DECOMPOSITION IN LAKE SEDIMENTS
of ONTARIO II

A STUDY ON THE DECOMPOSITION IN LAKE BOTTOM SEDIMENTS IN THE ORDOVICIAN AND POST-ORDOVICIAN OF ONTARIO

II

by

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INTRODUCTION

Limnologists have given a great deal of attention in recent years to the investigation of the biological productivity of inland waters and to the study of the factors which determine the level of biological productivity of lakes. Although the field has been investigated from many viewpoints, and a great deal of research carried out, only part of the answer to this complex problem has been established.

In the last few years, Dr. H. Kleerekoper has been directing a research project, by which an attempt is made to establish the relationships, if any, between the rate and type of decomposition of the organic matter in lakes and their biological productivity. The term biological productivity means here, the amount of organic material a lake is able to produce above the amount it consumes in a set time. The project is an extensive one and is being carried out partly at McMaster University and partly at the Biological Station at Mont Tremblant in the province of Quebec, under the direction of Dr. Kleerekoper. The particular part of the research being carried out here at McMaster was begun in 1950 by E. Larner, B.Sc., M.Sc., McMaster (8), continued by I. McGibbon, B.A., M.Sc., McMaster (9) and was carried out further by myself from 1952 - 1953. My own particular research of the project deals with the intensity of the decomposition of the organic matter in ten southern Ontario lakes. In the future it is hoped that a correlation of this decomposition may be worked out with the biological productivity of the lakes.

The productivity of any lake depends on its ability to form organic matter from the inorganic substances in the water, with the aid of solar energy. The immediate surrounding area is usually the source of these minerals with which the lake is supplied through ground water, streams, creeks, erosion, etc. Basically a lake is then a dilute solution of mineral constituents, which forms a nutrient medium for micro-organisms. These micro-organisms in turn provide food, either directly or indirectly, for larger organisms. The basis of the food chain is formed by the minerals in the lake which are derived from the surrounding area. As the quantity and quality of the minerals in the ground and surface waters are directly determined by the geological characteristics of the region, it becomes evident there must be an immediate relationship between the geology of the region and the biological productivity and ecological characteristics of its lakes. This, of course, does not apply if the lake is polluted by domestic, industrial or agricultural wastes.

The organic production of any body of water is mainly the product of phytoplankton which either directly or indirectly supplies all the other life present. In lakes of very small mean depth, higher vegetation often contributes considerably to the production of organic matter. In typical lakes, however, higher plants play only a secondary role in organic production in comparison with the amount of phytoplankton produced. Hence the total biological production of a lake depends on various environmental conditions. The most important of these conditions affecting the growth of phytoplankton are: light conditions, temperature, p^H, the morphology of the lake and the nutrients dissolved in it. Particularly, two chemical elements are of very great importance, because they are normally in very short supply in nature and often act as limiting factors of biological productivity. These elements are phosphorus and nitrogen.

We may consider the conditions in a hypothetical lake, supplied by ground water and not significantly affected by either run-off water or by losses through outlets. At the time of the formation of such a lake there is, therefore, only a dilute solution, containing chemical substances leached out from the surrounding geological formations. In this dilute solution of nutrients, micro-organisms develop which consist of three main ecological groups: producers, mainly phytoplankton, which produce organic matter; consumers, which feed on the producers; and reducers, mainly bacteria, which partly or completely, decompose the organic matter produced by the producers, the consumers and their waste products. The metabolism of the consumers and reducers leads to the hydrolysis of organic matter and to the freeing of vital minerals assimilated by the phytoplankton and locked up in the organic compounds.

The process of organic decomposition by consumers and reducers takes place in the trophogenic layer of the lake and continues in varying degree in the course of the descent of the organic matter both in the water and after its arrival on the lake bottom. If the decomposition were perfect and complete, the organic matter would be completely decomposed, and all the minerals would be liberated before the organic detritus became incorporated into the bottom sediment. All the minerals originally introduced by the ground water and which were used to form the organic matter, would be released again for further organic production. In the meantime, ground water would keep flowing into the lake and continue to add further nutrient minerals to it. The lake would, therefore, steadily increase in richness through the added nutrients of the ground water. No losses would occur because of the complete regeneration of nutrients from the organic matter formed in the lake. Eventually the lake would become eutrophic even if it were an extreme oligotrophic lake to begin with. This process might take time but it would eventually be completed. Since the nutrient cycle would be complete, no organic detritus would accumulate on the bottom of the lake. All the organic matter would be mineralized and its mineral constituents used over and over again.

In nature such lakes do not occur. Organic sediment does accumulate in lakes, more so in some than in others and all lakes do not develop into eutrophic ones of high productivity. If the organic decomposition is rapid, most of the detritus will be decomposed, nutrients will become rapidly available for new generations and little sediment will accumulate. If mineralization is slow, most of the organic matter will end up on the bottom as sediment, with only a small proportion of its nutrient minerals being returned to the water. As was pointed out previously, the decomposition of this organic matter takes place as it descends toward the bottom from the productive layer. It has been demonstrated by both field and laboratory observations, that decomposition is quicker and more complete under aerobic conditions. This is true whether considering decomposition in lake bottom sediments or decomposition of terrestrial organic matter. As soon as anaerobic conditions set in, the rate of decomposition decreases drastically.

In most lakes in the temperate region, during the summer, thermal stratification takes place. When this occurs, the hypolimnion is cut off from the epilimnion and often anaerobic conditions develop. Even if the lake is too shallow for a hypolimnion to form, organic sediment accumulated on the bottom develops anaerobic conditions a few millimeters below its surface. Hence, unless the organic matter is decomposed while still in the aerobic region of the lake, the chances of complete decomposition are small. After arrival at the bottom, the organic sediment is soon covered up with further detritus which leads to the development of anaerobic conditions. The result is often a deceleration of the organic decomposition and, therefore, an accumulation of organic matter on the bottom of the lake, containing critical nutrient elements. It is very unlikely that these nutrient elements in the sediment will ever be returned to the water and hence they are lost to the lake as far as its biological productivity is concerned. The accumulation of these organic sediments constitutes, therefore, a continuous drain on the mineral nutrients of the lake, preventing it from becoming eutrophic.

Therefore, the more thorough and faster the decomposition of the organic detritus while still in the water, the smaller the losses just mentioned. Since the availability of nutrients in the water is one of the decisive factors which determine biological productivity, we should expect to find a relationship between the rate and intensity of decomposition of organic detritus in the lake and its biological productivity.

The problem of determining this relationship constitutes the topic of the research now in progress at the Department of Biology, McMaster University and is divided into two aspects. The first one deals with a study of the rates of organic decomposition in lakes, as reflected by the relative amounts of breakdown products in lake bottom sediments. The second aspect refers to the determination of factors indicative for different levels of biological productivity. This thesis presents the partial observations dealing with the first mentioned aspect of the problem.

The original organic matter produced in lakes consists mainly of proteins, cellulose and small amounts of mono and disaccherides, hemi-celluloses, small amounts of pectins, lignins, fats and protobitumens, the latter being mainly in the form of waxes and resins (12). The relative amount of these components varies with the type of organic production of the lake, and particularly with the relative quantities of plant and animal substances. In the course of the decomposition of these components, a number of breakdown products are formed such as humus substances and their derivatives, mainly humic acids, complexes of amino acids and proteins formed by the reducing micro-organisms. A number of other substances of lesser importance may also occur. In addition minerals make their appearance as the result of hydrolysis.

The decomposition of the original organic components follows a definite pattern, by which the more readily hydrolyzible substances are attacked first (12). This differential rate of decomposition results in a change in the relative composition of the organic matter. It can be shown by experiment that the water soluble components are most easily attacked by the micro flora followed by pentosans such as hemicelluloses and finally cellulose. Most resistant of all are lignin and its derivitives. This difference in rate of decay leads to relative changes in chemical composition of the organic sediments, which may be indicative for the intensity and rate of the breakdown processes. Certain secondary microbiological activities, however, make the interpretation of data difficult at times. It is known, for example, that the protein content may increase in the process of decomposition; whereas hemicellulose may be formed from cellulose by certain microorganisms.

Therefore, by analysing the sediment for these different intermediate products, one may obtain an insight into the state of decomposition of the sediment and from this, ascertain the amount of re-mineralization that has taken place in the organic sediment. The intermediate products analysed for in my research were; bitumens, protobitumens, fats, pectins, water soluble carbohydrates and proteins, minerals, hemicelluloses, dilute acid soluble proteins, celluloses, humic acid and lignins. In addition the total carbon present in each sample of sediment was also determined. The nitrogen and phosphorus content of each sample was determined as well as their content in a number of the fractions just mentioned. Since the problem has been approached from a quantitative basis, it is hoped that the results will allow us not only to determine what kind of decomposition has taken place, but also how much decomposition has taken place.

Since the chemical composition of the ground water supplying lakes is one of the main factors directly determining the chemical characteristics of the lake water and, therefore, in part, its biological productivity, the research was carried out in lakes of geologically similar regions. It was decided, therefore, to carry out this investigation in a large number of lakes in the Ordovician and post Ordovician regions of southern Ontario. In this way a broad regional approach to the problem became possible. In the future, this research may be extended to the pre-Cambrian regions of Ontario and a comparison of the two regions may be obtained.

Although considerable work has been done on the chemistry of marine and lake sediments, no reports of the analysis of the intermediate products of decomposition could be found in the literature. Souci and others have done such analysis on moors in Europe but the results were used for different purposes.

Twenhofel, McKelvey, Nelson and Feray (19) determined the organic content of sediment from Trout Lake as from 41.22% - 69.52% The lignin content of this organic matter varied from 15.34% - 30.95% of the dry sediment. They also noted that the percentage of lignin increased with the depth of the core. The top of the core contained the least percentage of lignin and the bottom of the core the most. Twenhofel (19) also noted that this organic matter was chiefly decomposed by the metabolic processes of micro-organisms.

Allgeier, Peterson, and Juday (2) observed in the lakes they investigated, the organic matter in the sediment to be approximately 1/3 proteins and 2/3 non-nitrogenous.

Brauns (4) describes various methods for the determination of lignin in wood. He discusses the advantages of pretreatment on the samples with organic solvents, hot water and dilute acids. Hutchinson and Wollock (6) use the terms apparent lignin and true lignin. The former was the organic material insoluble in cold, 72% sulphuric acid. The true lignin was calculated by subtracting the protein equivalent of the nitrogen in the apparent lignin. Steiner and Meloche (13) found that for lake muds 30% - 48% of the total organic matter was lignin. The percentage of carbon in the lignin which had undergone the least decomposition was as high as 64%.

