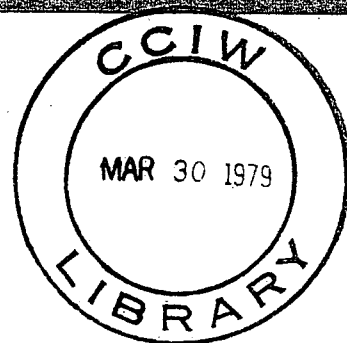


Massalski & Leppard



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A SURVEY OF SOME CANADIAN LAKES FOR THE  
PRESENCE OF ULTRASTRUCTURALLY-DISCRETE  
PARTICLES IN THE COLLOIDAL SIZE RANGE

A. Massalski and Gary G. Leppard

**UNPUBLISHED REPORT  
RAPPORT NON PUBLIE**

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To be published in J. Fish. Res. Bd. Canada

March 1979

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1 Running head: Massalski and Leppard: Survey of lake colloids.

2

3 A Survey of Some Canadian Lakes for the Presence of  
4 Ultrastructurally-discrete Particles in the Colloidal Size Range

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9 Massalski, A. and Gary G. Leppard. 1979. A survey of some Canadian  
10 lakes for the presence of ultrastructurally-discrete particles  
11 in the colloidal size range. J. Fish. Res. Board Can. 00:000-000.

12

13 Water samples from nine Canadian lakes were centrifuged and the  
14 pellets were analyzed by transmission electron microscopy. The pellets  
15 included small organisms, organic colloids and clay particles. In al-  
16 most all the samples, colloids were the major component revealed following  
17 thin-section analysis. When viewed at high magnification, much of each  
18 pellet consisted of morphologically-discrete particles, some of which  
19 were readily categorized. Electron-opaque fibrils of colloidal size  
20 were frequently encountered: (1) at different depths; (2) as a coating  
21 on the surface of algae and bacteria; (3) overlaying the sediments;  
22 (4) as an apparent adhesive between a variety of particles; and (5) as  
23 a component of froth at the water-air interface. They were common at  
24 all times and in lakes of varying trophic levels and sizes.

25

1 Key words: water, colloids, fibrils, lakes, electron microscopy.

2 \_\_\_\_\_

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## Introduction

Limnologically, the word "dissolved" is an operational term: the term "dissolved organic carbon", or "DOC", refers to all organic carbon in lake water from large colloids down to small molecules in true solution. Most "particulate organic carbon", or "POC", is non-living and consists of particles larger than  $0.45\ \mu\text{m}$  in smallest dimensions (Wetzel 1975), although aggregates of colloids may be operationally defined as POC depending on their retention by filters. The mean ratio of DOC to POC in many lakes is on the order of five to one (Wetzel 1975). The quantitative importance of DOC in lakes is such that understanding the functional role of it and of its major components is important. An understanding of its trophic role in lakes requires knowledge of the nature and regulation of its biogenesis as well as its interrelationships with POC.

In 1977 (Leppard et al.), a ribbon-like fibril, of from 3 to 10 nm diameter and having a considerable capacity to bind electron-scattering stains, was shown to be a common colloidal material of the DOC fraction of two lakes. Also, it was found in the POC fraction as a result of its capacity to form large clumps and its capacity to adhere to algae, bacteria, large debris and clay particles. The discovery of these fibrils led to laboratory investigations into the secretion of them by algae and to chemical analyses of fibril-rich materials isolated from lake water (Leppard et al. 1977; Burnison 1978). At the same time, it was realized that transmission electron microscopy allowed us to categorize much of the suspended fine material despite its chemical complexity. As was

1 predicted earlier (Leppard et al. 1977), ribbon-like, "electron-opaque"  
 2 fibrils and other kinds of electron-opaque fibrils of similar dimensions  
 3 are shown here to be common to the water and sediments of a variety  
 4 of lakes in a variety of situations. Illustrated here is a survey of  
 5 lakes for such fibrils, including a preliminary attempt to document  
 6 other common, distinctive, colloidal particles. The word "fibril" is  
 7 used in the standard dictionary sense meaning a "small filament or thread".  
 8  
 9

#### 10 Materials and Methods

11 Water samples were taken from nine Canadian lakes selected  
 12 because of current and previous limnological investigations and  
 13 variety in lake type.

