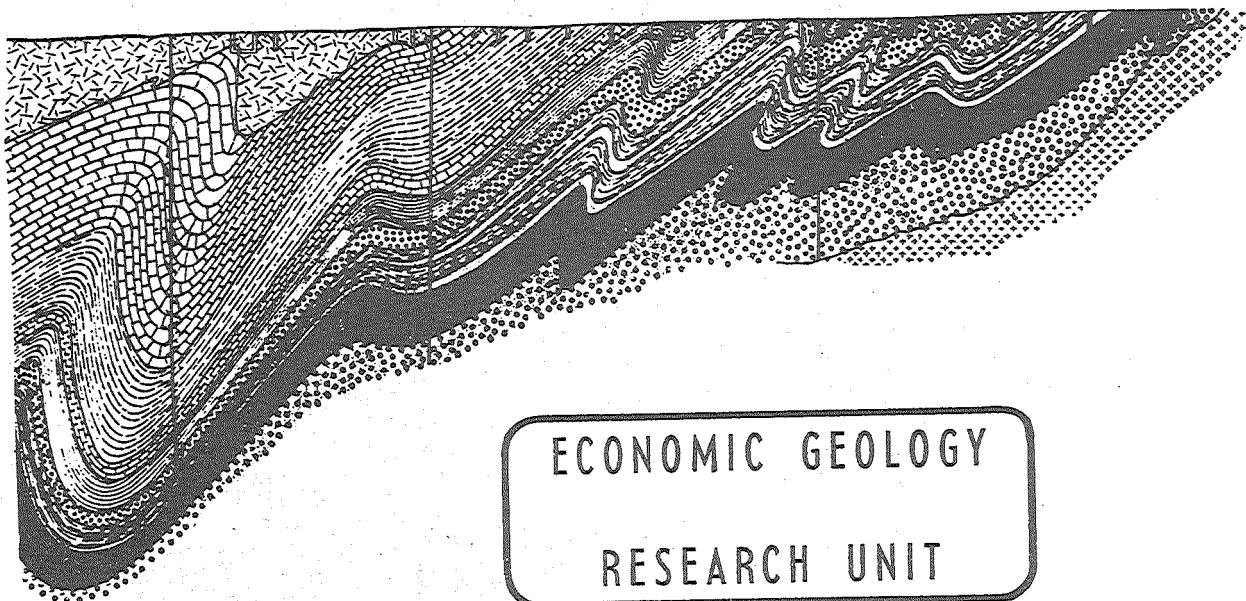




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STRUCTURED ORGANIC REMAINS FROM THE
FIG TREE SERIES OF THE
BARBERTON MOUNTAIN LAND

H. D. PFLUG

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STRUCTURED ORGANIC REMAINS FROM THE FIG TREE SERIES
OF THE BARBERTON MOUNTAIN LAND

by

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STRUCTURED ORGANIC REMAINS FROM THE FIG TREE SERIES
OF THE BARBERTON MOUNTAIN LAND

ABSTRACT

The Fig Tree Series of the Swaziland System in South Africa is, according to radiometric data, more than 3200 million years old. Cherts and shales, collected in the vicinity of the Sheba Gold Mine, near Barberton, have been studied for their microfossil content. Cut sections, thin-sections, and macerations have yielded an assemblage of organism remains. Chemical and optical investigations have been conducted to determine whether the walls of the bodies consist of organic material. Globular Type A structures resemble cysts of flagellates, while Filamentous Type C bodies are assigned to nostocalean blue-green algae. There are other structures of problematic affinity (Globular Type B, Filamentous Type D, and Irregular Type F). Finally, a thread-like structure has been identified as a pseudofossil.

Several of the fossil structures were chemically analysed by means of an electron probe X-ray microanalyser. The results yielded evidence that the algal bodies were able to precipitate metal salts (with cations such as copper, iron, calcium) from water by the action of their life processes. The observations suggest that similar biological processes could have been an important factor in the formation of the Pre-cambrian sedimentary ore deposits. The fossil findings lead to the conclusion that life must be older than 3200 million years. At that time, local conditions must have been present on Earth which permitted the existence of photosynthetic plants.

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STRUCTURED ORGANIC REMAINS FROM THE FIG TREE SERIES
OF THE BARBERTON MOUNTAIN LAND

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STRUCTURED ORGANIC REMAINS FROM THE FIG TREE SERIES
OF THE BARBERTON MOUNTAIN LAND

INTRODUCTION

A. SAMPLE COLLECTING

All material described in this paper was collected in the vicinity of the Sheba Gold Mine near Barberton. The samples represent rocks of the Fig Tree Series of the Swaziland System which radiometric measurements have indicated to be more than 3200 million years old (Nicolaysen, 1962).

In contrast to the high age, the alteration of the rock samples collected is remarkably low. Another surprising feature is the relatively high carbon content of several of the shales studied. Geochemical investigations of similar Fig Tree shales, conducted by Dr. T. C. Hoering of the Geophysical Laboratory in Washington, have yielded evidence that organic material is present (personal communication).

The following samples were examined for microfossils during the present investigations :

<u>Laboratory Catalogue No.</u>	<u>Rock-type</u>	<u>Location</u>
I32	shale	Sheba-Fairview road cutting, sample point 35/36.
I35	shale	Sheba Mine, Zwartkopje underground area, 5 Fracture.
I36	shale	Sheba Mine, dump material.
I37	banded jasper	Sheba Mine, Zwartkopje underground area, 5 Fracture.
I40	shale	Sheba Mine, dump material.
I53	shale	Sheba Mine, underground borehole cores, 4 Level, 5 Fracture.
I55	chert	Sheba Mine, underground borehole cores, 4 Level, 5 Fracture.
I56	shale	Sheba Mine, dump material.

B. PREPARATION TECHNIQUES

Microscopical examinations were made of :

- (a) cut sections under reflected light,
- (b) thin-sections under transmitted light, and
- (c) maceration residues under transmitted light.

(a) Cut Sections

Larger rock specimens, several inches in diameter, were needed for this method. A diamond blade was used for cutting the material. The cut surface, several square inches in size, was examined, immediately after preparation, under the microscope. Polishing procedures were avoided, since they might have introduced contamination into small fractures in the rock. The microscope was equipped with a Leitz Ultropak incident-light illuminator and a xenon lamp or a high-pressure mercury lamp. Under the intense light of these lamp-types, rocks usually became transparent to a certain depth. Structured inclusions located close enough to the rock surface were detected easily, and studied and photographed. Magnifications up to $\times 1000$ and numerical apertures up to 1.0 were possible by using Ultropack oil-immersion objectives.

