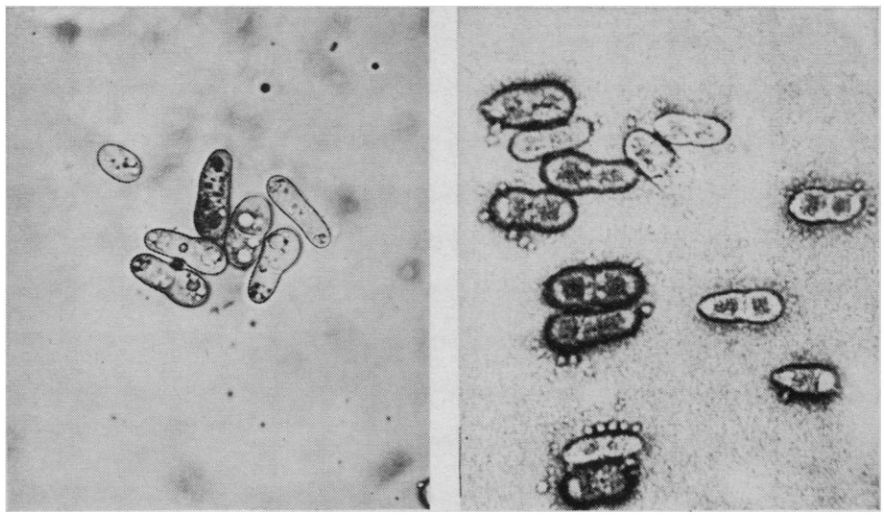

Fig. 2. *Ascochyta conidia* photographed in aqueous mounts. (Left) Photomicrograph (× 1000) made with blue light. This is a contact print from the negative. Note sharply defined cell walls and gutulae conspicuously revealed by blue light. (Right) The print is an enlargement (× 1000) from a contact negative made with 2600-angstrom monochromatic radiation. Note absorbance in areas where nucleic acids presumably occur, wide cell wall bands due to lens effect of curved edges of conidia, and substances extruded from cells. The nature of the substances revealed by this photograph has not been determined.

Negatives are made by placing objects on plates the same size as microscope slides (2.5 by 7.5 cm) and by exposing them to monochromatic ultraviolet radiation. The resulting negatives are printed to the size desired with appropriate microscope lenses. The requirements for critical images of cells and their contents are as follows. (i) The rays must be collimated before they strike the object. (ii) The subject must not be of such shape and composition that it itself functions as a lens. For example, starch grains on the surface of the emulsion function as little lenses and produce "hot spots" that do not resemble starch grains. (iii) Resolution is directly proportional to the closeness of the object, or part of the object, to the emulsion and inversely proportional to the wavelength of light. Depth of field, expressed as a function of usable magnification, is, however, far greater than can be obtained with microscope optics. Fortunately, this is especially true in the ultraviolet region, from 2300 to 3000 angstroms, where critical focus with quartz optics is difficult and time-consuming. There are no focus problems whatever in this approach to ultraviolet photomicrography. Tissues, blood smears, thin masses of cells, and other materials can be placed on a plate and exposed to monochromatic light; then the plate can be developed and a permanent record of absorbance phenomena in literally thousands of cells can be made in less than 10 minutes.

We make negatives in the ultraviolet with a 250-mm Bausch and Lomb diffraction grating monochromator, illuminated with a 900-watt xenon lamp, and a bandwidth of 60 angstroms. The high-resolution plates are mounted at the focal point of the light beam and a camera shutter is mounted near the exit lens. A metal shield with a 4- by 15-mm slit is placed in front of the emulsion to reduce scattering of light. Exposures average around 1/50 second at 2600 angstroms when the plates are developed as recommended by the manufacturer (*3*). Figures 1 and 2 show examples of the technique.

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References and Notes

1. Trial of high-resolution plates for photomicrography was suggested to us by Malcolm M. McWhorter of Stanford University, who had used them for making microelectronic circuits.
2. The utility of high-resolution plates for contact photomicrography with visible light was described at the symposium of the Biological Photographic Association at the University of Washington in Seattle, on 7 March 1965. This method of photomicrography should not be confused with anatomical analysis by microradiography, a process that does not require ultrafine-grain emulsions.
3. A discussion of the preparation of objects for exposure and of special methods of development is in preparation.

11 March 1966

Microorganisms Three Billion Years Old from the Precambrian of South Africa

Abstract. *A minute, bacterium-like, rod-shaped organism,* Eobacterium isolatum, *has been found organically and structurally preserved in black chert from the Fig Tree Series (3.1 × 10⁹ years old) of South Africa. Filamentous organic structures of probable biological origin, and complex alkanes, which apparently contain small amounts of the isoprenoid hydrocarbons pristane and phytane, are also indigenous to this Early Precambrian sediment. These organic remnants comprise the oldest known evidence of biological organization in the geologic record.*

During the past decade, and particularly within the past few years, there has developed a marked revival of interest in the classical problem of the antiquity of life on earth. Although parallel to a current expansion of interest in theoretical and experimental approaches to the origin of living systems, paleobiological research on the antiquity of life is developing within a geological and geochronological framework which is unique in the history of paleontology. To a great extent this derives from a firmly based and fast-growing body of data on the radiogenic age of the earth and, in particular, on the age of its Precambrian sedimentary rock systems. The application of electron microscopy to organic sediments, moreover, has made it possible to transcend the limits of optical microscopy in observing minute objects of possible biological origin. In addition, development of analytical instruments for the detection and characterization of organic compounds in sediments provides refined techniques for the detection of correlative evidence of past biological systems.