14 1) Lake Ontario (8 km offshore from Oshawa at the OOPS 11 IFYGL  
 15 Station);

16 2) St. George Lake (near Toronto, Ontario);

17 3) Thompson Lake (near Toronto, Ontario);

18 4) Jack Lake (50 km northeast of Peterborough, Ontario);

19 5) Lake Erie (both the Western Basin and Central Basin);

20 6, 7 and 8) Erickson-Elphinstone District Lakes, numbers L255,  
 21 L318 and L885 (in southwestern Manitoba, west of Lake Manitoba);

22 9) Kootenay Lake, British Columbia (at midlake station S-23).

23 Table 1 shows the sampling program. We defined two separate  
 24 colloid <sup>(containing)</sup> fractions, one of particular interest to us here and a second  
 25 for future analyses, <sup>(the latter)</sup> derived by high speed centrifugation of the

1 remaining fluid. Preliminary comparative studies on a variety of  
2 samples from St. George Lake (see also Leppard et al. 1977) revealed  
3 that the more readily characterized colloids were present in both  
4 fractions. This paper describes the readily sedimented fraction  
5 which contained some small organisms, many colloid-sized particles,  
6 as defined by Vold and Vold (1964), and complex aggregates of colloids.  
7 Because of the potential significance of observations on the physical  
8 relationships of natural fibril aggregates (Leppard 1975; Leppard and  
9 Ramamoorthy 1975; Leppard et al. 1977) and because of potential dis-  
10 ruption of these aggregates by ultracentrifugation, no attempt is made,  
11 in this early study, to describe the colloidal aggregates derived by  
12 sedimentation at great centrifugal forces.

13       Replicate portions of each freshly-taken sample were centrifuged  
14 at 1,000g to give loosely-packed pellets which were prepared for  
15 electron microscopy and stained with heavy metals according to Leppard  
16 et al. (1977). The general approach to the microtomy of the pellets  
17 was as outlined in Leppard et al. (1977). Several consecutive sections  
18 of approximately 50 nm thickness were cut from each pellet, followed by  
19 removal of several micrometers of pellet, then further cutting of  
20 consecutive "thin" sections and so on. This approach provides a gross,  
21 semiquantitative evaluation of the abundance of any given distinctive  
22 structure (see Discussion). Observations on stained sections and photo-  
23 graphs of them were made with a Siemens 101 transmission electron  
24 microscope. The data collection for this study consisted of about  
25 1600 micrographs derived from approximately 100,000 different discrete

1 images on the microscope screen. Serial sections were searched at  
2 4,000x with interesting grid windows searched later at 20,000x. Depending  
3 on the heterogeneity shown by a given pellet, the ratio of images  
4 studied to images photographed ranged from about one in ten to about  
5 one in one hundred. If a given distinctive morphological entity was  
6 found readily and if it was also the most frequently encountered entity,  
7 it was given an abundance rating of 3. If not detected at all within  
8 the time frame of the initial search, it was given an abundance rating  
9 of 0.

## 11 Results

13 All of the water samples revealed a variety of distinctive colloids  
14 (as defined by Vold and Vold 1964) which tended to fall into categories  
15 according to their dimensions, form, and electron opacity after staining  
16 with heavy metals. These categories included electron-opaque fibrils,  
17 clay particles, cell wall fragments, diatom frustules, fragments of  
18 invertebrate exoskeleton, electron-lucent fibrils, complex slimes,  
19 viruses, tripartite structures resembling membranes, algal scales,  
20 unusually small prokaryotes and a variety of granules.