Juday, Birge and Meloche (7) and Wiseman (25) have determined the carbon and nitrogen content on lake waters. The former workers carried out the investigation in the lakes of north eastern Wisconsin and the latter on the Arabian Sea. Similar work has been done by others.

Investigations on the effects of bacteria in decomposition have been carried out by several workers, including; Waksman and Vartiovaara (22) ; Hock (5); Waksman, Hotchkiss, Carey and Hardman (21) and Zobell (26). Waksman (20) also found that sugars, hemicelluloses and cellulose decompose rapidly, while lignin decomposes slowly. This is the case on land and it was assumed the same conditions would hold true in water.

LOCATION OF LAKES AND SAMPLING METHODS.

As was stated previously, the problem was approached from a regional standpoint, and as a continuation of a research problem carried on by I. McGibbon. Consequently the twenty lakes which I sampled were selected from areas which had not been sampled before. The sediment from ten of the twenty lakes I sampled was analysed. The position of the lakes studied, both by McGibbon and by myself, is seen on the map (fig. 1). The geographical location of the ten lakes I studied is given in Table 1. The latitude and longitude numbers in this table refer to the topographical maps published by the Geographical Section, General Staff, Department of National Defence.

Lakes which had been drained, dredged, were polluted, or showed signs of heavy erosion, silting or run off were not sampled. Only the lakes which were reasonably accessible were sampled. A single sampling station was selected for each lake away from any inlet or outlet and far enough from the shore to be free from shoreline disturbances. Since all these factors were considered before the lake was sampled, it was felt that all the sediment samples collected from the twenty lakes were representative for natural conditions.

The question may be raised that local variations in lake sediments may occur leading to different analytical results. Numerous stations would have to be chosen in each

TABLE 1

LOCATION AND DEPTH OF LAKES SAMPLED

Name of Lake	Location of Lake				Water depth at sampling station in meters
	Sheet number	Latitude	Longitude	County	
Lockhart Pond	$40\frac{P}{2}$	43°11'N	80°38'E	Oxford	3.00
Whittaker	$40\frac{1}{15}$	42°55'N	80°58'E	Middlesex	3.00
Heart	$30\frac{M}{12}$	43°44'N	79°48'E	Peel	2.50
Miller	$41\frac{H}{3-4}$	45°06'N	81°24'E	Bruce	1.50
Edward's	$41\frac{A}{8}W$	44°22'N	80°15'E	Simcoe	3.50
Little	$31\frac{D}{5}$	44°26'N	79°40'E	Simcoe	3.00
Bass	$31\frac{D}{N.W}$	44°36'N	79°30'E	Simcoe	3.50
Crow	$31\frac{C}{5}E$	44°29'N	77°44'E	Hastings	3.00
Belmont	$31\frac{C}{5}W$	44°29'N	77°49'E	Peterborough	3.00
Musselman	$31\frac{D}{3}$	44°02'N	79°16'E	York	3.00

lake to correct for this sampling error. Our approach, however, is a regional one, requiring the sampling of many lakes in a large area which will tend to lesson the significance of local variations. Furthermore, even with only one sampling station at each lake, the analysis is lengthy and expensive. If more than one sampling station were selected in each lake and the regional approach maintained, the analytical work would become too extensive.

At the sampling station, the p^H of the surface water was taken by the colourimetric method; the temperature was recorded at every metre with a standard reversing thermometer; the electro-conductivity of the water was also taken at every metre with the Cambridge Conductivity Bridge. A vertical plankton haul was made with the plankton net, from the surface of the sediment, to the surface of the water.

The samples of sediment were taken with the Lundquist and Hiller samplers, both of which permit one to take a core sample of sediment. The former samples the surface sediment with very little compression of the core. From it one can observe the stratification of the recent sedimentation taking place in the lake.

The Hiller sampler allows one to collect samples at a much greater depth. One obtains from this sampler a 50 cm. core of sediment, at the desired depth without contamination from the more recent sediment. This sampler does, however, compress the softer, surface sediment slightly. By connecting extension rods to this sampler, lower strata can be reached. The sampling at any station was carried out to as great a depth as practical. The maximum depth to which our sampler could penetrate was 7.5 metres.

While still in the samplers, the cores of sediment were noted for colour, texture, and the presence of H_2S, macro plant detritus and fossil molluscs. The samples were then placed in separate bottles, marked and preserved by adding chloroform.

In the laboratory, the samples were spread out in dishes and some of the fossil molluscs removed from the sediment for identification. Three microscope slides were made of each sample for future study of the microscopic nature of the sediment.

The remainder of the sediment was dried and used for the chemical analyses, which form the main body of this thesis. The analytical methods are described in detail by I. McGibbon (9).

RESULTS AND DISCUSSION OF ANALYSES

The results of my analyses are recorded both in tabular and graphic form. Table II shows the water depth at the sampling station, and the values of the water temperature, the electro conductivity of the water and the p^H of the surface water at the time of sampling.

Table III indicates, in percentage of the dry weight, the values of the water content, total carbon, total nitrogen and total phosphorus of the sediment. Table IV represents the amounts of bitumens, pectins, hemicelluloses and cellulose in the sediment in per cent of the dry weight. Table V shows the amounts of nitrogen in the hot water and hydrochloric acid filtrates and the amounts of phosphorus in the hydrochloric and sulphuric acid residues, in per cent of the dry weight. The figures illustrate by maps and graphs, the important points of the tables.

For figures 2 to 22 along the axis concerned with depth the number 0 refers to the sediment at the depth 0 to 50 cm. Likewise 50 refers to the depth 50 to 100 cm; 100 refers to the depth 100 to 150 cm., etc.

It must be pointed out at the beginning of this discussion, that this thesis represents only partial results of a research program designed to investigate the sediment of many of the lakes of the Ordovician and post Ordovician regions of southern Ontario. No definite general conclusions can be

TABLE 2

Water Temperatures, Electro Conductivity Measurements, and P^H of Lake Water At Time Of Sampling

Name of Lake	Water depth in meters	Water temperatures (°C)	Electro conductivity measurements (mhos)	P^H
Lockhart Pond	0.0	24.5	0.001527	7.4
	1.0	24.3	0.001515	-
	2.0	21.0	0.001515	-
	2.5	18.3	0.001587	-
	3.0	18.3	0.001587	-
	3.5	18.3	-	-
	4.0	18.3	0.001587	-
Whittaker	0.0	21.8	0.002532	8.8
	1.0	21.7	0.002621	-
	2.0	21.1	0.002667	-
	3.0	20.4	0.002703	-
	3.5	19.8	0.002703	-
Heart	0.0	22.1	0.001561	8.8
	1.0	21.3	0.001560	-
	2.0	21.0	0.001541	-
	3.0	20.4	0.001544	-
	4.0	17.5	0.001537	-
	5.0	14.2	0.001515	-
Miller	0.0	26.0	0.002339	8.8
	1.0	25.9	0.002345	-
	1.5	24.9	0.002472	-

TABLE 2 (continued)

Name of Lake	Water depth in meters	Water temperatures (°C)	Electro conductivity measurements (mhos)	pH
Edward's	0.0	25.6	-	7.6
	1.0	25.6	-	-
	2.0	25.2	-	-
	3.0	25.1	-	-
	3.5	20.5	-	-
Little	0.0	25.3	-	7.8
	1.0	25.2	-	-
	2.0	25.1	-	-
	3.0	24.0	-	-
Bass	0.0	24.1	-	8.8
	1.0	23.8	-	-
	2.0	23.4	-	-
	3.0	23.1	-	-
	3.5	23.1	-	-
Crow	0.0	23.6	0.001300	8.4
	1.0	23.6	0.001300	-
	2.0	23.6	0.001300	-
	3.0	23.4	0.001316	-
Belmont	0.0	24.0	0.001048	8.4
	1.0	24.0	0.001163	-
	2.0	23.9	0.001206	-
	3.0	23.5	0.001216	-

TABLE 2 (continued)

Name of Lake	Water depth in meters	Water Temperatures (°C)	Electro conductivity measurements (mhos)	pH
Musselman	0.0	23.0	0.001163	8.4
	0.5	23.0	0.001203	-
	1.0	22.5	0.001232	-
	2.0	22.3	0.001305	-
	3.0	22.2	0.001307	-

TABLE 3

Total Carbon, Total Nitrogen, Total Phosphorus and Water Content of the Bottom Sediments of Ten Lakes of the Ordovician and Post-Ordovician Regions of Ontario

Name of lake	Sample number	Depth of stratum from surface of sediment in centimeters	Thickness of stratum in centimeters	Percentage of Dry Weight				
				Water content	Total carbon	Total phosphorus	Total nitrogen	Presence of H_2S
Lockhart	C10	0.0	50.0	1664.06	35.801	0.110	3.923	-
	C11	50.0	50.0	1065.52	35.121	0.079	4.138	-
Pond	C12	100.0	50.0	986.81	50.998	0.107	3.939	-
	C13	150.0	50.0	687.59	43.514	-	4.386	-
	C14	200.0	50.0	1627.61	40.676	-	4.132	-
	C15	250.0	50.0	2190.85	25.989	-	3.540	-
	C16	300.0	50.0	940.57	30.228	-	3.321	-
	C17	350.0	50.0	731.47	29.915	-	3.652	-
Whittaker	C19	0.0	50.0	-	24.635	0.208	2.341	-
	C20	50.0	50.0	290.24	19.484	0.081	1.272	-
	C21	100.0	50.0	358.38	23.024	0.055	1.554	-
	C22	150.0	50.0	389.54	22.459	-	1.787	-
	C23	200.0	50.0	541.72	20.874	-	2.088	-
	C24	250.0	50.0	660.44	21.358	-	1.744	-
	C25	300.0	50.0	620.70	16.918	-	1.873	-
	C26	350.0	50.0	146.18	6.975	-	0.424	-

TABLE 3 (continued)

