Reports

Microorganisms from the Late Precambrian of Central Australia

Abstract. *An assemblage of structurally and organically well preserved microorganisms, interpreted as both green and blue-green algae, has been found in chert facies of the Bitter Springs limestone from the upper Precambrian of central Australia. This appears to be the earliest known occurrence of green algae in the fossil record. These organisms are among the oldest known multicellular and unicellular fossils exhibiting distinct histological preservation.*

Although the occurrence of stromatolites and other putative biohermal structures has long been accepted as evidence of algal life in Precambrian time, remarkably little effort has been directed toward study of the microconstituents of these sedimentary structures. In part this omission is due to the notable lack of organic matter in many Precambrian sediments; regional metamorphism and physical deformation and attendant devolatilization have effaced the organic matter initially present. Another factor is that emphasis has been placed on study of the calcareous or dolomitic facies of Precambrian reefs or reef-like structures instead of the much less common siliceous or cherty units.

The potentialities for three-dimensional structural preservation of microorganisms in primary cherts have been clearly shown in recent studies of the Gunflint Iron Formation of middle Precambrian age from northern Ontario (*1*). In this formation, approximately 2×10^9 years old, a diverse assemblage of relatively complex multicellular organisms occurs. These fossils constitute the oldest cellular and histologically preserved organisms known. Presumptive algal structures totally devoid of cellular organization but showing vestiges of calcareous gross colonial organization are, however, known from rocks of considerably greater age in the Southern Rhodesia shield (*2*). Graphitic imprints and carbonaceous films similarly devoid of histological features are known from middle to late Precambrian shales from the southern Canadian shield, the Labrador Trough, and parts of the Fennoscandian shield (*3*); none of these organic sediments is in any way related to stromatolitic structures. However, it should be noted that algal and possibly fungal remains showing rather poorly preserved but nevertheless distinct cellular detail have been isolated from shales of the 1000-million-year-old Nonesuch Formation of northern Michigan. In this formation the microfossils are associated with small amounts of crude oil and biologically significant organic molecules such as porphyrins, as well as the isoprenoid hydrocarbons phytane and pristane (*4*).

