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10 April 1973 ■

Sediments of Deep Canadian Shield Lakes: Observations of Gross Structure and Biological Significance

Abstract. *Sediments of deep Canadian shield lakes have a firm mud-water interface and an intricately structured, oxygenated surface. Surface relief is not uniform, but is broken by small ridges and upright chironomid tubes. The sedimentary material behaves like a weak jelly and becomes flocculent only when violently disturbed. Sculpins were observed to rest on and, when startled, to hide in the oxygenated layers. Sequestering of nutrients in the bottom sediments is enhanced by the structuring of the substrate surface below 10 meters, and may inhibit nutrient recycling at overturn.*

The sediments of deep small lakes are often so weak in structure that echo sounders barely record a trace at their surface. It is often difficult to determine the precise level at which a weight touches "bottom." When dredges return the material to the surface and it is held in aquariums, it takes months to settle even partially. For these and other reasons, it has been conjectured that the deep sediments are in a state of semisuspension, and that they are loosely flocculent, with no true interface. Mortimer (*1*) suggested that "near the bottom there generally exists an undulating detritus or silt layer containing organic complexes . . ." and this suggestion was repeated by Mortimer (*2*) and later by Milbrink (*3*). They and others have assumed that this upper "semisuspended" or "flocculent" layer of the sediments is a source of nutrients returned to the lake waters at turnover. So little is known of the nature of the sediments, however, that biologists and limnologists have sometimes used uncomplimentary words to describe them in conversation. My observations suggest that these assumptions are inappropriate in Canadian shield lakes.

Observations were made primarily in two lakes in Algonquin Park, Ontario. One was a large (6000 ha) oligotrophic lake [Lake Opeongo (*4*)] which stratifies in the summer, but turns over in fall. The maximum depth is 48 m. The shoreline is forested and the terrain is hilly. The action of a dredge in various sediment types was observed in shallow water by divers. The weaker the structure of the material, the deeper the dredge bit before coming to a stop. It was, therefore, a matter of conjecture how far into the "semisuspended" substrate of deep water the dredge sank before stopping and being subsequently triggered.

Gross examination of this deep-water sedimentary material revealed a high percentage of organic debris, including insect wings and decomposing wood. But in most areas the prominent and recognizable item was chironomid tubes, which imparted a pelletlike appearance to the material. A fine glacial silt forms the basic inorganic matrix. Microscopic examination indicated high abundances of diatoms (both Pennatae and Centricae) with lesser abundances of pollen grains such as pine and ragweed. Loss on ignition was 27 percent. (Other sediments from lakes in Algonquin Park lose up to 60 percent on ignition, whereas sediments from southern Ontario nonshield lakes lose 10 to 20 percent on ignition.)

To determine the depth to which dredges sank into this sediment we followed them down using scuba to depths of 35 m. At this depth and temperature (5.1°C), standard quarter-inch (6-mm) wet suits allowed exposure times of about 10 to 15 minutes with only a limited loss of objectivity. No weights were necessary to maintain neutral buoyancy at 33 to 35 m. Hand lights were necessary below about 22 m, and useful below 15 m. We found that it was impractical to overstay the no-decompression limits.