We now report results of the application of optical and electron microscopy to sediments exceeding 3000 million (3×10^9) years in age. The sediments are organic-rich black cherts, interpreted as primary chemical precipitates, in which are found discrete microfossils of bacterium-like size and form, as well as larger remnants of partially organized organic matter. Unpublished results of organic geochemical analyses establish that small concentrations of complex, high-molecular-weight alkanes are also present in this Early Precambrian sediment (*1*). Chromatographic

analyses indicate that the isoprenoid hydrocarbons, pristane and phytane, are minor constituents of the indigenous alkanes (*1*). These hydrocarbons, thought to be "of definitely biological origin" (*2*), have been identified in other fossiliferous Precambrian sediments (*2, 3*) and are commonly suggested to have been derived by the chemical alteration of carotenoid or chlorophyll pigments (*2, 3, 4*).

The black cherts under consideration were collected by E. S. Barghoorn in February 1965 from rocks of the Fig Tree Series of the Swaziland System, eastern Transvaal, South Africa. The exact locality of collection is an outcrop excellently exposed by road cutting, close to the entrance to the Daylight Mine (Barbrook Mining Co.), 28 km east-northeast of Barberton, South Africa. The Barberton district has long been an area of gold mining, and extensive geological study has been made of the complex geology of the Swaziland System and the immediately overlying Moodies System of sediments. The structural relations of the "Barberton Mountain Land" have been discussed by Ramsay (*5*), from whose extensive discussion of the Fig Tree Series we have drawn in part (*6*).

The Fig Tree sediments comprise a thick series of graywackes, slates, and shales, with interbedded well-developed horizons of banded chert, jasper, and ironstone. The cherts are the only wide-ranging reliable stratigraphic markers in little-deformed as well as in folded and contorted areas of the sedimentary sequence. Although it is probable that the thickest of the green and gray chert units (up to 175 m thick) are secondary replacements, it is our interpretation that the thinner black fossiliferous cherts of the Fig Tree strata represent primary chemical precipitates. In this respect they appear to be of the same or comparable chemical mode of origin as those of the Middle Precambrian Gunflint Iron Formation of Ontario, Canada (*7*) and the biohermal chalcedonic cherts of the Late Precambrian Bitter Springs Limestone of central Australia (*8*), both of which contain remarkably well-preserved three-dimensional microorganisms of considerable morphological diversity. In the field, the black cherts of the Fig Tree Series show a striking megascopic resemblance to certain of the massive blocky and waxy cherts of the Gunflint Iron Formation. Unlike the Gunflint cherts, however, they are not associated with stromatolitic gross algal structure. Ramsay (*5*) notes the presence of "oolites" incorporated as sedimentary constituents in one unit of the graywackes of the Fig Tree Series. These siliceous bodies appear to contain organic matter surrounding a finely crystalline silica core, and Ramsay suggests that they may be of algal origin (*9*). These "oolites" are stratigraphically and lithologically unrelated to the black cherts described here.

The age of the Swaziland System and that of the mineral belts in both South Africa and Southern Rhodesia has been the object of considerable geochronological study (*10*). The results have consistently indicated a very great age, certainly among the oldest determined from Early Precambrian rocks currently exposed on the earth's surface. Recent unpublished measurements on shales and graywackes from the Fig Tree Series, with the rubidium-strontium whole-rock method, indicate an age greater than 3100 million years for the last period of strontium isotopic homogenization for the sediments (*11*). These results confirm studies indicating an age for the Fig Tree sediments of at least 3 billion years (*10*).

The physical organization of organic matter in chert from the Fig Tree Series has been studied in thin sections and in macerations by optical microscopy, and in surface replicas and in macerations by electron microscopy. Optical examination of thin sections of the chert shows that the abundant dark-colored organic material is arranged in irregular laminations approximately parallel to the bedding planes, a distribution indicative of its original sedimentary deposition. The fact that much of the organic material transgresses chalcedony grain boundaries, as seen in thin sections in polarized light, indicates that it was emplaced prior to the crystallization of the surrounding silicic matrix, and is consistent with a primary sedimentary origin for the chert.