Name of lake	Sample number	Depth of stratum from surface of sediment in centimeters	Thickness of stratum in centimeters	Percentage of Dry Weight				
				Water content	Total carbon	Total phosphorus	Total nitrogen	Presence of H_2S
Heart	C39[1]	0.0	12.5	461.81	22.713	-	1.434	-
	C40.1	0.0	20.0	722.17	33.255	0.195	2.028	-
	C40.2	20.0	30.0	1094.63	41.118	0.112	1.520	-
	C41	50.0	50.0	638.98	34.799	0.196	2.041	-
	C42	100.0	50.0	1754.99	31.021	0.152	1.650	-
	C43	150.0	50.0	1502.91	28.720	-	1.093	-
	C44	200.0	50.0	1245.81	32.279	-	1.466	-
	C45.1	250.0	30.0	1063.64	30.257	-	2.141	-
	C45.2	280.0	20.0	335.34	20.145	-	1.895	-
	C46	300.0	50.0	722.19	17.874	-	1.438	-
	C47	350.0	50.0	3341.76	18.824	-	1.740	-
	C48	400.0	50.0	537.59	17.938	-	1.904	-
	C49	450.0	50.0	354.22	20.965	-	2.204	-
Miller	C59	0.0	50.0	557.02	20.888	0.093	2.240	-
	C60	50.0	50.0	602.62	25.615	0.101	2.445	-
	C61	100.0	50.0	562.21	23.016	0.082	2.583	-
	C62.1	150.0	20.0	918.84	23.379	-	2.351	-
	C62.2	170.0	30.0	365.76	27.572	-	0.864	-
	C63	200.0	50.0	414.08	16.140	-	0.981	-
	C64	250.0	50.0	437.64	16.130	-	1.067	-

TABLE 3 (continued)

Name of lake	Sample number	Depth of stratum from surface of sediment in centimeters	Thickness of stratum in centimeters	Percentage of Dry Weight				
				Water content	Total carbon	Total phosphorus	Total nitrogen	Presence of H_2S
Edward's	C71 (1)	0.0	23.0	620.58	16.097	-	0.921	+
	C72	0.0	50.0	524.32	14.969	0.040	0.920	+
	C73	50.0	50.0	496.95	15.119	0.045	0.950	+
	C74	100.0	50.0	425.06	15.770	0.060	0.792	+
	C75	150.0	50.0	410.62	21.337	-	0.887	+
	C76	200.0	50.0	433.68	16.358	-	0.881	+
	C77	250.0	50.0	310.99	14.745	-	0.670	-
	C78	300.0	50.0	347.02	18.762	-	0.782	-
	C79	350.0	50.0	256.26	17.796	-	0.624	-
Little	C81 (1)	0.0	29.0	566.52	17.577	-	1.420	-
	C82	0.0	50.0	933.48	22.951	0.394	2.242	-
	C83	50.0	50.0	1300.00	17.038	0.163	2.953	-
	C84	100.0	50.0	625.12	39.497	0.204	2.821	-
	C85	150.0	50.0	516.14	31.517	-	1.941	-
	C86	200.0	50.0	389.07	22.130	-	1.067	-
Bass	C98 (1)	0.0	15.0	418.89	14.394	-	0.856	-
	C99	0.0	50.0	346.11	14.649	0.054	1.149	-
	C100	50.0	50.0	525.76	18.682	0.072	0.615	-
	C101	100.0	50.0	500.09	18.667	0.062	1.244	-
	C102	150.0	50.0	306.81	16.979	-	0.891	-
	C103	200.0	50.0	166.29	16.296	-	0.326	-

TABLE 3 (continued)

Name of lake	Sample number	Depth of stratum from surface of sediment in centimeters	Thickness of stratum in centimeters	Percentage of Dry Weight				
				Water content	Total carbon	Total phosphorus	Total nitrogen	Presence of H_2S
Crow	C128[1]	0.0	15.0	671.85	22.699	-	1.806	-
	C129	0.0	50.0	1284.33	28.381	0.098	2.494	-
	C130	50.0	50.0	1516.68	26.207	0.062	2.295	-
	C131	100.0	50.0	1022.84	26.987	0.088	1.845	-
	C132	150.0	50.0	935.44	24.201	-	1.975	-
	C133	200.0	50.0	1258.21	25.331	-	2.394	-
	C134	250.0	50.0	1161.32	25.614	-	2.215	-
Belmont	C136[1]	0.0	15.0	523.88	13.320	-	1.148	-
	C137	0.0	50.0	1353.93	10.322	0.068	2.229	-
	C138	50.0	50.0	644.15	19.295	0.062	0.939	-
	C139	100.0	50.0	493.26	16.277	0.037	0.703	-
	C140	150.0	50.0	475.90	13.914	-	0.838	-
	C141	200.0	50.0	543.87	18.168	-	0.936	-
Musselman	C143[1]	0.0	28.0	327.81	10.532	-	0.733	-
	C144	0.0	50.0	971.05	17.203	0.149	1.809	-
	C145	50.0	50.0	1165.66	20.521	0.123	1.698	-
	C146	100.0	50.0	794.80	15.425	0.116	1.242	-
	C147	150.0	50.0	876.73	21.249	-	1.902	-
	C148	200.0	50.0	438.95	12.861	-	1.046	-
	C149	250.0	50.0	176.98	10.076	-	1.510	-

(1) - Samples collected with the Lundquist Sampler. Other samples were collected with the Hiller Sampler.

TABLE 4

Bitumens, pectins, hemicelluloses, cellulose in the bottom sediments of Ten Lakes of the Ordovician and Post-Ordovician Regions of Ontario

Name of lake	Sample Number	Percentage of Dry Weight			
		Bitumen	Pectins	Hemicelluloses	Cellulose
Lockhart Pond	C10	2.799	14.099	27.399	3.871
	C11	0.417	15.726	-	-
	C12	1.869	18.747	37.122	6.037
	C13	2.262	15.159	30.664	5.095
	C14	1.733	25.897	28.266	3.748
	C15	1.069	20.807	25.572	4.751
	C16	1.023	16.563	20.598	9.374
	C17	1.178	15.490	15.744	4.404
Whittaker	C19	0.681	10.832	7.627	6.711
	C20	0.546	7.082	9.766	2.577
	C21	0.739	7.701	12.242	2.192
	C22	0.645	7.833	12.226	3.208
	C23	0.826	13.613	5.958	4.207
	C24	0.898	9.663	8.676	4.512
	C25	1.009	12.949	48.970	1.999
	C26	0.173	3.772	6.670	1.002
Heart	C39	1.113	12.793	6.032	4.108
	C40.1	1.734	18.286	14.239	1.884
	C40.2	1.781	16.891	16.792	4.284
	C41	1.741	22.420	13.628	8.861
	C42	1.403	14.167	16.994	1.440
	C43	2.463	18.262	14.694	4.831

TABLE 4 (continued)

Name of lake	Sample Number	Percentage of Dry Weight			
		Bitumen	Pectins	Hemicelluloses	Cellulose
Heart (continued)	C44	-	-	-	-
	C45.1	2.329	18.209	14.024	0.510
	C45.2	-	-	-	-
	C46	0.975	8.580	20.961	7.609
	C47	0.887	11.391	15.128	5.841
	C48	0.742	10.609	9.776	5.831
	C49	1.499	14.516	16.278	3.036
Miller	C59	1.678	16.495	13.308	5.508
	C60	1.561	14.550	16.207	8.698
	C61	3.570	16.643	13.332	3.850
	C62.1	1.568	17.931	15.059	4.921
	C62.2	0.406	9.078	7.570	-
	C63	0.772	7.945	11.404	4.276
	C64	0.430	9.885	6.613	4.606
Edward's	C71	0.479	8.076	6.989	-
	C72	0.615	8.271	6.750	1.778
	C73	0.498	8.763	7.902	--
	C74	0.896	5.756	11.833	-
	C75	0.650	6.715	8.850	0.610
	C76	1.032	7.295	8.566	-
	C77	0.609	6.819	5.092	-
	C78	0.694	7.521	26.433	-
	C79	0.427	6.328	5.842	--

TABLE 4 (continued)

Name of lake	Sample Number	Percentage of Dry Weight			
		Bitumen	Pectins	Hemicelluloses	Cellulose
Little	C81	0.793	7.859	19.946	4.464
	C82	1.399	13.397	18.016	4.508
	C83	1.742	11.834	23.096	5.588
	C84	1.844	13.419	20.403	5.276
	C85	1.105	9.510	21.573	5.470
	C86	0.654	6.539	15.402	2.553
Bass	C98	0.405	11.081	2.745	-
	C99	0.391	4.421	7.443	-
	C100	0.476	8.882	13.600	1.819
	C101	0.779	7.294	17.205	-
	C102	0.443	5.885	6.900	3.779
	C103	0.232	2.792	5.601	-
Crow	C128	1.317	9.227	13.580	1.292
	C129	2.020	11.667	18.816	0.449
	C130	1.723	10.158	11.869	9.067
	C131	1.628	10.601	9.197	7.601
	C132	1.652	9.377	9.446	12.600
	C133	1.795	11.493	13.102	11.346
	C134	1.773	10.100	11.468	12.952

TABLE 4 (continued)

Name of lake	Sample Number	Percentage of Dry Weight			
		Bitumen	Pectins	Hemicelluloses	Cellulose
Belmont	C136	0.570	6.496	16.244	10.423
	C137	1.422	11.441	16.847	3.815
	C138	0.480	5.364	11.374	1.518
	C139	0.474	3.876	7.276	4.585
	C140	0.519	5.557	8.636	11.005
	C141	0.561	6.127	10.920	4.297
Musselman	C143	0.337	4.134	21.816	2.312
	C144	1.014	8.408	24.219	3.580
	C145	0.923	8.690	15.537	9.639
	C146	0.755	5.676	19.985	0.671
	C147	0.943	10.318	18.558	8.574
	C148	0.719	4.794	13.343	2.615
	C149	0.347	4.549	14.602	7.319

