core. The significance of the nonlaminated zones can be determined only after additional cores are taken to determine if the laminae might have been destroyed during the recovery and subsequent handling of the core. The nonlaminated zones were not observed in the other cores, the longest of which, core No. 3, recovered only 5.13 m of sediment.

X-ray diffraction analysis of the sediments show that quartz, feldspar, cordierite, iron chlorite, mica species (illite), and montmorillonoids occur in both the light- and dark-colored laminae.

The opal content of individual laminae was estimated by converting the opal in washed, carbonate-free sediment to cristobalite, and determining the amount of cristobalite by x-ray diffraction (*5*). Replicate determinations are reproducible within 10 percent.

The light-colored laminae have a uniformly higher opal content, due to a greater abundance of diatom frustules, than do the dark-colored laminae. The average opal content for the light-colored laminae is 28 percent by weight (ranging from 22 to 36 percent), while the average opal content of the dark-colored laminae is 21 percent (ranging from 19 to 25 percent). These differences are well outside experimental error. The light-colored laminae contain finer layers which appear to be almost pure opal. Unfortunately these finer laminae could not be separated for analysis.

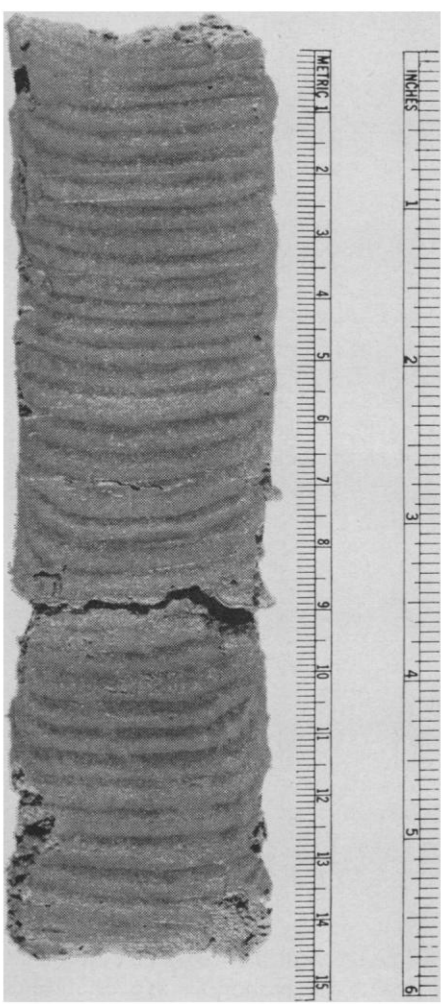

Fig. 2. Varved diatomaceous sediment from core No. 4 (depth in core: 500 to 515 cm). Note the distinct color change at the base of the lighter-colored laminae as contrasted to the gradual color change at the top.

There is apparently no significant difference in the total carbon, calcium carbonate, and nitrogen content between the light and dark laminae. The average nitrogen content is approximately 0.3 percent by weight. The average total carbon content is 2.0 percent and the average calcium carbonate content is 2.4 percent.

With these data it is possible to estimate the amount of sediment deposited each year in the central portion of Saanich Inlet. An accumulation rate of 4 mm of sediment per year consisting of 75 percent water (by weight) and 25 percent solid material (with a density of 2.4 g/cm^3), means that 0.24 g of sediment per square centimeter are deposited each year. Assuming that the sediment is deposited uniformly over the bottom of the inlet at depths greater than 100 m, approximately 9×10^4 metric tons of sediment are deposited in Saanich Inlet each year. The sediment consists of approximately 25 percent diatom remains with minor amounts of terrestrial plant debris. The remaining 75 percent is primarily silt and clay, presumably derived from the Cowichan and Fraser Rivers because there are no other major sources of silt- or clay-sized terrigenous sediment in or near the Inlet (*6*).

M. GRANT GROSS, SEVKET M. GUCLUER
JOE S. CREAGER, WILLIAM A. DAWSON
Department of Oceanography, University of Washington, Seattle 5

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7 June 1963

Unmineralized Fossil Bacteria

Abstract. *Unmineralized bacterial cells, mostly* Micrococcus *sp., but including also* Streptococcus *sp. and* Actinomyces *sp., were found in enormous numbers in lake beds of the Newark Canyon Formation of Early Cretaceous age, Eureka County, Nevada. The micrococci are black, and have an average diameter about 0.5 μ. Similar black micrococci (0.4 to 0.7 μ) were found in profusion in the bottom mud of Green Lake, New York. About 80 percent of this mud consists of minute idiomorphic calcite crystals and about 20 percent of these contain enormous numbers of the black micrococci. It is suggested that the Early Cretaceous bacterial cells owe their preservation to occlusion in calcite crystals that grew in a black, bacterial mud in a meromictic lake in which part of the Newark Canyon Formation accumulated.*

Lake beds are known to make up part of the Lower Cretaceous Newark Canyon Formation in the area south and east of Eureka, Eureka County, Nevada (*1*). One of the lacustrine beds in this formation, samples of which were collected by T. B. Nolan and C. W. Merriam, is a nearly black, unlaminated limestone, but other beds are of organic marlstone and are characterized by typical lacustrine varves.