Although the laminar organization of the organic matter is evident, individual constituents of the layers are generally too small to be optically well resolvable. The organic lamellae appear to be comprised of discrete, minute, apparently branching, threadlike structures and isolated, spheroidal or rod-shaped particles, but neither precise morphology nor definite biological organization is apparent. In chert residues resistant to hydrofluoric acid these minute organic objects appear to retain their individual filiform or particulate character, a fact that suggests they possess distinct organization and are not random aggregates of organic material.

We have used electron microscopy to determine the morphology of organic structures in the Fig Tree chert. Application of this technique is based on our similar studies of chert from the approximately 2-billion-year-old Gunflint Iron Formation. Electron microscopy of surface replicas of the Gunflint chert has demonstrated the occurrence of organically well-preserved rod-shaped and coccoid bacteria (*12*). Other investigators have used electron microscopy to detect remarkably well-defined imprints of fossil bacteria in pyrite 300 million years old (*13, 14*), and micrographs of minute structures of possible biological origin have been figured from a sediment at least 2.5 billion years old (*15*).

Although similar organic objects were micrographically observed in surface replicas and in hydrofluoric acid macerations of the Fig Tree chert, the maceration technique appears to be somewhat unreliable (*16*). Original organic microstructure is often altered or destroyed when fragile carbonaceous fossils are freed by the acid digestion of their encompassing silicic matrix. In addition, any contaminants introduced in the maceration technique are often very difficult to differentiate from indigenous organic particles.

Electron microscopy of surface replicas of the rock is not subject to the disadvantages inherent in the process of maceration. In this technique, minute organic fossils can be separated intact from their encompassing mineral matrix and micrographically examined in their original state of preservation. Moreover, evident physical relationships between the microfossils, their imprints, and associated mineralogical structures of the replicated matrix establish the indigenous nature of the organic entities.

Examination of surface replicas of thin sections of the Fig Tree chert proved the most rewarding method of studying the morphology of indigenous organic structures. Replicas of each of the several thin sections investigated were prepared in the following manner. A polished thin section was ground according to standard procedures with 0.05-micron γ-alumina on a rayon lap for the final polish (*17*). The thin section was optically examined at high magnification, and areas where organic

matter was exposed at the rock surface were noted on a traced outline map of the section. After washing with distilled water, the section was etched for 2 minutes by immersion in a 4.88-percent (by volume) solution of reagent-grade hydrofluoric acid and distilled water. After the section had dried under cover, the etched surface was flooded with a 5-percent (g/ml) solution of parlodion in amyl acetate (reagent grade) and allowed to dry.

The outline map was turned over to show an inverted image of the thin-section outline; transparent tape (sticky-side-up) was placed on top of the map, and half-centimeter squares of one-ply paper were attached to the tape at positions corresponding to areas of organic concentration noted on the map. The outline of the section was traced from the map onto the tape, and the tape was turned sticky-side-down and superimposed on the parlodion-coated thin section. The tape and the adhering parlodion surface replica were then stripped free from the etched rock surface.

In a vacuum evaporator the parlodion replica was shadowed with platinum at about a 2:1 angle and was replicated with an evaporated carbon film. The parlodion-platinum-carbon sandwiches overlying each of the small squares of paper were easily separated from the remainder of the replica and were immersed in amyl acetate (reagent grade). After a few hours the parlodion film dissolved and the remaining platinum-carbon replicas were picked up on microscope grids. Micrographs were taken with an RCA-EMU-3F electron microscope.

This double replica technique allows the correlation and morphological comparison of objects visible in the light microscope with those revealed by electron microscopy, and enables the investigator to ignore relatively unpromising areas of the rock surface. In addition, the outline map of the thin section serves as a record of the areas investigated and can be used repeatedly as a guide in the repeated replication of specific areas, with or without additional etching.

Minute organic structures, exposed on the rock surface by dissolution of their surrounding mineral matrix, often adhere to and are physically supported by the original parlodion replicas. Some of these structurally intact bodies, those which are transferred to the final platinum-carbon replicas, can be microgaphically examined in their original state of organic preservation. In this way, organically preserved rod-shaped cells and filamentous structures were separated from the chert and studied in their unaltered relationships to mineralogical structures (Figs. 4, 11, and 12).

In those cases in which the rod-shaped cells were not transferred from the parlodion film to the platinum-carbon replicas, imprints, shadowed as if they represented raised structures, were obtained in the final platinum-carbon replicas (Fig. 3). In some cases, upon dissolution of the parlodion film, the rod-shaped cells became displaced from their original positions in the replicated surface but adhered nearby to the platinum-carbon film (Figs. 1 and 2); these unusual occurrences show clearly the relationships between the organically preserved microfossils, their imprints in the rock surface, and the mineralogical structures of the replicated matrix.

Several types of organic structures having a characteristic and consistent morphology have been observed in surface replicas of the Fig Tree chert. Additional studies are necessary to fully characterize many of these structures and we here limit our discussion to two of the more interesting types—short, broad, bacterium-like rods (Figs. 1–9) and fibrous, branching threads (Figs. 11 and 12).

