Reports

Microorganisms from the Late Precambrian of the Grand Canyon, Arizona

Abstract. *An assemblage of cellularly well-preserved, filamentous and spheroidal plant microfossils has been detected in a cherty pisolite bed of the late Precambrian Chuar Group from the eastern Grand Canyon of the Colorado River. This newly discovered microflora, probably among the youngest Precambrian biological communities now known, appears to be of both evolutionary and biostratigraphic significance.*

The Grand Canyon of the Colorado River, deeply incised into a thick sequence of little-deformed Proterozoic sediments, has long been considered a promising locale for the detection of fossil evidence of early life. Beginning in the mid-1880's with the pioneering studies of C. D. Walcott (*1*), numerous megascopic, fossil-like structures have been reported from these strata. Although virtually none of these megascopic forms (with the exception of calcareous algal stromatolites) are now regarded as biogenic, bona fide Precambrian fossils of smaller size have been detected. Notable among these is *Chuaria*, a genus of originally spheroidal, millimeter-sized, planktonic algae first described by Walcott from the Chuar Group of the Grand Canyon (*1*) and now known from the late Precambrian of Sweden, Iran, India, Siberia, and Canada (*2*). We here report the discovery of a varied assemblage of plant microfossils, structurally preserved in cherty pisolite from approximately the same stratigraphic horizon and locality at which *Chuaria* was first detected. This diverse microbiological community, apparently the oldest pisolith-forming microbiota now known, is a notable addition to the fragmentary Precambrian fossil record (*3*).

As is shown in Fig. 1, the Chuar Group includes three formations, two of which have been subdivided into several members (*4*). The samples studied were collected on the flanks of Nankoweap Butte in the eastern Grand Canyon from a cherty pisolite bed, 60 cm thick, that forms a minor ledge about 20 m above the "flaky dolomite bed" which marks the base of the Walcott Member of the Kwagunt Formation (*5*). *Chuaria*, abundant in uppermost shales of the immediately underlying Awatubi Member, also occurs sparingly in shales of the lower Walcott [Fig. 1; (*4*)]. The Chuar Group underlies the "Great Unconformity" that marks the Precambrian-Cambrian boundary in the region. The group overlies the Nankoweap Group which, in turn, rests on the Cardenas Lavas that have a minimum radiometric age of about 850 million years and a probable age of about 1200 million years (*6*). Thus, the fossiliferous cherty pisolite is of assured Precambrian age. The stratigraphic position of this bed near the top of the Chuar Group, overlying sediments containing stromatolite form genera characteristic of the late Riphean in the Soviet Union (*4*), and the occurrence in closely associated shales of *Chuaria*, a genus known only from very late Precambrian deposits (*4*), suggest an age for the microflora of perhaps 800 ± 200 million years.

The cherty pisolite bed is comprised of concentrically laminated, fine-grained, siliceous pisoliths (Fig. 2f), encompassed by a matrix of pyritic and goethitic chert; siderite rhombs are abundant both in the pisoliths and in the enclosing matrix. Carbonaceous, cellularly preserved microorganisms (Fig. 2, a to c, e, g, h, and j to o) are limited in distribution to a thin, mat-like rind, a few hundred micrometers in thickness, at the periphery of the pisoliths; microfossils have not been detected in the surrounding matrix. Although organically preserved microorganisms are absent from interior portions of pisoliths, thallophytic filaments, infilled by pyrite (Fig. 2i) or by goethite after pyrite, are of relatively common occurrence. Based on these observations, and on a variety of geologic considerations (*4*), it seems evident that the siliceous pisoliths are of biological origin, formed in a shallow, gently agitated, marine setting by accretion of mineralic material on and within a loosely interwoven biocoenose (Fig. 2a). Petrographic relationships and the occurrence of carbonate lenses within the pisolite bed suggest that the pisoliths were initially calcareous. During early stages of pisolith formation, many of the Chuar filaments were infilled with pyrite, presumably formed through reaction of ferrous iron and bacterially generated hydrogen sulfide. Subsequently, during diagenesis, carbonate was replaced by silica and the peripheral, living biocoenose was permineralized in situ. Following silicifica-

