey in color.
OCCURRENCE: Only in the Muhos I drill core at
a depth of 142.00 m in the preparation No.
9.9—82. On account of the rarity and the high
degree of preservation in the maceration prepa-
ration the originality remains unconfirmed.

REMARKS: The holes in the sides may have
formed diagenetically and the vesicle may be
comparable to the sheath of an oscillatoricean
alga.

Branched filament with cystoid protuberances
Pl. XVIII, Fig. 243
DESCRIPTION: Length of filament ca 90 μ,
width ca 2 μ. The filament has distended into
protuberances spaced ca 20 μ apart, terminating
in protuberances at the ends of the branches.
OCCURRENCE: Only one observation in the
Muhos I drill core at a depth of 142.20 m.
REMARKS: On account of the single observa-
tion the primary origin remains controversial.
From the Yudomian cherts (age ca 675 Ma)
there have also been descriptions of branched
tubes with ellipsoidal inclusions, which have
been compared to blue algae or fungal hyphae.
Licari (1978) has described from the Beck
Springs dolomite the dichotomously and later-
ally branched filaments of *Palaeosiphonella
cloudii,* which is compared to either Chloro-
phyta or Chrysophyta. In type it resembles the
Muhos form, but is larger than it.

Problematic forms

Cylindrical form, structurally resembling
Volyniella
Pl. XX, Figs. 261, 262, 264

DESCRIPTION: The shape is a rectangle with
rounded apices, length 10—25 μ, width in a
compressed state 11—13 μ. A faint transverse
lineation is discernible, the lines spaced 1—2 μ
apart. It probably corresponds to the width of
a coiled filament. On the surface nodules are
discernible and in the larger form also spines
(Fig. 264).

REMARKS: In Fig. 262 a filament in a diagonal
position is dimly visible as a darker semicircle,
which has been interpreted as a sign of the hol-
lowness of the central area. These forms are not
as clear-cut as the *Volyniella* species presented
by Aseeva (1976) from the Soviet Union or by

Tynni and Donner (1980) from the Hailuoto
formation.
OCCURRENCE: Rare in the Tupos drill core at
the depths of 218.75 and 233.50 m, and in the
Muhos I drill core at a depth of 190.70 m.

Cylindrical form with ringlike distensions
Pl. VII, Figs. 101, 102
DESCRIPTION: Tube formed by four successive
rings. Diameter of rings ca 70 μ, width and
depth of rings in sight are deformed.
REMARKS: The form is a fragment of a larger
whole. *Toromorpha,* described by Timofeev
(1973) from the Vendian deposit of Podolia, is
a similar or identical form. The form differs
from the Hailuoto form *Volyniella cylindrica*
among other things because of its thinner wall
and lighter color.

OCCURRENCE: In the Tupos drill core from the depth of 218.75 m only one observation.

Spirosaccus n. gen.

TYPE SPECIES: *Spirosaccus punctata* n. sp.

DIAGNOSIS: Sacklike extremely thin-walled vesicle, tapering towards apices, surface punctate. The points form patterns of circles, bows or whirls. In the larger vesicles the points or small nodules also form regular liner patterns with 15 nodules in line of 10 μ. Length of vesicle extremely variable, 300—20 μ.

DERIVATION OF NAME: spiro (lat.) curl, saccus (lat.) sack.

Spirosaccus punctata n. sp.

Pl. XX, Figs. 257—260, 263

Elongated structures Tynni 1978, p. 8, Fig. 1.

DESCRIPTION: As for genus, especially according to species in Fig. 263. Length of tapering vesicle is 160 μ. On surface of vesicle small yellowish and black punctate nodules in spirally arranged chains. Spacing of nodules ca 0.5—1 μ. In the narrower tail-like part the nodules are grouped in dense spiral coils perpendicular to the longitudinal axis.

HOLOTYPE: Fig. 263. The Tupos drill core, from a depth of 165.47 m, GSF prep. No. 560.

OCCURRENCE: Common in the Tupos drill core at a depth of 165.47 m, in other places observations are lacking.

REMARKS: The form has been interpreted as a colony of bacterial filaments. The spiral arrangement of the filaments is characteristic. It appears at its clearest in small colonies of a few filaments. The largest colonies tend to form combinations of adjacent chains of filaments, covering large areas (Fig. 258).

The form resembles to some extent the pseudofilament type presented by Peat *et al.* (1978), which has formed during the erosion of large spheromorphs, or even more the type with dark cellular remains in ribbons and sheets of mucilage. In the Muhos formation the spiral form is on an average larger than the spheromorphous forms in horizons where preserved spheromorphs are met with. The lines of consecutive nodules comprise the most important structural feature, while the shape as a whole is a nonessential feature, since especially the sedimentary conditions have influenced it. The structures are presumably formed in strongly reducing conditions which are destructive to organisms, but where however bacterial activity has been going on.

Granulated irregularly formed vesicles
Pl. XX, Figs. 254—256

DESCRIPTION: On the surface of the vesicles there are semispherical swellings. Vesicle size variable 20—80 μ. The nodules are larger than in *Spirosaccus punctata*.

OCCURRENCE: In the Tupos drill core at a depth of 84.10 m some observations.

REMARKS: Possibly the form concerned is a bacterial colony formed by the disintegration of a spheromorph in connection with bacterial action. In the same horizon no preserved spheromorphs were found. The microfossil type C described by Manum (1967) from the Biskopås conglomerate, South Norway, probably corresponds to the type in the Muhos formation. The conglomerate concerned dates from the Late Precambrian.

MICROBIOTA OF THE MUHOS FORMATION AND BIOSTRATIGRAPHIC CORRELATION

The more abundant occurrence of microfossils is limited to a rather small portion of the drill cores from the Muhos formation. In the deepest drilling at Tupos the fossiliferous zone is at a depth of 215—234 m, in the Muhos I drilling it is thicker, ranging from a depth of

85 m down to 267 m. In the Tyrnävä drilling no abundant zone was found. In order to follow the floral succession the percentual shares of the most common forms from the Muhos I drill core have been presented. Also the size distribution of the *Leiosphaeridia* type at the depths of 85—267 m is shown (Text-figs. 6—8). On account of the high degree of wearing the result remains indicative.

In addition to the *Leiosphaeridia* type the following forms are met with, in order of frequency: *Synsphaeridium/Myxococcoides, Kildinella, Turuchanica, Favosphaeridium, Trachysphaeridium, Symplassosphaeridium,* growth- and sporangium forms of cyanobacteria. The share of filamentous cyanobacteria is relatively small. The foregoing forms have been described especially from the Late Precambrian deposits of the USSR, e.g. by Andreeva (1966), Timofeev (1966, 1969), Jankauskas (1979, 1982), Aseeva (1976), Naumova (1960, 1968), Schepeleva (1973), and Pychova (1973). The definition and naming of the microfossils may vary between the Muhos formation and the areas in the USSR, depending on the interpretation. In the occurrences in the USSR especially the share of *Leiosphaeridia* is markedly smaller than in the Muhos formation, possibly for the reason that in the latter many forms have been assigned to the genus *Leiosphaeridia* which in the USSR have been divided into other genera. This difference in division is not of great significance, since the forms concerned are not guide fossils.

The rarer forms are on an average of greater significance for dating purposes than are the common forms, as far as the structurally more highly developed primary occurrences are concerned. Rarer forms belonging to the acritarchs in the Muhos formation are *Turuchanica maculata* n. sp., *T. kulgunica* (Jankauskas), *Pterospermopsimorpha ornata* n. sp., *Pterospermella simica* Jankauskas, *Granomarginata* sp., *Eomicrhystridium* sp., *Leiovalia* sp., *Microvalia* sp., *Microvalia spinosa* n. sp., and *Lunulidea* sp. These forms are morphologically con-siderably further developed than the smooth spheromorphs. The known forms date in the USSR from the Riphean deposits, most often from the Upper Riphean (Jankauskas 1982). According to Keller and Khramov (1982) the Riphean of southern Ural corresponds, according to radiometric datings, to ages of 614/658—1592 Ma, while the limit between the Upper and Middle Riphean corresponds to an age of 1052/1126—1229 Ma. The radiometric age of the Muhos formation corresponds to the Lower Riphean or the limit between the Lower and Middle Riphean in the division of the USSR.

On the basis of the rare acritarchs one cannot necessarily claim the Muhos formation to be younger than in the present opinion and comparable to the Late Riphean, but one can presume that the acritarchs concerned appeared earlier in the Muhos area, especially since it is believed that there has been considerable advance in the development of microbiota near the limit between Early and Middle Riphean, when the size of the spheromorphs grew and the eukaryotic forms appeared (e.g. Schopf 1978). The rare forms may also have gotten into secondary positions from younger eroded deposits.

Since small vertical faults and slickensides are common in the Muhos formation, part of the younger microfossil material may have displaced from its original positions to a lower level. The possible share of this phenomenon is however extremely small, considering the erosion connected with the same situation. Rare occurrences may however be suspected to be of such a secondary origin. On the basis of the microfossils it is possible that the upper part of the Muhos formation corresponds to the Upper Proterozoic. In this case it would, on stratigraphic grounds, be close to the dating of the Hailuoto formation, which is interpreted to be Vendian (Tynni & Donner 1980).

The prokaryotic cyanobacteria found in the Muhos formation represent a fairly unchanging biotope, which is not believed to be of great sig-

nificance as regards dating. On the other hand the group of cyanobacteria is multiform and heterogeneous and it can be assumed that at times some short-lived forms with a greater significance for dating may have belonged to it. In microbiota dominated by cyanobacteria there is also a distinct growth in cell size in Proterozoic assemblages, as stated by Muir (1976) in his comparison of the microfossils of the ca 1500 Ma old Amelia Dolomite with those of the younger Bitter Springs, Beck Springs, Boorthanna and Skillogalee formations. The majority of the formations in the comparisons are dated younger than the datings of the Muhos formation, but part of the forms in common are originally from older formations. This situation is not in conflict with the radiometric datings.

The stratigraphic correlation of the Proterozoic microbiota is based on the results of microfossil studies in radiometrically dated sedimentary rocks. On the part of primitive bacterial forms the modern morphological systematics is the basis for evolutionary and ecological conclusions. The significance of the acritarchs, which do not exist today, in dating and correlation is based on the highly developed specialization of the spheromorphs and on the size development of the type *Leiosphaeridia*. The solving of the development of the Proterozoic set of organisms, based on a limited fossil material, is still at a developing stage, and the correlation based on only microbiota of sedimentary rocks not radiometrically dated is not conclusive for dating, especially not if the thanatotope concerned is of a very limited environment. Better opportunities for a more conclusive correlation is offered by the studies of Precambrian contemporaneous ecosystems as varied as possible.

According to Schopf (1970) one of the significant stages of development of the cyanophyta was the appearance of the non-colonial coccoid forms more than 3100 Ma ago. Simple filamentous colonies (Oscillatoriaceae) appeared more than 2700 Ma ago (Schopf *et al*. 1971). Cloud & Morrison (1979) interpret some early microfos-

sil observations as impurities or pseudofossils. However Awramik *et al*. (1983) describe filamentous bacteria from the ca 3500 Ma old Warrawoona Group, West Australia. This age comes near to the assumed first appearance of organic carbon in the sediments of the Earth, approximately 3.7×10^9 yr (Schidlowski 1979). As the oldest preserved forms Cloud & Morrison (1979) consider the filamentous forms found in the ca 2.3 Ga old stromatolitic limestone of the Malmani dolomite in South Africa (Nagy 1974). A more developed filamentous member of the family Nostocaceae is present earlier in the Gunflint formation, 1900 Ma ago (Licari & Cloud 1968). Its characteristic features are the specialized heterocyst and akinetes cells. In the contemporaneous Belcher Islands formation a colony-forming coccoid type, comparable to the family Entophysalidaceae, is the dominating form (Hofmann 1976). Otherwise the biotope of this formation resembles that of Bitter Springs in the fact that the biota is highly specialized as for the cyanophyta (Schopf 1968, Schopf & Blacic 1971). The similarities in formations of different age have been attributed to the similar environments of deposition of stromatolite — chert deposits (Hofmann 1976, Knoll *et al*. 1978, Knoll & Simonson 1981). In both formations the biota consists of benthic forms, although planktic or allogenic benthic individuals are met with also in the material from the Belcher Islands (Hofmann *op. cit.*).

The exclusion of plankton forms proper from Precambrian microfossil assemblages is to some extent a relative classification. The spheromorphs are able to float and readily form plankton, e.g. from growths loosened by the surf from the stromatolite zone. A spheromorph type foreign to the stromatolites possibly corrensponds to a biotope characteristic of the open sea, in other words various acritarchs, which are met with in clay- and siltstone. Timofeev used the name microphytoplankton of these forms in many connections. The Late Precambrian spheromorps described by Timofeev

Table 2. Characteristic features of some known Precambrian (1800—1000 Ma) microbiota.