The organic remains in these beds are astonishing. They consist largely of black bacterial cells and very small unidentifiable scraps of organic matter, which are yellowish brown. That these black spherules are not pyrite, as might be expected, was shown by the fact that x-ray fluorescence showed no iron and by the fact that they are decomposed by Clorox. A small number of cells, somewhat larger than the black organic cells, are colorless. These cells, which suggest bacterial spores, are silicified.

By far the greater number of these black bacterial cells are coccoid forms that are either dispersed individual cells or, much more rarely, ordered in small regular plates. These apparently are *Micrococcus* sp. and they are less than 1 μ in diameter. They are most abundant on and close to scraps of organic matter as shown in Fig. 1.

In addition to *Micrococcus* sp., there are a few *Streptococcus* sp., whose individual cells are essentially the same diameter as the micrococci,

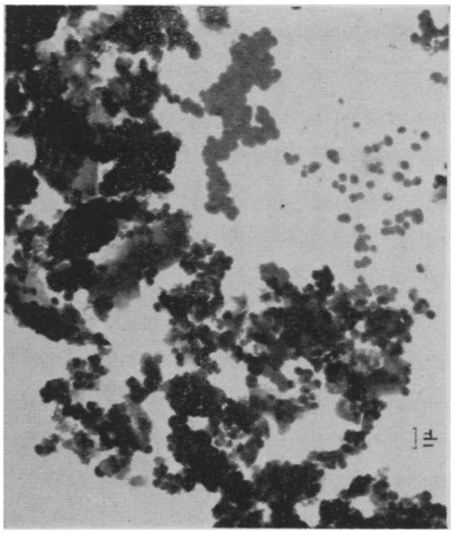

Fig. 1. Electron micrograph of coccoid bacteria from an organic marlstone in the Lower Cretaceous Newark Canyon Formation of the Eureka area, Nevada. Many of the bacteria are attached to small scraps of unidentified organic matter.

but they are arranged in chains of 2 to 15 cells. Irregular, forked, stubby cells are also fairly common and these are apparently *Actinomyces* sp. Short rods, less than 1 μ in diameter and about 2 μ long, were also found, but they are not at all numerous.

The calcite grains that make up all the rest of these rocks (except for a very few fine particles of quartz and feldspar) are clear and are fitted together in a mosaic, which indicates that they have been wholly recrystallized after deposition. Inasmuch as these lake beds apparently contain no dolomite and as there is no other evidence of salinity, it may be inferred that the lake was essentially fresh. Moreover, the formation contains unionids and small, presumably fresh-water fish. The unionids, fish, and fossil plants all indicate an Early Cretaceous age, which according to Kulp (*2*) is 110 to 135 million years old.

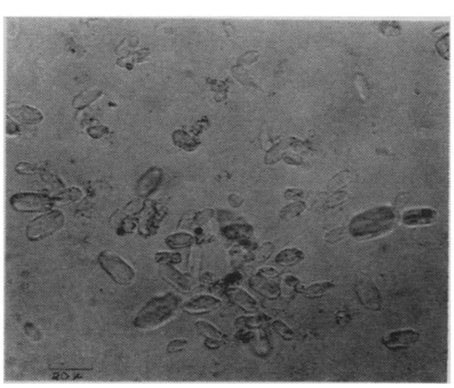

Fig. 2. Crystals of calcite isolated from the bottom mud of Green Lake, near Fayetteville, New York.

Fossil bacteria are rare but fossil forms still consisting of organic matter are so unusual that it seemed altogether improbable that any mechanism to help explain their preservation would be forthcoming. Nevertheless, in April 1963, Prof. J. R. Vallentyne of Cornell University sent me a sample of black mud, which he had collected from the bottom of Green Lake, near Fayetteville, New York. The characteristics of this black mud suggest that it is a modern counterpart of the limy mud that formed in the Lower Cretaceous lake, which gave rise to parts of the Newark Canyon Formation of Nevada.