Isolated, rod-shaped bacterium-like cells occur as constituents of the organic lamellae in the chert and are similar in morphology and in distribution to spheroidal or rod-shaped organic particles seen optically in thin sections. Forty-five of the cells, preserved either organically (Figs. 1, 2, and 4–6) or as imprints in the rock surface (Figs. 1–3) have been observed in surface replicas. Both intact, relatively undistorted cells (Figs. 1–3, and 5) and deformed or greatly altered cellular remnants (Figs. 4 and 6) are present. Well-preserved cells typically have rounded ends (Figs. 1, 4, and 5) and are longer than twice their breadth, characteristics exhibited by modern bacillar bacteria. The twelve organic, relatively undistorted cells plotted in Fig. 10 have an average length of 0.56 μ and an average width of 0.24 μ. The rod-shaped imprints appear to be slightly longer and broader than are the organic cells they originally contained (Figs. 1, 2, and 10).

Figs. 1–9. Negative prints of electron micrographs of platinum-carbon surface replicas of chert from the Fig Tree Series showing *Eobacterium isolatum*, n. gen., n. sp., preserved both organically and as imprints in the rock surface; line in each figure represents one micron.

Fig. 1. Electron dense, organically preserved rod-shaped cell about 0.6 μ long (white, below) and its imprint in the chert surface (above). During preparation of the sample the bacterium-like fossil was displaced from its original position in the chert matrix. The presence of imprints and the fact that they transgress structures of the mineralogical matrix, such as grain boundaries and polishing scratches, indicate that the minute organism is indigenous to the rock.

Fig. 2. Organically preserved cell about 0.5 μ long (white, below) displaced from its imprint in the rock surface (above). Note the irregular, granular texture of the cellular imprint. Subparallel, horizontally oriented lineations in the rock surface are polishing scratches; a prominent grain boundary is present to the right of the imprint.

Fig. 3. Rod-shaped imprint in chert surface. About 0.75 μ long, this is one of the longest imprints of *E. isolatum* observed.

Fig. 4. Organic, somewhat flattened bacterium-like cell transgressing chalcedony grain boundary. The continuity of the grain boundary, passing through the fossil organism, demonstrates that *E. isolatum* is indigenous to the rock and is consistent with a primary origin for the chert.

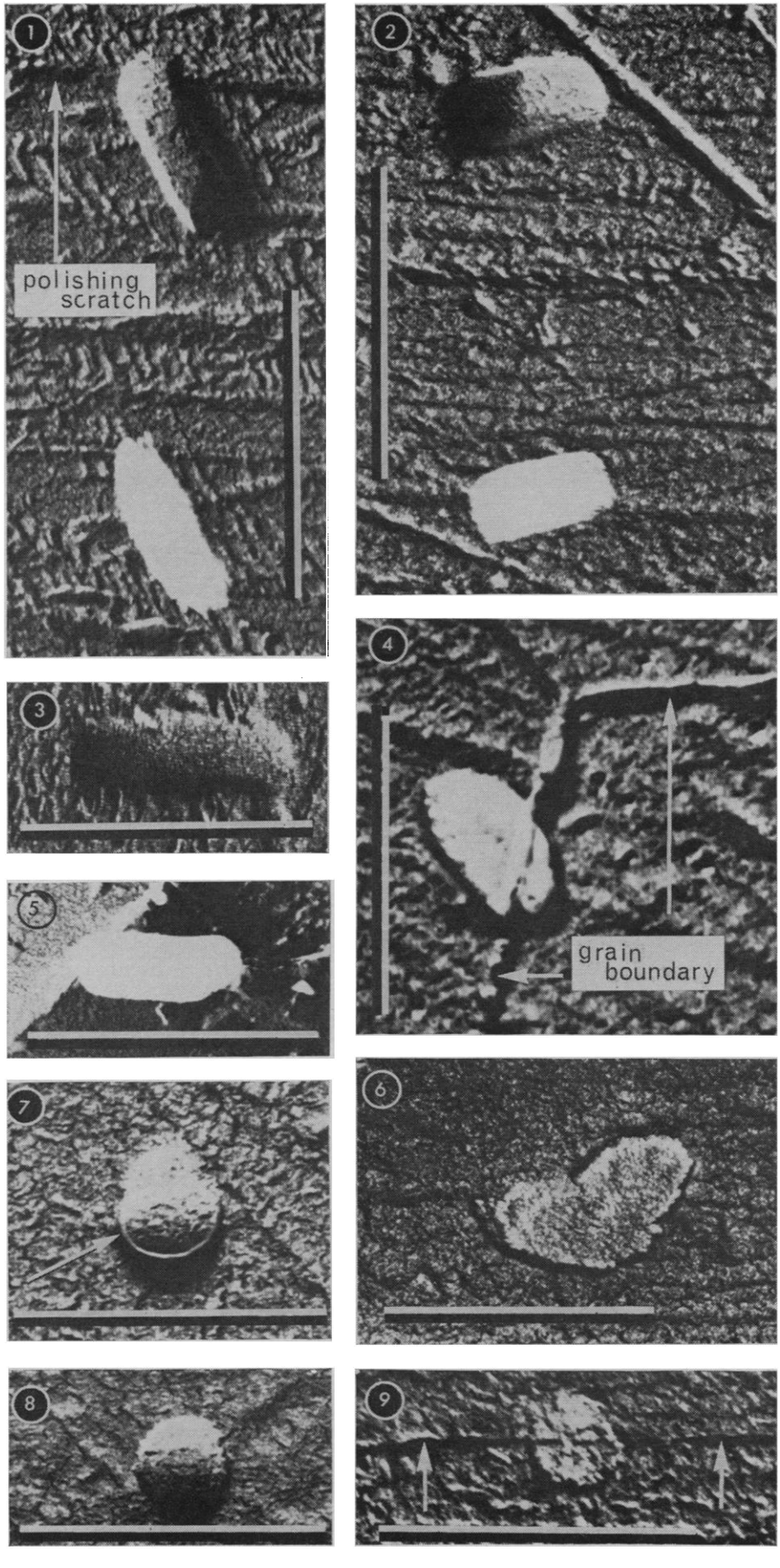
Fig. 5. Organically preserved cell of *E. isolatum* showing the short, broad, rod-shaped morphology of the fossil organism. This well-preserved cell demonstrates the morphological similarity of the ancient organism to modern bacillar bacteria.