TABLE 5

Nitrogen and Phosphorus in the Organic Fractions of the Samples

Name of lake	Sample number	Percentage of Dry Weight			
		Nitrogen in hot water filtrate (1)	Nitrogen in HCl filtrate (2)	Phosphorus in HCl residue (3)	Phosphorus in H_2SO_4 Residue (4)
Lockhart Pond	C10	0.616	1.460	0.018	0.014
	C11	0.357	-	-	-
	C12	0.413	1.751	0.010	0.007
	C13	0.432	1.971	-	-
	C14	0.145	1.638	-	-
	C15	0.936	1.683	-	-
	C16	0.923	0.947	-	-
	C17	0.859	1.964	-	-
Whittaker	C19	0.541	0.658	0.027	0.028
	C20	0.324	0.059	0.006	0.004
	C21	0.401	0.480	0.004	0.003
	C22	0.411	0.123	-	-
	C23	0.522	0.031	-	-
	C24	0.383	0.238	-	-
	C25	0.478	0.123	-	-
	C26	0.085	0.068	-	-
Heart	C39	0.636	0.211	-	-
	C40.1	0.895	0.405	0.019	0.011
	C40.2	0.646	0.393	0.014	0.008
	C41	0.949	0.381	0.008	0.005
	C42	0.466	0.508	0.027	0.020
	C43	0.802	0.286	-	-
	C44	-	-	-	-
	C45.1	1.139	0.459	-	-

TABLE 5 (continued)

Name of lake	Sample number	Percentage of Dry Weight: Nitrogen in hot water filtrate (1)	Nitrogen in HCl filtrate (2)	Phosphorus in HCl residue (3)	Phosphorus in H_2SO_4 residue (4)
Heart (continued)	C45.2	-	-	-	-
	C46	0.584	0.286	-	-
	C47	0.764	0.309	-	-
	C48	0.663	0.533	-	-
	C49	0.909	0.507	-	-
Miller	C59	0.781	0.589	0.020	0.011
	C60	0.767	0.711	0.019	0.014
	C61	0.966	0.548	0.015	0.020
	C62.1	0.985	0.598	-	-
	C62.2	0.513	0.165	-	-
	C63	0.340	0.219	-	-
	C64	0.436	0.210	-	-
Edward's	C71	0.411	0.211	-	-
	C72	0.420	0.212	0.003	0.002
	C73	0.462	0.232	0.002	-
	C74	0.267	0.238	0.004	-
	C75	0.314	0.212	-	-
	C76	0.356	0.171	-	-
	C77	0.294	0.179	-	-
	C78	0.338	0.157	-	-
	C79	0.309	0.136	-	-

TABLE 5 (continued)

Name of lake	Sample number	Percentage of Dry Weight: Nitrogen in hot water filtrate (1)	Nitrogen in HCl filtrate (2)	Phosphorus in HCl residue (3)	Phosphorus in H_2SO_4 residue (4)
Little	C81	0.440	0.333	-	-
	C82	0.714	0.583	0.024	0.007
	C83	0.596	0.951	0.020	0.004
	C84	0.726	0.809	0.023	0.016
	C85	0.498	0.434	-	-
	C86	0.319	0.207	-	-
Bass	C98	0.452	0.487	-	-
	C99	0.239	0.146	0.006	-
	C100	0.394	0.264	0.026	-
	C101	0.371	0.172	0.006	-
	C102	0.332	0.165	-	-
	C103	0.151	0.079	-	-
Crow	C128	0.477	0.472	-	-
	C129	0.511	1.331	0.038	0.010
	C130	0.471	0.523	0.026	0.017
	C131	0.510	0.402	0.022	0.010
	C132	0.512	0.447	-	-
	C133	0.498	0.493	-	-
	C134	0.471	0.529	-	-

TABLE 5 (continued)

Name of lake	Sample number	Percentage of Dry Weight			
		Nitrogen in hot water filtrate (1)	Nitrogen in HCl filtrate (2)	Phosphorus in HCl residue (3)	Phosphorus in H_2SO_4 residue (4)
Belmont	C136	0.318	0.273	-	-
	C137	0.444	0.443	0.034	0.014
	C138	0.039	0.183	0.053	0.039
	C139	0.267	0.127	0.004	0.004
	C140	0.149	0.193	-	-
	C141	0.245	0.185	-	-
Musselman	C143	0.276	0.203	-	-
	C144	0.455	0.755	0.021	0.016
	C145	0.509	0.521	0.053	0.039
	C146	0.357	0.420	0.030	0.024
	C147	0.484	0.587	-	-
	C148	0.232	0.306	-	-
	C149	0.199	0.121	-	-

(1) This filtrate contains, besides pectins, small amounts of nitrogenous compounds, mainly water soluble proteins.
(2) This filtrate contains, besides hemicelluloses, small amounts of nitrogenous compounds, mainly proteins of higher stability.
(3) Phosphorus content of substances not hydrolyzable by 2% HCl (cellulose, proteins, lignin and intermediate products of decomposition).
(4) Phosphorus content of substances not hydrolyzable by 75% H_2SO_4.

stated for the lakes in this region until the sediment of the remaining lakes which were sampled is analysed. The conclusions described here pertain only to ten lakes unless stated otherwise. No correlation between the rates and type of decomposition with the biological productivity is attempted here. This must wait until the sediment of the remaining lakes we have sampled is analysed and an accurate measure of their biological productivity is ascertained.

In general the carbon content of organic sediments increases with increasing depth and consequently increasing age. This increase is not apparent in the lake sediments referred to in this thesis. Figure 2 represents the average total carbon content of the dry sediment, at the various depths, of all the samples analysed in our investigations. It will be noted in this graph that there is a trend to a decreasing amount of total carbon with depth and consequently with age. This might be explained by a lower rate of organic production in the early stages of the lake. Consequently more clay, sand and inorganic material were deposited in sediment than at the present time, resulting in a lower content of total carbon in the older sediment. The point may be raised, if this lower amount of carbon is due to a relatively larger amount of sand and clay and hence to geological and climatic factors. Undoubtedly in the early stages of the lake, eroded material from the surrounding area would comprise an important portion of the sediment, whereas this generally represents only a minor fraction of recent sediment.

Lockhart Pond has the highest average carbon content, reaching a maximum at the 100 to 150 cm. depth, of 51.0%. Edward's, Bass and Belmont Lakes have the lowest average carbon content, all of them under 20% at all levels, except the 150 to 200 cm. stratum of Edward's Lake. The carbon content of the other six lakes lies in between these extremes, with that of the sediments of Whittaker Lake being close to the average carbon content of the sediment of all the lakes. In the sediment of the lakes analysed, there appears to be little correlation between the carbon content and the position of the lake in the province.

In figures 3 to 12 a correlation between the carbon content of the sediment, and the amount of nitrogen in the original sample is shown. This correlation may indicate that low carbon content at greater depths results from low productivity at the time of the sedimentation.

In general, the sediment with the higher carbon content also has higher contents of bitumens, pectins, hemicelluloses and cellulose. In my results, Lockhart Pond has, on the average, the highest amounts of bitumens, pectins, hemicelluloses and cellulose. Edward's, Bass and Belmont Lakes have the lowest proportion of these fractions. The sediment of Lockhart Pond contains, therefore, the highest and Edward's, Bass and Belmont Lakes the lowest organic content. The fractions of the other six lakes lie in between these extremes.

The bitumen content of the sediment is very small in all the samples. The highest bitumen content is 3.57% of the dry sediment at the 100 to 150 cm. depth of Miller Lake. The lowest content is 0.23% of the dry sediment weight at the 200 to 250 cm. level of Bass Lake. The bitumenous content of the sediment is thus very small in these lake sediments.

An interesting fact may be noted in the lakes from which a sample of the 300 to 350 cm. depth is shown. In all these lakes, except Lockhart Pond, the hemicellulose content rises sharply at this level. Even in Musselman Lake, where the samples do not go down to this level, the hemicellulose content rises at the 250 to 300 cm. depth. The cause of this increase in the hemicellulose content of the sediment at this depth, is not clear. Sphagnum is rich in hemicellulose and its occurrence may explain the phenomenon. Further investigation will be made regarding this problem.

In the sediment of the lakes analysed, with the exception of Lockhart Pond and Heart Lake, there is correlation between the amount of hot water extract and the total nitrogen in the dry sample. Initial observations indicate that most of this nitrogen is in the form of a water soluble protein. Some nitrogen also occurs in the dilute acid extraction, indicating the presence of dilute acid soluble proteins. The remainder of the nitrogen is most likely to be found in a more stable protein compound, only hydrolysed by stronger acids, i.e., 75% sulphuric acid. The nitrogen content of this extract is being investigated. It is hoped in the future, that the main proteins in the three extracts may be determined and that this may shed further light on the rate and type of decomposition taking place in the sediment.

The greatest amount of nitrogen is shown in the sediment of Lockhart Pond, where the highest amount of total carbon and organic matter were also found. Nitrogen content is above 3% in all the samples and reaches a high of 4.386% at the 150 to 200 cm. depth. This value is almost twice as great as the nitrogen content of the sediment from any of the other lakes investigated. The lowest amounts of total nitrogen are found in Edward's, Bass and Belmont Lakes. In these lakes the total nitrogen content is less than 1% in almost all the samples. The sediment of these three lakes also have the lowest amount of total carbon and organic material. It seems, therefore, that lakes with high nitrogen content in the sediment have also the highest organic content. Those with the lowest nitrogen content in the sediment have the lowest organic content. Under proper conditions the amount of nitrogen may increase in the sediment due to nitrification in the course of progressing decomposition. In the sediment of the ten lakes analysed here, the higher amounts of nitrogen generally occur where there are higher amounts of hemicelluloses.

The map in fig. 23 shows the phosphorus content of the 0 to 50 cm. depth of sediment for the ten lakes analysed by McGibbon and the ten lakes analysed by myself. It will be noted that generally the lakes with the lower phosphorus content (less than 0.1%) occur close to the Ordovician - Precambrian boundary. This probably indicates that ground water of low phosphorus content, likely of precambrian origin, supplies these lakes, which are themselves located in the ordovician and post ordovician formations. It is hoped that this research project may be extended to the Precambrian area of Ontario. The analysis of the sediment of the lakes in that region would shed further light on this part of the problem.

In figs. 24 to 26 the phosphorus content of the sediment is plotted against the carbon : nitrogen ratio, for the three depths on which the phosphorus data were available. It will be noted that five of the lakes present similar characteristics in each of the three strata. These are Lockhart Pond, Miller, Crow, Musselman and Heart Lakes. Little Lake might possibly be considered in this group but for its very high phosphorus content in all three strata. These six lakes are referred to below as Group I.

The remaining four lakes, namely, Whittaker, Edward's, Bass and Belmont, do not belong to the lakes of Group I, and yet they seem to form no separate, distinct group of their own. For the sake of convenience, they will be called Group II. Whittaker Lake has a high phosphorus content at the 0 to 50 cm. level, but the percentage drops sharply in the two lower samples. This high phosphorus content in the surface samples is, therefore, very likely due to agricultural pollution by fertilizers rich in phosphorus. This effect would only occur in recent times and the phosphorus content would only be high in the surface sediment. In the deeper and older samples, the phosphorus content has a much lower value.