Approxi-mate age	Geologic unit	Locality	Lithology	Examples of microfossils (diameter μm)	Reference
1000	Sukhaya Tunguska	Siberia Platform	Black chert	Eomycetopsis, Eoentophysalis, Eosynechococcus (3—45 μ)	Mendelson & Schopf 1982
1000	Biota from Boorthanna	South Australia	Black chert	Pleurocapsalean cf. Myxosacrina, eukaryotes (3—60 μ)	Schopf & Fairchild 1973
1000	Skillogalee Dolomite	South Australia	Dolomite	Pleurocapsalean cyanophyte	Schopf & Barghoorn 1969, Knoll et al. 1975
?1200	Tersk, Kildin fms	Kola Peninsula, USSR	Arkose, clayey schists	Kildinella, Protosphaeridium, Stictosphaeridium, Favosphaeridium (2—90 μ)	Timofeev 1969
1200	Dismal Lakes	NNW Territories, Canada	Chert lenses	Eoentophysalis, Sphaerophycetes, Myxococcoides, Oscillatoriopsis, Archaeoellipsoides (3—32 μ)	Horodyski & Donaldson 1980
1200	Avzjan	Southern Ukraina USSR	Dolomite	Kildinella, Leiosphaeridia, Turuchanica, Gloecapsamorpha, Synsphaeridium, Nucellosphaeridium, Pteromopsimorpha (1—80 μ)	Jankauskas 1982
1200	Muhos formation	W Finland	Siltstone, shale	Leiosphaeridia, Synsphaeridium, Turuchanica, Favosphaeridium, Eosynechococcus, Eomycetopsis (2—160 μ)	Tynni & Uutela present work
1300	Greyson Shale	Montana, U.S.A.	Shale	Megascopic algae	Walter Oehler & Oehler 1976
1300	Roper Group	Northern Territory, Australia	Carbonaceous shale	aff. Favosphaeridium, cluster (10 (7)—600 μ)	Peat et al. 1978
1300	Beck Spring Dolomite	SE California	Cherts — laminated carbonate stromatol.	Beckspringia, Abundacapsa, Maculatosphaera, Palaeosiphonella (2—62 μ)	Cloud et al. 1969, Gustadt & Schopf 1969, Licari 1978, Pierce & Cloud 1979
1400	Little Belt Mountains	Montana, U.S.A.	Shale	Siphonophycus, Lyngbya, Kildinella, Chuaria, aff. Entophysalis (12—440 μ)	Horodyski 1980
1500	Bungle Bungle Dolomite	NW Australia	Cherts — silicif. stromat.	Chroococcaceae, filamentous forms (1—5 μ)	Diver 1974
1600	Amelia Dolomite	NE Northern Territory, Australia	Cherts — silicif. stromat.	Eomycetopsis, Huroniospora, Sphaerophycus, Palaeoanacystis, Tetrahedral tetrads (1—13 μ)	Croxford et al. 1973, Muir 1976, Oehler et al. 1976
1650	Paradise Creek	NW Queensland, Australia	Silicif. carbonate stromat.	Narrow filaments, aff. Eocapsis (?) aff. Anacystis (2—12 μ)	Licari, Cloud & Smith 1969, Licari & Cloud 1972
1800	Shunga, Jatulian	Lake Onega, USSR	Shungite	Protosphaeridium (2—60?)	Timofeev 1969
1800	Belcher Group	S Hudson Bay, Canada	Chert linses	Eomycetopysis sp., Sphaerophycus, Myxococcoides, Eoentophysalis, acritarcha (2—31 μ)	Hofmann & Jackson 1969, Hofmann 1974, 1976

(1969) from the area of the USSR are of larger dimensions than the common Chroococcacean forms of a corresponding age, described from stromatolite-chert deposits of the shelf area.

The observation that the growing size of the spheromorphs is an evolutionary feature (Schopf 1978) probably applies most closely to the planktonic forms.

In the varved parts of the Muhos formation the organiferous varves, ca 1 mm thick, have formed in calm conditions, where the bottom streams have not influenced them. The estimated depth of the sedimentary basin has been more than 50 m. Presumably the planktonic forms have formed the bulk of the biota, but also Chroococcacean forms (e.g. *Eosynechococccus*) transported from the littoral zone, are present. A comparison of the floratype concerned with floras of dated cherts of the shelf area can only to a small extent concern common allochtonous forms.

Table 2 shows the most characteristic features of Proterozoic age (1800—1000 Ma) microbiota, chronologically relatively close to the Muhos formation. In the comparison of the results the lithologic association is of great importance. In connection with the stromatolites the share of small forms becomes emphasized. In the clay- and siltstones the occurrence of large spheromorphs and acritarchs is conspicuous in the biota concerned. For this reason the small spheromorphs may sometimes have passed unnoticed.

Comparisons with other microbiota regarding the *Leiosphaeridia* type is made difficult by the lack of data on the percentual size distribution. However thin-walled spheromorphs of the same size range as that of the Muhos formation have been described from the ca 1300 Ma old Roper Group, Australia (Peat *et al.* 1978).

PALEOECOLOGICAL ESTIMATIONS

The conditions prevailing at the time of deposition of a formation can be reconstructed on the basis of the lithology, the structure, and the type of microfossils found in the sediments, especially if the time of sedimentation is known.

On the basis of earlier investigations it can be said that of the sediments the sandstone corresponds to an arkose type and the finer-grained silt- and claystone portions to a weathering sediment, where the kaolinite is clearly discernible in the finer-grained fractions. Kaolinite is commonly formed by the hydrolysis of aluminosilicates. Its formation is favored by tropical conditions.

The sedimentary structure of the Muhos formation in the upper horizons studied corresponds to homogeneous silt and varved portions in thin packs (10—20 cm). The varved portions are either poor in organic material or contain apparently precipitated organic material, which forms thin films clinging to the sedimentary grains. In connection with it there are usually microfossils and disseminations of graphite and pyrite. Such parts of the sediment differ from the rest of the greyish or brownish sequence in its darker, almost black color. In these parts the sediment is relatively finer-grained than in the homogeneous silty portions. Probably they are also a sign of a deeper (more than 50 m) environment of deposition than are the homogeneous portions. In the three drill core sequence studied the majority of dark varved places are in the zone of 85—267 m in the westernmost, Muhos I core. In the Tupos drill core they occur only in the zone of 215—234 m. The upper portion of the Muhos I sequence probably represents a deeper part of the basin than do the contemporaneous horizons of the other drilling sites.

A comparison of sediments and microfossils shows that the 142.2 m level of the Muhos I drill core represents conditions of depth and environment which are comparable to the 218.35 m level of the Tupos drill core from 27.5 km

farther west. In the area between them this implies a gradient of ca 2.6 m/km sloping to the west.

The corresponding biostratigraphic horizon is lacking from the Hailuoto sedimentary rock sequence ca 50 km to the west-northwest of Muhos, possibly for the reason that the area west of the Muhos formation has been dry land at the time of deposition of the formation. On the basis of investigations carried out so far it seems likely that the extent of the Muhos formation was not significantly larger than today during the deposition of the silty sediments. Its present borders coincide with tectonic lines, which may have existed already when the sedimentary basin was formed. The brink of Kieksi conglomerate (Brenner 1944) on the northern bank of the Oulujoki river has formed after the sedimentation, probably in connection with strong block faulting. Possibly there were strong movements during the same cycle between Muhos and Hailuoto, too. It has not been possible to determine the position of the connection with the sea. Possibly the basin has been a lake, the other alternative is a sheltered bay of the sea.

The ecologic adaptability of the cyanophyta is extremely great with regard to among other things salinity, oxygen content, and ultraviolet radiation, which is lethal to other bacteria. Cyanophyta are met with in seas and freshwater basins, and they are either aerobic or anaerobic. The cyanophyte species *Eosynechococcus moorei* Hofmann found in the Muhos formation resembles the modern form *Synechococcus,* which is a common cyanophyte in hot springs. It is able of photosynthesis at temperatures as high as 73—75°C, although the genus also contains representatives of other biotopes. In addition other forms are known which are able of photosynthesis at a temperature of —30°C (Schopf & Blacic 1971).

At the time of deposition of the upper part of the Muhos formation the temperature has assumedly been fairly high. This assumption is supported by the presence of chemical clay mi-

nerals in addition to occurrences of cyanophyta and possibly sulfur bacteria. Action of sulfur bacteria occurs e.g. in the hot springs of the rift area of the Pacific Ocean (Corliss *et al.* 1979). The pyrite disseminations and crystals common in the sediment may be the result of the action of reducing sulfur bacteria. According to Schidlowski (1979 p. 300) the bacteria which reduce sulfates liberate H_2S as their main metabolic product, which readily combines to form sedimentary sulfide, mainly pyrite.

Part of the sulfur bacteria oxidize sulfur compounds, acting at the same time as a mild oxidant. The organic origin of the sulfur compounds appears from the isotope relations of the sulfur. According to Broda (1975) and Schidlowski (op. cit. p. 299) this photosynthetic action of purple and green sulfur bacteria as a mild oxidant of sulfates would have been a forerunner of the formation of free oxygen in the sea area 2.8—3.1 Ga ago.

In the continental area the oxidation of sulfur compounds is interpreted to have begun ca 2.2×10^9 years ago (Hattori *et al.* 1983). The microfossils interpreted as purple bacteria, found in the Tupos drill core at a depth of 165.47 m, can be considered as examples of oxidizing sulfur bacteria in the Muhos formation.

The fine-grained sediments of the Muhos formation have mainly formed under oxidizing conditions, which is indicated by the reddish color of ferric iron. Characteristic of the formation are also the sharply contrasting greyish-green reduced deposits; in whose connection the organiferous and pyrite-bearing portions occur as rarities. Mainly these redox variations are likely to be sedimentary, in which case significant factors for the redox potential have been the oxidizing and reducing action of the bacteria and possibly, during tectonically active times, also hydrothermal eruptions. However part of the reduction-oxidation phenomenon of the sediment has taken place afterwards, under the influence of reducing mineral assemblages.

The biogenic material preserved in the sedi-

mentary rock is exceptional with reference to recent sediments. The reducing redox conditions easily forming during the Late Precambrian even in shallow water can be considered as one of the preserving factors. According to the general opinion, which has its exceptions, the oxygen-rich atmosphere began forming under the influence of cyanobacteria during the Precambrian. Eskola's (1956) attention was attracted by the appearance of carbonate-binding algal reefs in Beltian and Cambrosilurian deposits all over the world. The abundant photosynthesis and the therewith connected exhalation of CO_2 is revealed by immense algal deposits. This in turn influenced the growth of the amount of oxygen in the air, as has been the case during all mountain-forming periods. In the beginning the photosynthetic oxygen was bound to the oxidizing minerals of the hydrosphere, and e.g. banded iron formations were formed (Cloud 1968), but the oxygen of the atmosphere formed gradually later towards the end of the Precambrian. At the time of deposition of the Muhos formation the share of oxygen was approximately 1 % (Cloud 1976). Under these conditions the chemical disintegration of the cyanophyta was limited. On the other hand the amounts of cyanophyta was large. According to Schopf & Blacic (1971) the cyanophyta reaced the peak of their development during the Late Precambrian, 900 Ma ago. The preservation of the cyanophyta was favored by the lack or rarity of organisms feeding on them.