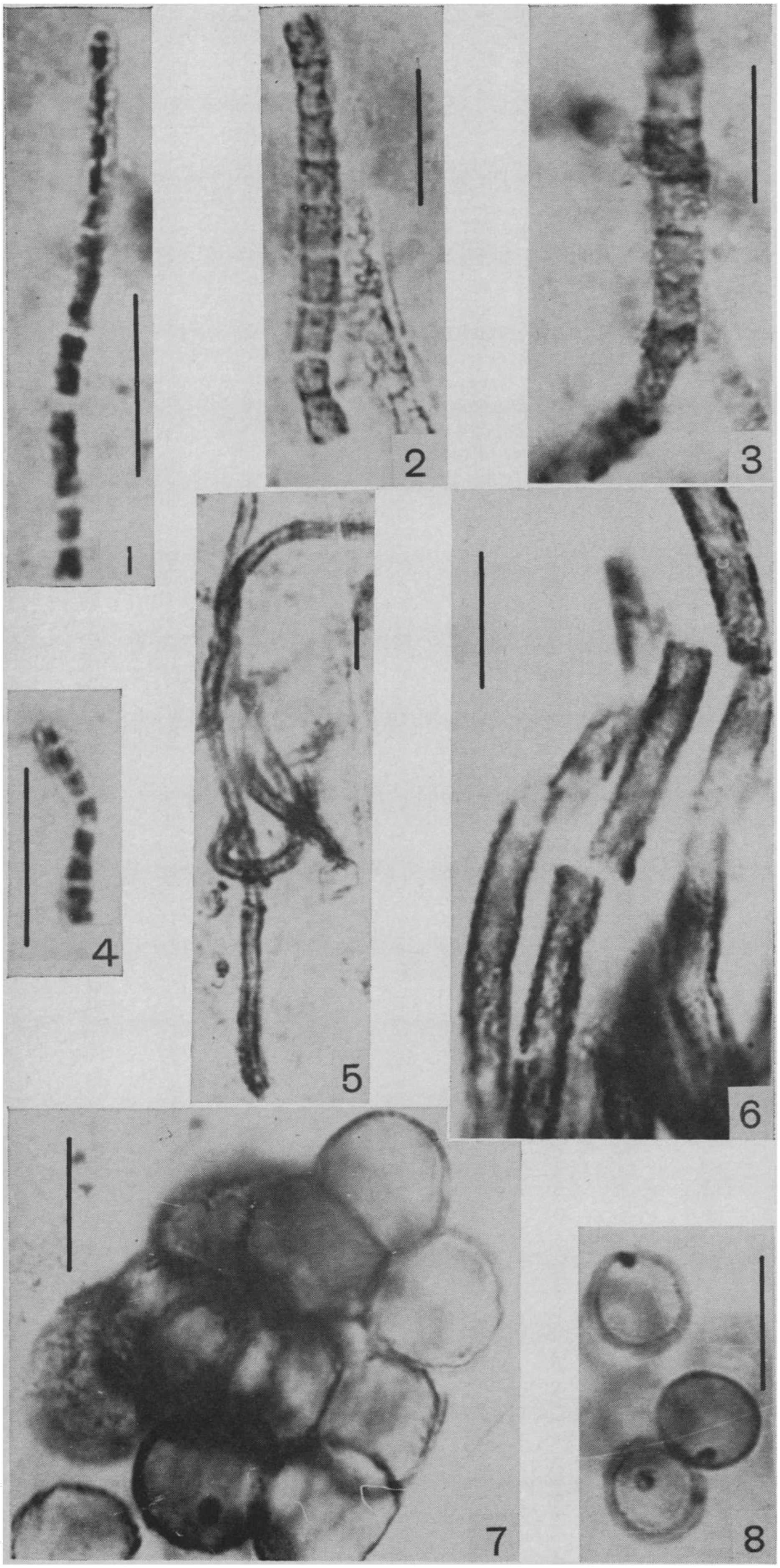
We now report the presence of remarkably well preserved algal filaments and aggregates of single cells in unmetamorphosed cherts from the late Precambrian of the north rim of the Amadeus basin in central Australia. These fossils constitute another link, stratigraphically one of the most recent links, in the expanding record of structurally preserved Precambrian organisms.

The organisms occur in dense black chert facies which are sporadically distributed throughout the Bitter Springs limestone in the area 48 to 80 km east of Alice Springs, Northern Territory, Australia. Because of the steep southward dip of the Bitter Springs beds in this area, and because of the blocky iron-stained weathering products of the formation in this arid climate, it was difficult to determine whether the chert was invariably a component part of a gross stromatolitic structure. In places, however, well-developed *Collenia*-type stromatolites were found to be composed of concentric laminations of black chert. The specimens from which the fossils shown in Figs. 1 to 8 were secured were found by Barghoorn in April 1965 on the south slope of a ridge of lower-to-middle Bitter Springs limestone approximately 1.6 km NNE of the Ross River Homestead (Loves Creek Homestead). The chert at this locality is well brecciated, and angular fragments were easily removed from the bedrock outcrop. In gross lithology the chert is black, slightly waxy in surface texture, and thinly and rather indistinctly banded. In thin section the banding is seen to comprise bedding planes of which the algal filaments and clumps of unicellular organisms often constitute the lower boundaries. The petrography of the translucent, cryptocrystalline chert, the relation of the algal threads to the beds, and the fact that the chert grain boundaries transgress the microfossils without deformation of organic structure indicate that the chert is a primary sediment precipitated from solution in and around the emplaced microorganisms and is not of secondary origin.

