A NEW CHROOCOCCACEAN ALGA FROM THE PROTEROZOIC OF QUEENSLAND

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Abstract and Summary.—Nannofossils§ here described are from the middle Proterozoic Paradise Creek Formation, along Paradise Creek in northwestern Queensland, Australia. These fossils, in chert blebs associated with branched stromatolites, comprise cubic colonies analogous to living *Eucapsis*, a member of the blue-green algal family Chroococcaceae. The age of the enclosing rocks, bracketed by the ages of older and younger granitic events, is about 1.6×10^9 years. We record, therefore, a new chronological and biological datum in the currently accumulating sequence of pre-Paleozoic microbiotas.

Field Relations and Associated Biogenic Structures.—Minute colonies of fossil blue-green algae occur in the Paradise Creek Formation on the south side of Paradise Creek, about 113 kilometers airline north of Mt. Isa, and downstream from Lady Annie Mine, Camooweal Sheet (scale 1/250,000), northwestern Queensland, Australia. The locality, local stratigraphy, and associated biogenic sedimentary structures (stromatolites) were described by Robertson in 1960.[1] He found a variety of "form-genera" of stromatolites in a 100-meter sequence about 1500 meters above the base of the 3000- to 4500-meter-thick and variably dolomitic, silty, and sandy Paradise Creek Formation reported by Carter, Brooks, and Walker.[2] The stromatolitic beds, consisting of chert, dolomite, and siliceous clastics, are divided by Robertson into three "suites"—named, in descending order, Alpha, Beta, and Gamma. They include interstitial breccias and other evidence of shallow turbulent water. The fine structure of these rocks and stromatolites was not studied by Robertson.

The area was visited by Cloud under the field guidance of Smith and other geologists of Mount Isa Mines, Ltd., in July 1965, for the specific purpose of obtaining samples for paleomicrobiological study. Specimens were obtained from seven different localities representing all three stromatolitic suites of Robertson. A number of these have now been studied in a preliminary way, using oil immersion techniques and phase contrast lighting. Studies by transmission and scanning electron microscopy are intended but have not yet proved feasible. Meanwhile these preliminary results seem worth reporting.

Most of the samples so far studied have yielded either no recognizable organisms or only vaguely filamentous and spheroidal structures that cannot be interpreted with confidence. One sample, however, from Cloud's locality 3 of 20/7/65 (Fig. 1) reveals abundant microspheroids arranged in strikingly distinctive square or rectangular aggregates 12–18 μ across.

These geometrically regular aggregates are associated with weakly branching, silicified stromatolites near the top of Robertson's Beta "suite" (or the base of Alpha). Individual digitate colonies are centered on high

FIG. 1.—Outcrop site (3 of 20/7/65). Silicified (formerly calcareous) biogenic encrustations envelope and cap low pinnacles of dolomite along Paradise Creek in northwestern Queensland, Australia. These 1.6-aeon-old encrustations contain the nannofossils here described. They grew about stacklike masses of pre-existing rock in the shore zone. (Hammer about 25 cm long.)

spots on the Proterozoic sea-bottom or envelop stacklike pinnacles of pre-existing dolomite—presumably in the ancient intertidal zone. They range from 1 to 8 meters in diameter and 0.5 to 2.5 meters high. The dolomite between the stromatolitic structures (Fig. 2) preserves fine laminations and includes isolated quartz clasts as well as particles and pockets of cherty stromatolitic debris. This implies either remarkable selectivity of silicification or a primary or early diagenetic origin for some of the chert. Because parts of the stromatolites are dolomitic and not silicified, because the silicification is often coarse and irregular, and because biogenic microstructures have not as yet been found deep within stromatolitic material, a primary origin for the silica seems excluded. Some of the silicification, however, necessarily occurred early enough to preserve delicate soft microstructures, so that the cherts observed may include both early diagenetic and secondary components.