The method has the advantage that the preparation procedure is quick and simple, and that there is practically no danger of the rocks becoming contaminated during the preparation procedure. The area available for examination is many times larger than that of a thin-section. Examination takes place of the structures *in situ*. However, the application of the technique is restricted to certain types of rocks. One of the necessary conditions is a clear, transparent matrix, such as is present in cherts and quartzites. Fine, granular clay minerals disturb the field of view, and shales are, therefore, less suited to the technique. In a shaly matrix, it is usually possible to recognise the organic remains, but impossible to identify them, or to study them in detail. Another disadvantage of the method is the time consumed in examination of rocks poor in structured inclusions. In certain instances, no conclusions can be drawn from observations of cut sections as to whether the structures detected are real fossils or pseudofossils, since they lack the necessary characteristics of shape and structure to distinguish them positively from inorganic inclusions. Overall, the investigation of cut sections under reflected light is of assistance in detecting and observing organism-like inclusions in rocks, but the final proof of the organic nature of these structures must be left to other methods.

In the present study, organism-like bodies were found in the cut sections of Specimens 135, 136, 137, 140, 153, and 155. The microscopic images obtained from Specimens 132 and 156 were not clear enough to allow of any positive conclusions.

(b) Thin-Sections

During the examination of the cut specimens, all areas which appeared to be rich in organism-like assemblages were marked for the subsequent preparation of thin-sections. Additional information, such as the birefringence of the material, was obtained from the examination of these thin-sections in transmitted, normal and polarized light. A larger number of thin-sections was made of the chert sample (155) and the jasper sample (137), since both these specimens appeared to be especially rich in well-preserved organism-like bodies.

Infrared light was applied to the structure which appeared opaque under normal light. The fluorescent characteristics were studied by utilizing ultraviolet and blue light of a mercury lamp. Both infrared and fluorescence techniques are suitable for thin-sections in transmitted light, and for cut sections in reflected light.

(c) Maceration Slides

The specimens listed previously were also subjected to maceration. Normally, organic remains of Precambrian age are delicate and very sensitive to chemicals, and, a special technique is necessary, in which all strongly reactive liquids are avoided. The crushed samples were treated with 1 per cent nitric acid which was added cold, the mixture being kept at room temperature. The maceration process was continued for three months, with the acid being renewed each day. After this treatment, organic matter was separated out in a heavy liquid consisting of a mixture of potassium iodide and cadmium iodide. The mixture was dissolved in water and adjusted to a density of 2.0. Glycerine was used as a mounting medium for the particles of organic matter thus obtained, the margins of the cover glass being sealed with lacquer.

(d) Avoidance of Contamination

All rock samples were carefully cleaned before one half of the sample was crushed in a jaw-breaker, and the other half in an hydraulic press. Both methods of diminution yielded good results. However, the advantage of the hydraulic press is that it can be fitted with an airtight envelop which prevents possible contamination by airborne dust. The portion of the specimen intended for the hydraulic press was placed in a cylindrical metal vessel, into the opening of which the piston of the hydraulic press fits exactly, so that practically no dust is produced during the crushing process. In addition, the cylindrical vessel, the piston, and the shank of the press were wrapped in an airtight plastic bag.

The samples crushed in the jaw-breaker could be kept clean to nearly the same extent, provided the crushed material was enclosed in plastic bags, and that, through the entire subsequent procedure, it did not come in contact with the atmosphere.

The beakers containing the macerating mixtures were placed in plastic bags. The centrifuge glasses were also surrounded by plastic to avoid contamination of the material by air movements during the centrifugal spinning.

All liquids used in the preparation of the material were filtered before use. As ordinary paper filters might introduce cellulose fibres, membrane or cella filters, with a pore diameter less than 0.2 micron, were employed.

With all the above precautions, contamination of the samples in the laboratory can practically be avoided. However, the possibility remains that the samples taken from surface exposures are already internally contaminated before they come into the laboratory. No procedure is known for removing particles filling fine fractures in the rock. Although the dump material (135, 140, 156) was collected shortly after being brought out from underground, the possibility of contamination still exists. Past experience has shown that borehole cores are normally free of contamination, and that the same holds true for samples taken directly underground (135, 137, 153, 155). Nevertheless, no possible organic material obtained from maceration has been acknowledged as a fossil unless specimens of the same kind have been observed in the matrix of thin-sections or cut sections.

(i) Where the interior of the structured bodies is filled with rock matrix or the remains are pierced by crystal needles, the presence of fossils is indicated.

(ii) Precambrian organic material usually does not show strong birefringence, while organic contaminations often do, especially if they contain cellulose.

(iii) Precambrian organic material usually exhibits no, or at best a weak, blue fluorescence, when excited by ultraviolet light. Probably, the tendency to fluoresce diminished during alteration. Contaminations containing cellulose-fibres fluoresce with a bright-white colour, wax-like contaminations with a yellow or brownish colour, and chitinous or similar materials with a reddish colour.

C. CHEMICAL ANALYSIS

Chemical analysis was employed to determine whether or not organic substances are present in the organism-like remains detected. The samples were powdered in a ball mill, and the fraction with a specific gravity less than 2.0 was separated in a cadmium-potassium iodide solution. C-H-N-analyses run on this material indicated that the greater portion of the carbon is present in the form of graphite. The elements H and N were found in amounts which indicate the presence of organic compounds. The same material was subjected to an infrared-spectrophotometric analysis which also revealed the presence of organically-bound carbon. Detailed information as to the nature of the bonds could not be obtained because the opaque graphite particles lowered the contrasts of the oscillations of the measurement curves. The same type of analysis was applied to the material after it was macerated with HNO_3 and then separated in a heavy liquid. The results obtained from this macerated material were similar to those obtained from the unmacerated, showing that the maceration process did not influence the chemical constitution of the organic matter.

This twofold analytical procedure was necessary as ball-milling destroyed all structures, rendering the crushed material unsuitable for further microscopic investigation.

