mountain building, and so forth), nor has it yet been possible to derive it from solar activity. On the other hand, the wavelength in question is of the right order of magnitude to be related to the basic astronomical motions of the earth. Now that a reliable time scale for the entire Brunhes epoch has been established, it should be possible to determine appropriate weightings for the various factors involved, so that the hypothesis that the astronomical motions of the earth are the basic cause of climatic change during the Pleistocene may be tested with more rigor than hitherto possible.

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Transvaal Stromatolite: First Evidence for the Diversification of Cells about 2.2×10^9 Years Ago

Abstract. *The well-preserved fossil remnants of filamentous blue-green algae have been found in petrographic thin sections of a dolomitic limestone stromatolite in the Transvaal Sequence of South Africa. Some of these filaments contain enlarged cells which are interpreted as akinetes. A new species and genus,* Petraphera vivescenticula, *is proposed for this microfossil, which is morphologically similar to the living cyanophyte genus* Raphidiopsis. *This would constitute the first known occurrence of cell diversification in the Precambrian with an age of about* 2.2×10^9 *years.*

Evidence is presented for the oldest known occurrence of the diversification of cells in the Precambrian with an age of approximately 2.2×10^9 years. Some of the microfossils are morphologically similar to certain recent cyanophytes.

A geological milestone in the study of early life-forms is the appearance of stromatolites (*1*). The oldest known stromatolite structures occur in a limestone of the Bulawayan Group in Southern Rhodesia (*2*, *3*). It is assumed that this stromatolite was formed by algal activity although microscopic examination has revealed

