Varved Marine Sediments in a Stagnant Fjord

Abstract. *Varved sediments, containing planktonic marine diatoms, occur in Saanich Inlet, British Columbia. An olive-gray lamina, rich in opal, apparently forms during the bloom of* Skeletonema costatum *in the spring or summer, after which an olive-black lamina is deposited.*

Saanich Inlet, the only fjord on the southeastern side of Vancouver Island, British Columbia (Fig. 1), is approximately 26 km long and varies in width from 0.4 to 7.6 km. The average depth in the inlet is approximately 120 m; the maximum is 236 m. A sill at the mouth of the inlet, which rises to within 70 m of the surface, restricts water circulation and prevents sediment transported along the bottom of Satellite Channel from entering the inlet (*1*).

Hydrogen sulfide apparently occurs in the bottom water during most of the year. Carter (*2*) reported that the upper limit of the oxygen-deficient zone varied from 150 m below sea level in December to 70 m in October. The bottom waters containing hydrogen sulfide are occasionally displaced by denser water which flows into the inlet from Satellite Channel (*3*).

No large rivers empty directly into the inlet and its drainage area is small. Some fresh water enters through the mouth of the inlet coming from the Cowichan River, which discharges into Cowichan Bay 12 km northwest of the entrance to Saanich Inlet, and from the Fraser River, which discharges into the Strait of Georgia approximately 50 km northeast of Saanich Inlet (*3*).