Fig. 6. Thin organic film, probably representing the remnants of a bacterium-like cell which was deformed during preservation.

Fig. 7. Circular structure interpreted as a transverse section through a cell of *E. isolatum*. Although the cellular contents appear to have been replaced by silica, the cell wall is organically preserved. The cell wall, about 0.015 μ thick, has a two-layered organization (shown at point of arrow) and is comparable in thickness and structure to cell walls of many modern bacteria.

Fig. 8. Circular imprint about 0.28 μ in diameter interpreted as a transverse section through the bacterium-like organism. The morphological uniformity of these structures (Figs. 7 and 9) and their size range (Fig. 10) support their interpretation as transverse sections of *E. isolatum*.

Fig. 9. Poorly preserved organic structure thought to be a transverse section of *E. isolatum*. The arrows point to a chalcedony grain boundary which passes through the circular structure and establishes the indigenous nature of these ancient organic remnants.



Fourteen circular structures, preserved both organically and as imprints, have been observed in replicas of the chert (Figs. 7–9). These structures, interpreted as transverse sections of the rod-shaped cells, are approximately 0.26 μ in diameter and typically have an outer wall about 0.015 μ thick (Figs. 7 and 8). In the best preserved structures the wall is seen to be composed of two layers (Fig. 7) and is comparable in thickness and in organization to cell walls of many modern bacteria (*18*).

Our interpretation that these structures represent transverse sections of the bacterium-like cells is supported by the following observations: (i) the circular structures are morphologically quite uniform (Figs. 7–9); (ii) their diameters are very similar to the widths of the rod-shaped cells (Fig. 10); (iii) they have been observed only in areas of thin sections in which the rod-shaped forms are also present; (iv) the occurrence of transverse sections is consistent with the apparently random longitudinal orientation exhibited by the rod-shaped cells. This interpretation is further strengthened by the bacterium-like morphology of both the elongate cells and the circular structures. The fact that no sheath or sheath-like residue has been observed in either transverse or longitudinal views of the microorganism is consistent with its apparently isolated, noncolonial growth habit. Although the apparent lack of flagella suggests that the organism may have been nonmotile, this lack may be the result of loss of such structures at death.

That these minute fossils are indigenous to the rock rather than laboratory contaminants is supported by the following six considerations: (i) the forms occur in replicas both organically preserved and as imprints in the rock surface and show variation in completeness of preservation; (ii) they are oriented in a variety of positions, not only parallel with but passing into the prepared rock surface; (iii) they transgress mineralogical structures of the chert matrix such as polishing scratches (Figs. 1 and 3) and chalcedony grain boundaries (Figs. 4 and 9); (iv) they are present in repeated replicas of specific areas of the same thin section, and in several areas of several thin sections; (v) they are similar in morphology and in distribution to organic structures seen optically in thin sections; and (vi) they are absent from

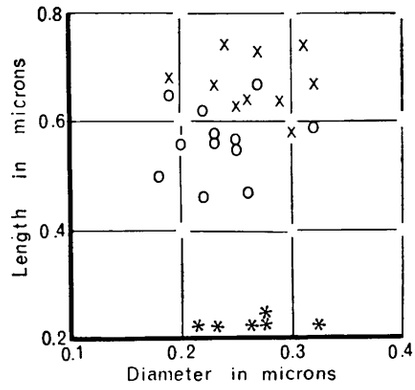


Fig. 10. Scatter diagram showing size distribution for 28 well-preserved cells of *Eobacterium isolatum n. gen., n. sp.*, observed in surface replicas of chert from the Fig Tree Series. "O's" show diameters and lengths of organically preserved cells; "X's" show diameters and lengths of rod-shaped imprints in rock surface. Asterisks show diameters of circular structures interpreted as transverse sections of the bacterium-like organism (note that lengths cannot be measured for these bodies). The rod-shaped imprints are generally slightly broader and longer than are the organic cells they originally contained.

glass microscope slides replicated side-by-side with thin sections of the chert, and are absent from preparations of Lakeside Cement, the mounting medium for the thin sections.