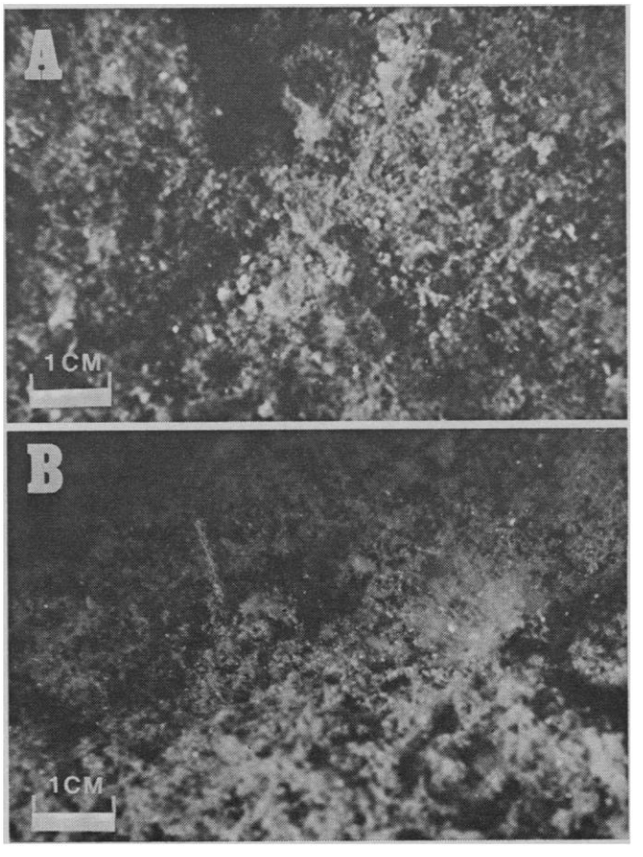


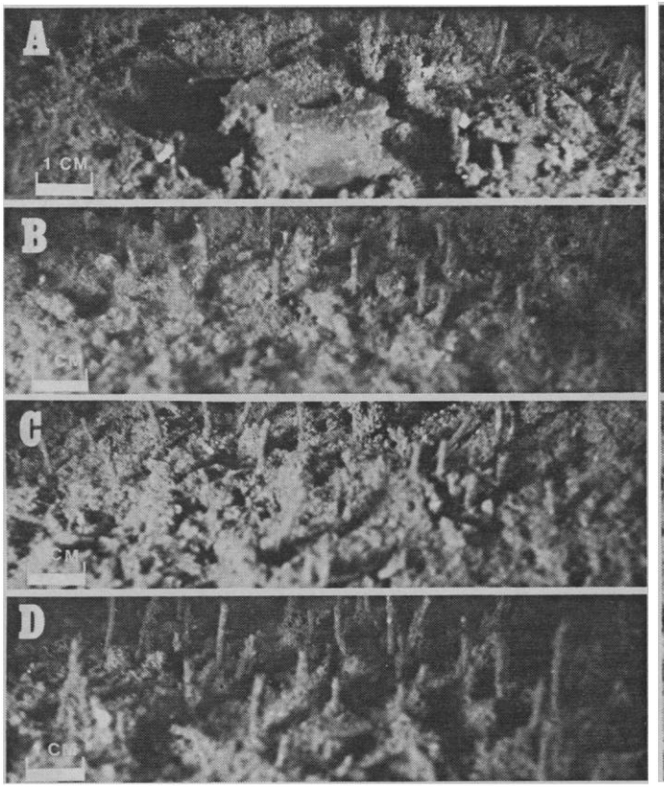
Fig. 1. (A) Photograph of the hole and ejecta left when a sculpin (*Cottus cognatus*) dived through the surface of the bottom sediments of Lake Opeongo in an apparent attempt to escape from divers. (B) Detail of bottom sediments of Lake Opeongo at a depth of 33 m, showing chironomid tubes and a fungal mat.

Lacking the above information on our first dive, we used about 2½ to 3½ kg of weight. The diver carrying the Ekman dredge (sample size, 244 cm^2) sank immediately to shoulder depth in the ooze, and disappeared as it billowed up around us all. Despite our initial difficulties we subsequently found that the dredge sank 1 to 3 m into the material before stopping.

During these experiments we discovered that the sedimentary material is not really semisuspended and does not have a loose surface. Although it is weakly structured compared to an Ekman dredge or an overweighted diver, it is nevertheless highly structured considering the conditions present. Horizontal visibility was approximately 8 to 10 m with the lights at a depth of 33 m, but was less than 3 m at the surface at night, which implies a near absence of currents in deep water. Photographs (Fig. 1) show chironomid tubes standing upright, the presence of fungal mats, and other animals. The surface is not smooth, but has many small ridges and valleys. Furthermore, the material has an almost jellylike behavior. A diver can cause an area many meters in diameter to jiggle if he inserts an arm through the interface and moves his hand and arm quickly a few centimeters back and forth in a sideways motion. Further evidence of this jellylike nature was the fact that "splits" occurred which were up to 1 m deep but only 20 to 30 cm wide, with sheer, sharp edges. In one area, part of the material appeared to have slumped down a low hill, and a sheer cliff some 3 m high was left. One sustained slope of over 70° was estimated to have extended 10 m (from a depth of 30 m to 40 m).