The maceration residue was dried and placed under a microscope equipped with a heating stage. When a temperature of 220°C was exceeded, the organism-like bodies started disintegrating. Only a tar-like spot and some flakes of clay, which had coated the walls of the bodies, were left when the temperature reached 500°C . The mineral and the graphite remained unaffected at temperatures up to 400°C . These observations gave evidence that part of the organic substance previously detected by chemical analysis must be located in the structured bodies.

D. THE MODE OF OCCURRENCE OF THE ORGANIC MATERIAL

Examination of Specimen I35 showed the matrix of the chert to consist of interfingered quartz grains averaging 20 microns in diameter. Layers of finer and coarser material alternate, indicating a bedding structure. The bituminous substance, both structured and unstructured, is oriented in the bedding planes and concentrated in small dark layers which are intercalated with the lighter-coloured material. Euhedral rhombs of calcite and other carbonates occur scattered in the matrix. These measure about 35 microns in diameter. The quartz grains show undulatory extinction, which

may be evidence for crystallization from silica deposited as a gelatinous mass. Undulatory extinction in quartz grains from low temperature veins has been described by Adams (1920) who attributes the phenomenon to slight differences in orientation caused by coalescence of small crystals to produce large ones, and not to internal strains. The three-dimensional mode of preservation and distribution of organic material in the matrix of the Fig Tree cherts leads to the conclusion that it must have been suspended and sealed within a gelatinous silica mass.

In some instances, the organic structures and the carbonate crystals apparently were displaced or deformed by the subsequent crystallization of the silica. Locally, veins can be observed which are filled with coarser quartz and calcite crystals. They may belong to a considerably more recent period.

THE MICROFOSSILS OF THE FIG TREE ROCKS

A. GLOBULAR TYPE A MICROFOSSILS

Group A1 represents opaque, egg-shaped bodies found in thin-sections of the chert (Plate 1, Figs. 1 and 2). They are hollow, as can be seen in specimens cut by the surface of the thin-section (Plate 1, Fig. 11). The wall appears to consist entirely of a dark organic substance. The surface does not show a distinct pattern. Often, two or more specimens are connected at their poles, and are arranged in line (Plate 1, Figs. 1, 2, and 5), so that the whole assemblage forms a thread-like colony.

Where the wall has disintegrated into minute particles, only the gross contours of the original bodies are preserved. For the most part, the contours have been deformed (Plate 1, Fig. 7) by subsequent crystallization processes in the rock matrix, a phenomenon visible under polarised light (Plate 1, Fig. 3). In the final stage of crystallization or recrystallization the body has been totally destroyed, and the organic substance has become an interstitial filling between mineral grains (Plate 1, Fig. 4). In some cases, it seems as if the thread-like colonies were originally surrounded by a sheath-like cover (Plate 1, Fig. 10).

The sizes of the Type A1 organisms, measured along the long axes, lie between 20 and 60 microns.

Group A2 (Plate 1, Figs. 26-28) also comprises ellipsoidal bodies. However, they differ from Type A1 structures in that the materials forming the walls are more transparent and appear to consist of a mixture of an organic substance and a fine-grained mineral which differ in their birefringences under polarised light (Plate 1, Fig. 27). In the upper body of Plate 1, Fig. 28, the wall is marked by a double line which might indicate that it originally consisted of two layers. The wall in Plate 1, Fig. 16 shows thick, opaque parts, which might suggest that it was originally thicker than is indicated by its normal preserved thickness. Most of the bodies taper gently towards the ends of the long axes. As globular shapes are rare (Plate 1, Fig. 26, left lower corner), it seems that the tapering form near the poles has been caused, or at least influenced, by crystal growth. Type A2 bodies often are united in thread-like colonies, but their long axes are not precisely ordered in line, as is the case in Group A1.

Long axes of specimens of Group A2 measure 30 to 70 microns.

Specimens of Groups A1 and A2 were isolated from the rock by careful maceration. Isolated in glycerine, they exhibit a disc-shaped or lens-shaped body and a circular equatorial contour (Plate 1, Figs. 8, 9, 14, and 15). The wall is composed of tiny, irregular, dark particles, intermixed with a fine-grained mineral. In a few of the structures, the wall substance seems to consist of fine fibres (Plate 2, Figs. 11 and 17). A round opening in the wall is characteristic of many of the specimens (Plate 1, Figs. 14 and 15). This pore is usually located at the poles, and is surrounded by a neck (Plate 1, Fig. 19, and Plate 2, Fig. 2). Some of the bodies are torn open (Plate 1, Fig. 17 and 18). In a few cases, twins have been observed (Plate 2, Fig. 3).

The normal size of these bodies lies between 30 and 60 microns. However, very small specimens also occur (Plate 1, Figs. 22 and 23).

It would appear that the Group A structures represent the skins of primitive one-celled organisms. The morphological similarity to cysts of recent primitive algae is apparent. It would seem impossible for spheroidal bodies of this nature, consisting of organic matter, to have been formed by any non-biological process.

B. GLOBULAR TYPE B MICROFOSSILS

These are perfect globes, 5-50 microns in diameter, with a very delicate outside layer composed of agglutinated particles of differing composition, such as dark fragments of organic material (Plate 2, Fig. 18), plate-shaped mineral grains (Plate 2, Fig. 12), and crystal needles (Plate 2, Figs. 13 and 20). No distinct patterns can be recognized on the surfaces, and in no case do the skins show perforations. Type B bodies (Plate 2, Figs. 12-16, 18-21, 23-28, and 32) have been found in maceration slides only, but similar-looking bodies have been also observed in thin-sections, where they usually appear to be connected to filament-like remains (Plate 2, Fig. 22). It is doubtful that these structures and the Globular Type B forms are identical.

The perfect spherical shape of Globular Type B microfossils, the hyaline appearance of the bodies, and the absence of any differentiation, such as distinctly sculptured elements, patterns, and perforations, make it very improbable that Type B structures represent skins or other components of organisms. It is believed that they are drops of oil or similar substance liberated from the bituminous rock material during maceration. Probably, these drops were able to attract solid particles to their surface by mechanical processes. Similar findings were described by Barghoorn, Meinschein, and Schopf (1965) from the Precambrian Nonesuch Shale of Michigan. These authors came to the conclusion that "phenomena involving emulsification or some mechanisms for alveolation of the organic matter during its implantation in the shale or during sample preparation" might have formed these bodies.