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Plate I
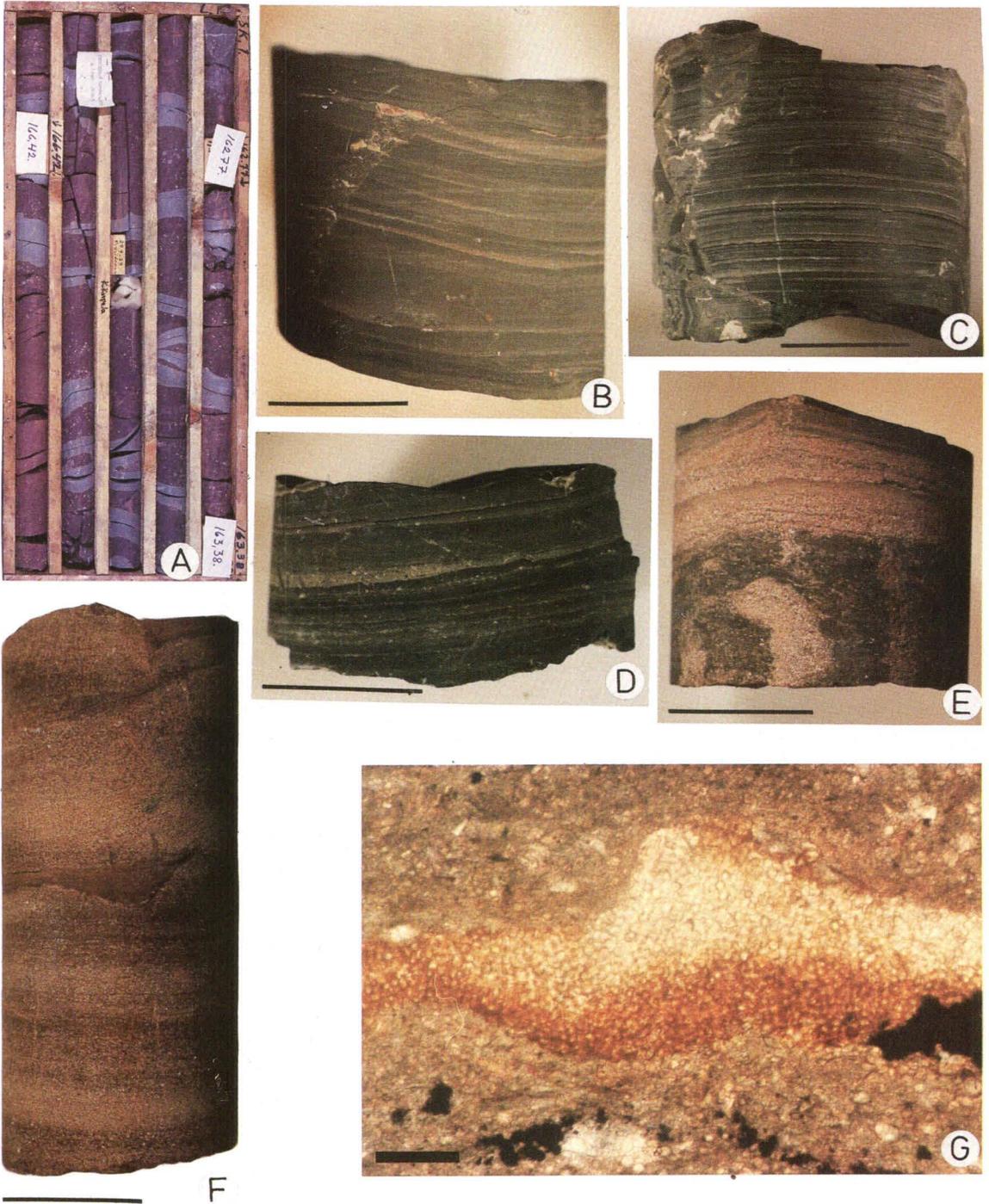
A. Reddish and greenish grey siltstone at a depth of ca 162.5—167.2 m, Tupos drill core. B. Greenish grey varved siltstone, depth 153.36 m. C. Dark grey varved claystone, depth 218.70 m. D. Dark grey varved claystone, depth 234.10 m. E. Arkosic sandstone, depth 712.92 m. F. Arkosic sandstone, depth 969.0 m. G. Recrystallized carbonate tinted red by hematite in greenish grey siltstone, depth 165.47 m. Black area CuS. Bar equals 2 cm in Figs. B—F.

Plate II

Geological Survey of Finland, Bulletin 330
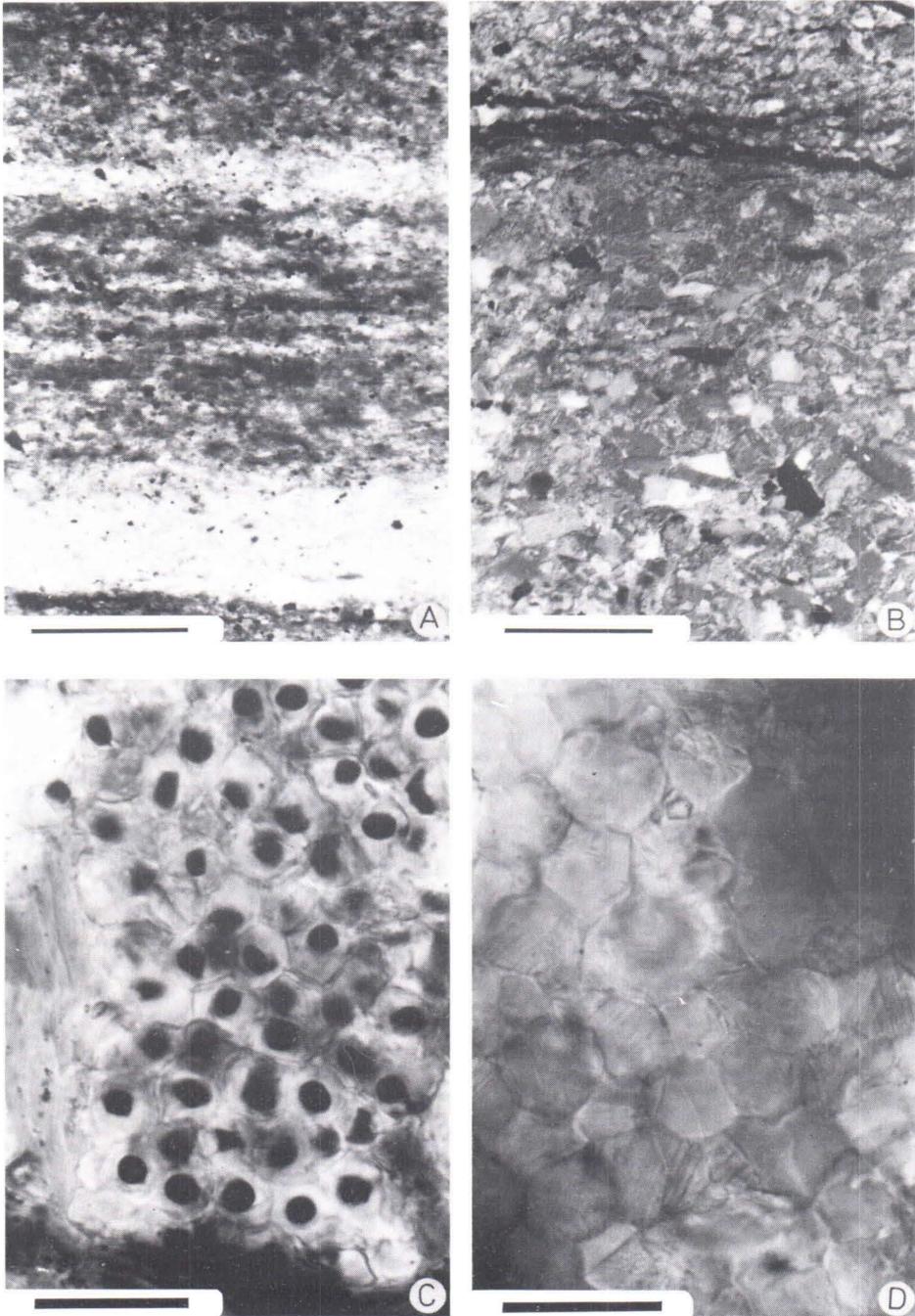
Sedimentary structures in thin sections from the 7upos drill core. A. Graded bedding in varved claystone, depth 218.40 m. B. Silty portion in partly recrystallized claystone, depth 218.40 m. C. Recrystallized carbonate around organic particles. Horizontal section, claystone, depth 234.30 m. D. Recrystallized carbonate in coarse-grained portion of claystone, depth 218.70 m. Bar equals 0.5 mm Figs. A and B, in Figs. C and D 20 μm.
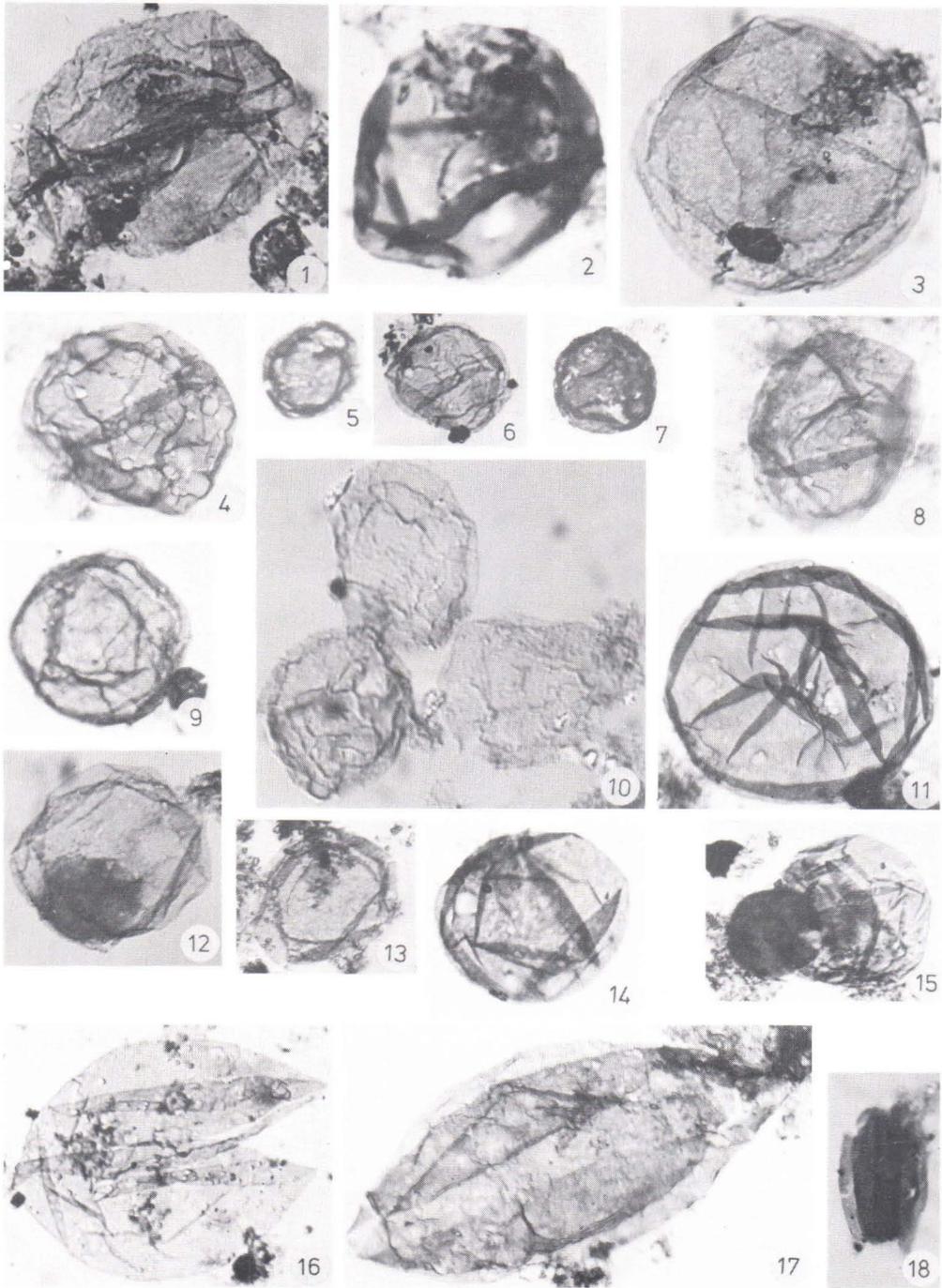
1—18. Relatively well preserved *Leiosphaeridia*-type fairly large spheromorphs from varved dark siltstones in the Tupos and Muhos I drill cores. Bar equals 20 μ.