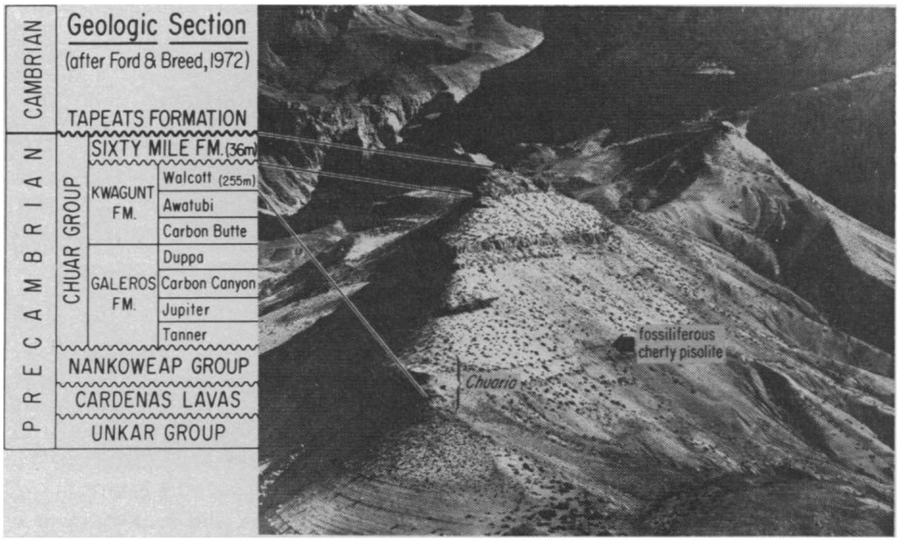

Fig. 1. Aerial photograph of Nankoweap Butte in the eastern Grand Canyon, Arizona, showing stratigraphic relationships of the fossiliferous cherty pisolite and *Chuaria*-bearing shales of the late Precambrian Chuar Group; stratigraphic section after Ford and Breed (*4*). [Photograph by Parker Hamilton]

tion of most of the pisolite bed (the remainder becoming dolomitized), many of the pyritic microfossils were oxidized to goethite by reaction with aerated ground water.

The diverse microfossil assemblage detected in the Chuar pisoliths, including at least eight morphologically distinct types of microorganisms, will be described formally after additional studies have been completed. For this discussion, we divide the microflora into two broad categories—spheroids and filaments—and consider briefly its possible evolutionary and biostratigraphic significance.

Spheroidal members of the assemblage (Fig. 2, j to o) range from about 10 to 60 μm in diameter, exhibit finely granular or psilate surface textures, and occur singly or in clusters of a few to many cells. Some unicells (Fig. 2m) are encompassed by a thinly laminated, sheath-like investment. The relatively large size of many of these spheroids suggests possible affinity with unicellular green or red algae. However, the majority of these cells are of small diameter; this, together with their occurrence in ooids similar to those formed by modern cyanophytic communities (*7*) suggests that many of these forms are probably related to coccoid blue-green algae. Chroococcacean cyanophytes of similar morphology are well known from other late Precambrian cherts (*3, 8*).