21 Of the 30 different kinds of samples, 29 revealed electron-opaque  
22 fibrils as shown in Table 1. Of the nine lakes studied, eight had such  
23 fibrils, with five of these lakes showing evidence that they were  
24 quantitatively important. Fifteen of the 30 kinds of samples revealed  
25 these fibrils to be the most abundant of the morphologically distinctive

1 colloids, with St. George Lake being a particularly good source  
2 regardless of situation. Considering individual samples, the fibrils  
3 were most dominant in the six meter summer sample from Jack Lake,  
4 followed by the 0.5 meter summer sample from Lake 318 and then by  
5 several different samples from St. George Lake. They were found in  
6 the summer surface froth of St. George Lake and in the metalimnia  
7 of both Jack Lake and St. George Lake.

8 All sediment traps contained fibrils. Two water samples  
9 (Thompson Lake and Lake 885) were characterized by an extreme wealth  
10 of algal cells; one showed the fibrils while the other did not. In  
11 the case of Thompson Lake, all the fibrils in the surface water were  
12 part of bacteria-alga associations. The sole lake which was sampled  
13 extensively (St. George Lake) revealed fibrils in abundance in all  
14 four seasons. The sole lake (Lake 885) showing a fibril abundance  
15 rating of 0 (see Table 1) was reinvestigated to give a second rating  
16 of 0.

17 The electron-opaque fibrils came in several distinctive varieties,  
18 although long ribbon-like types were the most frequently encountered.  
19 The next most abundant category of colloidal material consisted of  
20 irregular, angular, electron-opaque tablets and leaflets of various  
21 kinds suggestive of different kinds of clay particles. Such particles  
22 were particularly abundant near lake bottoms; they had a patchy dis-  
23 tribution as did those categories of colloids found infrequently. There  
24 were some revealing physical associations between fibrillar colloids  
25 and the biota; these are described in detail and discussed in Massalski

1 and Leppard (1979).

2        Fig. 1 illustrates a common situation in lake water, an algal  
3 cell with a surface coating of fibrils whose thickness is similar  
4 to the diameter of the cell proper. Sometimes such a thick coating  
5 is associated with encystment. Extensive examination with the electron  
6 microscope reveals many fibrils to be of great length, a feature not  
7 often conveyed by the micrographs. Fig. 2 shows some fibrils having  
8 little curvature and running in the plane of the section. Serial-  
9 sectioning results and views such as Fig. 2 indicate that many electron-  
10 opaque fibrils of ribbon-like aspect are very long with respect to  
11 their diameter. Diameters of approximately 5 nm are commonly associated  
12 with lengths of thousands of nanometers. Fig. 3 illustrates thick  
13 fibrils having thin branches. These fibrils are all associated with  
14 one side only of a fragment of algal cell wall, in this case the distal  
15 side (external surface). Such asymmetry of wall fragments was common.  
16 Interlaced branched fibrils forming a porous three dimensional network,  
17 are shown in Fig. 4. Such aggregates are found frequently on the surface  
18 of algae and as an apparent adhesive between fragments of debris. Surface  
19 froth at the lakewater-air interface of St. George Lake in summer  
20 contains extremely fine fibrils as shown in Fig. 5. These fibrils are  
21 the thinnest which can be clearly distinguished as electron-opaque  
22 fibrils.