The microstructures observed, rather than being all through the stromatolitic rock, are found only in disrupted rinds of chert around the exterior of the stromatolite "fingers," or within sand-sized blebs of chert in laminae of detrital dolomite interstitial to the stromatolite "fingers" (Fig. 2). From this we deduce that, during early diagenesis, silica in solution diffused through the calcareous sediments and stromatolites, selectively precipitating in the presence of organic matter. Parts of the contraction-cracked outer rind of the stromatolites, and some of the particles within the interstitial dolomite, were replaced by silica

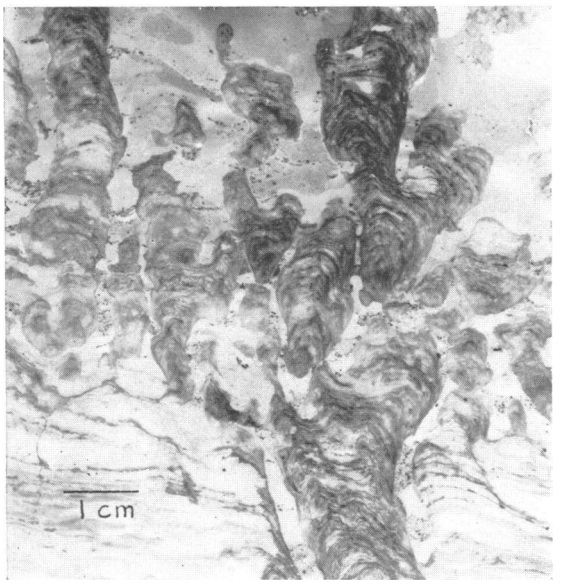

FIG. 2.—Gross structure of the stromatolites. Polished surface of a section of the branching algal encrustations, showing fine laminations within the stromatolitic "fingers" and a well-stratified matrix of dolomite. The algal nannofossils were found in chert blebs between the "fingers" and along their rindlike margins (×1).

early enough to seal in and preserve the microstructures observed. Microstructures within the inner laminae of the stromatolites evidently underwent autolysis or bacterial degradation before becoming perfused with silica and transformed to chert, possibly during a much later postdepositional alteration. It seems that a lucky coincidence of rapid burial and local early silicification has permitted us to add this new datum to the yet very spotty but growing record of pre-Paleozoic microbiology.

Radiometric Age.—The Paradise Creek Formation occurs near the top of a broadly conformable sedimentary sequence deposited between two radiometrically dated granitic events that are widespread in northwest Queensland. Its age, therefore, lies between that of these granites and probably nearer to the younger. These granites were dated by J. R. Richards and colleagues using ratios of lead to uranium and thorium in zircons, the potassium-argon method on micas, and the rubidium-strontium method on whole-rock samples. Results are summarized by Richards,[3] who gives 1.76×10^9 for the older granite and 1.54×10^9 for the younger one.

The age implied for the Paradise Creek beds is thus roughly 1.6×10^9 years. This is equivalent to the "model age" of the syngenetic "Mount Isa Lead" cited by Richards[3] on authority of Kanasewich—a lead that occurs in rocks considered by Carter, Brooks, and Walker[2] to be approximate time-equivalents of the Paradise Creek Formation.

Morphology and Affinities of Microorganisms Observed.—Viewed in random cross sections, the approximately 200 cellular aggregates observed in 13 thin sections characteristically appear as four rows of four to eight closely spaced (but separated) irregular circles or half-circles 2 to 3 μ in diameter, defining a rectangular outline (Fig. 3*b–e*). Focusing at successive levels reveals that the circles are cross sections of globular bodies, and that one rectangular array is