In the lakes of Group I, the hemicellulose content for the 0 to 50 cm. level of sediment, varies between 13.31% to 27.40% while in the lakes of Group II for this same level, three of the lakes have values near 7%. Only Belmont Lake has 16.85%. At the 50 to 100 cm. level, the lakes in Group I have a hemicellulose content varying from 13.63% to 24.22%, while in Group II the content varies from 7.90% to 13.60%. At the 100 to 150 cm. level, the hemicellulose content is 9.20% to 37.12% while in Group II it is 7.28% to 17.21%. In all three cases the percentage of organic matter present in the Group I lakes is higher than in the lakes of Group II.

The same situation exists when pectins are considered. In the lakes of Group I for the 0 to 50 cm. level, the percentage of pectins ranges between 8.41% to 18.29%, while in the lakes of Group II the content ranges from 4.42% to 10.83%. At the 50 to 100 cm. depth the content of pectins in Group I lakes varies between 8.69% to 22.42%, while in Group II lakes it is 5.30% to 8.88%. At the 100 to 150 cm. depth, the pectin content in Group I lakes varies from 5.6 8% to 18.75%, while in the Group II lakes it varies from 3.88% to 7.70%. Here again the higher percentage of pectins in Group I lakes indicates a higher organic content of the sediment of Group I lakes than in Group II lakes.

The same situation is noted when the carbon content of the sediment is considered. At the 0 to 50 cm. level, the carbon content of the sediment ranges between 17.20% to 35.80%, whereas in the lakes of Group II, the carbon content varies from 10.32% to 24.68%. At the 50 to 100 cm. depth of sediment, the percentage of carbon in the lakes of Group I varies between 17.04% and 35.12%, whereas in the lakes of Group II, at this level, the carbon content ranges from 15.12% to 19.48%. At the 100 to 150 cm. depth of sediment, the carbon content in the sediment of Group I lakes varies from 15.43% to 51.00%, while in the lakes of Group II it ranges from 15.77% to 23.02%. Again it will be noted that the carbon content of the Group I lakes is higher than the content of Group II lakes, indicating a higher organic content of the sediment in Group I lakes than in Group II lakes.

In all three instances, hemicelluloses, pectins and total carbon, the values are higher in Group I lakes than in Group II lakes. This would indicate a higher organic content of the sediment of Group I lakes than of Group II lakes.

Three of the lakes in Group II, namely Edward's, Bass and Belmont, have a total phosphorus content of the 0 to 50 cm. level, of less than 0.1% and are situated near the boundary of the Ordovician and Precambrian regions. These three lakes seem to form a group of their own, in that they are very similar in many respects. They have the lowest average percentages of nitrogen, phosphorus, total carbon, pectins and hemicelluloses of the ten lakes.

Lakes in which the organic matter in the sediment is richest in nitrogen are also the lakes which have the highest total phosphorus content in their sediment. They are also the lakes in which the greater percentage of the nitrogen is found in the hydrochloric acid extract, which might indicate that this nitrogen is tied up in a dilute acid soluble protein. With the exception of Musselman Lake, the sediment which contains the highest amount of hemicelluloses is also the sediment which has the highest amount nitrogen and the lowest carbon : nitrogen ratio. In other words, the organic matter of this sediment is relatively richest in nitrogen.

When the sediment of the remaining lakes which we have sampled is analysed, a fuller and more complete understanding of the decomposition taking place in the sediments of Ordovician and post Ordovician lakes may be gained. An estimate of the biological productivity in these lakes will be made and the relationship between the rate and type of decomposition taking place in the sediment and productivity may be established.

The above stated findings may be summarized as follows:

1. Lakes of higher electro conductivity have a smaller total carbon content in their bottom sediments.
2. In the surface sediments total phosphorus content is independent of the carbon : nitrogen ratio. The deposition of P is, therefore, most likely of a mineral nature.

3. Phosphorus seems to be incorporated in the lower strata in the form of a water soluble protein and as mineral phosphorus.
4. The inorganic phosphorus becomes of relatively little importance in depths greater than 20 cm.
5. Total carbon decreases sharply at the depth of 250 - 300 cm.
6. Total carbon correlates with the amounts of bitumens, pectins, hemicellulose and cellulose.
7. Nitrogen content and hemicelluloses correlate, indicating a bacterogenic origin of the nitrogen.
8. Nitrogen seems to be present mainly as a water soluble protein.
9. There are two groups of lakes as to their total P content at any level of the sediments. These groups show distinct correlations with their geological locations and with the amounts of hemicelluloses in their sediments.

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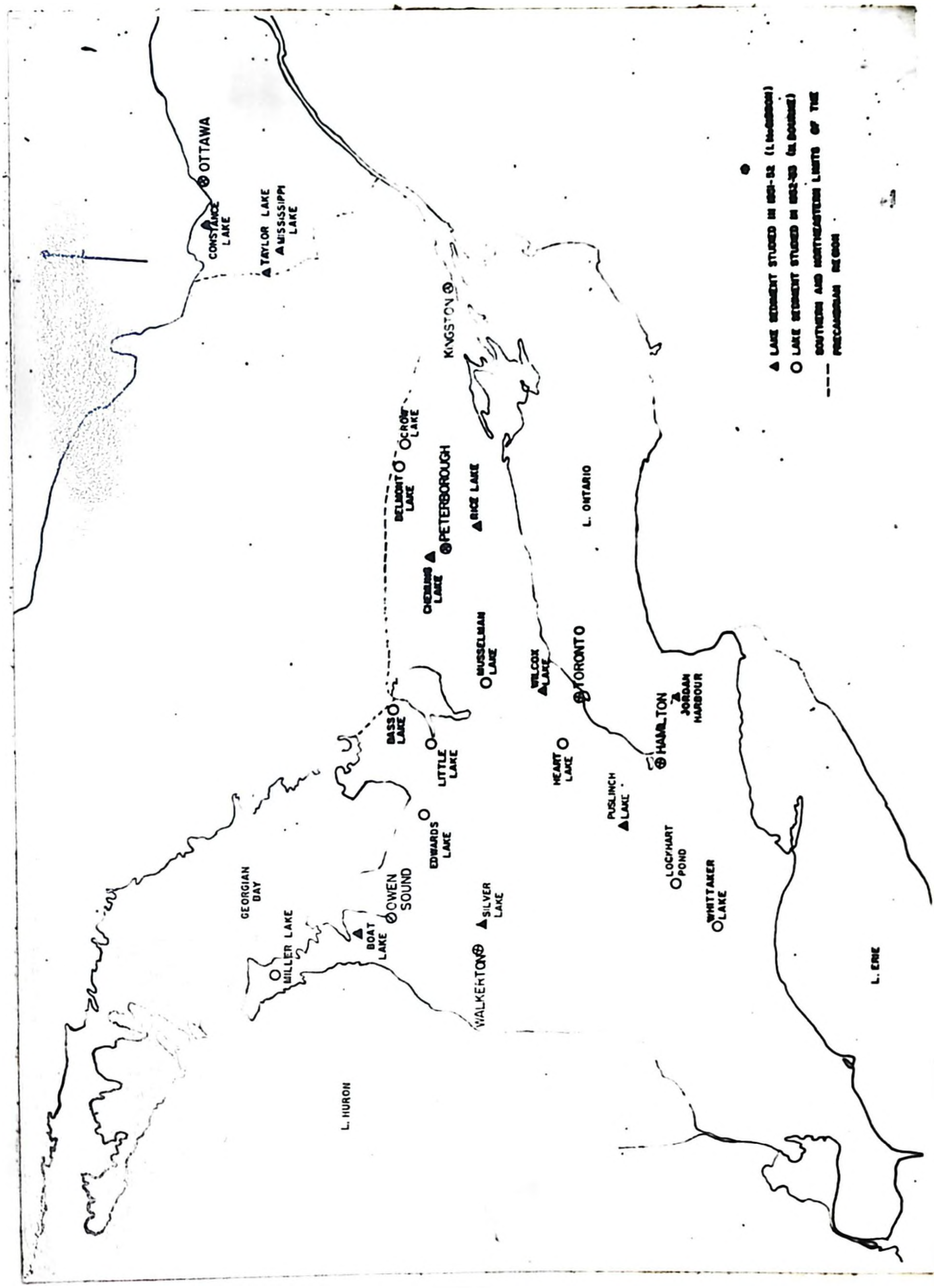
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MISSISSIPPI LAKE
KINGSTON
CROW LAKE
BELMONT LAKE
PETERBOROUGH
RICE LAKE
CHEMUNG LAKE
L. ONTARIO
MUSSELMAN LAKE
WILCOX LAKE
TORONTO
HAMILTON
JORDAN HARBOUR
BASS LAKE
LITTLE LAKE
HEART LAKE
PUSLINCH LAKE
EDWARDS LAKE
LOCKHART POND
WHITTAKER LAKE
GEORGIAN BAY
OWEN SOUND
SILVER LAKE
MILLER LAKE
BOAT LAKE
WALKERTON
L. HURON
L. ERIE
SOUTHERN AND NORTHEASTERN LIMITS OF THE PRECAMBRIAN REGION

Figure 1.