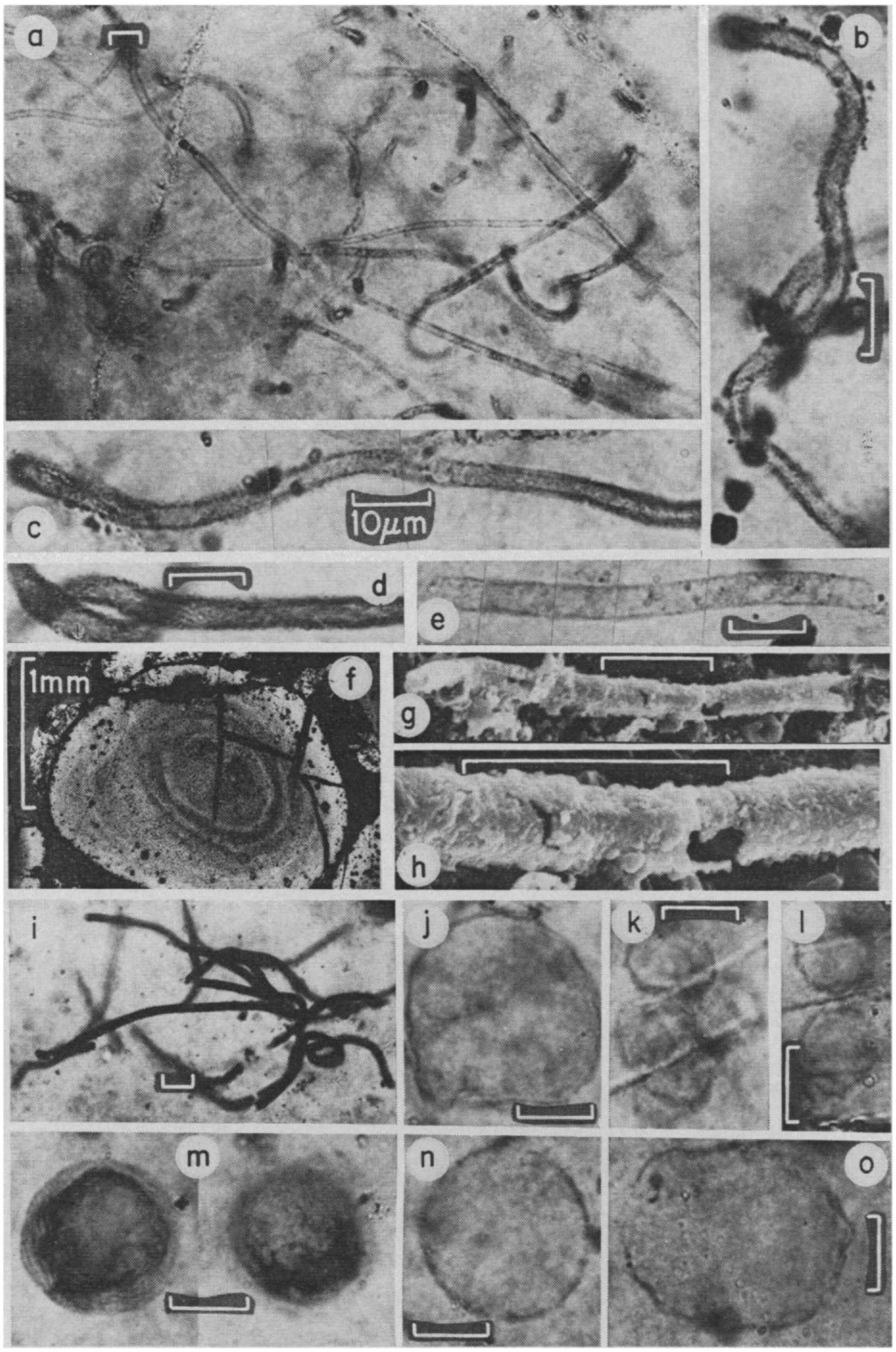

Fig. 2. Optical photomicrographs and scanning electron micrographs (g and h) showing a siliceous pisolith (f) and structurally preserved thallophytes in thin sections (a to c, e, i to o) and in an acid-resistant residue (g and h) of the late Precambrian Chuar chert; *Eomycetopsis* (*8*) in a thin section of Bitter Springs chert is shown for comparison (d). Composite photomicrographs are shown in parts (c) and (e); the cell in part (m) is shown at two focal depths; except as noted, lines for scale represent 10 μm.

The dominant members of the Chuar microflora are robust, tubular, filamentous thallophytes (Fig. 2, a to c, e, g, and h). Of the several filament types detected in the assemblage, the most abundant (Fig. 2, b and c) bears a striking resemblance to *Eomycetopsis* (Fig. 2d), a microscopic thallophyte first described from bedded cherts of the approximately 900-million-year-old Bitter Springs Formation of central Australia (*8*) and recently reported from "Eocambrian" oolitic cherts of northern Greenland (*9*). Like *Eomycetopsis*, the most common Chuar filaments are sinuous and unbranched, range from about 2.5 to 4.5 μm in diameter, have a coriaceous surface texture, and occur in loosely entangled aggregations. Although *Eomycetopsis* is comparable in several respects to phycomycetous fungi (*8*), it is also similar to certain algae; neither its systematic position, nor that of the Chuar filaments, is known with certainty.

The principal implications of this newly discovered, late Precambrian microflora appear to be as follows:

1) Current inferences regarding the course of Precambrian biological evolution are based almost wholly on studies of four or five, well-preserved, stromatolitic microfossil assemblages. It seems possible, however, that these exceptional stromatolitic communities may contain restricted, atypical samples of the early biota (*3*); if so, inferences of early evolutionary development could be quite inaccurate. The pisolith-forming Chuar microflora, the first nonstromatolitic microbiological community to be reported from the Precambrian, provides data with which to assess, at least partially, this possibility. Thus, although important differences (for example, in biological composition and species diversity) probably exist between stromatolitic and pisolitic assemblages, and although it is likely that neither is entirely representative of the contemporary biota, it

nevertheless seems notable that the Chuar microorganisms are comparable in their limited degree of complexity to known stromatolitic microfossils of a similar age (*3*, *8*). This apparently primitive level of organization and, in particular, the absence from the microflora of features characteristic of even moderately advanced microscopic thallophytes (such as true branching and polarity of organization) suggest that the Chuar organisms could predate, perhaps substantially, the emergence of megascopic, multicellular life.

2) The occurrence in the Chuar pisolite and in cherty oolite from Greenland of filaments essentially indistinguishable from *Eomycetopsis* of the Bitter Springs cherts, and the fact that comparable forms are apparently unknown in the Phanerozoic, suggest the possible use of this thallophyte as a late Precambrian "index fossil." In a broader context, it now seems possible that such fossils as *Eomycetopsis* and *Chuaria* may eventually provide a reliable basis for biostratigraphic zonation of the late Precambrian.