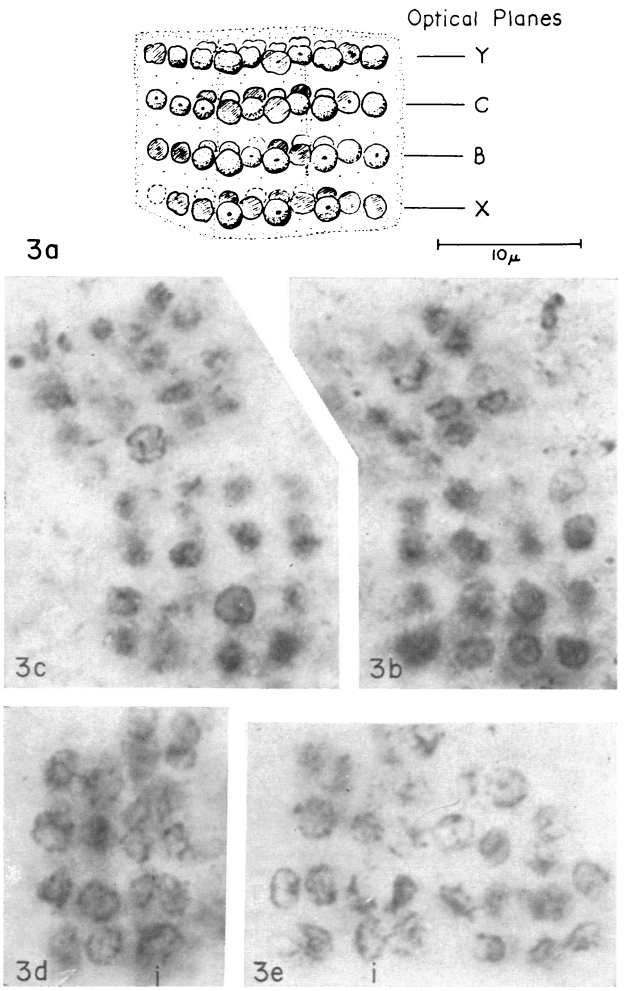

FIG. 3.—*Eucapsis*(?). (*a*) Reconstruction of the basic geometry of the Proterozoic alga based upon four successive photomicrographs through a colony—cells crossed by oblique lining are present but poorly defined; cells illustrated by broken circles are missing; possible cell granules are indicated by dark, nearly central spots; surrounding sheath is conjectured. The lower aggregates of (*b*) and (*c*) are the "templates" from which optical planes *B* and *C* of part (*a*) were drawn; adjacent to them above are parts of an offset (dividing?) colony. (*d* and *e*) Groups of seemingly dividing cells. Magnification for allillus trations given by bar scale at upper right.

succeeded by others in vertical succession. Rarely four layers of cells can be discerned, each in good registry with those above and below. Such observations, added to the characteristic four-cell rows and 16-cell arrays seen in two dimensions, lead us to infer that the basic geometry of these aggregates approximates a cube with four microspheroids on an edge, held together within a gelatinous sheath (Fig. 3*a*). These cubic to rectangular aggregates measure 12 to 18 μ on a side (characteristically 16 to 18 μ). Many separate aggregates may be associated, each with a slightly different orientation.

The individual microspheroids of some aggregates appear to include or consist of pairs of opposed semicircular cells (Figs. 3*d*, *e*, and 4*b*), as if they had just undergone cell division. In such instances there may be up to eight cells in half the rows. This suggests that the characteristic 64-celled cubical aggregates may be produced by the breakup of 128-celled aggregates, following that cell division (e.g. Fig. 3*b* and *c*?). We found few intermediate stages to indicate that they normally result from six successive divisions of individual cells, although that was what we expected to see.

Many cells possess nearly central spots. We are uncertain how to interpret these spots in view, among other considerations, of the fact that the rather special morphology observed so strongly implies procaryotic and not eucaryotic affinities.

In size of cells, geometry of colony, and inferred growth pattern, the Proterozoic assemblages from Paradise Creek are indistinguishable from colonies of the living myxophycean alga *Eucapsis*,[4] the only organism known to us to form a cubic colony of similar dimension, cellular geometry, and cell spacing (Fig. 4*a*).

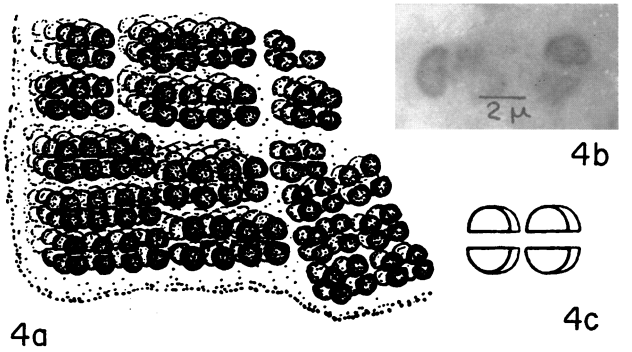

FIG. 4.—Living algae compared with the nannofossils. (*a*) *Eucapsis alpena* Clements and Shatz.[4] ×1155. (*b*) Paired, flat-sided, dividing cells from one of the Paradise Creek colonies. ×3000. (*c*) Diagram of flat-sided cells of *Eucapsis minuta* Fritsch after cell division.[4] ×4000.

