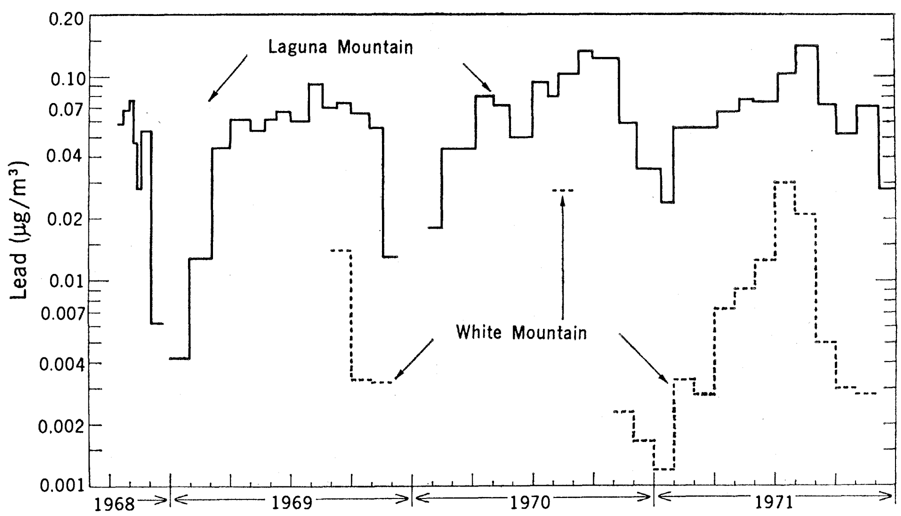

Fig. 2. Seasonal trend of lead aerosol concentrations at White Mountain and Laguna Mountain, California.

determined by the isotope dilution method.

Figure 1 represents the correlation between the percentage of lead present in the suspended particulate matter and the amount of total particulate in the samples taken at Laguna Mountain during a 3-year period. These two parameters show a negative regression relationship, which indicates that the two components originate from different sources. The suspended particulate matter is mainly composed of siliceous dusts and fine flakes of muscovite from the windblown soil. Analyses of soil samples from Laguna Mountain and White Mountain showed lead contents of 6 and 8 parts per million, respectively. The lead aerosols, which constitute 0.22 to 1.1 percent of the suspended particulate matter in the atmosphere at Laguna Mountain, could not possibly be derived from airborne local soil. The lead aerosols more likely originate from the combustion exhaust of automotive fuels in distant cities and are eventually diffused to these locations.

Figure 2 represents the seasonal trend of monthly average lead aerosol concentrations at the White Mountain and Laguna Mountain stations. The White Mountain site is the highest-altitude station for continuous year-round air sampling in existence. A severe winter resulting in loss of electrical power at the White Mountain laboratory curtailed sampling during part of 1969 and 1970. For 1971 the lead aerosol concentration at White Mountain ranged from 0.0012 to 0.029 $\mu g/m^3$, and the annual average was 0.0080 $\mu g/m^3$. The lead aerosol concentrations at Laguna Mountain ranged from 0.0040 to 0.141 $\mu g/m^3$ for 1969, 1970, and 1971, and the annual averages were 0.048, 0.070, and 0.069 $\mu g/m^3$, respectively. The lead aerosol concentration at White Mountain was lower than that at Laguna Mountain because the former location is at a higher altitude and farther away from sources of pollution than the latter. However, both mountain sites showed the seasonal trend, with a minimum lead concentration in the winter months, a gradual increase in the spring, and a maximum during the summer and early autumn. This trend of summer maximum and winter minimum is the reverse of what we have observed at San Diego (*8*); this is because our San Diego stations are located near the seashore, with summer sea breezes dispersing the lead aerosols, and the thermal (radiation) inversions, which commonly occur in the winter, trapping the lead pollutants in the atmosphere. The sampling sites at Laguna Mountain and White Mountain are well above the thermal inversion boundary, which reaches an altitude of 200 to 1000 m. However, summer traffic on the mountain roads and near the sampling sites may also contribute to the summer maximum.