In the absence of absolute radiometric age determinations the age of the Bitter Springs fossils cannot be stated with certainty. In the regional late Precambrian sedimentary sequence of the Ross River area the Bitter Springs limestone is overlain by the Areyonga and Pertatataka formations, which, in turn, are overlain by the Arumbera sandstone, the formation comprising the Cambrian-Precambrian boundary (*5*). The top of the Bitter Springs limestone is approximately 1300 m below the lowest of the Arumbera sediments. Because neither the rates of sedimentation of these formations overlying the Bitter Springs nor the duration of any intervening erosional periods is known, it is impossible to calculate with accuracy the age of the middle-to-lower Bitter Springs sediments from which these fossils were secured. However, on the basis of widely accepted values of 600 million years for the base of the Cambrian it seems entirely reasonable to suggest a probable age of between 700 and 900 million years for the organisms described here.

Spheroidal bodies and septate and nonseptate filaments are locally abundant in the chert facies of the Bitter Springs limestone. Almost without exception these microfossils are oriented or aggregated parallel to the bedding planes of the rock, an orientation which is indicative of their original sedimentary emplacement in the deposit. The microfossils vary in color from yellow amber to brownish amber and appear to be organically, as well as structurally, well preserved. In Figs. 1–8, all the organisms are shown in thin sections of the rock, photographed in transmitted light. This assemblage will receive formal taxonomic treatment after additional investigations have been made. Here, for purposes of this discussion, we divide the microorganisms into four morphologically distinct categories: spheroidal bodies, nonseptate filaments, small septate filaments, and large septate filaments. A brief discussion of the four types and of their possible phylogenetic affinities follows.

The spheroidal bodies (Figs. 7 and 8) are spherical-to-subspherical, hyaline, yellow-amber bodies, 7 to 10 μ in diameter. The cell wall, approximately 0.7 μ thick, is often folded and is occasionally ruptured; the surface texture is finely reticulate. A minute granular peripheral dark body (eye spot?), subcircular in shape, is often present on the inner surface of the cell wall (Fig. 8); the cell wall may be invaginated at this point. The spherules occur singly or, more frequently, in clumps of a few to more than 100 individuals; no constant number or ordered geometrical arrangement of spheroids is observed in these masses. However, the frequency of occurrence of the masses and the close



Figs. 1–8. Structurally preserved organisms from the chert facies of the Bitter Springs limestone in thin sections of the rock, photographed in transmitted light. In each figure the scale represents 10 μ. Fig. 1. Small septate filament about 40 μ long. Note the gradual tapering of the filament toward the terminus. Fig. 2. Large multicellular filament showing distinct septations. Fig. 3. Large, unbranched septate filament showing irregularly granular surface texture. Fig. 4. Small septate filament, possibly originally enclosed in a hyaline sheath. Fig. 5. Nonseptate, sinuously wound, unbranched filaments oriented approximately parallel to bedding planes. Fig. 6. Nonseptate, cylindrical, angularly fragmented filaments about 3 μ in diameter. Fig. 7. Thick-walled spheroidal bodies, approximately 10 μ in diameter, tightly clumped in an irregular mass. Fig. 8. Loosely clumped spheroidal bodies of finely reticulate surface texture, each showing a peripheral dark body.

packing of the associated individuals suggest that this association is related to the biology of the organism rather than the result of inorganic processes in the depositional history of the rock. A general morphological similarity of these spheroids to resting zygotes of certain modern green algae (for example, *Chlamydomonas*) has been noted, inasmuch as the resting zygotes often form masses not unlike those observed in the fossil material.

The nonseptate filaments (Figs. 5 and 6) are unbranched, cylindrical amber filaments, 3 to 4 μ in diameter. The cell wall, approximately 0.5 μ thick, is of finely granular texture. The filaments frequently occur as sharply broken, short straight segments (Fig. 6), but they may occur as gently curved to sinuously wound threads (Fig. 5) more than 150 μ long. The filaments generally occur in clumps of subparallel orientation. Morphologically they may be compared to certain siphonalean green algae. However, no evidence of reproductive structures has been observed. As observed in transverse section, the filaments are almost perfectly circular in cross-sectional outline and show no signs of collapse or compression.