The myxophycean genus *Merismopedia* undergoes cell division in two planes, producing two superimposed layers of cells of rectangular arrangement and resulting in a colonial form that is that of a rectangular parallelepiped, not a cube like *Eucapsis*.

Rectangular and boxlike aggregates of cells are also found among certain living bacteria, notably the genera *Lampropedia* and *Sarcina*. *Lampropedia*, however, is composed of small (1 μ) lenticular cells which form one-cell-thick sheets.[5] *Sarcina* reproduces to give a cubic colony of eight cells 2 to 4 μ in diameter; but, unlike *Eucapsis*, the cells are in contact, and colonies are isolated.[5] Virus molecules which may give a regular lattice structure are orders of magnitude smaller than these Proterozoic fossils.[6]

Considering the abundance of specimens, the narrow size ranges of cells and colonies, the complexity and uniqueness of form, the evidence implying cell division, the lack of objects of nonvital origin with which a close comparison can

be made, and the implications of evolutionary continuity with living organisms, there is no reasonable doubt that the Paradise Creek structures are of vital origin. They were, moreover, by all appearances, photosynthesizing units referable to the chroococcacean blue-green algae. Their endemism to the rock in which found is assured by their matrix relations as observed in thin section.

A pertinent question is whether the Queensland nannofossils should be called *Eucapsis* or given a distinctive systematic name. We have as yet, however, been unsuccessful in finding any consistent morphological difference between these fossils and *Eucapsis*; and, granting that there may well have been now-undetectable biochemical differences, we are unwilling to use their great age alone as a taxonomic criterion. To be sure our Eucapsis (?) sp. almost certainly lived in intertidal or very shallow marine waters, and modern *Eucapsis* lives in fresh water; but evolutionary euryhalinity[7] appears to be characteristic of the myxophycean algae. Pending the results of research into the ultrastructure of these and other pre-Paleozoic microfossils now being studied by us, therefore, we designate these fossils simply as Eucapsis (?).

Significance of the Paradise Creek Eucapsis (?).—The fossils here described contribute to the growing but yet very fragmentary understanding of pre-Paleozoic life in several important respects:

(1) They show that stromatolitic material probably originally calcitic (or dolomitic) may become silicified early enough after burial to preserve structural details of easily degradable soft organic matter.

(2) They suggest that the most recently living outer layer (or its detritus) may be the best place to seek microfossils in such chertified stromatolites.

(3) They indicate the morphological structure of living *Eucapsis* to have very ancient analogs and they reinforce the concepts of morphological conservatism, ecological plasticity, and evolutionary euryhalinity among the blue-green algae.[7, 8]

(4) Their procaryotic affinities suggest (but by no means prove) that the first appearance of the eucaryotic (mitosing) cell may have been a later event.

Eucaryotes are now known from much younger Proterozoic beds in central Australia[9, 10] and the USSR.[11] A diverse procaryotic (nonmitosing) microbiota is known from the roughly 1.9×10^9-year-old Gunflint Iron Formation of southern Ontario.[12–15] The Paradise Creek beds of intermediate age have so far revealed only the single procaryotic genus here reported. Cloud has suggested,[16] however, that conditions may have been barely suitable for the appearance of the eucaryotic cell as much as 1.8 to 2×10^9 years ago. Sagan[17] would expect it much later. It remains to be seen whether continued study of rocks as old as the Paradise Creek Formation or older will eventually reveal eucaryotes, or whether their first appearance at a later time will be supported by the geologic record.

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field guidance and information over a large part of the continent. The University of California, Los Angeles, provided facilities and help in the preliminary stages of the laboratory studies. The work was completed with support from National Aeronautics and Space Administration grant no. NGR-05-007-107. We are grateful to all of these for their help.

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§ We use "nanno," rather than "nano," as the prefix, for consistency with nannoplankton, conventional in biological oceanography.

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