C. FILAMENTOUS TYPE C MICROFOSSILS

Type C1 structures (Plate 3, Figs. 1 and 2) consist of an exterior sheath, which appears to envelop corkscrew-like contorted threads. No segmentation has been observed. The length of the fragments measures about 70 microns, while the diameter is about 15 microns.

Type C2 bodies (Plate 3, Figs. 3, 4 and 5) are similar to those of Type C1, but seem to contain spheroidal structures in the sheath. Similar specimens were observed in thin-sections (Plate 2, Fig. 22, and Plate 3, Fig. 10).

Type C3 microfossils (Plate 3, Fig. 6) are composed of several segments, which also occur separately as individual cylindrical "cells" in the maceration slides, each about 20-30 microns long and 10-15 microns broad. Possibly, Type C1 and Type C3 remains belong to the same organisms.

All representatives of the Group C microfossils resemble blue-green algae with some resemblance to those of the order Nostochinales. Similar findings in Pre-cambrian rocks have been described by Tyler and Barghoorn (1954), Barghoorn and Tyler (1965), Cloud (1965), and Pflug (1965).

D. FILAMENTOUS TYPE D MICROFOSSILS

These are very delicate, colourless, thread-like sheaths found in maceration slides (Plate 3, Figs. 9, 13-15, 17, and 18). The body consists of minute dark, or brownish, particles, probably of an organic nature. A few mineral grains are also present which might be foreign bodies sticking to the wall. Some portions of the threads appear to be inflated, with vesicle-like (Plate 3, Figs. 13 and 14) or spherical organic bodies attached to the threads (Plate 3, Figs. 17 and 18). No septation and no branching were observed. The largest specimens reach a length of more than 200 microns. The nature of these structures is problematic. Filaments similar to Type D were found in thin-sections (Plate 1, Fig. 10, Plate 2, Fig. 22, and Plate 3, Fig. 10), and appeared to be of an organic nature. Usually they are oriented in the bedding plane. Spore-like bodies of Group A appear to be attached to some of the filamentous walls. The material does not show birefringence in polarized light. On the other hand, structures resembling Type D were observed in thin-sections to be of probable inorganic origin. These structures are thin layers of deposited organic matter, subsequently deformed tectonically into narrow zig-zag folds (Plate 3, Fig. 17).

E. TYPE E PSEUDOFOSSELS

All photographs of Type E bodies were taken of thin-sections (Plate 3, Figs. 19 and 20). It has been observed that these structures, which resemble filaments, are pseudofossils formed in rock fractures. Fine fractures often contain organic matter which probably migrated through the pore spaces of the matrix and was concentrated in openings in the rock. The fractures subsequently were healed by percolation and crystallization of mineral substances. Growing crystals compressed the organic matter partly against the walls of the fractures and partly into the spaces between the crystal grains. A structure similar to a segmented filament resulted.

F. TYPE F IRREGULAR STRUCTURES

Black, opaque, irregular branched bodies were isolated by maceration (Plate 2, Figs. 29-31, 33, 36, and 37). The branches are partly filamentous (Plate 2, Figs. 29 and 31) and partly laminar. They are not identical with interstitial fillings between mineral grains, which structures can be observed abundantly in thin-sections of cherts. The Type F bodies have been found in shales, where larger mineral grains,

which could form such structures, are not present. In a few cases, the masses have been found to be connected with tiny crystal needles (Plate 2, Figs. 29, 34, 35, and 37). Because of their small size, the needles could not be identified with certainty.

Some of the aggregates of Type F structures resemble colonies of bacteria, but it remains possible that some others are of inorganic origin.

G. THE ORIGINS OF THE STRUCTURED REMAINS

A critical examination of the results leads to the conclusion that most specimens of the Globular Type A and the Filamental Type D groups are real fossils. This statement can be substantiated by the following points :

(i) The specimens consist completely, or preponderantly, of organic substance. This conclusion is based upon the facts that (a) the elements, carbon, oxygen, and sulphur were detected in the walls of the bodies, (b) the specific gravity of the bodies, if not coated with inorganic matter, is less than 2.0, (c) chemical analyses of the fraction lighter than 2.0 prove the presence of carbon hydrates, (d) the bodies show no birefringence, (e) the bodies can be coked at relatively low temperatures, while the graphite particles remain unaffected, and (f) the isolated bodies are usually transparent in normal, or at least infrared, light and exhibit a weak blue fluorescence, while the graphite particles are opaque in normal, as well as in infrared, light and do not fluoresce at all. Points (a)-(d) exclude the possibility that the bodies are minerals, and (e)-(f) render it improbable that the bodies are graphite concretions.

(ii) The shapes of the remains (globular or filamental), their occurrence in colonies, and the arrangement of the individuals in the colonies, all match similar features observed by investigators of younger Precambrian microfossils.

(iii) The differentiations observed, such as pores, patterns, and internal structures, are typical of known, recent and fossil, primitive organisms. The origin of such structures cannot be explained satisfactorily by any inorganic process.

(iv) The fossils are found in cherts and shales, sediments usually associated with optimum conditions for excellent preservation. Nearly all significant findings in Precambrian strata come from sediments of this kind (Tyler and Barghoorn, 1954; Barghoorn and Tyler, 1965; Cloud, 1965; Pflug, 1965).

(v) The remains observed in thin-sections of the chert appear to have been affected by crystallization processes; consequently, the organic structures must be older than the period, or periods, of crystallization. It is concluded that the organisms were suspended in, and sealed by, gelatinous silica masses which were deposited at the time when the organisms flourished, since the fossil bodies are preserved in three dimensions

(vi) The specimens have been examined both in thin-sections and in maceration slides, thus minimising the possibility of contamination.

The Globular Type B, the Filamental Type D, and the Irregular Type F structures are also mainly composed of organic material. However, it is questionable whether these forms have retained any vestiges of the original shape of the organisms.

Type E remains consist of an organic substance. The filamentous appearance, however, was most probably formed under inorganic conditions, such as crystallization of the material in a fracture.