3) Despite its abundance in the overlying and underlying Chuar shales, *Chuaria* is absent from the pisolite bed; the converse is true of the *Eomycetopsis*-like filaments which, although prevalent in the cherty pisolite, have not been detected in the associated shales (*10*). These observations indicate that the distribution of at least some Precambrian fossils is probably facies dependent. Recognition of such dependence has obvious bearing on evolutionary and biostratigraphic interpretations and will become increasingly important as additional paleobiologic data become available from the Precambrian.

4) Although the mode of origin of pisolitic sediments has been a subject of considerable controversy (*7*), the evidence here presented indicates that some ancient pisolites are demonstrably biogenic. Cherty pisolitic units appear to represent a promising, largely untapped source of evidence regarding the diversity and evolution of Precambrian life.

J. William Schopf
Department of Geology, University of California, Los Angeles 90024
Trevor D. Ford
Department of Geology,
University of Leicester,
Leicester LE1 7RH, England
William J. Breed
Museum of Northern Arizona,
Flagstaff 86001

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10. Results of palynological studies of the *Chuaria*-bearing shales are summarized by C. Downie in an appendix to: T. D. Ford and W. J. Breed, in *Geology and Natural History of Grand Canyon Region, Guidebook to the Fifth Field Conference*, D. L. Baars, Ed. (Four Corners Geological Society, Flagstaff, Ariz., 1969), p. 121.
11. We thank Hatch River Expeditions, Arizona, and authorities of the Grand Canyon National Park for assistance in fieldwork, which was supported by Grand Canyon Natural History Assoc., Univ. of Leicester Research Board, and a Fulbright travel grant to T.D.F. Laboratory studies supported by NSF grant GA 23741 and, in part, by NASA grant NGR 05-007-292.

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Fossil Lepidopterous Leaf Mines Demonstrate the Age of Some Insect-Plant Relationships

Abstract. *The discovery of impressions of 11 kinds of lepidopterous leaf mines, together with a reevaluation of previous reports, contributes significantly to the fossil record for that insect order. It is also concluded that some specific insect-plant associations have persisted from the Miocene to the present.*

The discovery of fossil leaf mines of 11 species of Lepidoptera from mid-Tertiary deposits in western North America significantly increases the minimum age of the families involved and demonstrates the persistence of some specific insect-plant relationships. Furthermore, three previous reports of fossil mines (*1–3*) appear to represent incorrect interpretations.

Most primitive families of Lepidoptera consist entirely of leaf-mining species (*4*). The ability to detect such leaf mines and to identify the insects responsible for each characteristic mine form provides the potential to further our knowledge of the early history of the order (*5*). The only evidence indicating the presence of Lepidoptera before the Tertiary period is provided by the head capsule of an advanced ditrysian larva discovered in Canadian amber of the Late Cretaceous (*6*). Various reports of fossil Lepidoptera from the Tertiary indicate that most modern families had evolved at least by the Oligocene (*7*).

One of the "healed wounds" on a fossil leaf of *Proteoides wilcoxensis* Berry (? Proteaceae) from the Wilcox deposits of Tennessee (lower Eocene) (*1*) is a clear impression of a leaf mine made by a member of the Nepticulidae, whereas the previous report (*2*) of a

Table 1. Additions to the fossil record for leaf-mining Lepidoptera.

Fossil locality	Time	Host	Miners
Temblor Range, California	Middle Miocene	cf. *Quercus virginiana*	*Nepticula*
Upper Goldyke, Cedar Mountains, Nevada	Late middle Miocene	*Quercus hanibalii* Dorf	*Nepticula* *Lithocolletis*
Thorn Creek, Idaho	Middle to upper Miocene	*Lithocarpus* *Quercus simulata* Knowlt.	*Nepticula* *Eriocraniella* *Nepticula* *Cameraria*
Buffalo Canyon, Nevada	Upper Miocene	*Quercus hanibalii*	*Nepticula* *Bucculatrix*
Stewart Valley, Nevada	Upper Miocene	*Populus trichocarpa* var. *ingrata* (Jeps.) Parish	*Lithocolletis*
Stinking Water, Columbia Plateau, Washington	Upper Miocene	*Quercus pseudolyrata* (Lesq.)	? *Nepticula*
Trout Creek, Oregon	Upper Miocene	*Quercus consimilis* Newb.	? *Acrocercops*
Aldritch Station, Nevada	Mio-Pliocene	*Quercus hanibalii*	*Nepticula* ? *Evippe*