That these microorganisms are both organically preserved and often relatively undistorted is consistent with the occurrence of complex organic molecules within the rock, and is not surprising in view of the occurrence of similar bacterial fossils in other Precambrian cherts (*12*). The Fig Tree organisms are comparable in size, shape, complexity of structure, and isolated habit to many modern bacillar bacteria. Although they may have had a nonphotosynthetic metabolism, there is insufficient information available about their paleobiochemistry to realistically evaluate such a suggestion. In view of the fact that more than 3 billion years of evolutionary history separate these forms from possible modern counterparts, and more than 1 billion years separate them from the oldest previously reported bacterium-like microfossils (*12*), physiological and environmental conclusions based upon a morphological comparison between them and more recent microorganisms would be of questionable significance.

For purposes of reference, it seems desirable to propose a formal taxonomic designation for this ancient bacterium-like microorganism. The photographic record must serve as "type material" for this taxon inasmuch as the original replicas are perishable and unique (*19*). In the absence of definitive information regarding the physiology of this organism, the binomial here proposed designates a morphological genus based solely on form.

Eobacterium, new genus.

Diagnosis: Short, broad rods, usually with well-rounded ends and approximately circular in transverse section. Length usually between two and three times greater than diameter. Thickness of cell wall usually between 0.05 and 0.10 times the cell diameter. Cell wall may have two distinct layers; external surface may appear granular.

Etymology: With reference to Early Precambrian age and rod-shaped form of type species.

Type Species: *Eobacterium isolatum*, new species.

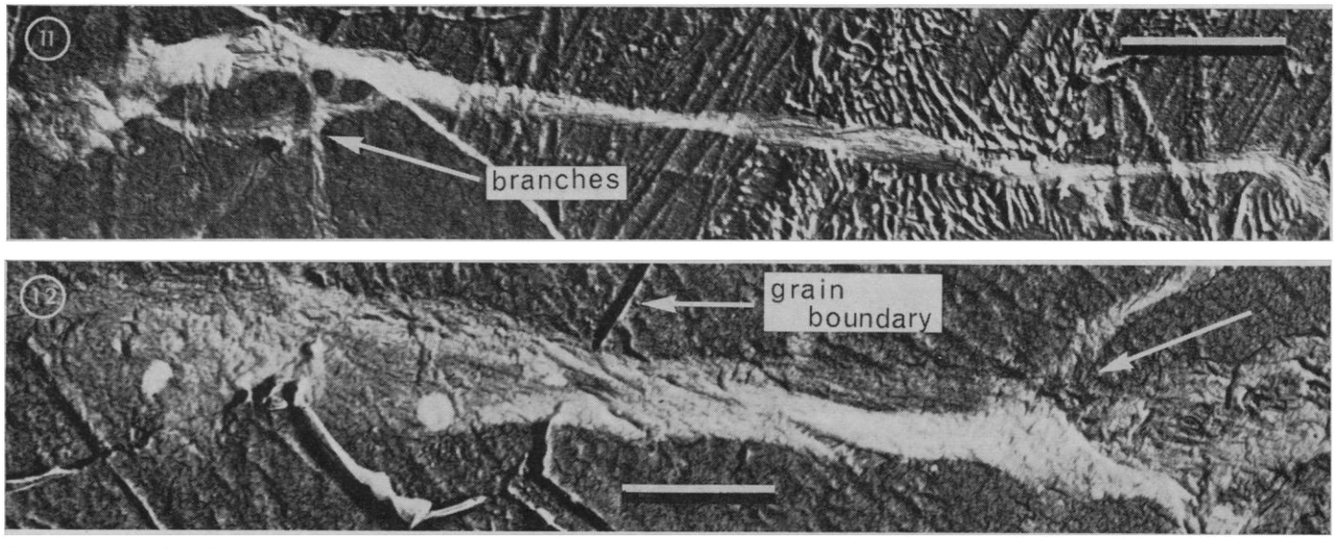
Diagnosis: Unicellular, isolated rods. Length usually between 0.45 and 0.70 μ, with average length of about 0.55 μ; diameter usually between 0.18 and 0.32 μ, with average diameter of about 0.25 μ. Cell wall approximately 0.015 μ thick, composed of two layers of approximately equal thickness. Cells lack sheath or sheath-like residue. External surface often appears granular.

Etymology: With reference to noncolonial, unicellular growth habit.

Type Locality: Black chert facies in upper third of Early Precambrian Fig Tree Series, exposed by road cutting 100 m northwest of surface opening to Daylight Mine (Barbrook Mining Co.), 28 km east-northeast of Barberton, South Africa.