The identification of microfossils of Types A and B suggests that life extends as far back as 3200 million years ago. It would appear that bacteria, blue-green algae, and primitive flagellates were already in existence at that time. The flora resemble those of the Gun Flint Series of North America, which is considered to be about 2000 million years old. However, the nature of the Fig Tree assemblages is much more uniform, and no fossils of complicated organization, such as occur in the Gun Flint strata, have been observed in the Fig Tree rocks. Surprisingly, the average sizes of the Fig Tree microfossils exceed those of the Gun Flint remains and those of similar flora from the Beltian Series. No explanation can be advanced at present to account for this phenomenon. The results of the present study suggest that 3000 million years ago very primitive life conditions must have existed, at least locally, which were not essentially different from those prevailing at the present time.

THE CHEMICAL COMPOSITION OF THE MICROFOSSIL REMAINS

A. RESULTS OBTAINED WITH THE ELECTRON PROBE X-RAY MICROANALYSER

To obtain more information about the chemical composition of the microfossil remains observed, thin-sections of the chert Specimen 155 were analysed by means of a JXA-3A Electron Probe X-Ray Microanalyser, manufactured by the Japan Electronic Optics Laboratory Company Limited. The technique is characterized by nondestructive analysis of a selected spot of about 1-2 square microns in a thin-section surface. The specimen is irradiated by an electron beam, and X-rays are emitted from the focus point. The wave-length and the intensity of the emissions are measured by X-ray spectrometers. Since the X-rays penetrate the specimen to a depth of approximately 1-2 microns, the volume analysed represents several cubic microns of the thin-section. Constituent elements in the minute mass and their relative concentration are determined. The degree of absorption of electron beams into the specimen surface depends on the elements present. Parts composed of light elements show up brightly in the photograph. The higher the atomic number of the element, the darker the spot in the picture. If several elements are present, the brightness modulation is determined by the atomic numbers of the relevant elements and their mass concentration.

Examples of the results obtained are shown on Plate 4. Figures 2 and 3 are composition-scanning images of two specimens of Globular Type A structures which are both included in the thin-section, the surface of which cuts parts of the bodies. The structure in Fig. 2 is smaller in size and completely preserved, while the body in Fig. 3 is a fragment, the left side only of which is present.

The gray tone forming the background of Figs. 2 and 3 indicates the presence of silica. It can be seen that the interior of the organic bodies appears brighter than the exterior background, proving that elements lighter than Si must be present in the interior. X-ray analysis showed that this brighter shading is associated with the elements carbon and oxygen. Hydrogen is probably a member of the compound, but the presence of this

light element cannot be proved by such analysis. The internal parts of the bodies thus appear to be composed mainly of organic material.

Type A remains in Fig. 2 appear to be coated with a black layer. The dark colour of this layer indicates that elements of high atomic number must be present to a considerable extent. The structure in Fig. 3 shows a similar coating along its left margin, which belongs to the original surface of the organism, but no coating on the right side. X-ray images of the coating were produced for the elements between $_{11}\text{Na}$ and $_{92}\text{U}$. Copper in greater amounts, accessory calcium and iron, and traces of nickel were detected in the coating of the body in Fig. 2. The coating in Fig. 3 was found to be composed of a mixture of iron and calcium compounds. The X-ray image of aluminium in the structure of Fig. 3 is shown in Fig. 5. Only a single spot (a in Fig. 3) exhibited a concentration of aluminium. This particle is also rich in iron, and it might represent a tiny piece of clay sticking to the wall of the organism. In Fig. 6 the $_{14}\text{Si}$ X-ray image of Fig. 3 is reproduced. No conspicuous contrast between the organic body and the mineral matrix can be recognized. This means that the organic material must be completely penetrated by silica. Fig. 4 reveals the distribution of sulphur in the structure of Fig. 2. Apparently, most of the sulphur is concentrated in the organism's body and in the coating containing the heavier metals. The greater amount of the sulphur appears to have been bound in the organic matter of the fossil, but some of it migrated into the coating and reacted with the metals to form sulphides.

Fig. 1 shows the image of the surface morphology of the structure in Fig. 2. The coating covering the algal body has a positive relief, rising above the surrounding silica matrix. (The thin-section surface has been carefully polished with diamond powder).

B. INTERPRETATION OF THE RESULTS

The following conclusions have been drawn from the results of the chemical analyses :

- (i) The greater amounts of carbon, oxygen, and sulphur detected in the bodies of the organisms provided evidence that organic material is present.
- (ii) The algal bodies appear to be completely penetrated by silica. Optical observations have shown that the organisms are preserved three-dimensionally in the rock matrix. Consequently, the organisms must have been silicified during their lifetime, or shortly thereafter.
- (iii) The coating which consists mainly of compounds of copper, iron, nickel, calcium is impregnated with silica to the same extent as is the interior of the organic bodies. Consequently, the coating process must be older than the silification process. Observations on the fragmented structure in Fig. 4 yielded the additional information that only the left margin of the body represents the original wall contour, and that only this part bears a coating, while the margin at the right side, formed by a fracture line, appears to be uncoated. A coating process occurring subsequent to the silification process would probably have covered all parts of the surface equally. Careful examination of the thin-section gave evidence that the structure in Fig. 4 was already a fragment when imbedded in the silica. Therefore, the coating must have been formed in advance of the silification and the fragmentation process, probably during the time of biological activity of the organism.

(iv) The sulphur present in the coating and bound in metal sulphides apparently originated from the organic matter of the algal body (Plate 4, Fig. 4).

The phenomena noted above resemble those associated with recent algal life, where substances dissolved in the water have been precipitated by photosynthetic processes and have coated the algae. Copper, calcium, and iron are the main components detected in the coatings of Figs. 2 and 3 on Plate 4. Possibly, other metals could be precipitated under suitable conditions, so that the association of carbon hydrates and ore minerals in certain Precambrian rocks, and the rich assemblages of algae found in maceration slides of the same rocks suggest that biological processes might have been important factors in the formation of Precambrian sedimentary ore deposits.

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Key to Figures

Plate 1 (500x)

- Figs. 1, 2 and 5 : Globular Type A1 bodies - colonies of specimens
photographed in thin-section of chert Specimen 155.
- Figs. 3 and 7 : Globular Type A1 bodies deformed by subsequent re-
crystallization. Fig. 3 : light polarized. Thin-section
of chert Specimen 155.