Plate IV   Geological Survey of Finland, Bulletin 330
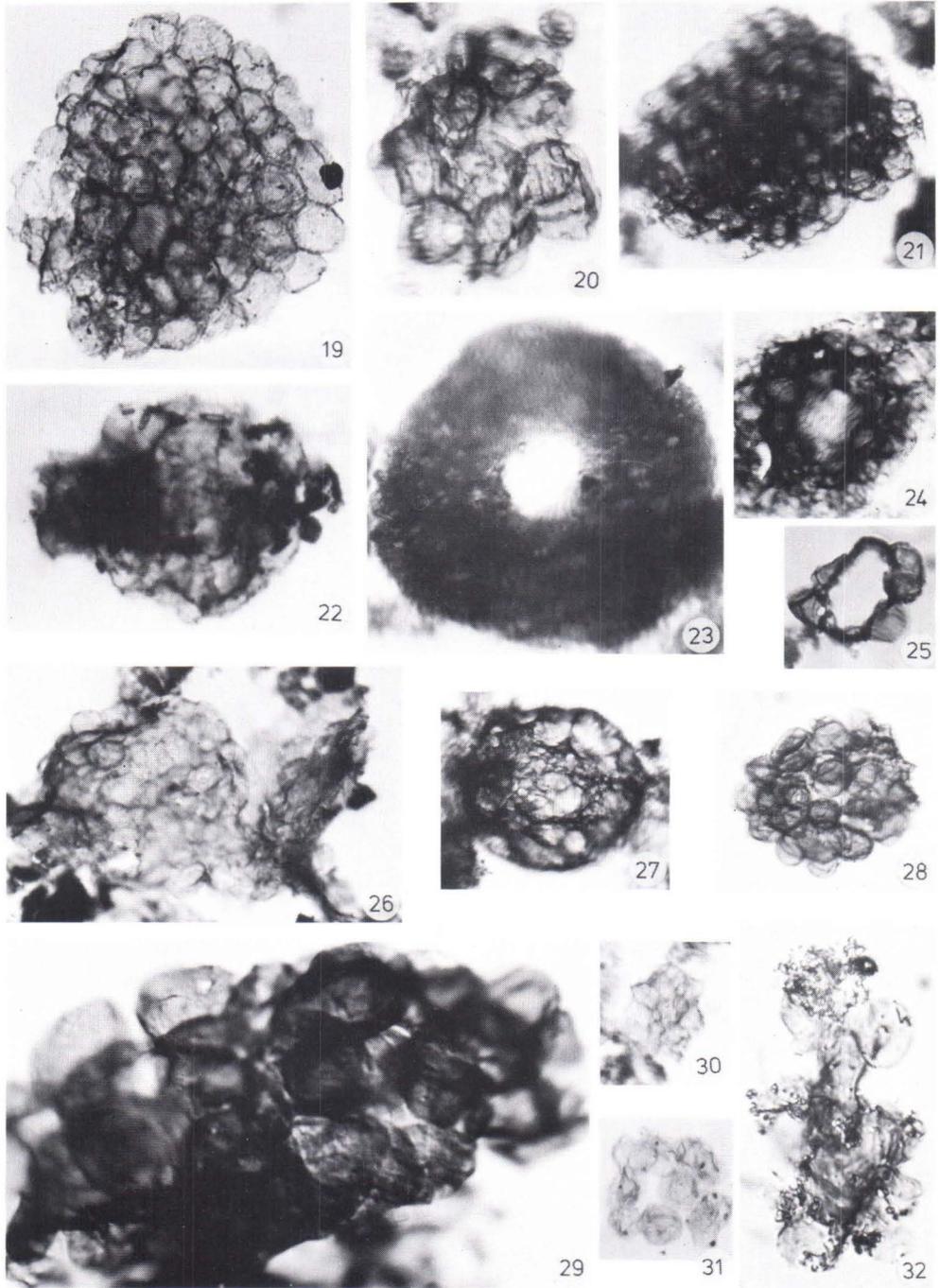
Types of colonies of spheromorphs. 19—21, 28, 30, 31. Types of *Synsphaeridium,* 22—24, 26, 27. Types of sporangia, 29, 32. Vegetative (?) cell colonies, 25 Fragment of sporangium ? Bar equals 20 μ.
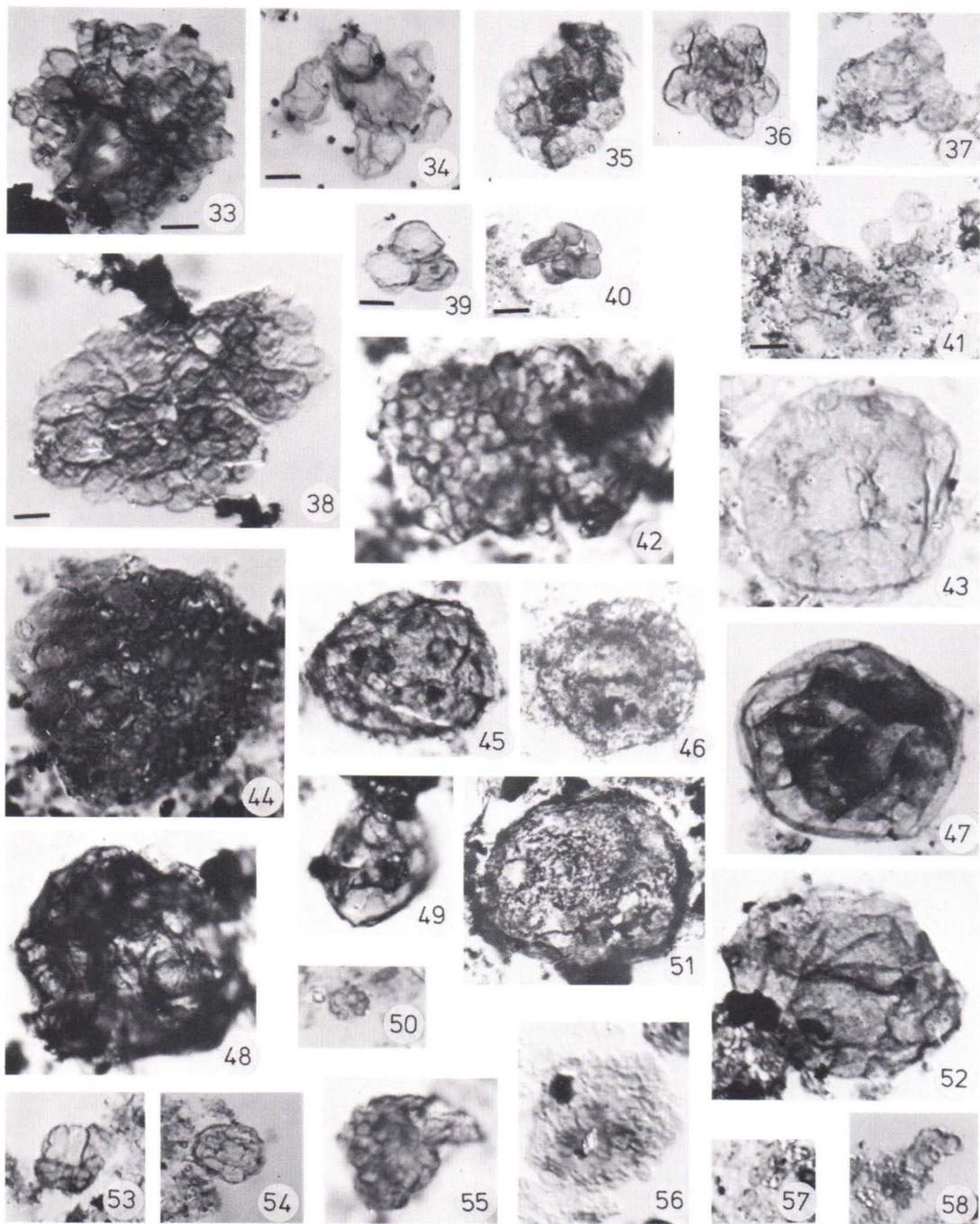
Types of colonies of spheromorphs. 33, 34, 39, 40. Synsphaeridium sp., 35, 36, 37. *Floritheca muhosensis* n. sp., 41. colony of spheromorphs, 38. *Gloecapsomorpha* sp., 42. *Palaeoanacystis* sp., 43—49, 51, 52. *Favosphaeridium* sp. 1., 50. *Bavlinella* typ., 53, 54, 55. *Palaeopleurocapsa* sp., 56—58. Colonies of small cells. Bar equals 10 μ.

Plate VI   Geological Survey of Finland, Bulletin 330
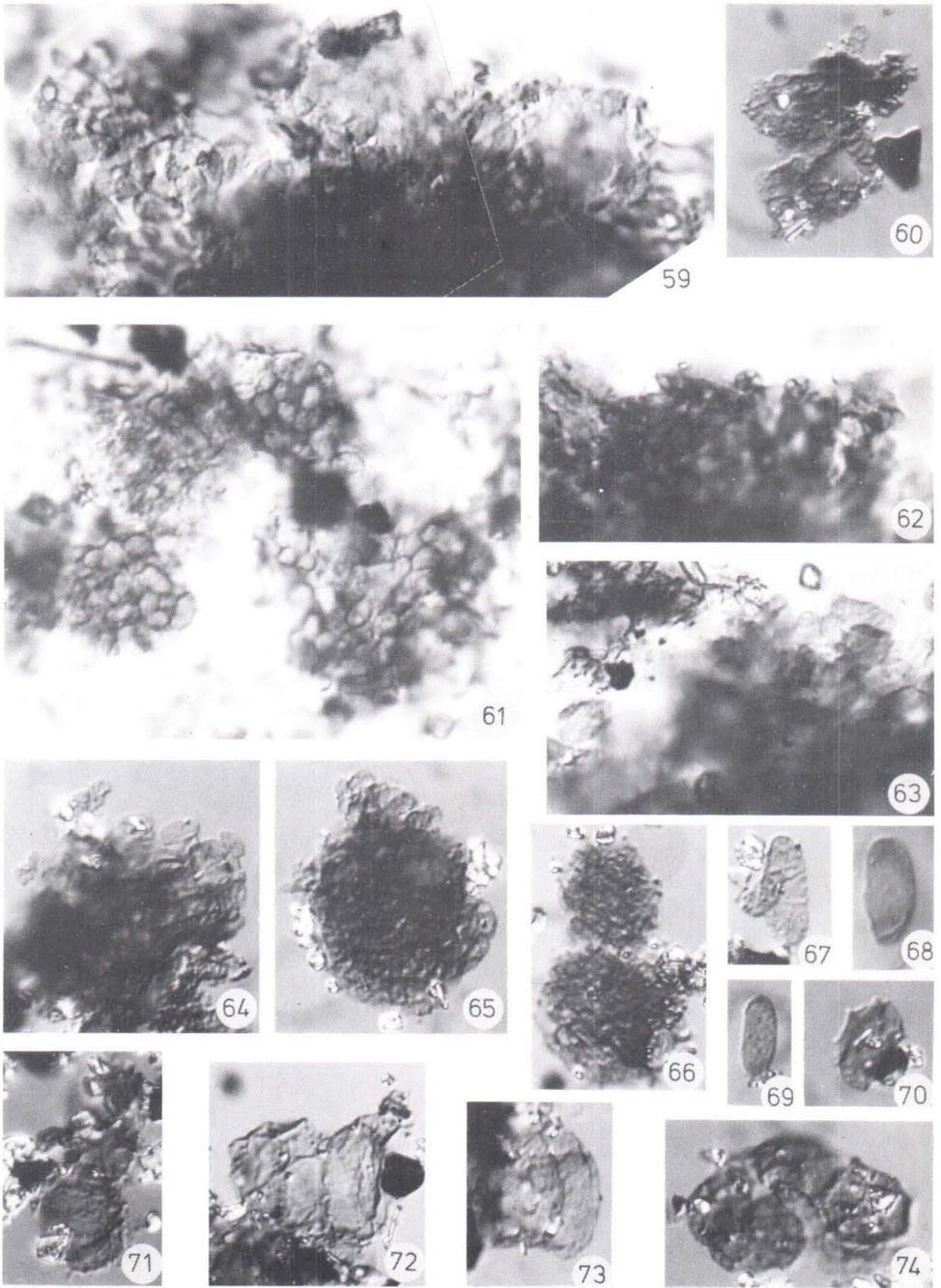
Small spherical and ellipsoidal cell colonies and solitary cells. 59, 61, 62, 63, 64. *Eosynechococcus moorei,* 60, 65, 66, 74. *Sphaerophycus* aff. *parvum,* 67, 68, 69. *Microvalia spinosa,* 70. *Eomicrhystridium* sp., 71, 72, 73. *Microvalia* in colonies. Bar equals 10 μ.
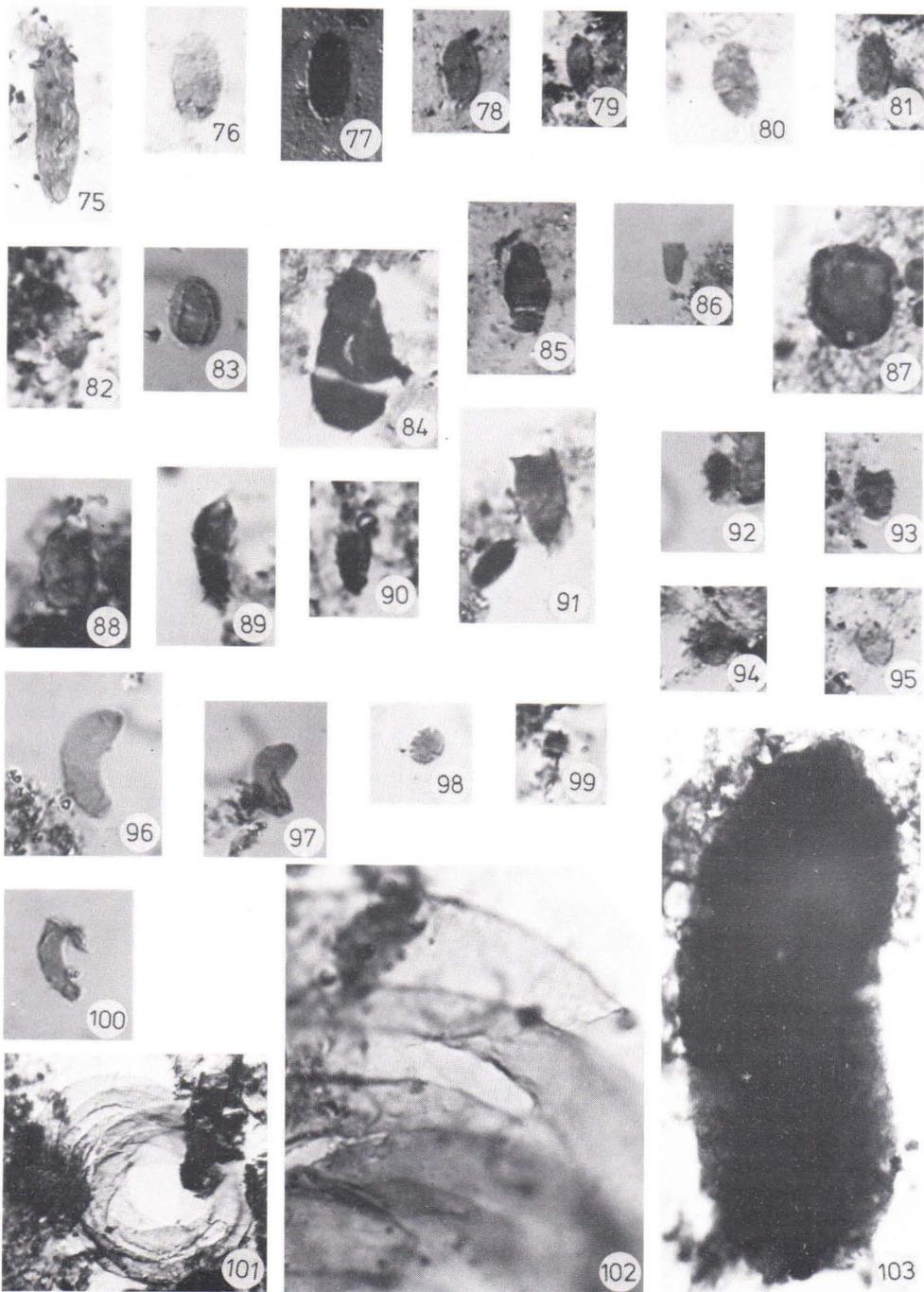
Ellipsoidai and curved cells, ring-sheath. 75. *Leiovalia* sp., 76—83, 88. *Microvalia spinosa,* 84—87. Oval cells, 89—93. Oval cells with dentate outlines, 94, 95, 98, 99. *Eomicrhystridium* sp. 2., 96, 97, 100. *Lunulidia nana,* 101—102. Ring-sheath, 103. Problematic form. Bar equals 10 μ, except in Figs. 101 and 103 where it equals 50 μ.