23        Electron-opaque fibrils, although typically distinctive, can be  
24 confused on rare occasions with other categories of colloid. Fig. 6  
25 is an example of a granular slime layer on the surface of a green

1 alga. Where the packing of the granules is less dense, there are  
2 indications of fine fibrils whose diameter is at the resolution limit  
3 for sections. Thus, one cannot be certain whether densely-packed  
4 portions of this mucilage consist entirely of small granules or a  
5 mixture of granules plus curved fibrils whose images in cross-section  
6 appear as granules. Fig. 7 presents another problem in categorization  
7 found occasionally. Enmeshed in a cell wall coating of at least two  
8 varieties of electron-opaque fibril are some electron-lucent (Leppard  
9 and Colvin 1978) fibrils with an electron-opaque sheath (see arrows).  
10 Under suboptimal viewing conditions and at low magnifications, such  
11 sheathed fibrils appear entirely electron-opaque. The cell wall proper  
12 shown in Fig. 7 presents many electron-lucent fibrils arranged in a  
13 criss-cross pattern characteristic of cellulosic walls; small aggre-  
14 gates of these were noted rarely in the survey as were algal surface  
15 scales of similar texture.

16 Fig. 8 illustrates clay particles cross-connected by fine fibrils  
17 and Fig. 9 illustrates a cell wall fragment connected to clay particles  
18 via fibrils attached to one side only of the wall. Similar observations  
19 have been made recently by botanists on samples not subject to centri-  
20 fugation (Guckert et al. 1975; Leppard and Ramamoorthy 1975). Fig. 10  
21 shows virus-like particles embedded in a meshwork of fine fibrils  
22 giving rise to an aggregate of "viruses" whose diameter is ten times  
23 that of an individual virus. As one would expect, individual viruses,  
24 free of associated material, were not seen in the pellets of the readily  
25 sedimented fraction. Figs. 8, 9 and 10 are three of many kinds of examples of

1 fibrils apparently acting as adhesives.

2 Many distinctive varieties of cell wall fragments, exoskeleton  
3 fragments, frustules, granule aggregates and membrane-like structures  
4 could be characterized according to dimensions and morphology, but  
5 not to species (Figs. 11, 12).

6 Rarely, electron-opaque fibrils are found on the proximal side  
7 of a cell wall. This is shown in Fig. 13 as another example of the  
8 unusual asymmetry of cell walls with respect to the attachment of  
9 fibrillar coatings. The wall (Fig. 13) is an apparently disintegrating  
10 wall but one can find examples of normal walls, associated with  
11 healthy-appearing cells, which have a coating of fibrils on the  
12 proximal side. In every example of the latter case, however, there  
13 was a much more extensive coating on the distal side. Thus, the  
14 proximal coating may not have represented an attached coating but may  
15 possibly have represented, instead, fibrils in transit from the cell  
16 to the external milieu. This topic is treated more fully in Massalski  
17 and Leppard (1979).

18 Fig. 14 shows strips of algal cell wall (peeling away from an  
19 apparently healthy green alga, not shown) associated with electron-  
20 opaque fibrils displaying a great range of diameters and an extremely  
21 coarse appearance. If the more typical fibrils were not present, then  
22 the coarse fibrils might not have been recorded as fibrils per se.  
23 Both Figs. 14 and 15 illustrate fibrils which just barely fit the  
24 dictionary definition (Webster's New Collegiate Dictionary, 1974) of  
25 the word "fibril".

1 Figs. 15, 16 and 17 illustrate a feature of Jack Lake worthy  
2 of further inquiry. In one 18 m sediment trap sample, three distinct-  
3 ive types of electron-opaque fibrils were recorded frequently. Fig.  
4 15 shows apparently short, irregularly-shaped fibrils, Fig. 16 shows  
5 apparently rigid, long, fine fibrils arrayed almost geometrically, and  
6 Fig. 17 shows curved ribbon-like fibrils which are the most common type  
7 yet encountered.

8 As a result of this survey, it is now clear that electron-opaque  
9 fibrils can be subcategorized into many well defined types with some  
10 occurring frequently in nature. We have documented individual fibrils  
11 as fine as 2 nm and, rarely, as thick as 40 nm. Within this range there  
12 are long, short, straight and curved ones. They can be subcategorized  
13 as: branched or unbranched; tapered or uniform in diameter; rod-like,  
14 ribbon-like or irregular in longitudinal view; with tip differentiation  
15 or without it. Some appear to have a granular substructure and there  
16 is considerable variation from one sample to another in their ability  
17 to take up stains. Additional documentation of the various subcategories  
18 can be found in Leppard et al. (1977) and Massalski and Leppard (1979).