The upper surface of the substrate is distinctly greenish with pale brown material mixed in. A few centimeters below this it is bright orange, and below that black. It is assumed to be anoxic in the black zone. The green is from recently settled phytoplankton, primarily diatoms, and the orange layer is probably in an intermediate stage of decomposition with perhaps a ferrous component imparting the color. The importance of the oxygenated layer at the surface of the substrate was emphasized when specimens of *Cottus cognatus*, the slimy sculpin, were encountered resting on the surface. If disturbed, the sculpins dived into the substrate, leaving a distinct hole and throwing the orange material to the surface (Fig. 1). Judged from the continued faint motion of the material, the fish may have turned and continued to swim horizontally below the surface. It is possible that many species avoid predation in this way. Only one large fish (*Salvelinus namaycush*) was encountered at this depth, and it too rested on the surface of the "ooze"; it did not dive into the substrate, however, but swam rapidly away from us.

In another, much smaller lake nearby (Billy Lake, 100 ha) at a depth of 10 m, photographs of the same type of bottom (Figs. 2 and 3) were taken during turnover (30 September 1971). There was no evidence that the structure of the bottom was breaking down under the influence of moving water masses. At lesser depths, including areas of algal and higher aquatic plant growth, the surface was somewhat flocculent and easily stirred up by the slight current of water over it. This resulted in very turbid water at all depths.



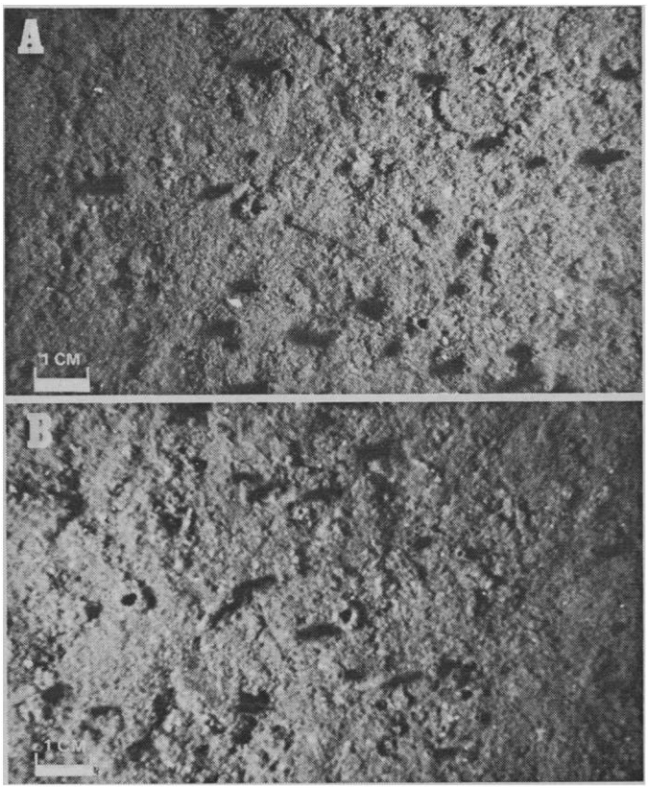


Fig. 2 (left). Photographs of the interface at a depth of 10 m in Billy Lake on 30 September 1971 during turnover. The interface is firm, possibly held together by the cementing action of chironomids. These pictures were taken by setting the camera into the substrate and aiming more or less parallel to the interface. Thus, only a narrow part of the field is in focus. Fig. 3 (right). Photographs of the interface at 10 m in Billy Lake during turnover. These photographs were taken by aiming the hand-held camera straight down. The images thus resemble what remotely controlled oceanographic cameras record in the ocean.

Rapid nutrient recycling during overturn may be dependent on wave action and therefore may be largely restricted to water shallower than 10 m in lakes which have a structured deepwater substrate. The sequestering of nutrients may be a requirement for survival of the microecosystem in the depths of nutrient-poor oligotrophic lakes. The upper extent of the depth range of the firm interface may define the depth to which rapid recycling occurs.

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Photoacoustic Spectroscopy of Biological Materials

Abstract. *A new technique for performing optical spectroscopy on solids has been developed. Photoacoustic spectra of cytochrome c and hemoglobin show how this technique can be used to obtain information about optical absorptions and subsequent de-excitations in solid biological materials, particularly those which cannot readily be studied by conventional means.*

Although many biological materials occur naturally in a soluble state, others are membrane-bound or part of the bone or tissue structure. These materials are insoluble and function biologically within a more or less solid matrix. Optical data on these materials are usually difficult to obtain, since when isolated they are generally not in a suitable state for conventional transmission spectroscopy, and when solubilized they are often structually altered.