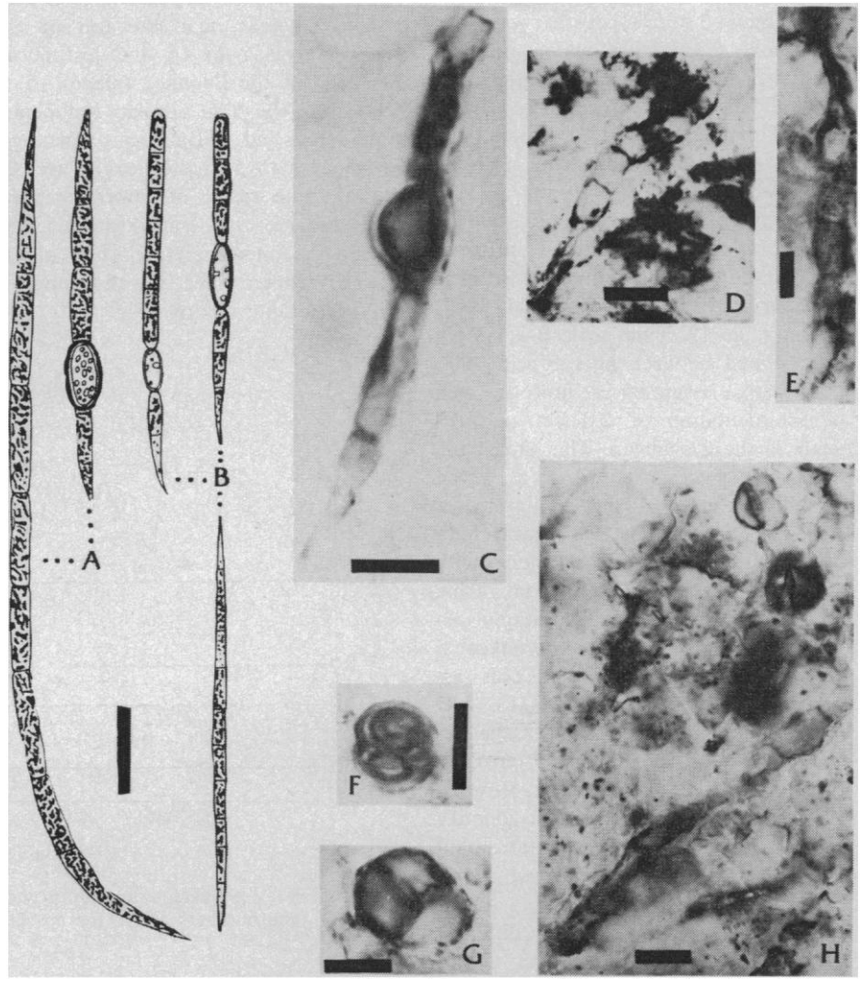

Fig. 1. (A and B) Comparison drawings modified from Desikachary (*17*) of the recent blue-green algae *Raphidiopsis mediterranea* and *Raphidiopsis indica*, respectively; scale bar, 10 μm. (C) New microfossil, *Petraphera vivescenticula*, showing enlarged akinete-like structure; scale bar, 10 μm. At the completion of this investigation the slide (No. TR1A) containing the type specimen will be deposited in the algal herbarium collection of the Academy of Natural Sciences of Philadelphia. (The specimen is marked with a diamond scribe.) (D and E) Broken filamentous forms; scale bar, 10 μm. (F and G) Simple round forms which could represent coccoid blue-green algae; scale bar, 5 μm. (H) Assemblage of a broken filament and round forms; scale bar, 10 μm. All the Transvaal photomicrographs are from petrographic thin sections.

no microstructures (*2*). Table 1 is a list of Precambrian ages and events that are pertinent to this discussion.

Within the Transvaal Sequence in the eastern Transvaal of South Africa, Precambrian stromatolites have been known for some time (*4*). Isotopic age determinations of some of the igneous rocks have yielded an age of 1954 ± 30 million years at the top and more than 2300 ± 100 million years at the base of this sequence (*5*). Recently, nine new stromatolite horizons have been reported in this area (*6*). These structures are included in thin sedimentary members which are associated with a succession of basic lavas. Some of these stromatolites were probably formed in a lacustrine environment. The stromatolite used in this investigation was located geographically north of Burgersfort and stratigraphically approximately 750 m above the basement granite. From this and other information its age has been calculated to be approximately 2.2×10^9 years (*7*). According to the classification of Logan *et al.* (*8*) this stromatolite is of the laterally linked type and is composed of a finely laminated dolomitic limestone. Isotopic studies of the carbonate fraction showed that $\delta^{13}C$, the per mil enrichment in ^{13}C compared to the standard Pee Dee belemnite (PDB), was -0.8 per mil, which is in the marine limestone range (*9*). According to Craig (*10*) the majority of marine limestones have a $\delta^{13}C$ value close to zero.

In 1968 Cloud and Licari (*11*) published data which implied that morphologically simple spherical structures found in the banded iron formations of the Pretoria Series (1.9×10^9 years old) located at the top of the Transvaal Sequence were probably of biological origin. The criteria proposed by Cloud and Licari (*12*) for biogenicity give useful guidelines for understanding the origin of morphologically simple structures.

The well-preserved fossil remnants of filamentous and coccoid blue-green algae have been found in petrographic thin sections of the Transvaal stromatolite. Some of these structures resemble members of the living cyanophyte families Nostocaceae and Rivulariaceae and are morphologically similar to the genus *Raphidiopsis*. Single filaments of the genus *Aphanizomenon* also have a superficial similarity to this new fossil form. Microscopic examination of these petrographic thin sections revealed well-preserved, tapered, segmented filaments, some containing large spherical or elongated cell-like structures 6 to 12 μm in diameter. These cell-like structures are of the same amber color as the filament but some appear darker and are interpreted as akinetes (*13*) in the case of the new microfossil described in this report. Other structures, which are to be described elsewhere (*14*), are interpreted as heterocysts (*13*) and they may well belong to a different taxon. Licari and Cloud (*15*) found both heterocysts and akinetes in algal filaments in sediments from the Gunflint Iron Formation (2.0×10^9 years old). Their heterocysts were nearly transparent in contrast to the darker adjacent cells, presumably because of differential mineralization of the pigmented and nonpigmented adjacent cells. While most modern blue-green algae produce nonpigmented heterocysts, there are some species of *Rivularia* and other genera whose heterocysts retain their pigment for long periods (*16*).