The annual average lead aerosol concentration at the White Mountain station, which is 0.0080 $\mu g/m^3$, may be considered as the present baseline concentration for atmospheric lead for the continental United States.

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Siliceous Algal and Bacterial Stromatolites in Hot Spring and Geyser Effluents of Yellowstone National Park

Abstract. *Growing algal and bacterial stromatolites composed of nearly amorphous silica occur around hot springs and geysers in Yellowstone National Park, Wyoming. Some Precambrian stromatolites may be bacterial rather than algal, which has important implications in atmospheric evolution, since bacterial photosynthesis does not release oxygen.* Conophyton *stromatolites were thought to have become extinct at the end of the Precambrian, but are still growing in hot spring effluents.*

Growing algal and bacterial stromatolites (*1*) composed of nearly amorphous silica occur in the alkaline effluents of hot springs and geysers in Yellowstone National Park, Wyoming (see Fig. 1). They are the subjects of a continuing study, but because of their significance for current research programs we are reporting our first results here. These are: (i) The stromatolites are primarily siliceous. (ii) Photosynthetic flexibacteria are very abundant in the stromatolites. (iii) There are growing *Conophyton* stromatolites, a distinctive group previously thought to have become extinct near the Precambrian-Cambrian boundary. The immediate relevance of these results is twofold: (i) They indicate that bacteria may build stromatolites and, thus, that some fossil stromatolites, especially those in the Archean, can be bacterial rather than algal. This has important implications in atmospheric evolution, since bacterial photosynthesis does not release oxygen. (ii) They prove that stromatolites can be primarily siliceous, and thus support interpretations of the primary origin of the silica in Precambrian iron formations (some of which include siliceous stromatolites built by a microbiota comparable with that in hot spring effluents).

The silica is precipitated nonbiogenically, due to the cooling and evaporation of the water (*2*). It encrusts the bacterial and algal filaments, building tubules and eventually a solid rock permeated by microbial filaments. All of the samples analyzed by x-ray diffractometry are nearly amorphous opaline silica, opal-A in the classification of Jones and Segnit (*3*).

Microbial mats occur in Yellowstone at temperatures up to about 70°C (*4*). Animal grazers are restricted to temperatures less than 50°C (*5*) and have no effect on most of the structures described. Mats at temperatures above about 30°C consist of fine filamentous cyanophytes ("blue-green algae") and bacteria, whereas those in cooler parts of the effluents are formed by coarse filamentous cyanophytes (*Calothrix* sp. and *Mastigocladus* sp.). The *Calothrix* mats are crudely laminated and are generally stratiform with wavy surfaces and infrequent small domes or, rarely, clusters of contiguous domes, but no columnar forms are known. In contrast, the higher temperature mats are usually finely laminated, and in a number of springs they form small columns with a relief of up to 3 or 4 cm and a width of 1 or 2 mm up to 2 or 3 cm. Their maximum relief is governed by the depth of water in which they grow. Columns have not been found at temperatures above 59°C, a temperature near that at which the mats reach their maximum thickness (*6*).

There are two types of columns, flat-topped and conical. Both are vertical and apparently do not branch. They form beds from 1 cm to more than 10 cm thick. Lenticular gas cavities occur between the laminae of many columns. The flat-topped columns (Figs. 1 and 2A) are known from the effluents of only one geyser. During an eruption the columns are covered by rapidly flowing water with a *p*H of 7.5 to 8.5, but between eruptions they are exposed to the atmosphere, although they remain wet. The columns show no orientation related to the current flow: most have nearly circular transverse sections. They consist of almost flat to gently convex laminae, which bend down abruptly near the column margins, forming a wall. The laminae are alternately light and dark, the light ones being 20 to 100 μm thick and the dark ones 15 to 50 μm thick. In the dark laminae the filaments are contiguous and intertwined and lie in the plane of the lamina. In contrast, in the light laminae the filaments are more or less vertical and are more widely spaced (Fig. 2B). The filaments in the walls are vertical. Several of these stromatolites were marked in the field with carborundum powder, and their growth was measured. After 4 days some has not grown, but one had four pairs of light and dark laminae above the carborundum layer. Growth of the columns is interpreted as a phototactic response, with the filaments moving upward during daylight hours but lying prostrate at night. The bacteria and cyanophytes are capable of gliding motility (*7*).