The small septate filaments (Figs. 1 and 4) are multicellular, unbranched, brownish-amber filaments tapering from a diameter of approximately 1.4 μ in the medial portion to a diameter of less than 1 μ toward the terminus; cells in the thicker portion of the filament are essentially isodiametric. Toward the terminus the cells are increasingly rectangular in longitudinal view; the terminal cell of the filament appears ellipsoidal (Fig. 1). Possibly these filaments, some of which are more than 75 μ long, were originally enclosed in an amorphous, hyaline sheath (Figs. 1 and 4). The tapering, possibly sheath-enclosed organization of these septate filaments of small diameter is strikingly similar to the morphology exhibited by certain modern blue-green algae (Oscillatoriaceae and Nostocaceae).

The large septate filaments (Figs. 2 and 3) are multicellular, unbranched, amber filaments, 2.3 to 3.4 μ in diameter. The cells vary in form from isodiametric to slightly elongate parallel to the long axes of the filaments. The filaments, some of which are more than 40 μ long, commonly have an irregularly granular surface texture (Fig. 3). An organic residue is often present within the cells (Fig. 2). In general appearance the larger filaments are very suggestive of certain modern green algae (for example, Ulotrichales).

Until further studies are made of the organic residues of these fossils—such as determination of their stable carbon isotope ratios and of their possible retention of the biologically significant hydrocarbons phytane and pristane—it is suggested, on morphological grounds alone, that we are dealing with a microflora of photosynthetic blue-green and green algae. The spatial relations of the microfossils to the laminations of the chert bands indicate that the organisms probably were growing at the time the silica was emplaced in shallow, possibly gently flowing, highly siliceous water. The exceptionally clear and relatively undistorted morphology of these minute organisms indicates that there has been little or no postdepositional metamorphism of the enclosing rock. As for their evolutionary and phylogenetic significance, certain of the microfossils are noteworthy as probable representatives of a transitional period in the evolution of Precambrian plant life during which the simpler green algae were diversifying.

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Hydrogen Emission Line $n_{110} \rightarrow n_{109}$: Detection at 5009 Megahertz in Galactic H II Regions

Abstract. *The hydrogen emission line* $n_{110} \rightarrow n_{109}$ *at the frequency 5009 megahertz which was predicted by Kardashev has been detected in M 17, Orion, and nine other galactic H II regions with the 42.7-m (140-foot) telescope and a 20-channel receiver at the National Radio Astronomy Observatory. The measured product of the half-power width of the line times the ratio of line-to-continuum brightness temperature is larger than that predicted by Kardashev's theory. The radial velocity obtained for M 17 and Orion agrees well with optical measurements. The search for a similar line of excited helium was without success.*

In 1959 Kardashev (*1*) pointed out that it should be possible to detect emission lines of hydrogen which were due to transitions between energy levels with very large quantum numbers n. He showed that in the recombination process occurring in H II regions the transitions $n \rightarrow (n - 1)$ have the highest probability.

One of us tried in 1960 (*2*) to detect the line at 2.8 gigahertz, using the 25-m telescope of the University of Bonn, but could not pursue these observations because of lack of telescope time. In 1963 we started the development of a receiver at the National Radio Astronomy Observatory in order to search for the line. Part of a 20-channel receiver built for extragalactic 21-cm line observations (*3*) was incorporated in this receiver. A first series of observations with the NRAO 25.9-m (85-foot) telescope was started in the fall of 1964, but the results were too inconclusive to yield a positive detection of the line. In July 1965, the search for the line was resumed with a somewhat improved receiver, and with the recently completed NRAO 42.7-m (140-foot) telescope, having at 5 Ghz an effective antenna area about 2.7 times that of the 25.9-m telescope. The line was positively detected in M 17 during the first observation on July 9. Since then, observations of the line profiles of both thermal and nonthermal radio sources have been attempted. We give here a brief account of our observations of M 17, the Orion Nebula, Cygnus A, and Taurus A.