Plate VIII

Geological Survey of Finland, Bulletin 330
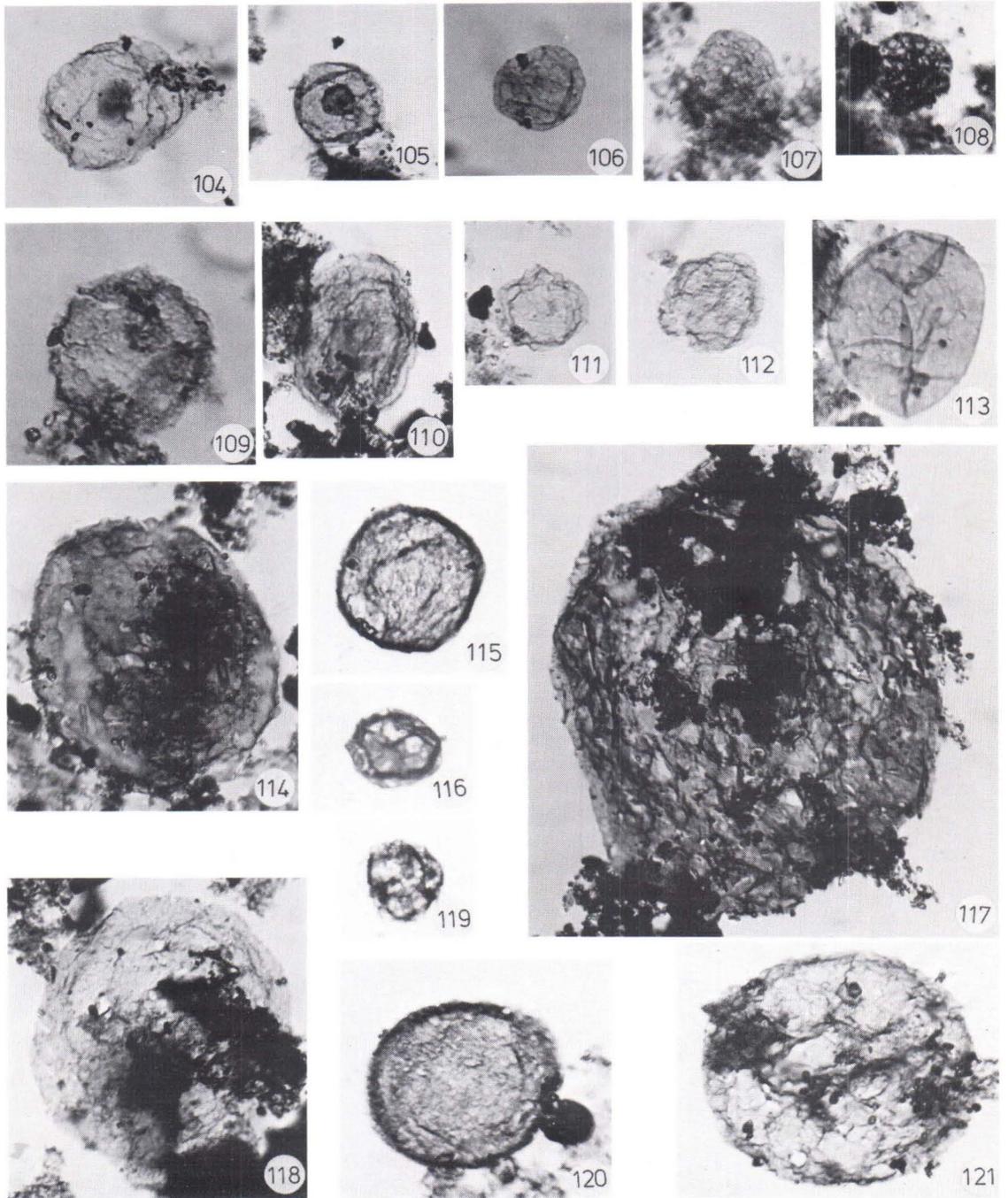
Spheromorphs with cellular inner structure. 104, 112. *Symplassosphaeridium* sp., 105—111, 113—121. *Favosphaeridium*
type 2. Bar equals 10 μ.
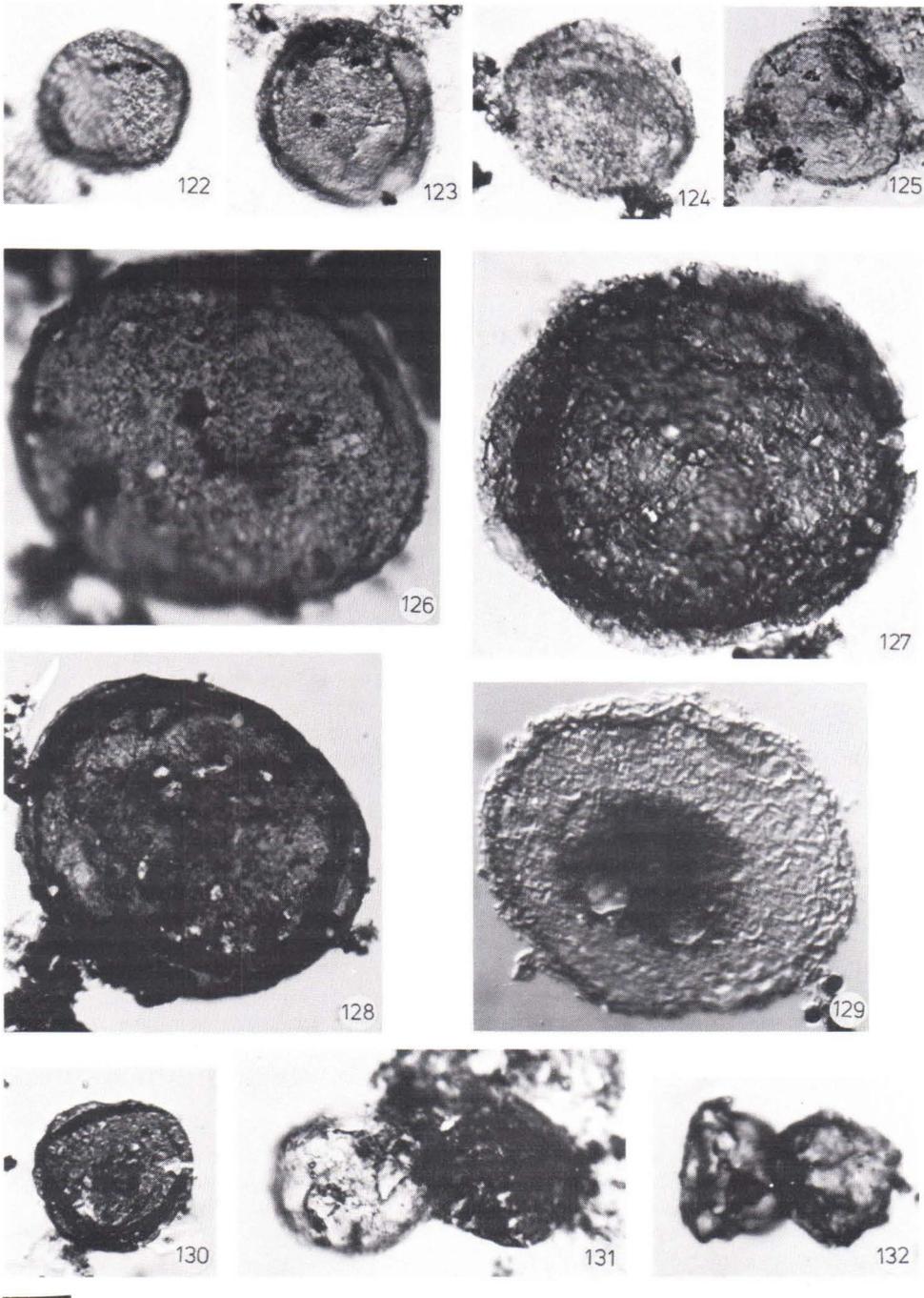
Spheromorphs with a rough surface. 122—125. *Trachysphaeridium levis,* 126—129. *Trachysphaeridium laminaritum,* 130. *Trachysphaeridium* sp., 131. *Trachysphaeridium* joined with a lighter spheromorph, 132. *Trachysphaeridium,* twin form. Bar equals 20 μ.