The conical columns (Fig. 2C) are built from acutely conical laminae with their apexes directed upward. They have been found in the effluents of several springs and geysers at temperatures up to 59°C, and in several pools with temperatures in the range of 30° to 50°C. They occur in a wide variety of hydrologic regimes ranging from subaqueous and almost stagnant through subaqueous with rapidly flowing water

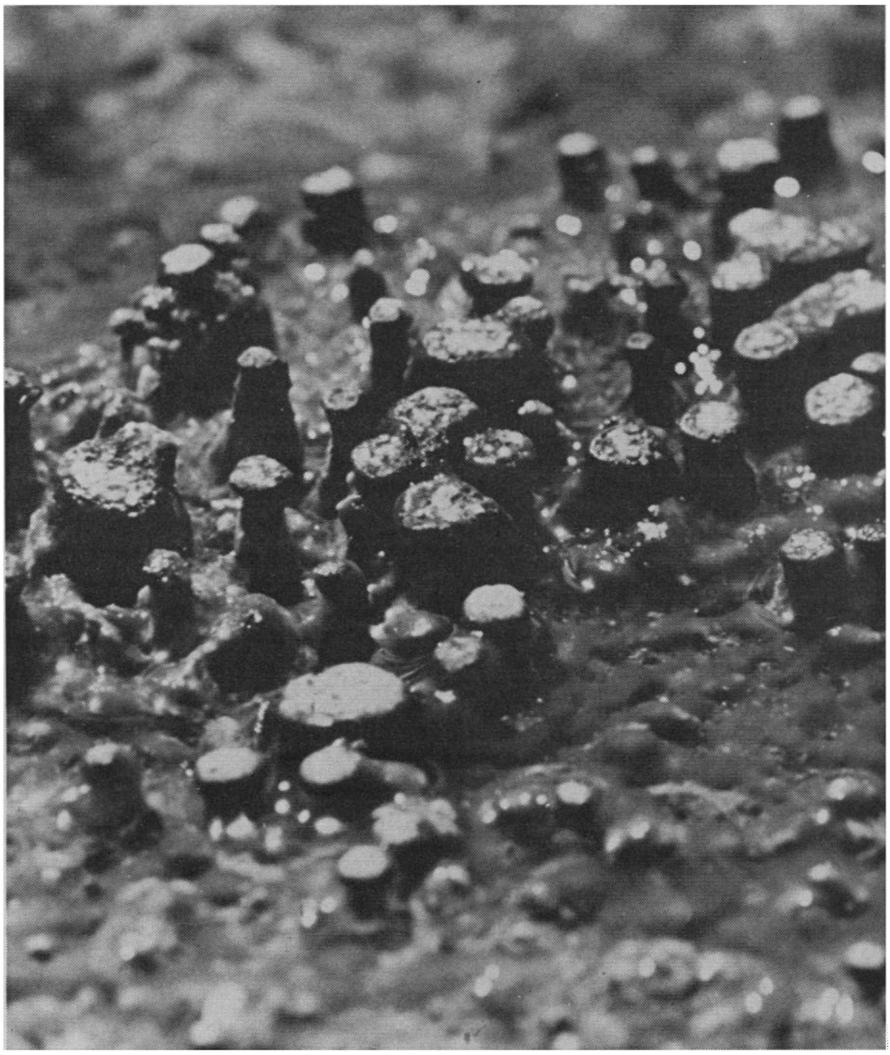

Fig. 1. Heavily silicified columnar stromatolites in the effluent of a geyser, Yellowstone National Park. Approximately two-thirds natural size.