Figure 1, A and B, shows drawings, modified from Desikachary (*17*), of two recent species of cyanophytes (*Raphidiopsis mediterranea* and *Rhaphidiopsis indica*, respectively). These species often show bent or curved trichomes and the terminal cell is narrowed to a sharp point; the end of a broken filament will usually become rounded. The cells of these species are, respectively, two to four and six to eight times as long as they are wide, and the akinetes are two to three times as long as they are wide. However, other recent species belong to this genus (*18*). Fritsch and Rich (*19*) described this genus as nonheterocystous but containing spores or akinetes.

Figure 1C shows a segmented tapered filament in petrographic thin section from the Transvaal stromatolite with an enlarged and elongated akinete-like structure; these filaments are interpreted as being blue-green algal in origin. The name *Petraphera vivescenticula* is proposed for this new microfossil (*20*), which is 55.2 μm long; the akinete-like structure is 10.8 μm long. One end of the best-preserved fossil form is broken, therefore it is not possible to estimate the original total length of the type structure. A number of microfossils of this type have been found in these petrographic thin sections. However, the best-preserved specimen was chosen for presentation in this report. There are morphological differences between the two recent species and the fossil form but the comparison is good. These petrographic thin sections also contain numerous broken segmented filaments (Fig. 1, D and E) and single round forms. The latter (Fig. 1, F and G) may represent remnants of coccoid blue-green algae; they are 9 and 5 μm in diameter, respectively. Figure 1H illustrates an assemblage of a broken filament and two round forms.

Table 1. Pertinent Precambrian ages and events.

Age (years)	Event and location	Reference
$(3760 \pm 70) \times 10^6$	Oldest dated terrestrial rocks; Godthaab district, West Greenland	(*21*)
$(> 3355 \pm 70) \times 10^6$	Simple round microstructures of uncertain origin; Lowermost Onverwacht Horizon, eastern Transvaal, South Africa	(*22*)
$(3355 \pm 70) \times 10^6$	Oldest dated sedimentary rock; Onverwacht Series, eastern Transvaal, South Africa	(*23*)
$(3.1–2.7) \times 10^9$	Oldest known stromatolite; Bulawaya, Southern Rhodesia	(*2, 3*)
$(2980 \pm 20) \times 10^6$	Rod shaped bacteria; Fig Tree Series, eastern Transvaal, South Africa	(*24*)
$(> 2.2–< 2.3) \times 10^9$	Oldest diversification of cells; Transvaal Sequence, South Africa	This report
$(2.0–2.1) \times 10^9$	Unequivocal filamentous microfossils; Gunflint Iron Formation, Canada	(*15, 25*)
$(1.4–1.2) \times 10^9$	Oldest known nucleated eukaryotic cells; Beck Springs, California	(*26*)
$(\sim 900) \times 10^6$	First large assemblage of eukaryotic cells and evidence of sexual reproduction; Bitter Springs, Australia	(*27*)

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13. Heterocysts are large, usually colorless or pale yellow, thick-walled cells placed at regular intervals along a filament. They are found situated either in the middle of the filament (intercalary) or at the ends of the filament (terminal heterocysts). They are associated with nitrogen-fixing activity; akinetes or "resting cells" are enlarged, thick-walled, pigmented germination cells which can occur adjacent to heterocysts as single cells. However, not all akinetes form next to heterocysts. Akinetes are considerably longer and larger in diameter than heterocysts. They can remain viable for long periods of time and can stand desiccation and elevated temperatures. F. E. Fritsch, *Proc. Linn. Soc. Lond.* **162**, 194 (1951); N. J. Lang, *J. Phycol.* **1**, 127 (1965); M. M. Miller and N. J. Lang, *Arch. Mikrobiol.* **60**, 303 (1968).
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Chlorinated Hydrocarbons in the Sargasso Sea Atmosphere and Surface Water