Plate X   Geological Survey of Finland, Bulletin 330
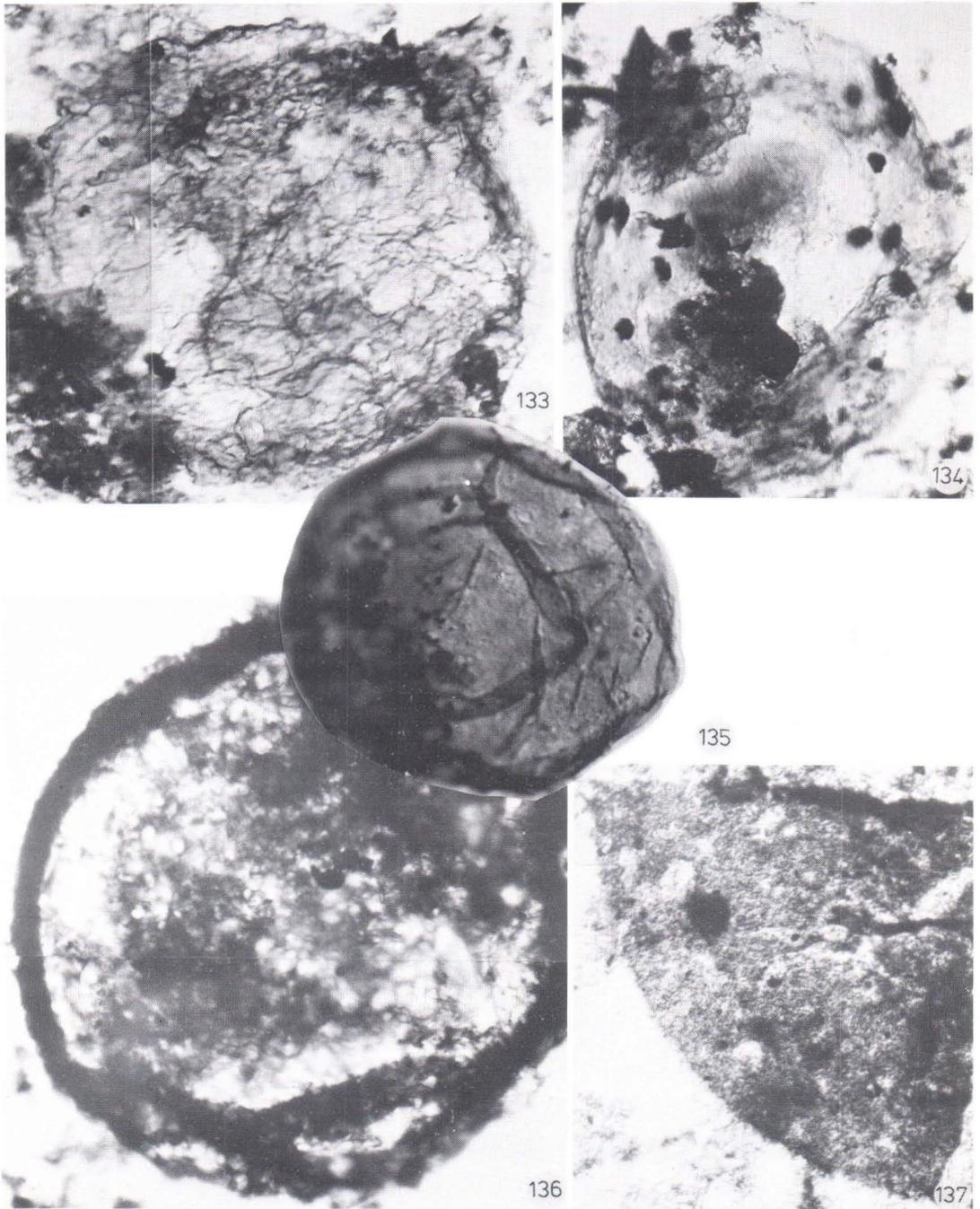
Large spheromorphs. 133—135. Spheromorphs with smooth surfaces, densely or sparsely folded, 136. Cellular surface, possibly *Protosphaeridium* sp., 137. Large spheromorph with a nappy surface, estimated diameter 250 μ. Bar equals 20 μ.
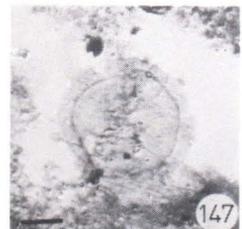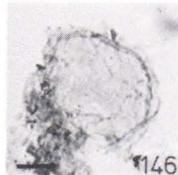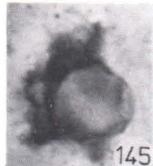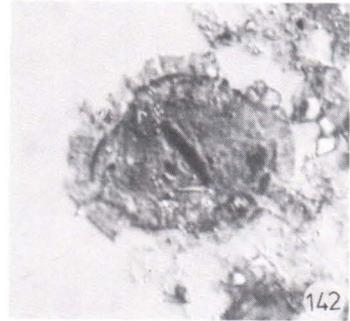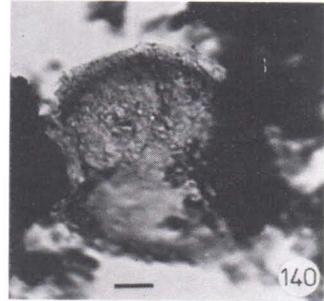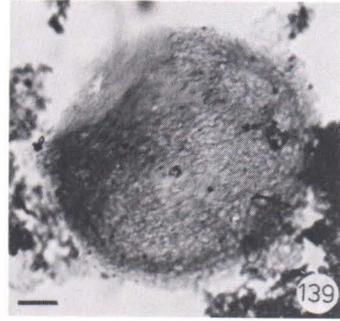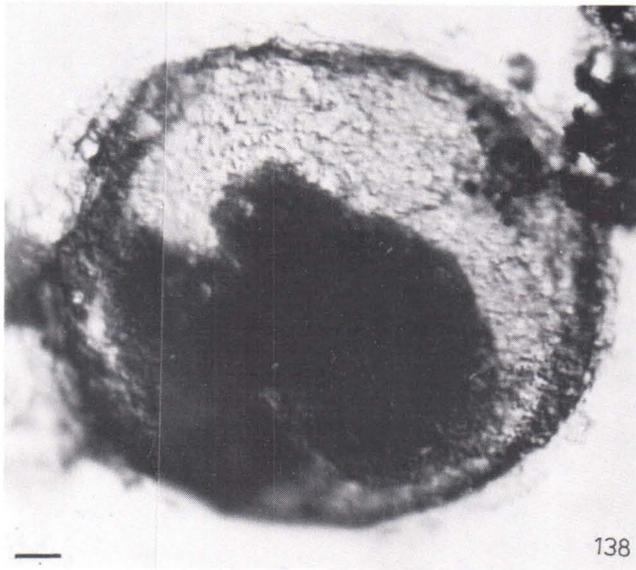
Spheromorphs with vesicle surrounded entirely or at the equatorial zone by a veil-like outer membrane. 138—141. *Pterospermopsimorpha ornata,* 142, 147. Granomarginata sp., 143, 144, 145 (in thin section). *Pterospermella simica,* 146. ? *Granomarginata* sp. Bar equals 10 μ.

Plate XII   Geological Survey of Finland, Bulletin 330
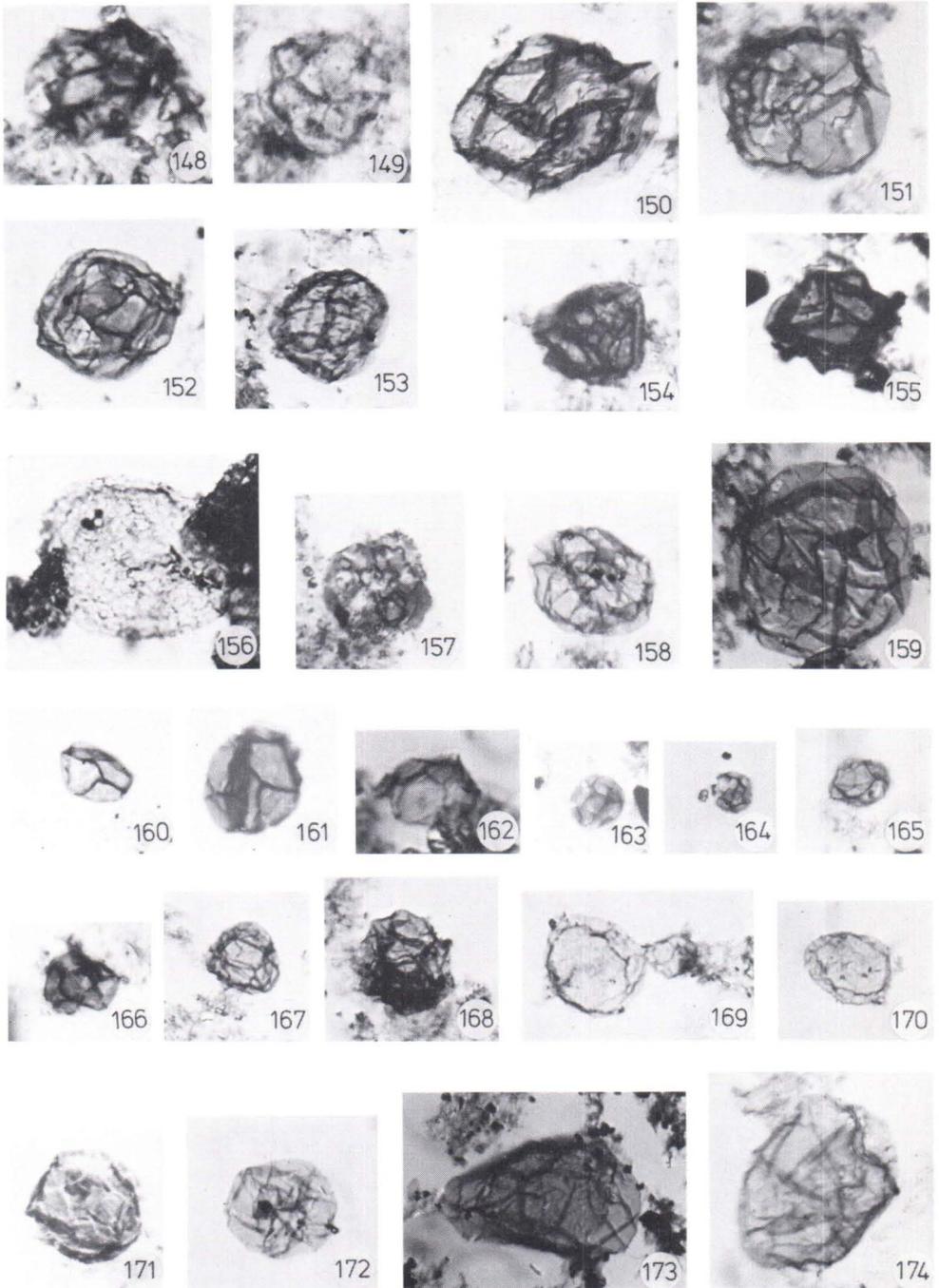
Spheromorphs with folded surface, mainly deformed forms of *Leiosphaeridia*. 148—150. Deformed form, resembling *Trachysphaeridium,* 151—168, 171—174. Deformed forms, resembling *Cymatiosphaera,* 169, 170. *Eosphaera* sp. Bar equals 10 μ.
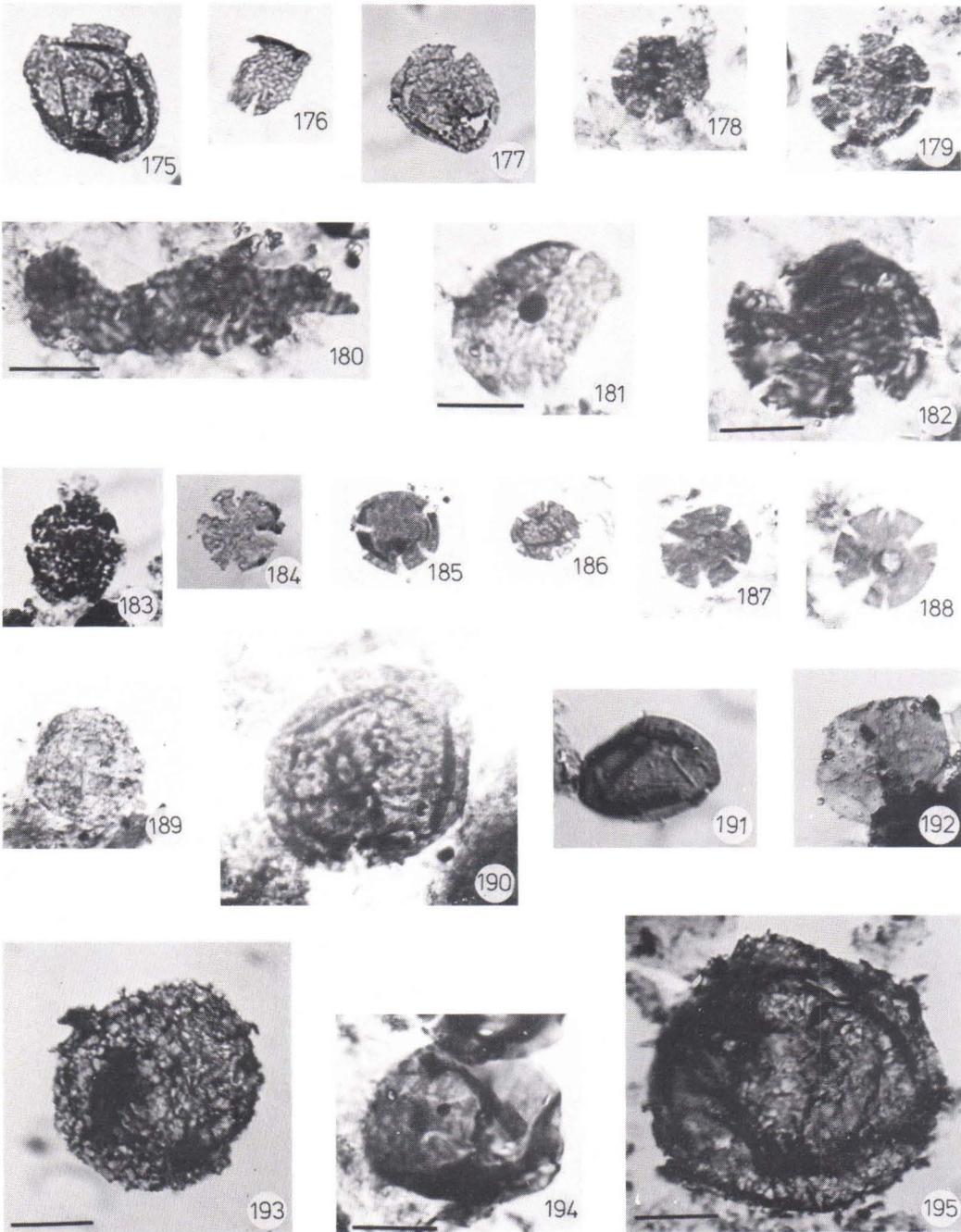
Spheromorphs with discernible structural pattern on surface. 175—186. *Turuchanica maculata,* 187, 188. *Turuchanica kulgunica* (Jankauskas) n. comb., 189—191. Spheromorphs with granulated surface, 192. ? Spheromorph with granulated surface, 193, 195. Spheromorphs with reticulate surface, 194. *Ooidium*-type spheromorph (spinous structures on the left may be due to rupturing). Bar equals 10 μ.