19

20

21

## Discussion

22 Electron-opaque fibrils of various types, whose diameters fall  
23 in the range of 2-40 nm (.002-.040  $\mu\text{m}$ ), are common in Canadian lakes.  
24 They are found throughout the water column of at least some lakes and  
25 they form coatings on many kinds of particles including cells. As

1 shown earlier (Leppard et al. 1977) ribbon-like fibrils can be separated  
2 from other kinds of particles by physical techniques. This survey  
3 suggests that the "dissolved organic carbon" fraction of lake water,  
4 as defined operationally, might also be separated into other distinct-  
5 ive categories of colloids, using the electron microscope as an instru-  
6 ment for confirming purification steps.

7       Because of the shape and dimensions of the fibrils and the large  
8 numbers of pellets (and their replicates) to be sectioned, we were  
9 unable to calculate exact fibril contributions to the volume of the  
10 pelleted materials. Preliminary experiments indicate that many of the  
11 electron-opaque fibrils do not become part of a pellet unless centrifugal  
12 forces on the order of 100,000 g are applied for several hours. Thus,  
13 quantitative estimates of fibril abundance will depend on further  
14 development of separation techniques permitting direct weight measure-  
15 ments accompanied by accurate estimates of purification losses. Some  
16 steps have been taken in this direction (Burnison 1978).

17       Two problems in estimating fibril abundance were observed. First,  
18 fibrils having a diameter near 2 nm are too fine to be resolved unless  
19 they are extremely well stained. Even when successfully stained,  
20 they still escape detection at low magnifications. Consequently,  
21 our survey technique tends to underestimate the abundance of the finest  
22 fibrils. Second, we encountered several types of electron-lucent  
23 (Leppard and Colvin 1978) fibrils having electron-opaque coatings whose  
24 appearance at search magnifications (4,000x) on the viewing screen  
25 of the electron microscope was that of an electron-opaque fibril.

1 Any departure from the highest standards of microscopical and photo-  
2 graphic technique led to an incorrect categorization of such fibrils.

3 Prior to this survey, we had focussed on ribbon-like fibrils  
4 because of their abundance in St. George Lake and in the Bay of Quinte,  
5 a eutrophic bay on the northern shore of Lake Ontario. However, the  
6 presence of a variety of electron-opaque fibrils other than ribbon-  
7 like types from several of our surveyed lakes has caused us to make  
8 conceptual adjustments in trying to understand their chemistry and  
9 biological roles (see Leppard et al. 1977). It is clear now that  
10 considering all electron-opaque fibrils to be chemically and physiolo-  
11 gically similar is a dangerous assumption. Furthermore, one should  
12 not ignore less abundant categories of distinctive colloids (as defined  
13 microscopically) in future attempts to understand the roles of fibrils  
14 in lakes. This is emphasized by Figs. 8, 9 and 10 which illustrate  
15 physical relationships between fibrils and other colloids having poten-  
16 tially important roles. The nature of these relationships is such  
17 that they are not likely to have been created by the sedimentation  
18 step in sample preparation and they are subject to verification by  
19 more specialized technology (see Guckert et al. 1975). As documented  
20 in Fig. 8, an examination of aggregates of clay leaflets reveals a  
21 fibrillar linkage between some of them. A study of cell wall fragments  
22 reveals them to be cross-connected occasionally to somewhat distant  
23 clay particles by means of fibrils (Fig. 9). Fig. 10 suggests that  
24 viruses may be present in lake water as aggregates which will not pass  
25 fine filters in filtration procedures used in sampling for viruses.

1 Further microscopical surveys are needed to assess the significance  
2 of these viral aggregates as well as <sup>(of)</sup> some of the other components of  
3 DOC.