to alternately subaerial and subaqueous with rapidly flowing water; the *p*H of the water ranges from 7.5 to 9.0. Their shape bears no obvious relationship to directions of water flow; column transverse sections are subcircular even in areas of rapid unidirectional water flow. The range of morphological variation suggests the following growth sequence: A series of minute nodes a millimeter or so wide develop on a flat mat. These consist of filaments which are growing and spreading out over the underlying mat. The growth from these centers may directly form tiny vertical spines with conical laminae. Frequently the growth is horizontal and crudely radial and forms a network of anastomosing ridges, a millimeter or so in relief and spaced several millimeters apart. Vertical growth is favored at the nodes and where several ridges intersect, and at these points columns progressively develop. Growth also occurs intermittently between the columns, so some laminae continue through adjacent columns. The column microstructure is banded (*8*) with laminae 5 to 30 μm thick, but distinct laminae are not always present. The microbial filaments usually parallel the lamination; this produces a microlamination on a scale of 1.0 to 1.5 μm, the thickness of the silica-encrusted filaments. There are infrequent lenticular or irregular knotty thickenings in the laminae, especially near the column axes (Fig. 2D); in these the filament arrangement is more complex.

Both column types and the mats from which they grow contain filamentous flexibacteria of a kind shown to be photosynthetic (*7*). These organisms will grow aerobically in the light or dark on a mineral medium supplemented with 0.05 percent yeast extract. Under anaerobic conditions in the light, cultures grow photoheterotrophically and also show light-stimulated CO_2 fixation (photosynthesis). Pure cultures of these organisms contain bacteriochlorophylls a and c as determined by the absorption spectra in methanolic extract. Natural material removed from the stromatolites also contains bacteriochlorophylls a and c.

Microscopically it is difficult to distinguish between the largest diameter flexibacteria and narrow trichomes of cyanophytes such as *Phormidium*. Such filaments comprise a large proportion of the stromatolite microbiota. The relative importance of the flexibacteria and cyanophytes in the building of the stromatolites is being investigated. Unicellular cyanophytes (*Synechococcus lividis* and *S. minervae*) frequently form the surface layer of the dominantly bacterial mats (*7, 9*), but such a covering is not ubiquitous, nor is it present on columns, although these have some *Synechococcus* cells embedded in their surface layers. Coarsely filamentous cyanophytes are sparsely and irregularly distributed through the bacterial mats.

The hot spring and geyser environment combines two features that were of wider occurrence during the Precambrian: (i) nonbiogenic deposition of silica at temperatures at which microorganisms can grow prolifically and (ii) a metazoan-free, prokaryote-dominated microbiota. Stromatolites can be primarily siliceous. Credit for this discovery must go to Weed (*10*), who produced an excellent description of the microbial structures and sinter in Yellowstone long before the true nature of stromatolites was known. Barghoorn and Tyler (*11*) recognized that the Yellowstone stromatolites were potentially significant in the interpretation of the Gunflint Formation chert stromatolites, and our data are used elsewhere