Plate XIV

Geological Survey of Finland, Bulletin 330
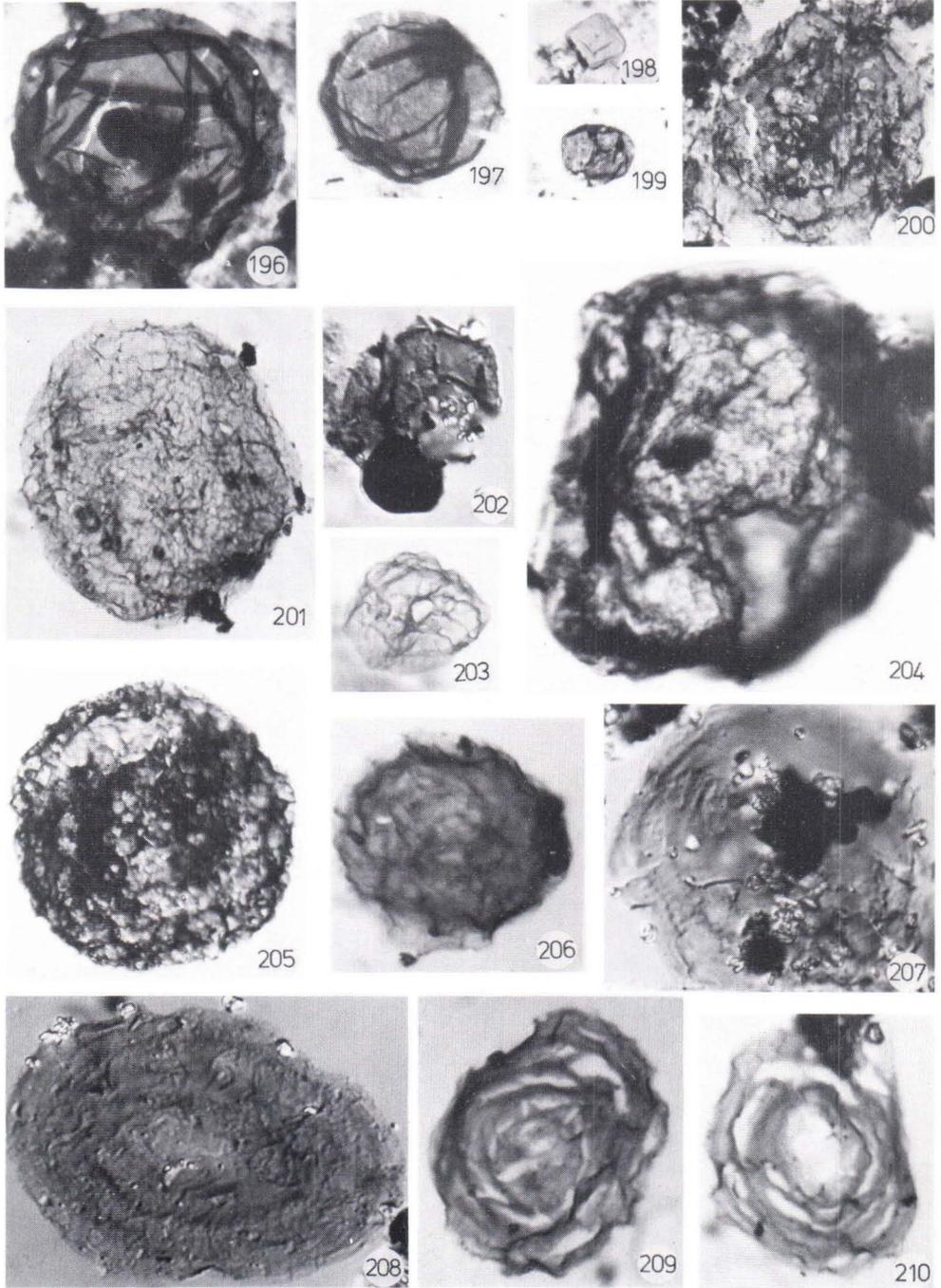
Mainly deformed spheromorphs. 196, 197. *Nucellosphaeridium* sp., 198. Quadratic vesicle, 199—206. Spheromorphs patterned by mineral grains, 207—210. Flattened spheromorphs with discernible banding or wearing along the outline. Bar equals 10 μ.
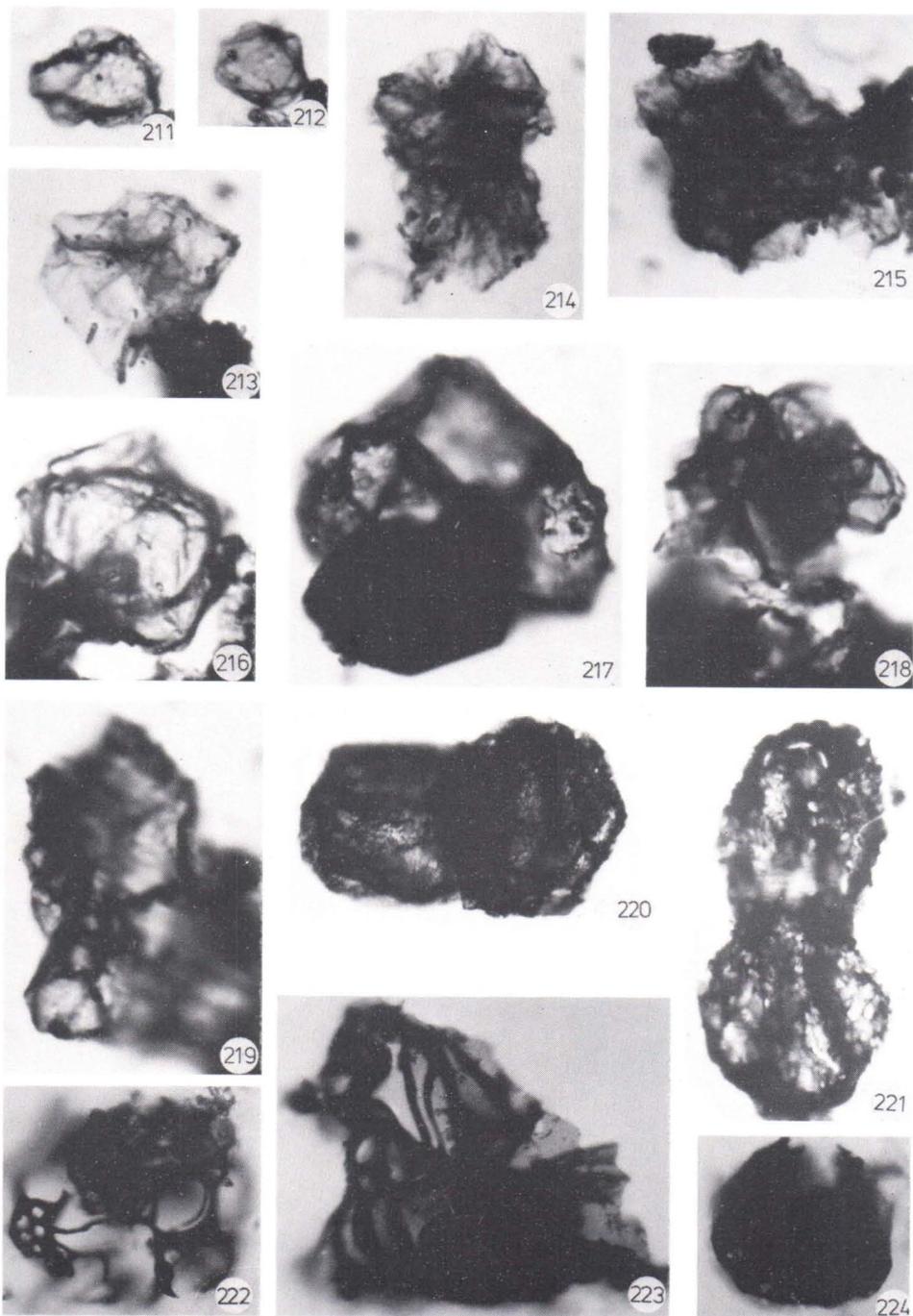
Deformed vesicles (211—224). 211—213. *Octaedryxium* type, 215. *Polyedryxium* type, 222—224. Vesicles deformed by heat, Tupos drill core, depth 388.4 m. Bar equals 10 μ.