Type Material: Figures 1–9 show representative members of species; Fig. 10 shows ranges of size and shape of species; Figs. 1, 2, 5, and 7 are cited as primary "type material."

In addition to *E. isolatum*, electron microscopy of surface replicas has revealed the presence of filamentous organic structures in the Fig Tree chert (Figs. 11 and 12). Although these organic residues lack the regularity and



Figs. 11 and 12. Filamentous organic material of probable biological origin shown in negative prints of micrographs of platinum-carbon replicas of chert from the Fig Tree Series; line in each figure represents one micron. Fig. 11. Threadlike organic structure approximately 8.5 μ long. The branching, fibrillar nature of this organic residue, comparable in appearance to degraded plant material, is suggestive of biological origin. Fig. 12. Linear organic residue similar to that shown in Fig. 11. The texture and varying thickness of the structure and the fact that it transgresses chalcedony grain boundaries demonstrate that it is indigenous to the rock. Arrow at right points to the origin of a lateral branch.

clearly biological character of the bacterium-like organism, they are significant inasmuch as they appear to show a greater degree of structural complexity. Their evident physical association with mineralogical structures of the matrix (Figs. 11 and 12) and their similarity in morphology and distribution to filiform structures seen optically in thin sections establish that these elongate threadlike forms are indigenous to the chert. Their origin, however, is difficult to determine.

The fibrillar (Fig. 11), branching (Figs. 11 and 12) morphology of these complex structures is suggestive of the high degree of molecular and polymeric order characteristic of living systems; their general appearance is not dissimilar from degraded plant material. However, the fact that they appear to lack such structures as cell walls or transverse septae, and are generally quite irregular in form, suggests that although their molecular components are probably biogenic the branching morphology may be an artifact of inorganic processes operating during crystallization of the matrix. Additionally, these forms might represent ordered remnants of organic material produced abiotically in the early stages of organic evolution (*20*). Although we regard these threadlike forms as almost certainly biogenic, additional investigation is necessary to clarify their mode of origin.

The Middle Precambrian Gunflint chert from southern Ontario contains the oldest known structurally preserved evidence of multicellular plant life (*2, 7*). The diversity and complexity of this approximately 2-billion-year-old microfossil assemblage, and the occurrence of possible biogenic remnants in sediments thought to be older than 2.5 billion years (*15, 21*), have constituted putative, yet somewhat equivocal, evidence suggesting that biological systems originated early in Precambrian time. The occurrence of bacterium-like microfossils, presumably biogenic organic filaments, and complex biologically important hydrocarbons in the Early Precambrian Fig Tree chert establishes that organisms were in existence at least 3.1 billion years ago, and indicates that life on earth must have originated during the preceding 30 percent of the earth's history.