Plate 1 (500x) Continued

- Fig. 4 : Globular Type A1 bodies - structures disintegrated as result of subsequent crystallization. Thin-section of chert Specimen 155.
- Fig. 6 : Globular Type A3 bodies. Maceration slide of shale Specimen 135.
- Figs. 8 and 9 : Globular Type A3 bodies. Maceration slide of shale Specimen 140.
- Figs. 10 and 11 : Globular Type A1 bodies. Thin-section of chert Specimen 155.
- Figs. 12 - 15 : Globular Type A3 bodies. Maceration slide of shale Specimen 135.
- Fig. 16 : Globular Type A2 bodies. Thin-section of chert Specimen 155.
- Figs. 17 - 25 : Globular Type A3 bodies. Maceration slide. Figs. 17, 18, and 20-23 of shale Specimen 135. Fig. 19 of shale Specimen 136. Figs. 24 and 25 of shale Specimen 153.
- Figs. 26 - 28 : Globular Type A2 bodies. Thin-section of chert Specimen 155.

Plate 2 (1 scale unit = 10 microns)

- Figs. 1 - 11, and 17 : Globular Type A3 bodies. Figs. 11 and 17 : 1300x (see scale below Figs. 12 and 13). Figs. 1-10 : 500x (see scale below Figs. 26-28). Figs. 1-10 : shale Specimen 136. Figs. 11 and 17 : shale Specimen 132.
- Figs. 12 - 16, 18 - 21, 23 - 28, and 32 : Globular Type B bodies. Figs. 12-16, and 18-20 : 1300x (see scale below Figs. 12 and 13). Figs. 21, and 23-28 : 500x (see scale below Figs. 26-28). Figs. 20 and 21 : light polarized. Maceration slides. Figs. 12, 15, 16, 21, 25, 26, and 28 : shale Specimen 135. Figs. 13, 14, and 20 : shale Specimen 156. Fig. 17 : shale Specimen 132. Figs. 18, 19, 24, 27, and 32 : shale Specimen 136.
- Fig. 22 : Thin-section of chert Specimen 155 (500x), showing filamentous and globular structure.
- Figs. 29 - 31, and 33 - 37. : Irregular Type F bodies. Maceration slides. Figs. 29-31, 36, and 37 : 1300x. Figs. 33-35 : 500x. Figs. 29, 33-35, and 37 : shale Specimen 135. Figs. 30, 31, and 36 : jasper Specimen 137.

Plate 3 (500x)

- Figs. 1 - 8 : Filamentous Type C bodies. Maceration slides. Figs. 1 and 2 : Type C1. Figs. 3-5 : Type C2. Figs. 6-8 : Type C3. Figs. 1, 2, and 5 : shale Specimen 132. Figs. 3, 4, and 6-8 : shale Specimen 136.
- Figs. 9, 13 - 15, and 17 - 18. : Filamentous Type D bodies. Maceration slides of shale Specimen 132.
- Figs. 10 and 11 : Filamentous structures. Thin-sections of chert Specimen 155.
- Fig. 12 : Globular Type A2 bodies. Colony photographed in thin-section of chert Specimen 155 (200x)
- Fig. 16 : Meandering organic layer, which may simulate filamentous structures. Thin-section of chert Specimen 155.
- Figs. 19 and 20 : Fracture-filling, which may simulate filamentous structure (Pseudofossil E). Thin-section of chert Specimen 155.

Plate 4 (1200x; 1 scale unit = 10 microns)

Electronic scanning-images of Globular Type A1 bodies in chert Specimen 155.

- Figs. 1, 2, and 4 : Specimen a. Fig. 1 : morphology scanning-image. Fig. 2 : composition scanning-image. Fig. 4 : X-ray image : S (K alpha).
- Figs. 3, 5, and 6 : Specimen b. Fig. 3 : composition scanning-image. Fig. 5 : X-ray image : Al (K alpha). Fig. 6 : X-ray image : Si (K alpha).

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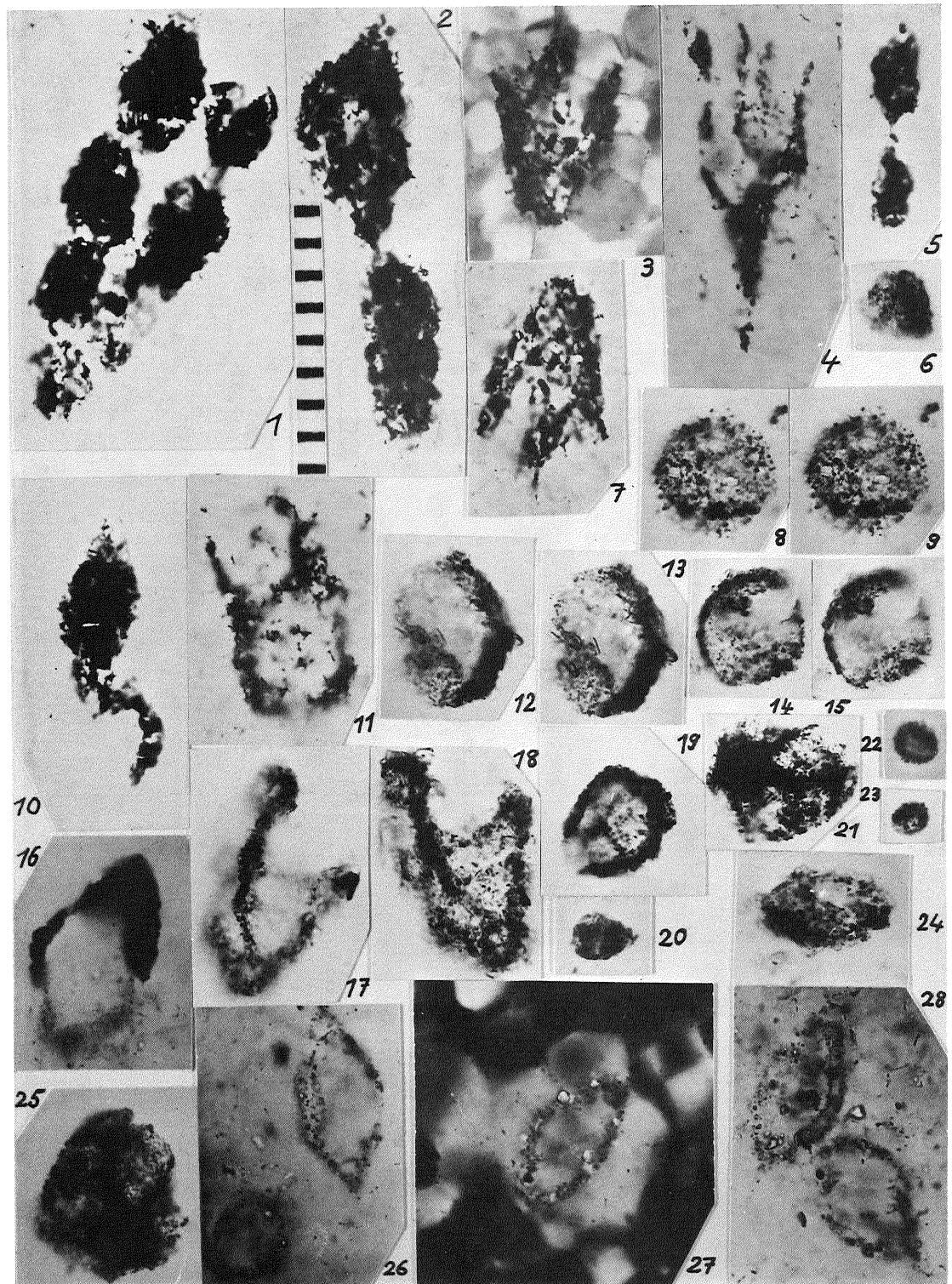