Green Lake is a small, deep lake that occupies the plunge pool of a Pleistocene waterfall (*3*). It has an area of only 27 hectares but a maximum depth of 59 m. This is a meromictic lake, the water below about 20 m being permanently stagnant. Deevey (*4*), in discussing the fractionation of sulfur isotopes in this remarkable lake, says that according to Eggleton (*3*) the stagnant lower part of the lake, the monimolimnion, makes up nearly half the volume of the lake and, in 1939, the water contained more than 30 mg of sulfur per liter as H_2S. Eggleton also reported that the water at 20 m is bright magenta because of a massive growth of the purple sulfur bacterium *Lamprocystis roseopersicina* Cohn.

The mud from the deep part of Green Lake is quite as remarkable as the lake itself. More than 80 percent by volume of it consists of discrete, idiomorphic crystals of calcite. Most of these are short, stubby prisms that have all angles smoothly rounded (Fig. 2).

In addition to the prisms there are also a few rhombohedra. Some crystals appear to consist dominantly of two scalenohedrons, but the additional faces, especially the terminal faces, are rounded and obscure. The crystals range in length from about 5 to 40 μ and average about 20. An estimated 20 percent of these crystals are gray and contain about 2.2 percent of organic matter in the form of enormous numbers of minute, black, spherical bacterial cells. The inclusions are so numerous they reduce the average density from 2.71 of pure calcite to 2.635 and the omega index from 1.658 to 1.642 (*5*). An x-ray powder pattern of the crystals showed that the crystalline part is pure calcite (*6*).

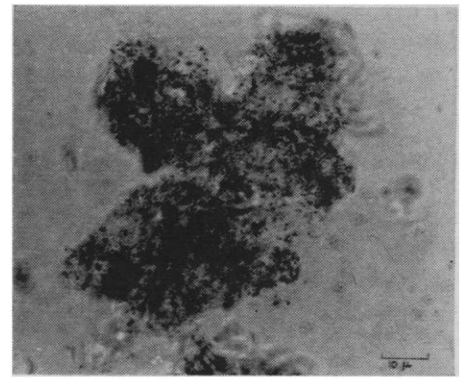

Fig. 3. Massed bacterial cells and a few scraps of organic matter that retain the form of the four calcite crystals from which they were isolated by dissolving the crystals in formic acid. The crystals with their occluded bacteria were separated from the bottom mud of Green Lake, near Fayetteville, New York.

The noncalcite part of the mud consists of a slurry of black, spherical, bacterial cells, a small quantity of unidentifiable fragments of organic matter, diatom valves, and a few particles of clastic quartz. Deevey (*4*) reported "so little sulfur in the bottom deposits that we have been unable to measure it." J. R. Vallentyne and I, however, found a few minute pyrite spherules. Vallentyne verified the pyrite spherules he found by reflected light and I verified the ones I found by the fact that they persisted after the

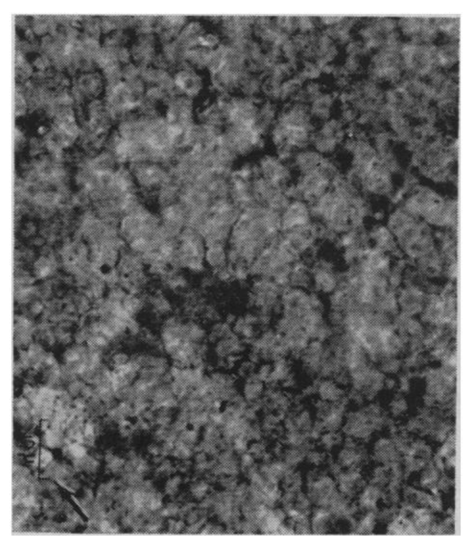

Fig. 4. Crystals of calcite, ranging from about 4 to 10 μ in length, in a black, lacustrine limestone from the Newark Canyon Formation of Nevada. The dark lines and areas between crystals are made up almost wholly of black, coccoid bacterial cells, which are inferred to have been originally occluded in the crystals.

bacterial cells had been destroyed with 30 percent hydrogen peroxide.

The bacterial cells range in diameter from a little less than 0.4 to nearly 0.7 μ, the larger ones being jet black and the smallest ones dark brown. In addition to these there are a very few short rods and a few larger cells (about 1 μ in diameter) that are clear and highly refringent. These larger cells suggest bacterial spores.