Abstract. *Polychlorinated biphenyls (PCB), DDT, and chlordane concentrations were measured in air sampled from a tower on the south shore of Bermuda and in Sargasso Sea surface water approximately 80 to 320 kilometers south of Bermuda. The atmospheric chlorinated hydrocarbons appeared to be gaseous, and the DDT concentration was two orders of magnitude higher than previously reported particulate values. The PCB and DDT were enriched in the surface microlayer (150 micrometers) relative to their concentrations in water at a depth of 30 centimeters. Atmospheric residence times for PCB and DDT of 40 to 50 days, calculated from the concentrations in the air and water, are 20 times shorter than values previously estimated for DDT from rainfall and DDT production data.*

The presence of polychlorinated biphenyls (PCB) and DDT (*1*) and its metabolites in fish and seabirds is a well-documented fact, and the contamination of marine zooplankton (*2*) and seawater itself (*3*) by PCB has recently been reported. Suggestions have been made that a major transport route of these pollutants to the oceans is via the atmosphere. This hypothesis has been supported by the identification of PCB and organochlorine insecticides in rainwater (*4, 5*) and the detection of DDT in dust carried by the northeast trade winds (*6*). Recently we developed a method which allows hundreds of cubic meters of air per day to be sampled for chlorinated hydrocarbons (*7*). During the period from February through June 1973 we measured PCB, DDT, and chlordane (*1*) concentrations in the marine atmosphere and surface water in the Bermuda–Sargasso Sea area of the North Atlantic as part of a program at the University of Rhode Island to investigate the atmospheric transport and deposition of organic and heavy metal pollutants on the ocean surface.

Air was pulled at 0.4 to 0.8 m^3/min through a glass-fiber filter (20 by 25 cm) (Gelman A) and then through a 15-cm plug of polyurethane foam (10 cm in diameter). The efficiency of the collection system for PCB vapors was better than 90 percent (*7*). Air samples were collected during February through April 1973 from a tower 20 m high located at High Point, Bermuda (*8*). Samples 1 through 4 (Table 1) were collected regardless of wind direction, whereas samples 5 through 8 were taken only while the wind blew from the open-ocean sector (90°E through 240°SW). Marine air was also sampled from a tower 8 m high on the bow of the R.V. *Trident* during a cruise from Bermuda to Narragansett, Rhode Island, in June 1973. Local collections of atmospheric organochlorine compounds were made on the University of Rhode Island campus and in downtown Providence, Rhode Island, without regard to wind direction.

Seawater from the Sargasso Sea was collected in 3.8-liter glass jugs from a rubber raft operated several hundred yards away from the R.V. *Trident* or its wake. We sampled the surface microlayer (150 μm) by means of the screen technique of Garrett (*9*), using stainless steel screens 40 by 40 cm (16 mesh) (*10*). We collected subsurface water by holding the jug approximately 30 cm below the surface. The samples were preserved with dichloromethane and were analyzed within 1 month of collection.

The chlorinated hydrocarbons were recovered from the glass-fiber filter and polyurethane foam by reflux or Soxhlet extraction with petroleum ether. We extracted the unfiltered seawater with dichloromethane and removed the chlorinated solvent before analysis by adding hexane and evaporating to a small volume. The extracts were separated into PCB and pesticide fractions by silicic acid column chromatography and analyzed by electron-capture gas chromatography (Tracor Microtek 220, ^{63}Ni detectors) on OV-17/QF-1 and SE-30/QF-1 columns. The identities of DDT and chlordane were confirmed by dehydrochlorination reactions. The analytical recovery for seawater spiked with Aroclor 1254 was 80 percent. Details and analytical results for the atmospheric and seawater samples are given in Tables 1 and 2.

Only a small amount of the chlorinated hydrocarbons was found on the glass-fiber filter (Table 1), which is capable of removing 98 percent of the particles having radii greater than 0.015 μm (*11*). Most of the PCB, DDT, and chlordane was trapped on the polyurethane foam. This finding suggests that PCB and chlorinated insecticides reside in the atmosphere mainly as vapors