PLATE 1

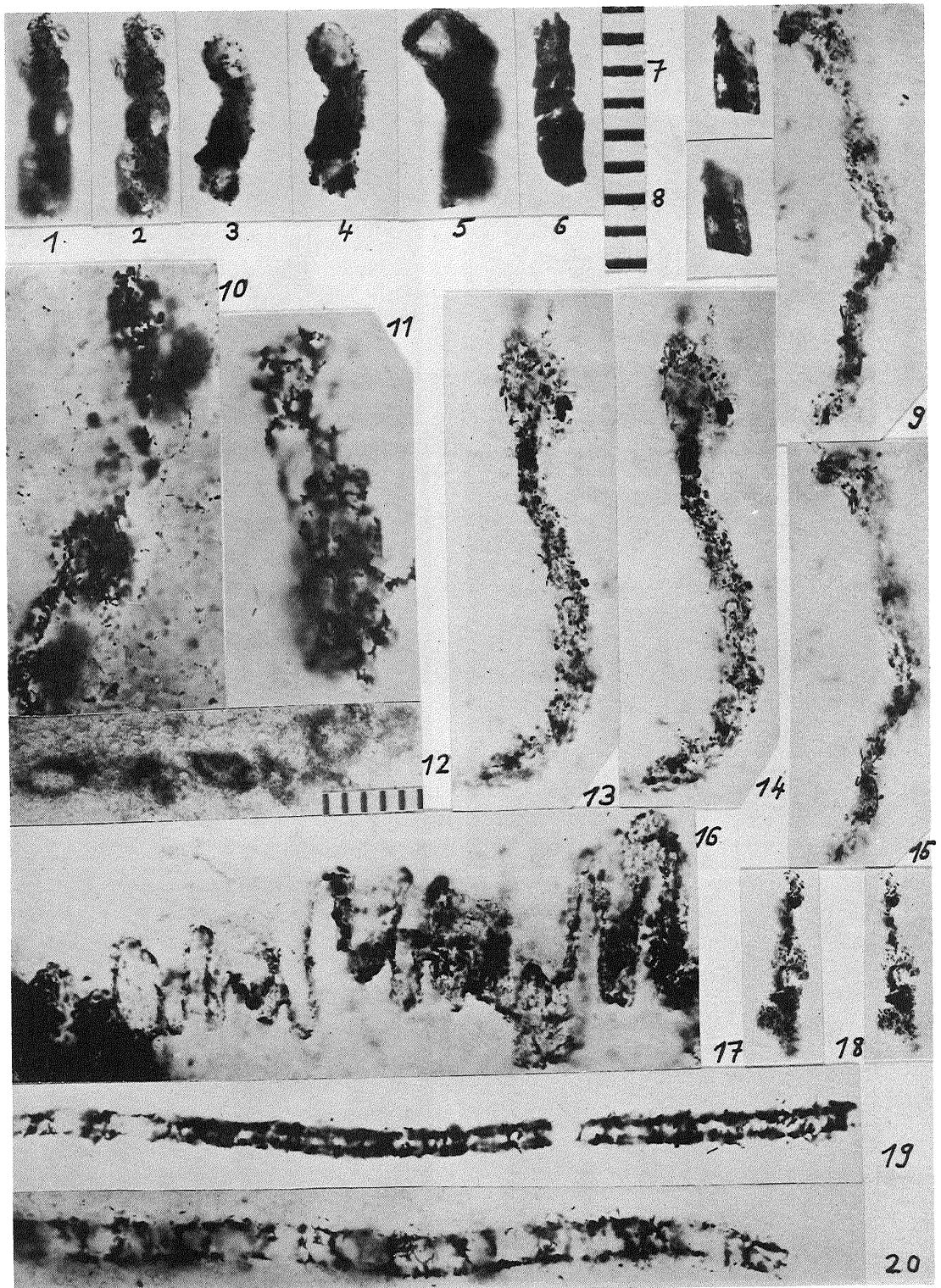
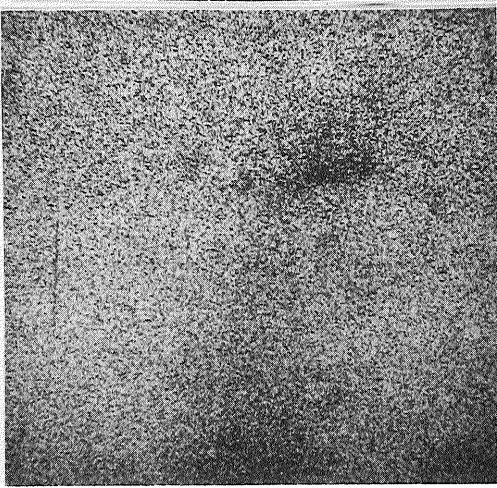
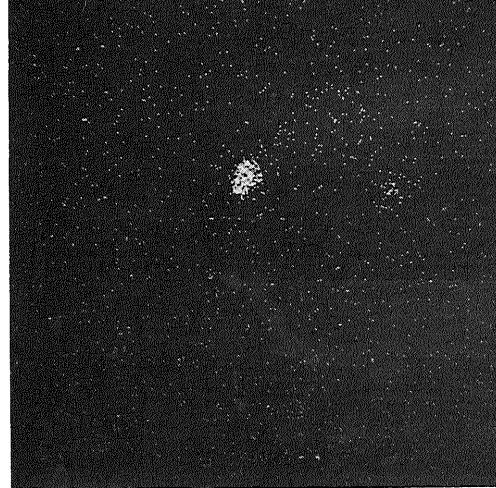
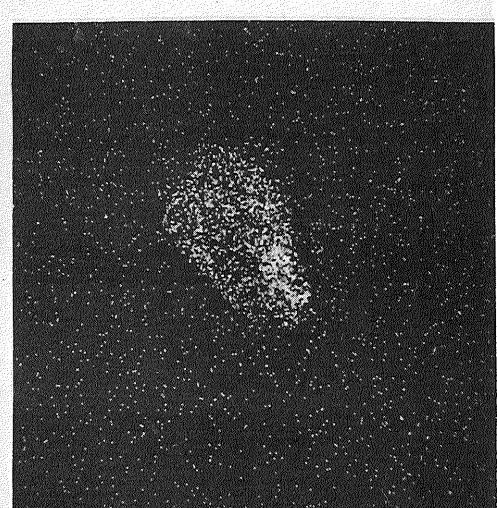
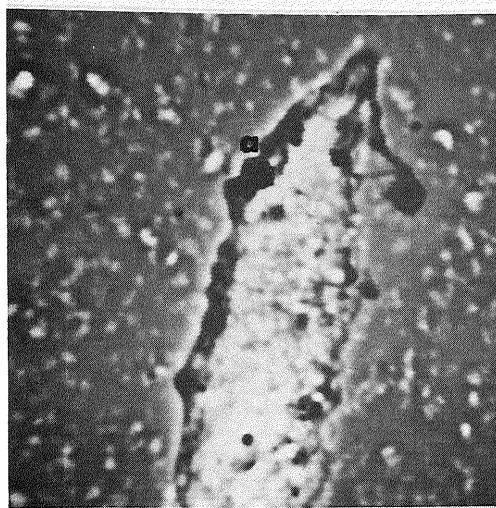