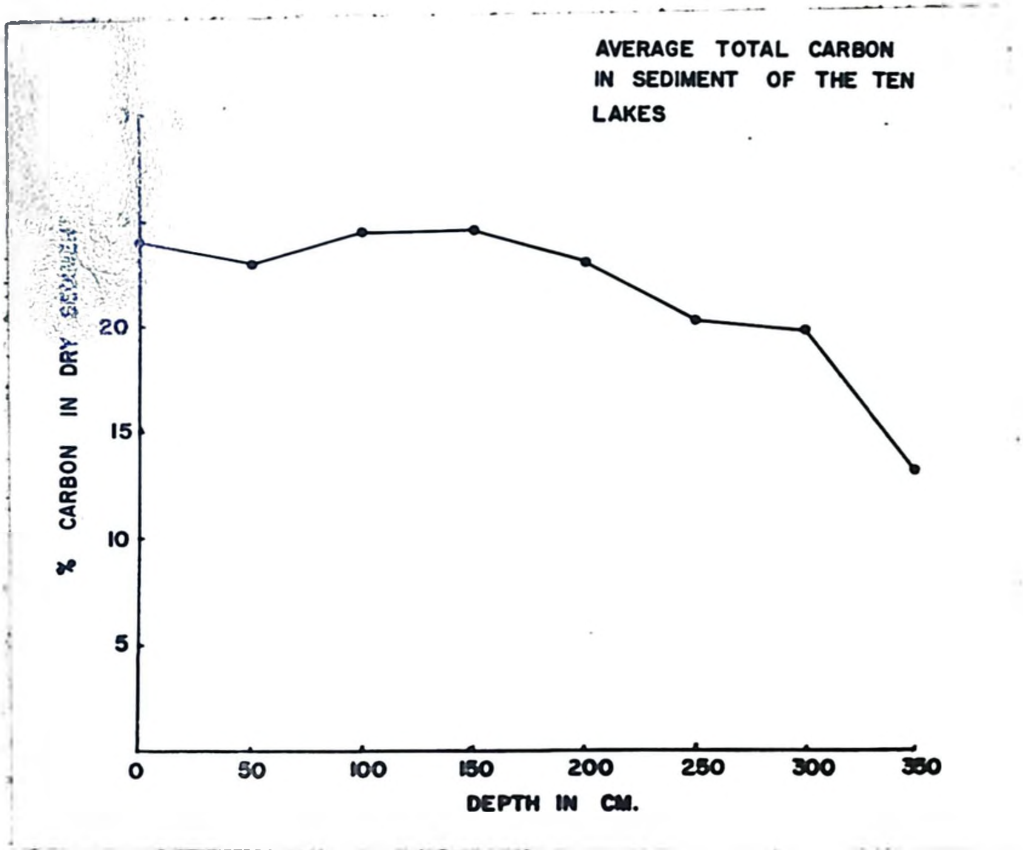
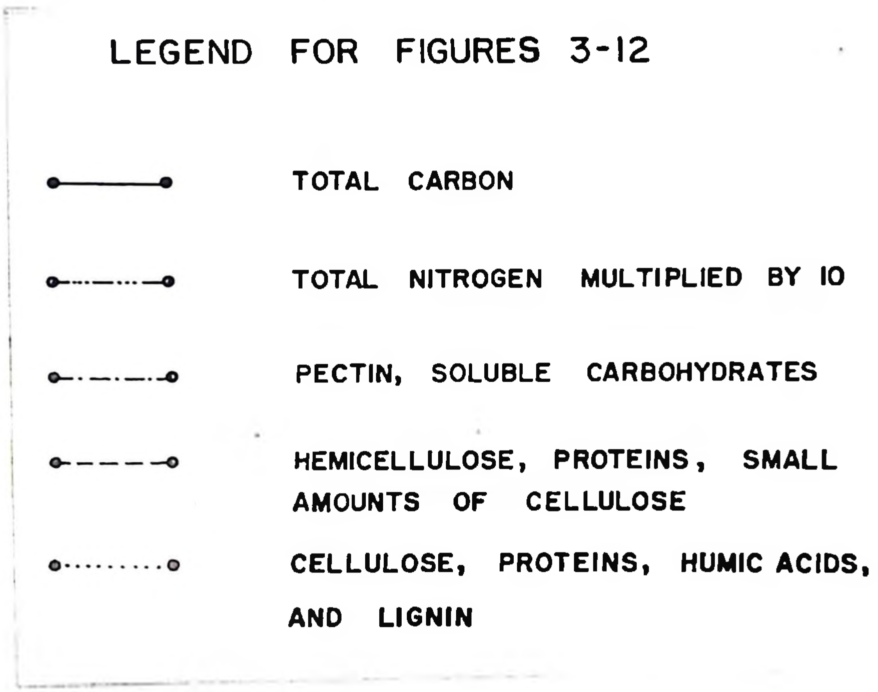

AVERAGE TOTAL CARBON
IN SEDIMENT OF THE TEN
LAKES
% CARBON IN DRY
20
15
10
5
0
50
100
150
200
250
300
350
DEPTH IN CM.

Figure 2.



Legend for figures 3-12.

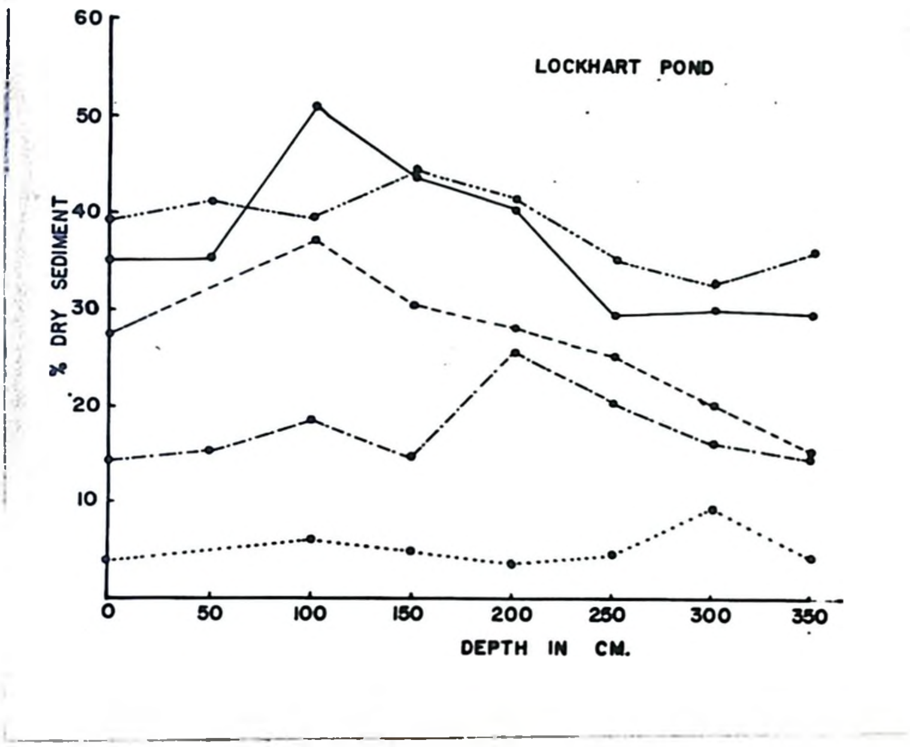


Figure 3.

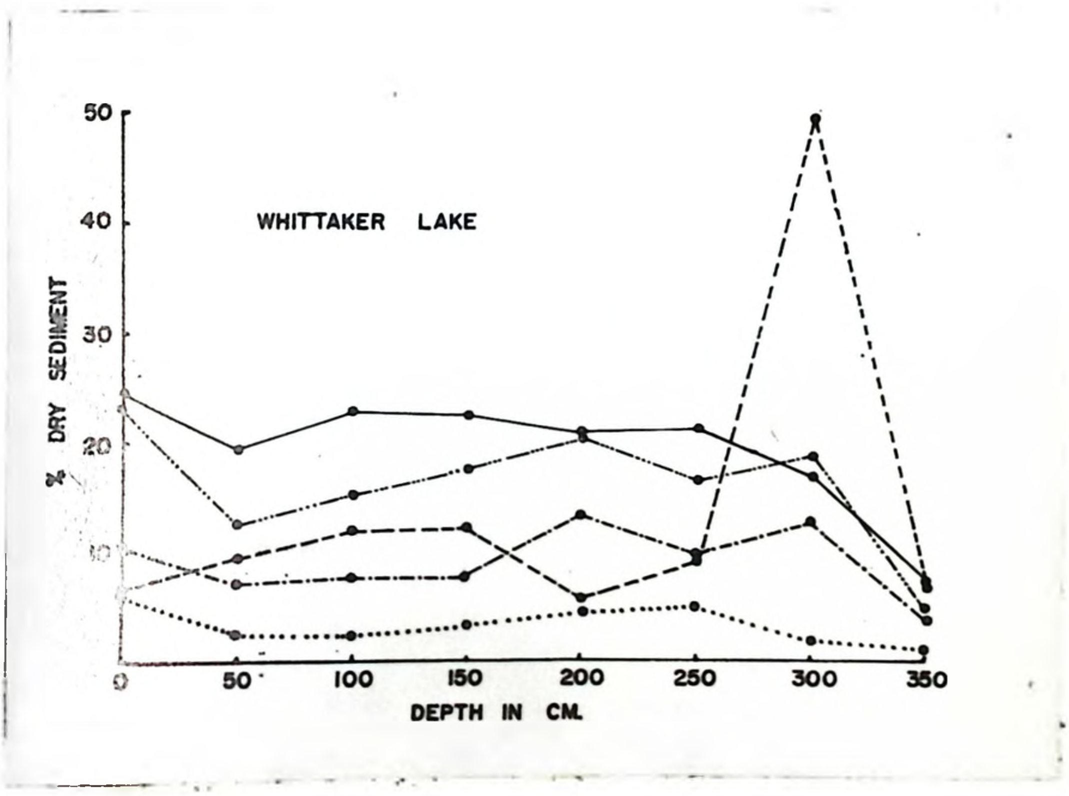


Figure 4.

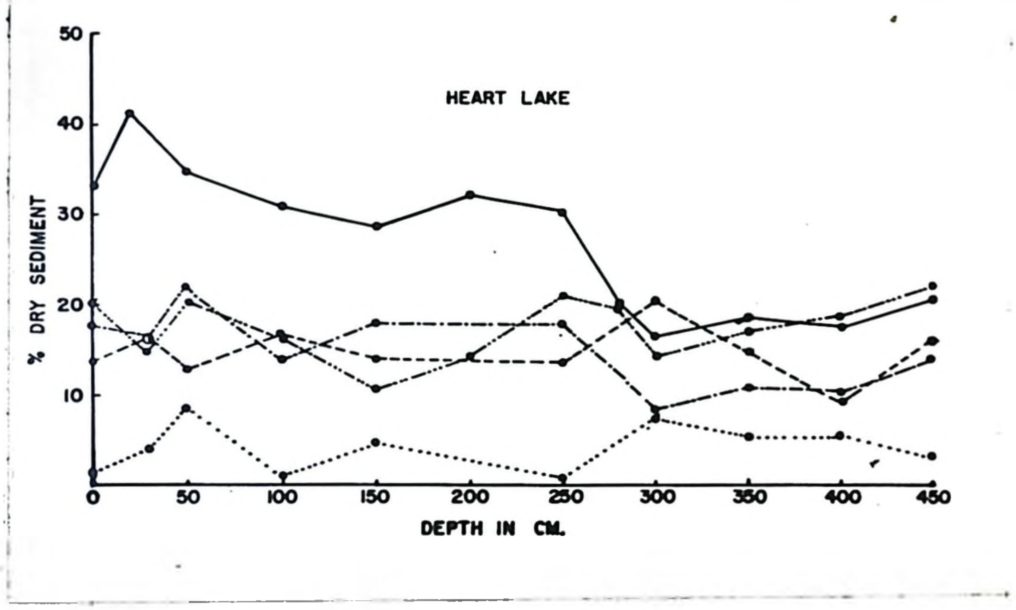


Figure 5.