The evident similarity between the Lower Cretaceous Newark Canyon lake beds, especially the black limestone, which consists of minute calcite crystals and black bacterial cells, and the black mud from Green Lake, which consists of calcite crystals, black bacterial cells, and diatom valves, suggests that the Newark Canyon black limestone was originally a black mud nearly identical with that now forming in Green Lake. Because the Green Lake mud is so unusual it seems reasonably safe to infer that the Newark Canyon black mud also accumulated in a relatively deep, meromictic, fresh-water lake, which supported a luxuriant growth of photosynthetic sulfur bacteria at or near the base of its epilimnion. This inference, of course, carries with it the assumption that the black bacteria in each sediment are predominantly the remains of pigmented sulfur bacteria. This is an assumption that has not been tested for Green Lake and cannot be tested for the Lower Cretaceous lake unless, perhaps, infrared spectra of the bacteria from each locality should show similar and highly distinctive characteristics.

One further speculation seems warranted. The fact that many of the calcite crystals in the Green Lake mud contain enormous numbers of black bacterial cells must mean that those crystals grew in the mud and occluded the bacteria as they grew (Fig. 3). Indeed, not only are the bacteria distributed all through these crystals but in some they are concentrated in closely spaced planes parallel to the crystal faces. Occlusion of such motes of organic matter in a crystal appears to be a nearly perfect mechanism for preserving them intact. Might it not be that the Newark Canyon bacteria, and the scraps of organic matter to which they clung, were similarly occluded in calcite crystals that grew in the mud of the Lower Cretaceous lake? That they are not now within the calcite crystals but are concentrated in films between the crystals (Fig. 4) is not an argument against this suggestion because the calcite crystals were all recrystallized during diagenesis, and it is well known that crystals rid themselves of inclusions during such a regeneration.

The unmineralized bacteria of the Newark Canyon Formation are more than 100 million years old, whereas the bacteria in the calcite crystals in the Green Lake mud may have become fossilized last year, or within the past decade. The processes by which the Green Lake bacteria are entombed still go on, though we do not yet know exactly how they operate. The important point is we can observe and measure these present-day processes. Geologists are continually on the alert for present-day analogs because they help us understand and explain what we find in the geologic record (*7*).

W. H. BRADLEY

United States Geological Survey, Washington 25

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3 July 1963

Sucrose: Precise Determination of Crystal and Molecular Structure by Neutron Diffraction

Abstract. *This analysis provides the first precise molecular parameters for sucrose. All hydrogen atoms are included. Carbon-carbon distances are 1.51 to 1.53 Å; carbon-oxygen 1.40 to 1.44 Å; carbon-hydrogen 1.08 to 1.11 Å; oxygen-hydrogen 0.94 to 0.99 Å. The furanose ring conformation differs from that in sucrose sodium bromide dihydrate. Hydrogen bonds (two of them intramolecular) utilize every hydroxyl group except one.*

The structure of the molecule of sucrose ($C_{12}H_{22}O_{11}$) has not previously been determined with the precision that modern diffraction techniques afford. An x-ray determination by Beevers and Cochran (*1*) in 1947 of the structure of sucrose sodium bromide dihydrate (SSBD) confirmed the chemically assigned relative configurations (*2*) of the asymmetric carbon atoms of the molecule. A subsequent x-ray determination of the structure of sucrose itself (*3*) was somewhat less satisfactory, since refinement was terminated at an early stage because the data were felt to be of poor quality; the agreement between calculated and observed structure factors was just close enough to suggest that the phase problem had been essentially solved, without, however, furnishing conclusive proof of the structure proposed (*4*).

This report concerns a precise three-dimensional neutron-diffraction analysis of the structure of crystalline sucrose, for which the starting point was the rough structure of Beevers *et al.* (*3*). The neutron technique was chosen because it, unlike the x-ray technique, allows determination of coordinates of hydrogen atoms with nearly the same precision that can be attained for the coordinates of the heavier atoms (*5*). Determination of this structure is by far the largest problem ever undertaken in neutron-diffraction analysis, both with respect to the number of structural parameters determined and with respect to the number of data obtained. The results demonstrate clearly the power of the neutron-diffraction method in structural studies of complex crystals.

Three different crystal specimens, weighing approximately 80, 10, and 5 mg, were employed. For the intense reflections, data from the smaller crystals only were used, in order to minimize extinction errors. About 5800 individual intensity measurements were made to provide averaged data for some 2800 independent reflections accessible to measurement on the Oak Ridge automatic neutron diffractometer (*6*). Before averaging, the intensity data were corrected for absorption effects and the Lorentz effect, then placed on an absolute scale by comparison with data from a standard crystal of NaCl.

From the coordinates of the 12 carbon and 11 oxygen atoms in the asymmetric unit of the structure of Beevers *et al.* we calculated reasonable coordinates for the 14 hydrogen atoms at-