#### Acknowledgements

7 We thank the following scientists from the National Water  
8 Research Institute for their invaluable assistance: Dr. D.R.S. Lean,  
9 Dr. B.K. Burnison, Dr. B. Brownlee, Mr. T.P. Murphy and Mr. M.N.  
10 Charlton.

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16  
TABLE 1. Sampling program for a microscopical analysis of sedimentable colloids in lake water.

Lake	Time	Depth from Surface	Notes <sup>1</sup>	Abundance <sup>2</sup> of electron-opaque fibrils
Lake Ontario	June 1976	1 m		1
		10 m		1
		40 m		1
		2 m above bottom	sediment trap - 3 days	1
St. George Lake	February 1976	bottom	sediment trap	3
	March 1976	1 m above bottom	sediment trap - 5 weeks	3
	April 1976	5 m		3
		1 m above bottom	sediment trap - 2 weeks	3
	May 1976	0 m		3
		4 m		3
		13 m		3
	July 1976	0 m	surface froth	3
	September 1977	0 m		3
		7 m		3

TABLE 1. (continued)

St. George Lake Second Basin	September 1977	6 m	metalimnion	2
Thompson Lake	August 1978	0 m	dominated by <u>Anabaena</u> <u>spiroides</u>	1
Jack Lake	August 1978	6 m	sediment trap - 1 week	3
		8 m	metalimnion	1
		11 m	sediment trap - 1 week	2
		18 m	sediment trap - 1 week	3
Lake Erie Central Basin	September 1976	1 m above bottom	sediment trap - 6 days	2
		3 m above bottom	sediment trap - 6 days	2
Lake Erie Western Basin	September 1976	1 m above bottom	sediment trap - 2 1/2 days	2
	October 1977	2 1/2 m		1
		5 m		1

TABLE 1. (continued)

Erickson-Elphinstone District Lakes				
L255	July 1977	1/2 m		3
L318	July 1977	1/2 m		3
L885	July 1977	1/2 m	dominated by <u>Aphanizomenon</u>	0
Kootenay Lake				
	July 1977	2 m		3
		8 m		1

<sup>1</sup>Samples are conventional water samples unless indicated as being from a sediment trap. The time that the sediment trap was suspended in the water column is indicated.

<sup>2</sup>A rating of 3 for abundance means that the electron-opaque fibrils were both readily encountered and the single most common material observed. A rating of 0 for abundance means that they were not observed during the initial stages of the search.

# Figure Legends

1

2 All figures were produced from material fixed in glutaraldehyde-  
3 ruthenium, postfixed in osmium-ruthenium, and poststained with uranium  
4 and lead. All printing was done deliberately at maximum contrast to  
5 present an optimal view of the fibrils. The bar represents 0.5  $\mu$ m.

6 FIG. 1. ~~The~~ Surface of a green alga showing densely-packed, fine  
7 fibrils external to the cell wall. 0.5 m water sample  
8 from Erickson-Elphinstone District Lake 318.

9 FIG. 2. Loosely-packed fibrils extending a great distance into  
10 the water from an eukaryote alga. Note ~~the fact~~ that some  
11 fibrils can be traced individually for up to several micro-  
12 meters. Also note, in the center, a rare case of several  
13 coalesced fibrils giving the impression of a thicker straight  
14 fibril. 0.5 m water sample from Erickson-Elphinstone Dis-  
15 trict Lake 318.

16 FIG. 3. ~~A~~ Detached cell wall in the process of disintegration showing  
17 an attachment of surface fibrils on one side only. 13 m  
18 water sample from St. George Lake.

19 FIG. 4. Thick branched fibrils and their thin branches. Note the  
20 apparent, three-dimensional network formed by the associa-  
21 tion of the branches. 2 m water sample from Kootenay Lake.