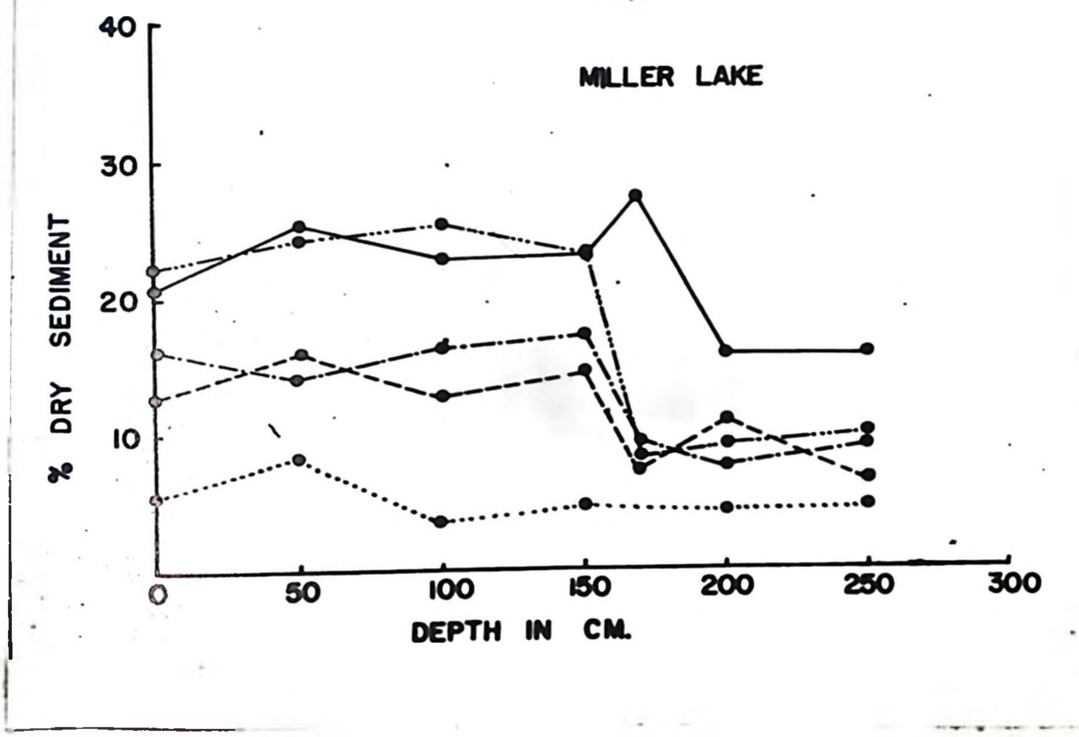


Figure 6.

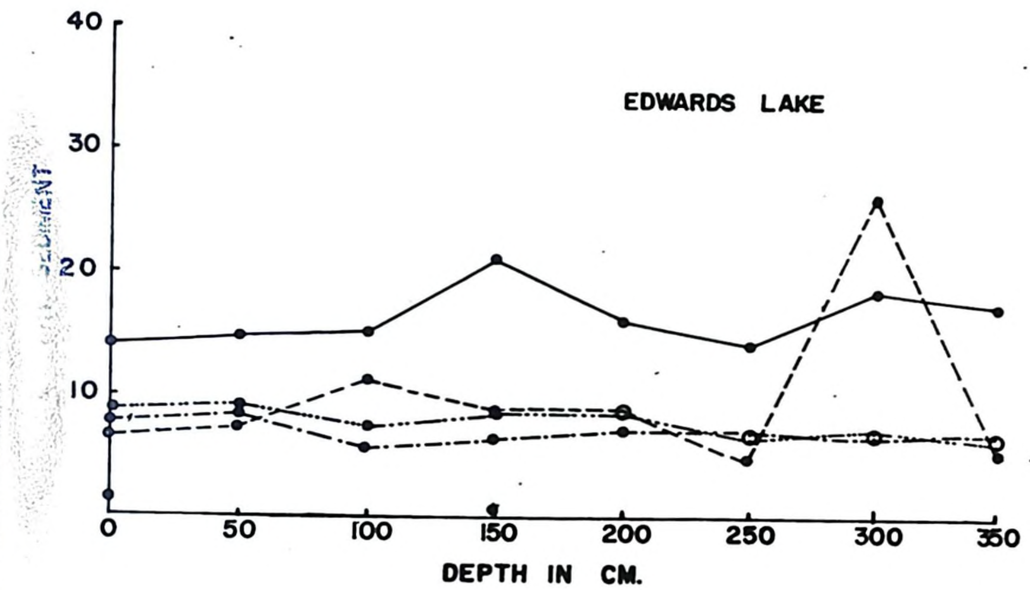


Figure 7.

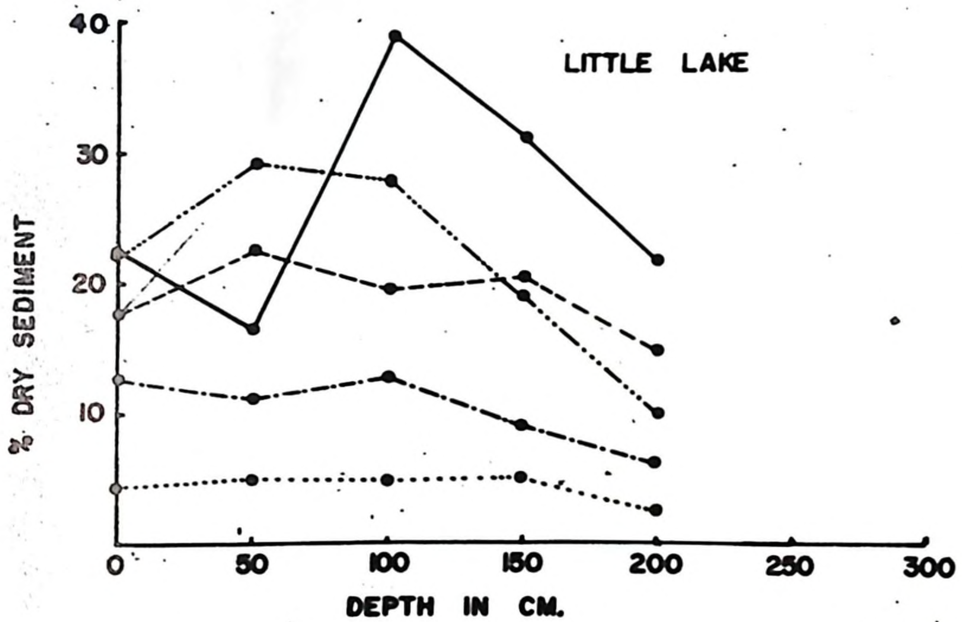


Figure 8.

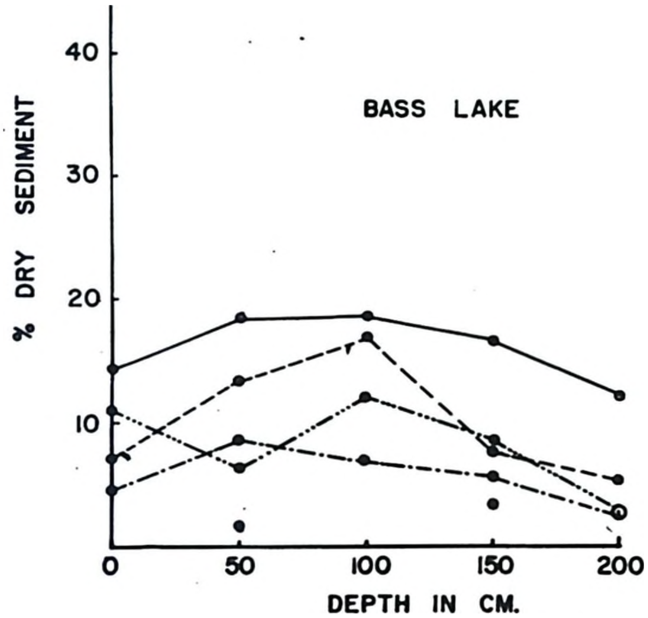


Figure 9.

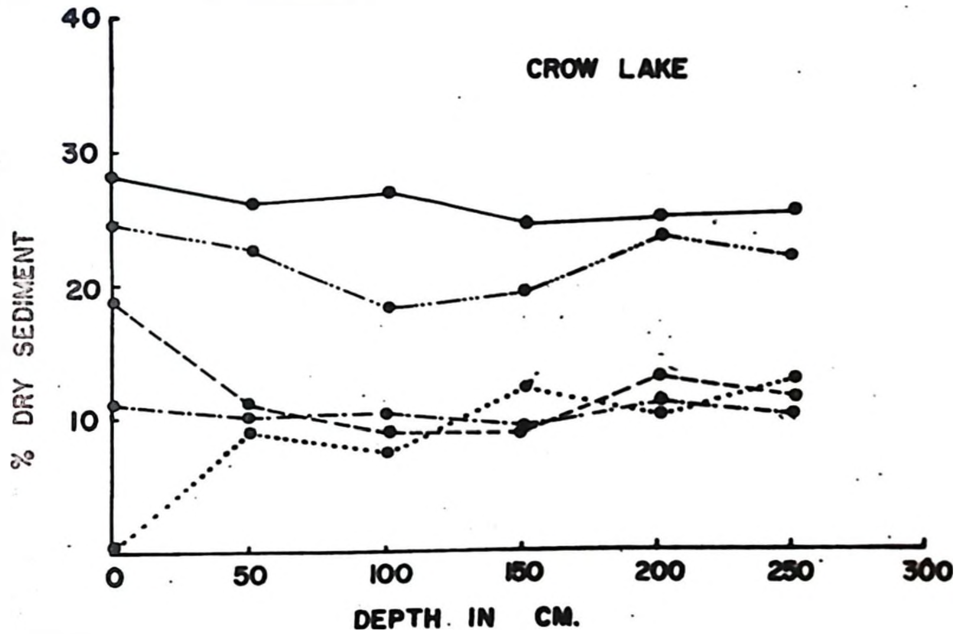


Figure 10.

