

Neoarchean Biomineralization by Benthic Cyanobacteria

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Archean cyanobacteria are of interest because they have the ability to produce O₂ photosynthetically and to promote mineralization (1, 2). Most reports of Archean microfossils are from silica rocks (cherts) because carbonate crystallization generally destroys prokaryotic cell-sized structures. In the Campbellrand Subgroup, cyanobacterial filaments [*Siphonophycus transvaalensis*, <2516 million years old (Ma)] are preserved in euhedral dolomite crystals, embedded in chert, and exhibit minute needles (originally aragonite?) inside their sheaths (3); *Eoentophysalis* sp. next to other coccoids and filaments were also reported from this subgroup (4).

Our microfossiliferous sample (RK11) was collected from the stromatolitic Peritidal Member of the 2588 ± 6 to 2549 ± 7 Ma (5) Nauga Formation, Campbellrand Subgroup, at Prieska, South Africa. The sample is a flat pebble carbonate conglomerate, embedded in carbonate matrix, with small-scale cross bedding and micritic, sapropel-rich intercalations. Microfossils are dispersed irregularly in a fine carbonate-arenite and are particularly well preserved in micritic carbonate (Mg-calcite) and sapropel-rich laminae, beneath the flat pebbles. They were made visible by etching polished rock platelets for 5 to 10 s with 5% formic acid, rinsed subsequently with distilled water, and sputtered with platinum before scanning electron microscopy examination.

Two types of biostructures are distinguish-

able: (i) spherical bodies, averaging 15 to 35 μm in diameter, visible as pits surrounded by 3- to 5-μm-thick rims, occasionally forming small groups, and (ii) groups composed of smaller subglobular to irregularly polygonal units, 3 to 10 μm in diameter, discernible as pits separated by distinct, 2- to 3-μm-thick walls. These sizes correspond well with the *Eoentophysalis* sp. from Campbellrand cherts and modern *Entophysalis* (4). Our interpretation is supported by comparison to the calcification activity and taphonomy of living benthic colonial cyanobacteria (*Entophysalis* and *Pleurocapsa*) from Lake Van, Turkey; Lake Vai Si'i on Niuafo'ou Island, Tonga; and Sulejow Dam, Poland (Fig. 1). The microfossils are essentially similar to capsules and mucilage sheaths of modern chroococcalean cyanobacteria from family Entophysalidaceae, Xenococcaceae, and Hyellaceae. Characteristic of these cyanobacteria is the capsular organization of mucilaginous sheaths surrounding individual cells and cell clusters forming colonies. Relatively thin inner sheaths enclose single cells and small groups of cells; thicker sheaths enclose larger groups of cells or constitute the outer sheath (capsule) of a colony. In decaying modern *Pleurocapsa* and *Entophysalis* (6), intracellular material and the relatively thin inner sheaths decompose first, whereas the thicker sheaths often remain as the only fossil traces of primary colonial organization.

Heterotrophic bacteria occupying or degrading cyanobacterial cells bind various ions and may serve as nucleation centers for clay minerals (7). Thus, mineralization of the Nauga cyanobacteria may reflect heterotroph action upon the dead biomass. Microprobe analyses show that the interiors of the pits are composed of almost pure calcium carbonate, whereas the rims and walls are calcium carbonate with high admixtures of Al-Fe sili-

cates and dolomite, composition almost identical to calcified modern coccoid cyanobacterial mats from the highly alkaline Lake Van, Turkey (8).

Carbon isotope values of the conglomerate pebbles, the cross-bedded matrix, and the dark carbon rich laminae range between -2.7 and -3.1 per mil (‰), indicating calcification within the diagenetic oxidation zone, perhaps with some contribution from bacterial sulfate reduction. δ¹⁸O values measured on the same points scatter between -10.43 and -12.07‰ and indicate recrystallization at low to moderate temperatures.

The geologically abrupt appearance of widespread and thick stromatolitic carbonate platforms such as the Campbellrand platform, at about 2.9 to 2.6 Ga, and the mechanisms of biocalcification and carbonate precipitation are unexplained (9). Rates of sediment accumulation and organic production on Neoproterozoic carbonate platforms are similar to those on modern platforms and in living microbial mats (4). Although extant cyanobacteria are capable of direct calcification only in alkaline, hypersaline, or freshwater environments, most Precambrian stromatolites presumably thrived under marine conditions; they are extremely finely laminated and rarely show evidence for sediment trapping and binding. Higher alkalinities and calcium carbonate oversaturation (10) may have increased the calcification potential of Neoproterozoic benthic cyanobacterial communities, leading to mass production of fine-grained limestones.

We suggest that cyanobacterial biocalcification was active in Neoproterozoic seas and analogous taphonomic and fossilization processes like those of today were in operation. Thus, microbially produced fine-grained carbonates must have been abundant in the Neoproterozoic but are difficult to recognize because of strong diagenetic neomorphism.

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Supporting Online Material

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Figs. S1 to S4

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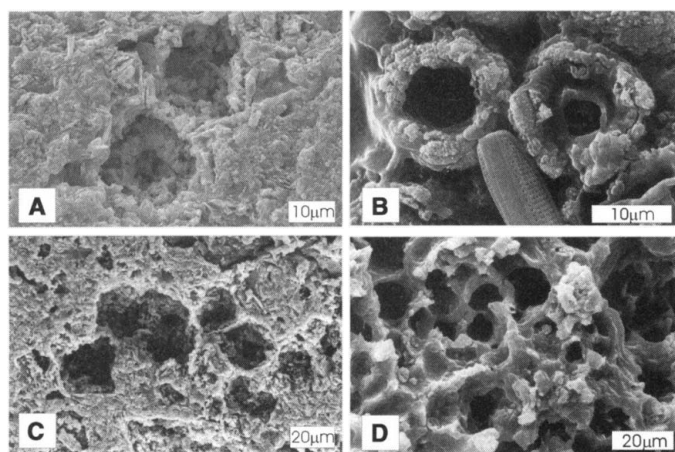


Fig. 1. (A) Mucilage capsules from the Nauga Formation cyanobacterial mat, mineralized by calcium carbonates and Al-Fe silicates. (B) Similarly mineralized modern capsules from Lake Vai Si'i, Tonga. (C) Section of the Neoproterozoic mat resembling capsular mucilage sheaths of modern pleurocapsaleans from Sulejow Dam, Poland (D).