Plate XVI

Geological Survey of Finland, Bulletin 330
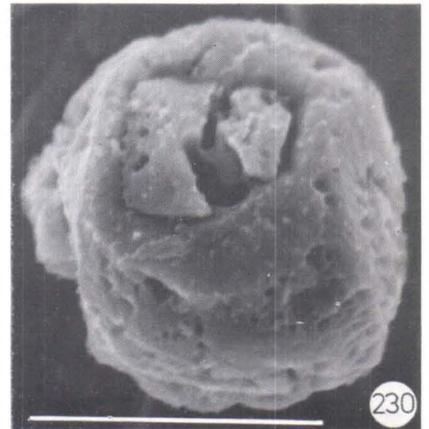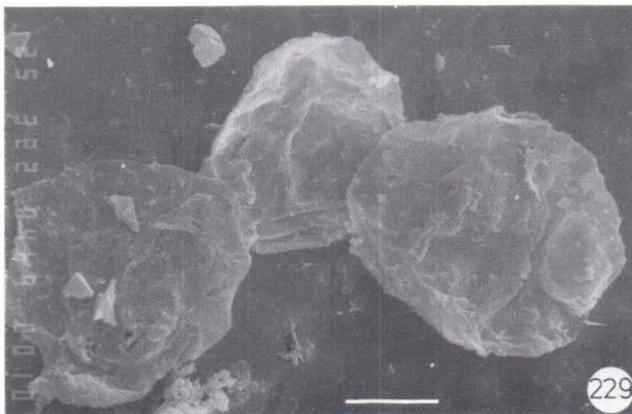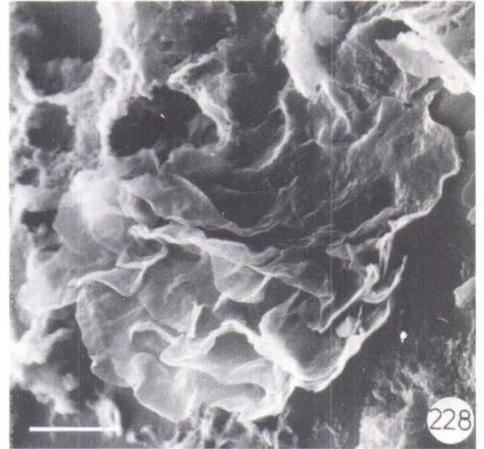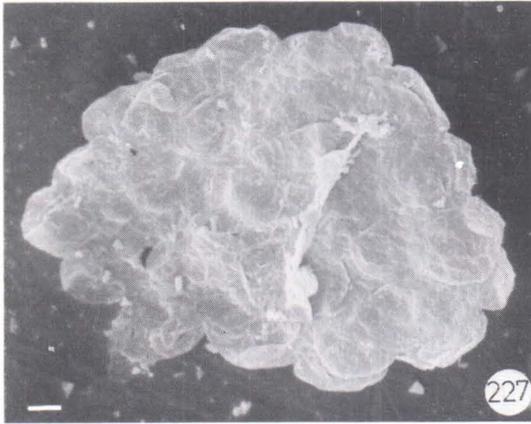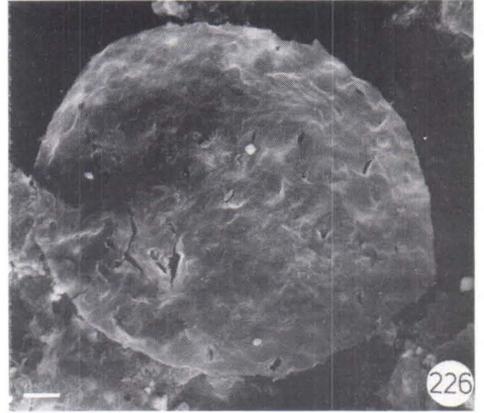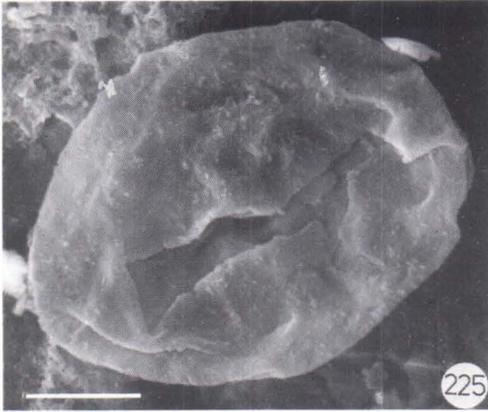
Electron micrographs of spheromorphs. 225, 226. *Leiosphaeridia* sp., 227. *Synsphaeridium* sp., 228. *Synsphaeridium*, vesicles completely flattened, 229. Group of small spheromorphs, 230. *Eomicrhystridium* sp. 1.
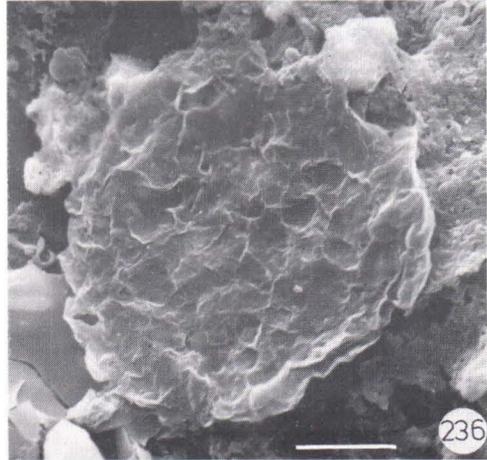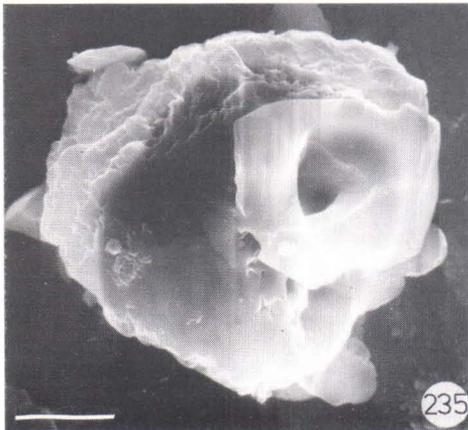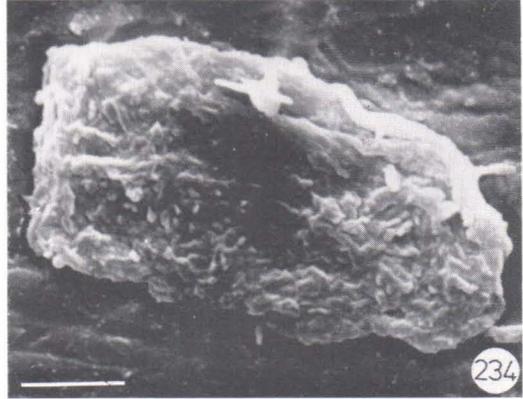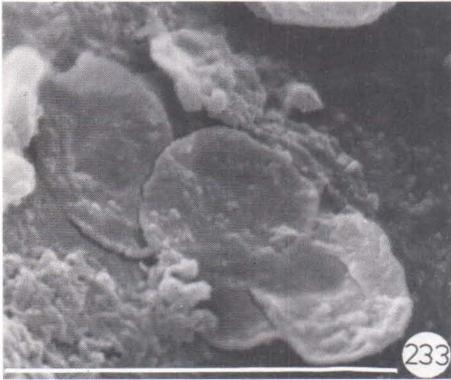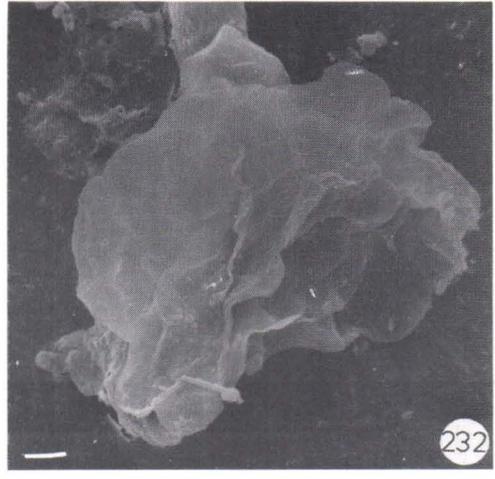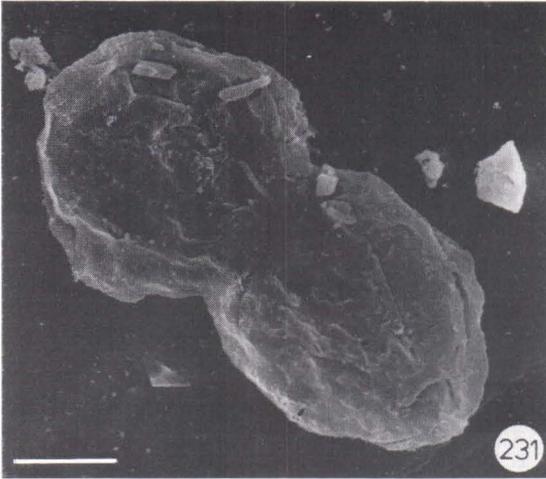
Electron micrographs of preserved and deformed spheromorphs. 231. Twin vesicle, 232. Flattened *Synsphaeridium,* 233. *Sphaerophycus* aff. *parvum,* 234. ? *Turuchanica* ribbon-punctata, 235. Ruptured spheromorph, 236. *Leiosphaeridia* sp., with surface patterned by mineral grains; common form.

Plate XVIII   Geological Survey of Finland, Bulletin 330
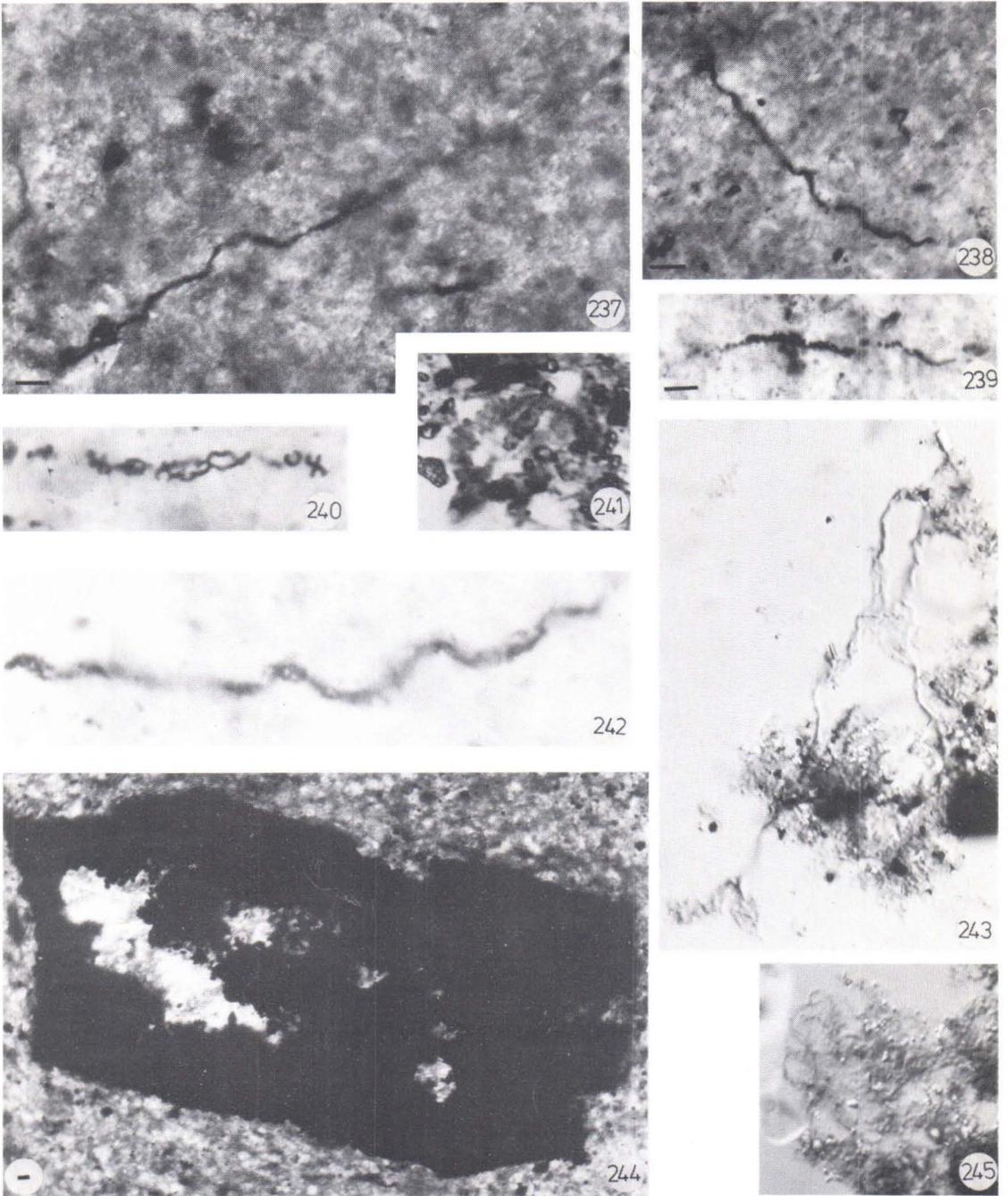
Filamentous forms in thin sections (237—240, 243, 244) and in maceration preparations (241, 243, 245). 237—240, 242. *Eomycetopsis* sp., 241. *Heliconema* sp., 243. Filament with cystoid protuberances, 244. ? Fragment of a large filament, 245. ? *Contortothrix* sp.

Filamentous cyanophyta. 246. Giant filament, 247—249. Sheathlike tube, 250—253. *Siphonophycus* sp.

Plate XX   Geological Survey of Finland, Bulletin 330
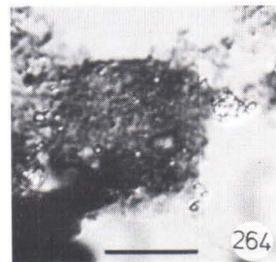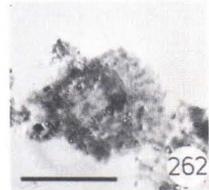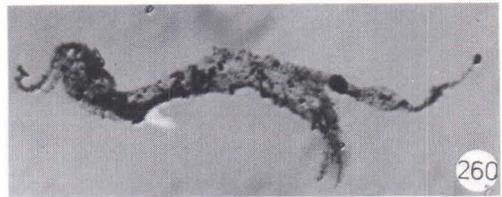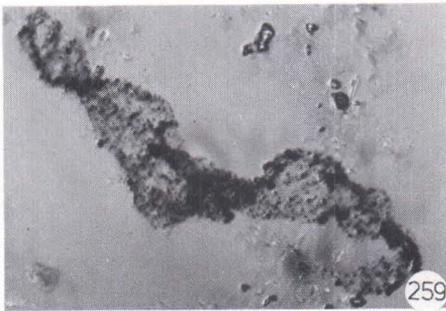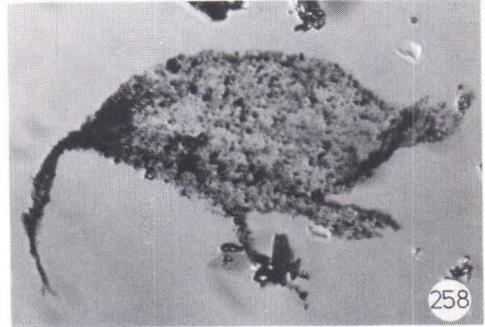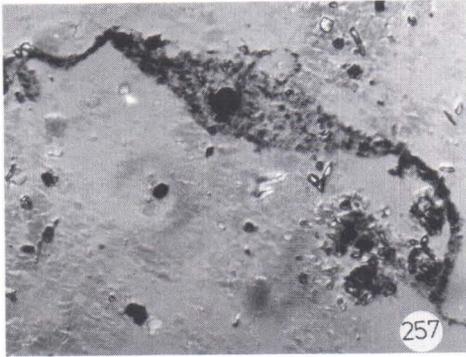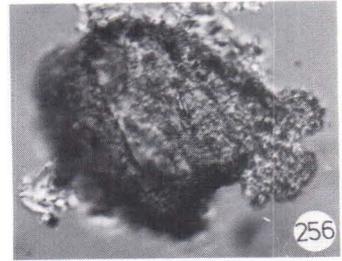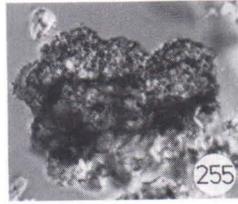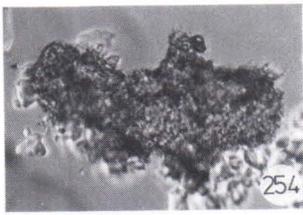
Problematic forms. 254—256. Granulated vesicles, 257—260, 263. *Spirosaccus punctata,* 261, 262, 264. *Volyniella* type.