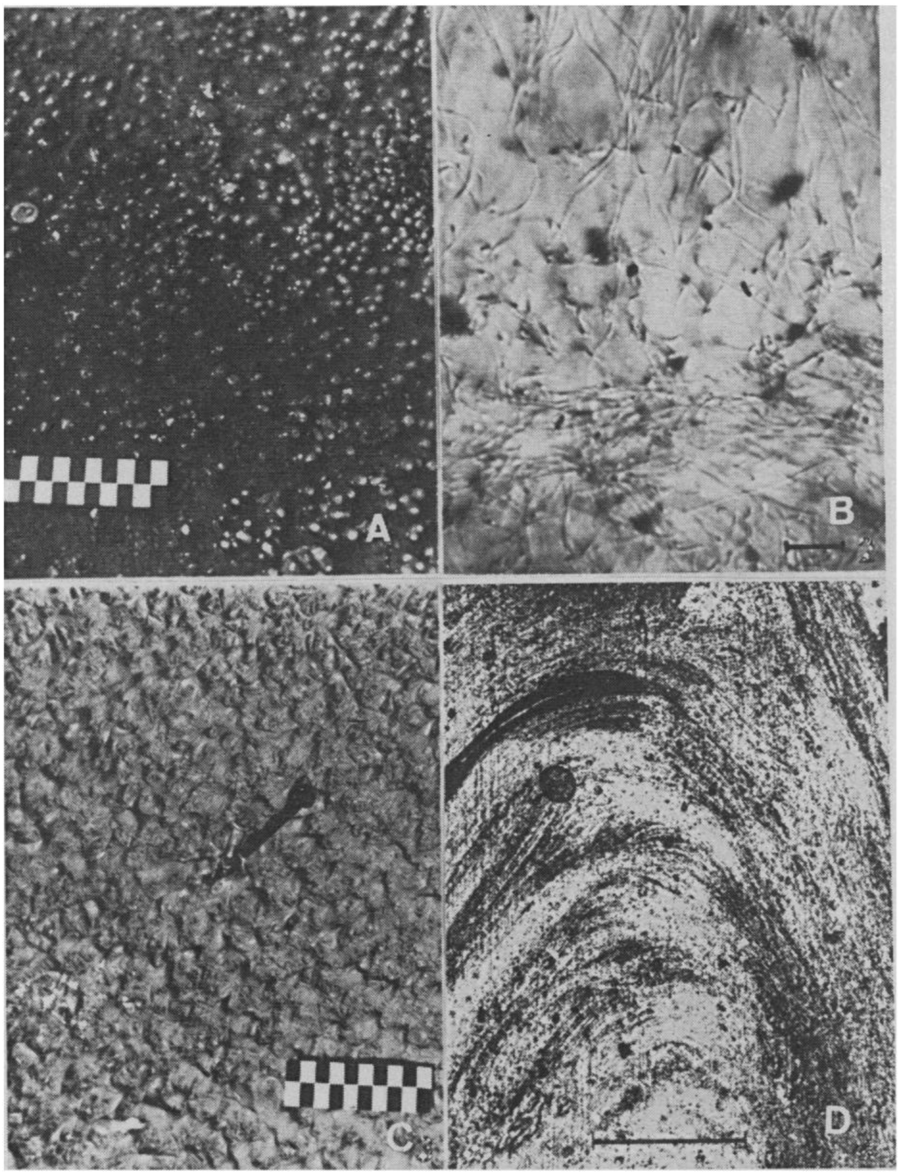

Fig. 2. (A) Columnar stromatolites with convex laminae in the effluent of a geyser, Yellowstone National Park. Scale in centimeters. (B) Thin section perpendicular to the lamination of a stromatolite like those in (A), showing the horizontal bacterial and cyanophyte filaments of a night lamina overlain by the vertical filaments of a daylight lamina. Scale line 10 μm. (C) Columnar stromatolites with conical laminae (*Conophyton* f. nov.) in the effluent of a hot spring, Yellowstone National Park. In this field of view only the conical tops of the columns project above their substrate. Scale in centimeters. (D) Thin section along the vertical axis of a column like those in (C), showing only the axial zone. Groups of laminae are thickened in the axial zone. The dark circles and vertical lines are artifacts. Scale 500 μm.

to develop a model for the depositional environment of Precambrian iron formation stromatolites (*12*).