PLATE 3



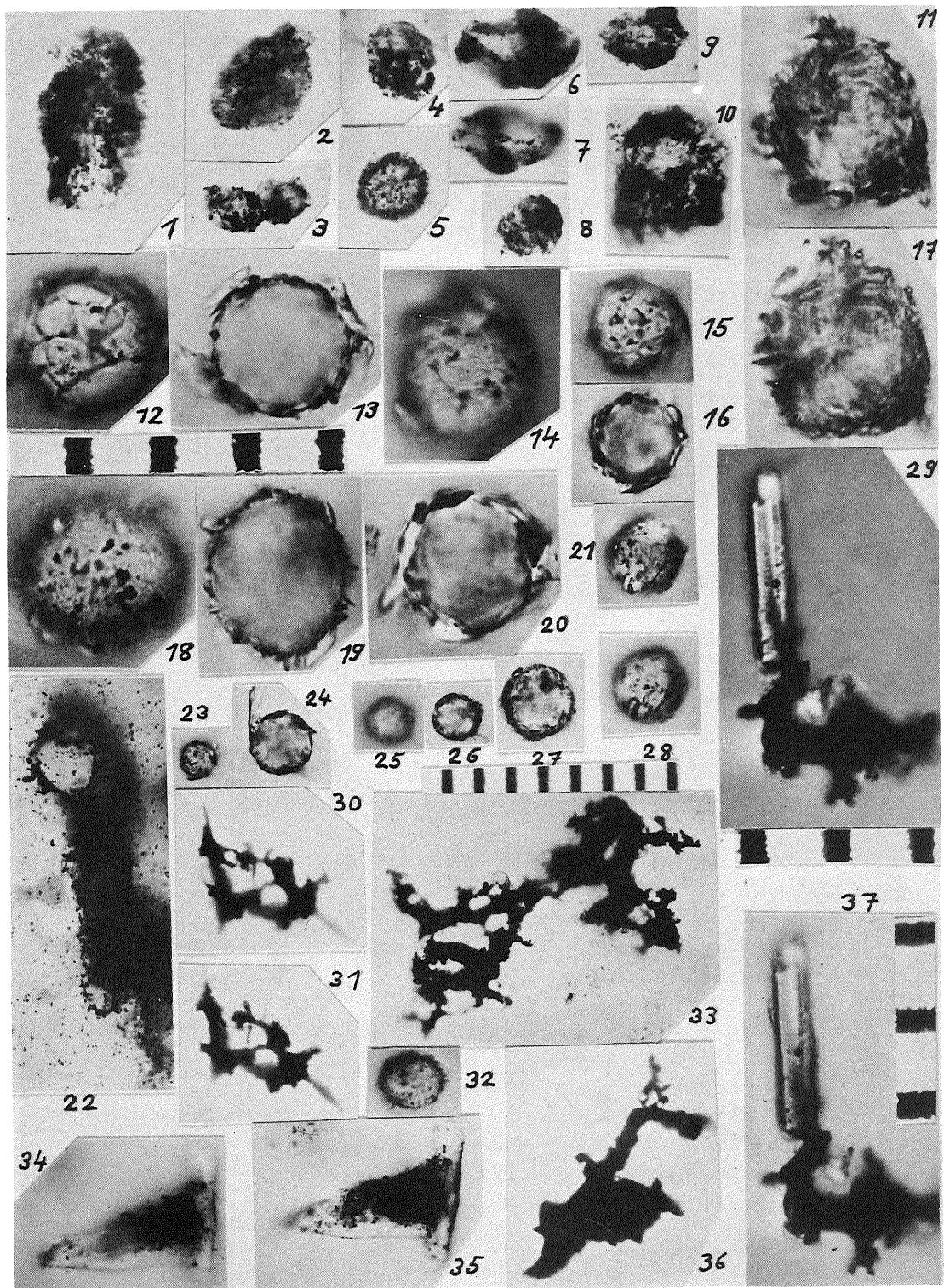


PLATE 2