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References and Notes

1. W. G. Meinschein, private communication, 20 December 1965; alkanes from Fig Tree sediments have also been reported by T. C. Hoering in *Carnegie Institution Year Book 64* (Washington, D.C., 1965), p. 215.
2. J. Oró, D. W. Nooner, A. Zlatkis, S. A. Wikström, E. S. Barghoorn, *Science* **148**, 77 (1965).
3. W. G. Meinschein, E. S. Barghoorn, J. W. Schopf, *ibid.* **145**, 262 (1964); E. S. Barghoorn, W. G. Meinschein, J. W. Schopf, *ibid.* **148**, 461 (1965); G. Eglinton, P. M. Scott, T. Belsky, A. L. Burlingame, M. Calvin, *ibid.* **145**, 263 (1964).
4. J. C. Bendoraitis, B. L. Brown, L. S. Hepner, *Anal. Chem.* **34**, 49 (1962); M. Blumer and W. D. Snyder, *Science* **150**, 1588 (1965).
5. J. G. Ramsay, *Trans. Geol. Soc. So. Africa*, in press.
6. ———, permission by private communication, 14 December 1965.
7. S. A. Tyler and E. S. Barghoorn, *Science* **119**, 606 (1954); E. S. Barghoorn and S. A. Tyler, *ibid.* **147**, 563 (1965); P. E. Cloud, Jr., *ibid.* **148**, 27 (1965); E. S. Barghoorn and S. A. Tyler, *Ann. N.Y. Acad. Sci.* **108**, 451 (1963); E. S. Barghoorn and S. A. Tyler, in *Current Aspects of Exobiology*, G. Mamikunian and M. H. Briggs, Eds. (Jet Propulsion Laboratory, Pasadena, 1965), p. 93; W. W. Moorhouse and F. W. Beales, *Trans. Roy. Soc. Can. Sect. III Ser. 3* **56**, 97 (1962).
8. E. S. Barghoorn and J. W. Schopf, *Science* **150**, 337 (1965).
9. Other supposed biological structures from Swaziland rocks have been referred to by H. Pflug in the newspaper "Die Welt" 30 October 1965.
10. L. O. Nicolaysen, in *Petrographic Studies: A Volume in Honor of A. F. Buddington*, A. E. J. Engel *et al.*, Eds. (Geological Society of America, New York, 1962), p. 569; H. L. Allsopp, H. R. Roberts, G. D. L. Schreiner, D. R. Hunter, *J. Geophys. Res.* **67**, 5307 (1962).
11. T. J. Ulrych, private communication, 7 Dec. 1965; information pertaining to these measurements will appear in an article in preparation by T. J. Ulrych and H. L. Allsopp.
12. J. W. Schopf, E. S. Barghoorn, M. D. Maser, R. O. Gordon, *Science* **149**, 1365 (1965); J. W. Schopf and E. S. Barghoorn, Abstr. Ann. Meeting, Geol. Soc. Amer., Kansas City (1965), p. 147.
13. J. M. Schopf, E. G. Ehlers, D. V. Stiles, J. D. Birle, *Proc. Amer. Phil. Soc.* **109**, 288 (1965).
14. E. G. Ehlers, D. V. Stiles, J. D. Birle, *Science* **148**, 1719 (1965).
15. P. E. Cloud, Jr., J. W. Gruner, H. Hagen, *ibid.* **148**, 1713 (1965).
16. The maceration technique has been described by Schopf *et al.* (*12*).
17. AB Gamma Micropolish and AB Microcloth were obtained from Buehler, Ltd., Evanston, Ill.
18. K. V. Thimann, *The Life of Bacteria* (Macmillan, New York, ed. 2, 1963), p. 109.
19. As is noted by J. M. Schopf *et al.* (*13*) in an analogous circumstance: "This is permissible according to regular exemptions given in the Botanical Code of Nomenclature (Art. 9, Note 3) and the International Code of Nomenclature of Bacteria and Viruses (Rule 9d, Note)."
20. We here refer to the abiotically produced organic compounds suggested by A. I. Oparin as the precursors of biological systems (A. I. Oparin, *The Origin of Life on the Earth* (Oliver and Boyd, London, ed. 3, 1957); also *The Origin of Life on the Earth*, Proc. 1st Symposium Moscow, 1957, F. Clark and R. Synge, Eds. (Pergamon, London, 1959). If this speculation were substantiated, *E. isolatum* might have been heterotrophic, metabolizing this organic matter.
21. A. M. Macgregor, *Trans. Geol. Soc. So. Africa* **43**, 9 (1941); T. Belsky, R. B. Johns, E. D. McCarthy, A. L. Burlingame, W. Richter, M. Calvin, *Nature* **206**, 446 (1965); W. G. Meinschein, *Science* **150**, 601 (1965); K. M. Madison, *Trans. Illinois State Acad. Sci.* **50**, 287 (1957).
22. We thank Dr. W. G. Meinschein for access to unpublished data on the organic geochemistry of Fig Tree sediments, Drs. J. G. Ramsay, T. J. Ulrych, L. O. Nicolaysen, H. L. Allsopp, and D. Macauly for assistance in the field and/or for allowing access to unpublished data on the geology of the Fig Tree Series, Dr. M. D. Maser for helpful suggestions on techniques of electron microscopy, and Mrs. Dorothy D. Barghoorn for assistance in the field. This work was supported by NSF grants GP-2794 and G-19727 and Public Health Service grant GM-06637 to Harvard University. J.W.S. is a NSF graduate fellow.

27 January 1966

Upper Atmosphere and Ionosphere of Mars

Abstract. *It is argued that the single-layer ionosphere at 125 kilometers discovered in the Mariner IV occultation experiment is an F1 region coinciding with the ultraviolet photoionization peak. The CO_2 density there must be of the order of 10^{11} molecules per cubic centimeter. Such a density is consistent with the properties of the lower atmosphere by Mariner IV and the temperature model of Chamberlain and McElroy if the atmosphere is mainly CO_2 below 70 kilometers. The absence of an F2 region can be explained even if the density ratio of O to CO_2 is 100 at 230 kilometers on the basis of the rapid conversion of O^+ to O_2 by CO_2. Thus a model with an exospheric temperature of 400°K, a modest degree of CO_2 dissociation, and diffusive separation above 70 kilometers is possible.*

Chamberlain and McElroy (*1*) have shown that radiation from CO_2 and CO in the Martian upper atmosphere is not rapid enough to inhibit the development of a thermosphere in the region where the solar ionizing ultraviolet is absorbed. According to their calculations the temperature must rise from the neighborhood of 160°K at 100 km to about 400°K at 300 km. Thus the low densities required at 125 km that would permit the single ionospheric layer there (*2*) to be an F2 region (*3*) are not attainable. It is also difficult to understand why, if the ionosphere is an F2 region, it disappears in the Martian night (*2*).

If the temperature profile above 50 km calculated by Chamberlain and McElroy (*1*) is correct and if the Martian lower atmosphere consists mainly of CO_2 (or CO_2 and another heavy gas) with density and scale height similar to those measured by Mariner IV, then the