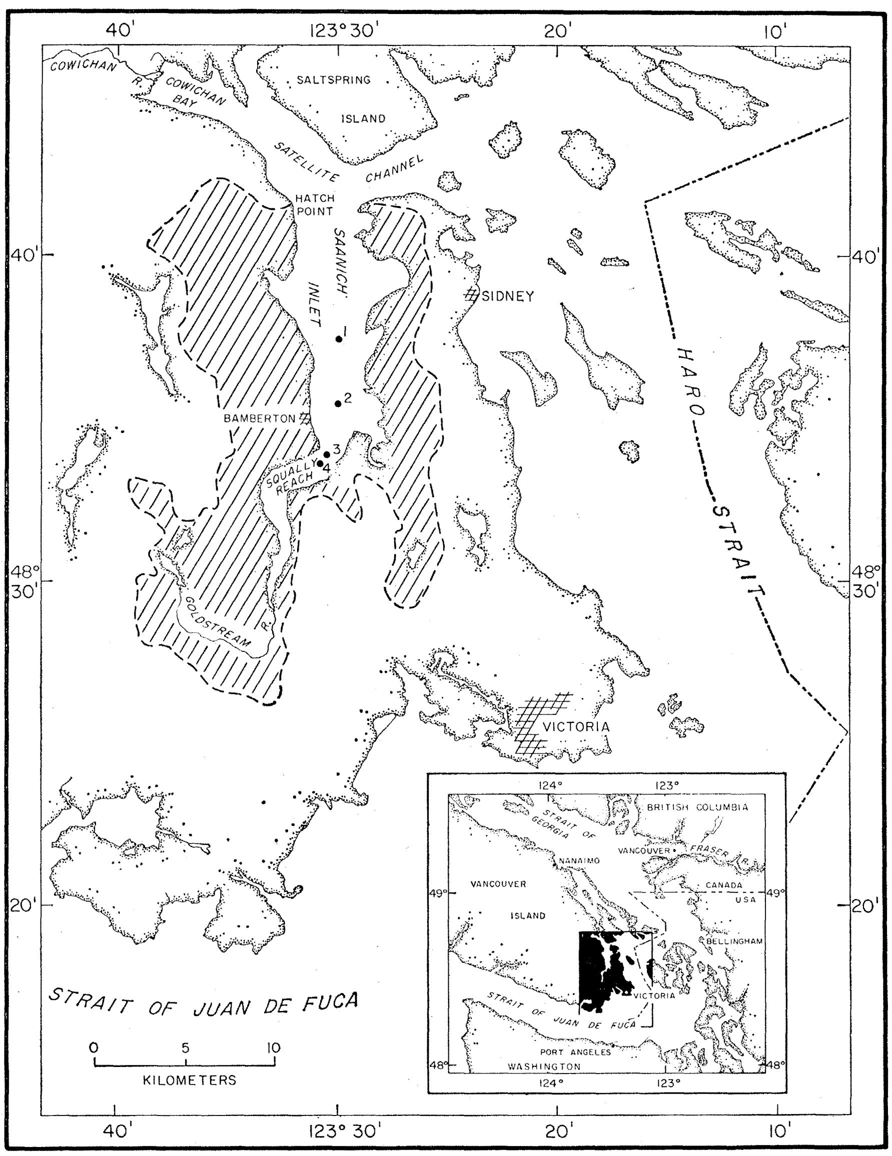

Fig. 1. Saanich Inlet and its drainage basin (ruled area) shown in relation to the Fraser and Cowichan rivers. The location of the cores within the Inlet is shown by the dots. Core No. 4 is the 20-meter piston core.

Olive-gray to black, hydrogen sulfide–bearing, clayey silts, containing diatom frustules, occur in the central portion of the basin at depths greater than 100 m.

The sediments (Fig. 2) consist of alternating laminae of an olive-black color and laminae of an olive-gray color. In general, each pair of laminae is 4 mm thick. The dark laminae tend to be more regular in thickness, ranging from 2 to 4 mm. The light laminae range from 1 to 7 mm in thickness. In general, a distinct color change marks the base of the lighter-colored laminae. X-ray radiographs, however, show a gradual change in density between laminae.

The diatoms in the sediments are predominantly marine planktonic forms well known in adjacent marine waters (*4*). Frustules of *Skeletonema costatum* are most abundant in the light-colored laminae where they may make up 80 percent of the recognizable frustules. *Skeletonema* also occurs in the dark-colored laminae but *Melosira sulcata, Thalassiosira decipiens*, and *Coscinodiscus excentricus* are the dominant forms.

We believe that the light laminae form during the *Skeletonema costatum* bloom which probably occurs in the late spring or summer. In May and June the peak discharge of the Fraser River may also contribute some sediment to the light-colored laminae. During the rest of the year diatom production apparently is less, and most of the terrigenous sediment in the dark laminae is probably derived from the Cowichan River, which has a peak discharge during the winter (*3*).

Assuming that each pair of laminae represents 1 year's deposit of sediment, approximately 4 mm of sediment are deposited each year (4 m per 1000 years). A piece of bark from core No. 3, whose apparent age, estimated on the basis of the varves as approximately 600 years, was dated by carbon-14. The activity of carbon-14 indicates an age of 500 (± 150) years. The agreement between the estimated age and the carbon-14 age establishes the varved nature of these sediments.

In core No. 4, which is 20 m long, there are nonlaminated, olive-black zones, ranging in thickness from 2 to 51 cm. The nonlaminated zones are more or less regularly spaced in the 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.

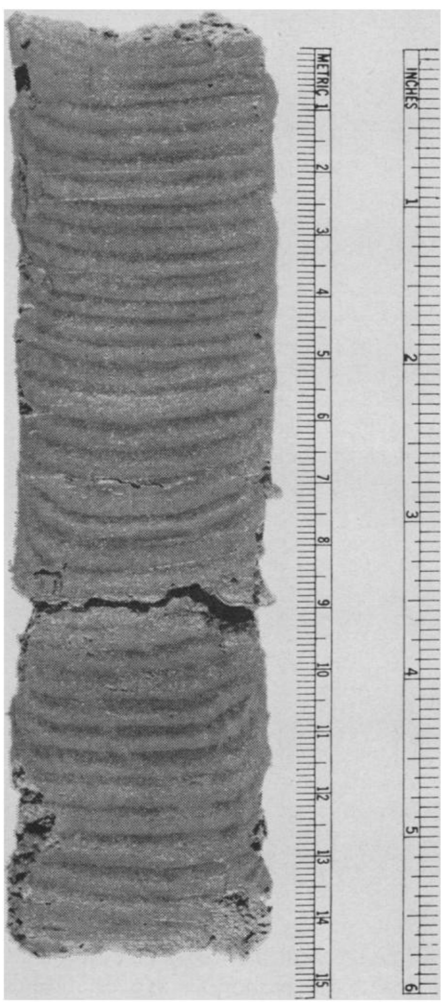

Fig. 2. Varved diatomaceous sediment from core No. 4 (depth in core: 500 to 515 cm). Note the distinct color change at the base of the lighter-colored laminae as contrasted to the gradual color change at the top.

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*).

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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,