I describe, briefly, a new technique which can be employed for investigating the properties of such biological materials, both in situ and when separated from the native materials. This technique is based on the optoacoustic or photoacoustic effect discovered in 1881 by Tyndall (*1*), Röntgen (*2*), and Bell (*3*). The photoacoustic effect occurs when a gas in an enclosed cell is illuminated with periodically interrupted or chopped light. Any energy absorbed by the gas is converted entirely or partially into kinetic energy of the gas molecules, thereby giving rise to pressure fluctuations within the cell. In 1881 these pressure fluctuations were detected as audible sound by the ear.

The photoacoustic effect in gases has been used fairly extensively since 1881, primarily for gas analysis, and commercial gas spectrophones utilizing microphones have long been available (*4*). Although the photoacoustic technique has been thoroughly developed for gases and is used for gas analysis (*5*) and photochemical studies (*6*), the analogous effect in solids and liquids does not appear to have been pursued in spite of some initial experiments along this line by Bell (*3*). I have recently demonstrated that modern photoacoustic techniques can be successfully extended to the study of solids (*7*, *8*). I have studied many different inorganic, organic, and biological solids and believe that this technique can be of considerable benefit in determining the optical properties of solids, particularly those which do not lend themselves readily to conventional spectroscopic techniques.

The photoacoustic experiments (*8*) are performed with a high-pressure Xe lamp; the light passes through a monochromator and chopper and then onto the solid sample in a cell containing a sensitive microphone. The signal from the cell is fed into a phase-sensitive amplifier locked onto the chopping frequency. As the range of the monochromator is slowly scanned, the analog signal from the lock-in amplifier is digitized and stored in a multichannel analyzer to facilitate further processing.

My experiments indicate that the acoustic signal comes from the cyclic heating and cooling of the solid sample by the absorbed light, and then the direct transfer of this heat energy to the surrounding gas. Adsorbed gas on the surface of the solid appears to play no major role, in contrast to what was originally thought (*8*). The cell used can detect approximately 10^{-7} watt of

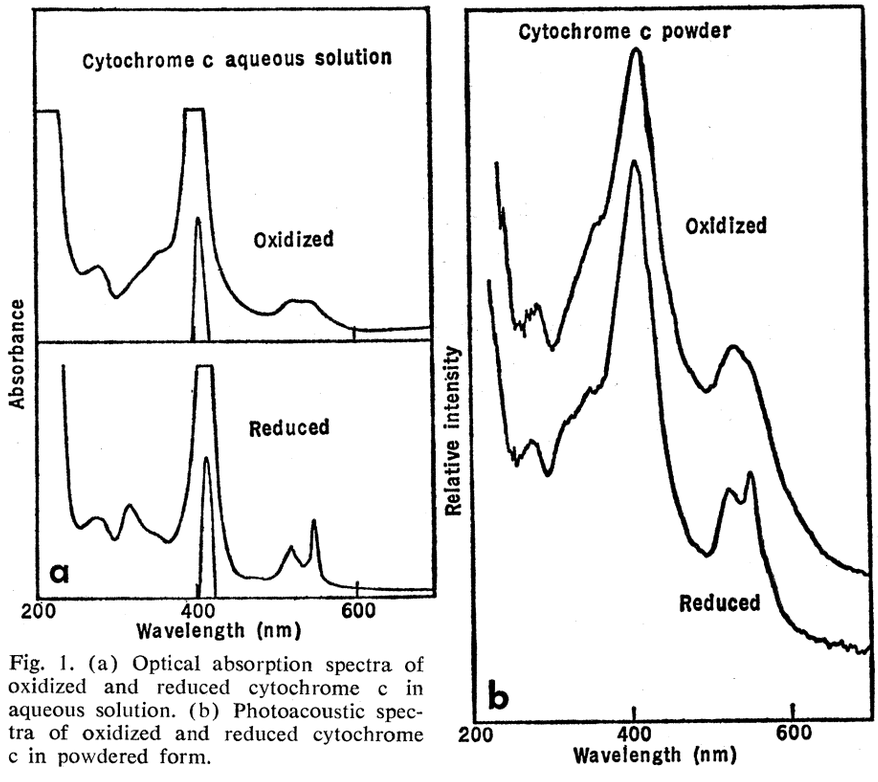

Fig. 1. (a) Optical absorption spectra of oxidized and reduced cytochrome c in aqueous solution. (b) Photoacoustic spectra of oxidized and reduced cytochrome c in powdered form.