Photosynthetic flexibacteria have the essential characteristics required for stromatolite building: They are filamentous and capable of gliding motility, and so can trap sediment, and they will grow or move up through covering sediment toward the light. It is possible that some Precambrian stromatolites were built by bacteria, rather than cyanophytes or eucaryotic algae. Since bacterial photosynthesis does not release oxygen (*13*), correlations between the appearance of Precambrian stromatolites and the origin of an oxygenated atmosphere (*14*) may not be valid. This is particularly relevant in interpreting the Archean Bulawayan stromatolites of Rhodesia, the oldest known. The evidence previously used to indicate a cyanophytic origin for these stromatolites (*14*) is equally consistent with a bacterial origin now that photosynthetic flexibacteria are known. Here we are suggesting that organisms lacking the oxygen-releasing photosystem II could have built the Archean stromatolites, not that they were necessarily built by photosynthetic flexibacteria identical to those in Yellowstone.

The most abundant components of the famous Gunflint microbiota closely resemble the hot spring microbiota. The similarity in size and morphology of *Gunflintia minuta* Barghoorn and the photosynthetic flexibacteria and *Phormidium*-like cyanophytes is striking. The occurrence of *G. minuta* in stromatolites is used to support identification as a cyanophyte, although most authors note its resemblance to filamentous bacteria (*11, 15*). However, Licari and Cloud (*16*) report putative specialized cells (heterocysts and akinetes) from this fossil, and no similar cells are known from filamentous bacteria although they occur in cyanophytes.

The columnar stromatolites with conical laminae closely resemble the Precambrian form *Conophyton*. This was thought to have become extinct near the end of the Precambrian (*17*) and has been used to define the Proterozoic-Paleozoic boundary (*18*), although that definition was later found to be untenable (*19*). The Yellowstone form could be convergent with those in the Precambrian, but its close resemblance to some of them makes this unlikely. Particularly notable similarities are the banded microstructure, the irregular apical thickenings of the laminae, and the scalloped transverse sections of many columns. In these features and in size it resembles *Conophyton* cf. *garganicum* from the Sibley Group of Canada (*20*). Its columns are a little narrower than in that form, and much narrower than in most Precambrian forms. It has thinner laminae than any Precambrian *Conophyton* and cannot be equated with any described forms. Few, if any, Precambrian conophytons grew in hot springs. We predict that a careful study of fossil hot spring deposits will lead to the discovery of Phanerozoic conophytons.

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Polar Motion from Laser Tracking of Artificial Satellites

Abstract. *Measurements of the range to the Beacon Explorer C spacecraft from a single laser tracking system at Goddard Space Flight Center have been used to determine the change in latitude of the station arising from polar motion. A precision of 0.03 arc second was obtained for the latitude during a 5-month period in 1970.*

A preliminary analysis of range data collected by a laser tracking station at Goddard Space Flight Center, Greenbelt, Maryland, during a 20-week period in 1970 indicates that the orbital inclination of the Beacon Explorer C spacecraft can be determined to a precision of better than 0.03 arc second from data collected over 6 hours. This result suggests that a single laser tracking system can measure changes in the position of the pole of rotation of the earth in the meridian of the tracking station to a precision of at least 1 m with a time resolution of ¼ day. The value of ultimately having high-precision, high-resolution information about polar motion is in its usefulness for understanding the dynamics of the earth and, in particular, the correlation between earthquakes and polar motion (*1*).

The laser at Goddard is a 1-joule ruby system with a pulse rate of 1 per second; it is capable of measuring the distance (ranging) to satellites equipped with laser reflectors (*2*). These measurements can be made during both day and night (weather permitting). Tests of the laser ranging systems and comparisons of independent stations have shown that the measurement reproducibility and the root-mean-square scatter in the range measurements is of the order of ± 30 cm (*3*). The satellite used in the experiment, Beacon Explorer C (BE-C), has an orbit with an inclination of 41.1°, an apogee of about 1300 km, and a perigee of about