22 FIG. 5. ~~A~~ Sample of surface froth revealing extremely fine fibrils.  
23 These are the thinnest fibrils which can be clearly dis-  
24 tinguished. Note the magnification and compare with the  
25 fibrils in Fig. 3 and Fig. 4. Surface water sample from

1 St. George Lake.

2 FIG. 6. ~~The~~ Surface of a green alga surrounded by an electron-opaque  
3 slime layer which, at its edges, rarely reveals some  
4 extremely fine fibrils approaching the resolution limit of  
5 the electron microscope for sections. Erickson-Elphinstone  
6 District Lake 318.

7 FIG. 7. ~~A~~ Discarded mother cell wall of a green alga showing several  
8 distinctly different fibrillar materials. The wall proper  
9 reveals a typical cellulosic wall pattern, in which layers  
10 of rigid fibrils appear oriented in a criss-cross manner.  
11 Projecting into the external milieu is a layer of at least  
12 two varieties of electron-opaque fibrils attached to the wall  
13 proper. Some fibrils are electron-lucent with an electron-  
14 opaque coating - see arrows. Erickson-Elphinstone District  
15 Lake 318.

16 FIG. 8. Near the bottom of a lake, many of the colloidal particles  
17 can be tentatively identified as clay. Sometimes a network  
18 of fibrils is found between these clay particles. 40 m  
19 water sample from Lake Ontario.

20 FIG. 9. ~~A~~ Cell wall fragment showing fibrils extending from one  
21 side only. These fibrils appear to penetrate adjacent  
22 colloidal particles. Some of the adjacent particles may be  
23 tentatively classified as clay. Sediment trap, 2.5 day  
24 sample taken 1 m above bottom, Lake Erie, Western Basin.

25 FIG. 10. Virus-like particles embedded in a meshwork of fine fibrils.

- 1 Note the clear regions of different dimensions around  
2 some particles. Sediment trap, 5 week sample taken 1 m  
3 above bottom, St. George Lake.
- 4 FIG. 11. ~~Fig~~ Example of a distinctive particle of probable  
5 biological origin. Note the highly organized geometrical  
6 substructure. Ill-defined fibrillar extensions can be seen  
7 attached to each structure. Sediment trap, 6 day sample  
8 taken 1 m above bottom, Central Basin of Lake Erie.
- 9 FIG. 12. Another example of readily characterized particles  
10 (readily categorized according to dimensions and form)  
11 which may be tentatively identified as fragments of exo-  
12 skeleton. Sediment trap, 5 week sample, taken 1 m above  
13 bottom, St. George Lake.
- 14 FIG. 13. ~~Fig~~ Empty cell whose wall is in the process of disinte-  
15 gration. The internal layer of wall reveals a multitude  
16 of electron-opaque fibrils projecting into the lumen. This  
17 is an unusual case; such fibrils found either on the surface  
18 of the walls of living cells or on decomposing cell walls  
19 are usually associated with the outer surface of the wall.  
20 Sediment trap, 1 week sample, 18 m, Jack Lake.
- 21 FIG. 14. Thick and thin fibrils attached to a wall layer which is  
22 being released into the external milieu from the cell wall  
23 of a green alga (not shown). Surface water sample, Thompson  
24 Lake.
- 25 FIG. 15. ~~Fig~~ Electron-opaque, fibrillar material associated with a

1 blue-green alga. Sediment trap, 1 week sample, 18 m, Jack  
2 Lake.

3 FIG. 16. ~~A~~ Unique example of an aggregate of electron-opaque fibrils  
4 which are arrayed geometrically. These fibrils are  
5 unusually straight and frequently cross at right angles.  
6 Sediment trap, 1 week sample, 18 m, Jack Lake.

7 FIG. 17. One of the most common varieties of electron-opaque  
8 fibrils. These are found frequently in many locations.  
9 At least some of the granular structures are cross-sections  
10 and near cross-sections of fibrils. Sediment trap, 1 week  
11 sample, 18 m, Jack Lake.

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