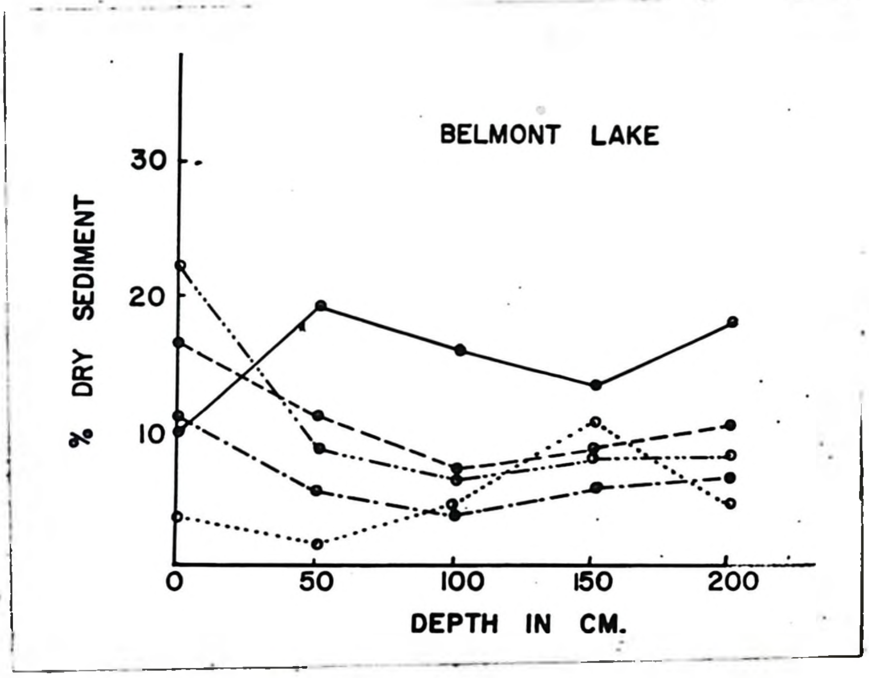


Figure 11.

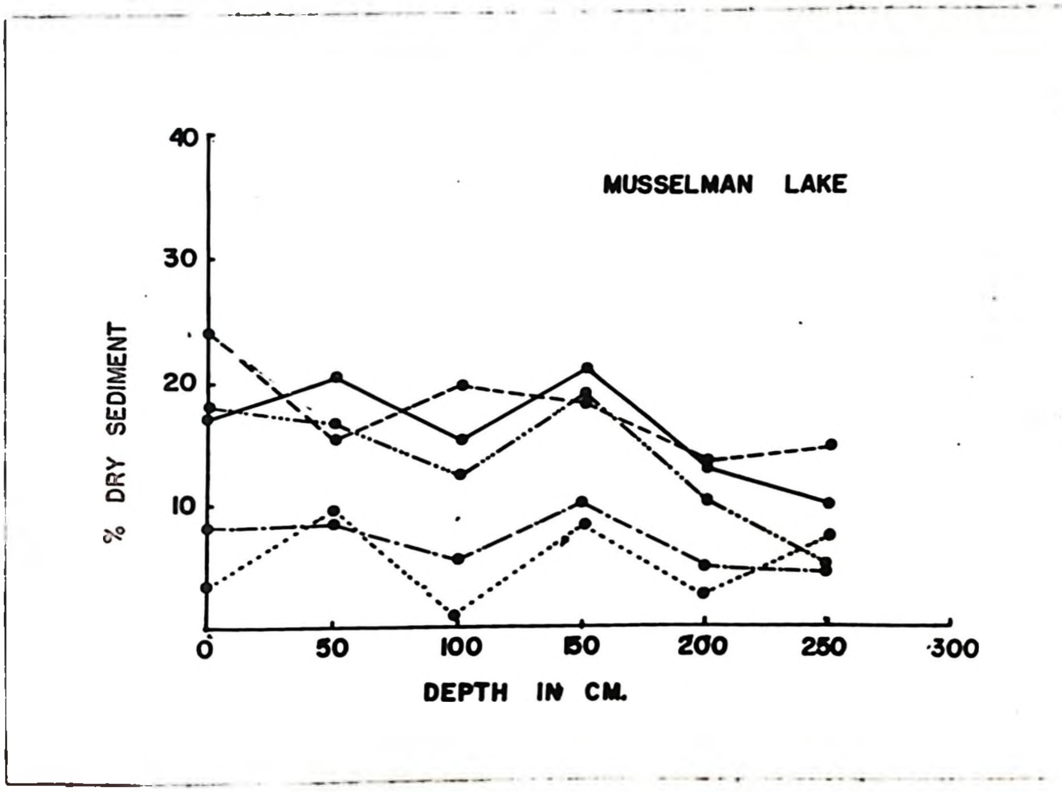
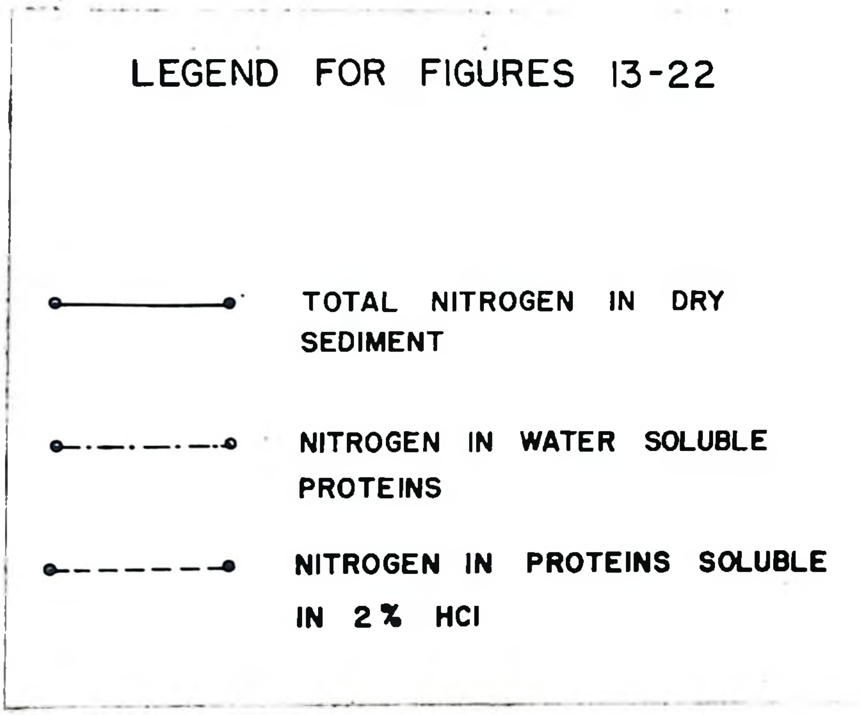


Figure 12.



Legend for figures 13-22.

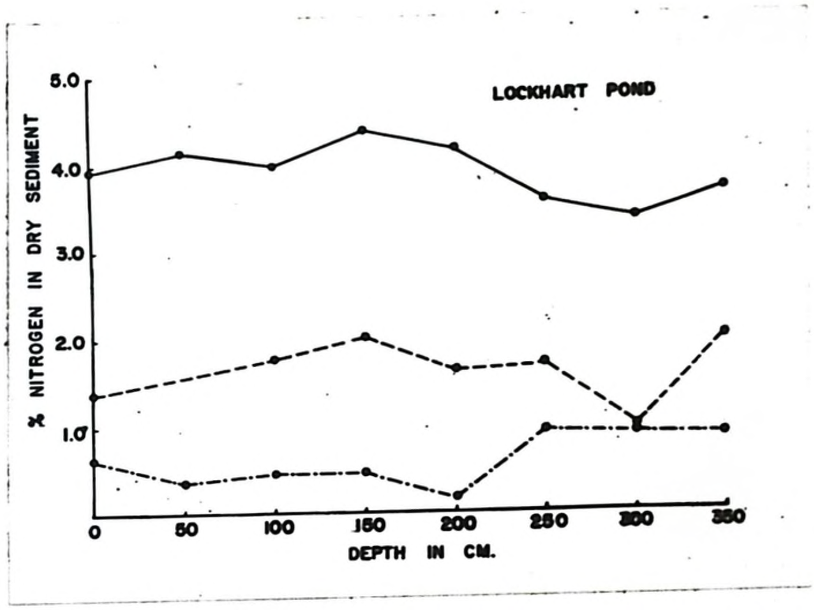


Figure 13.

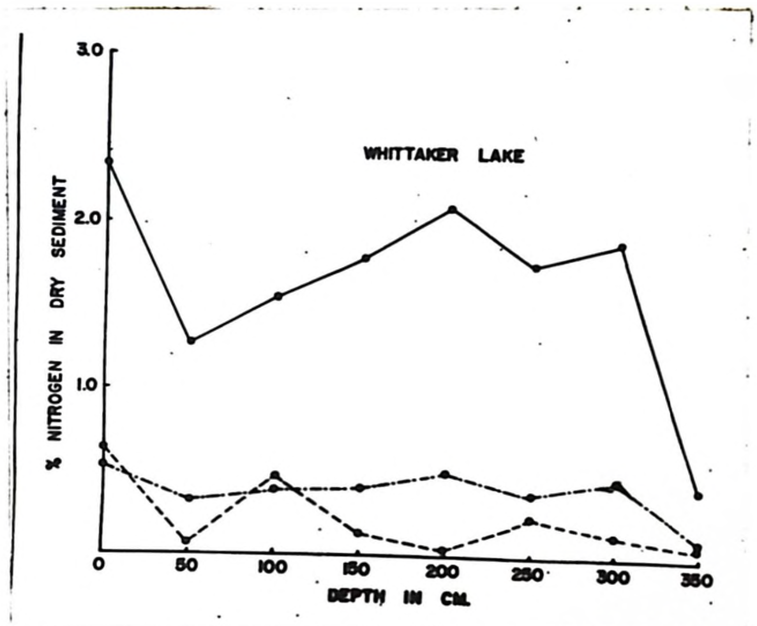


Figure 14.

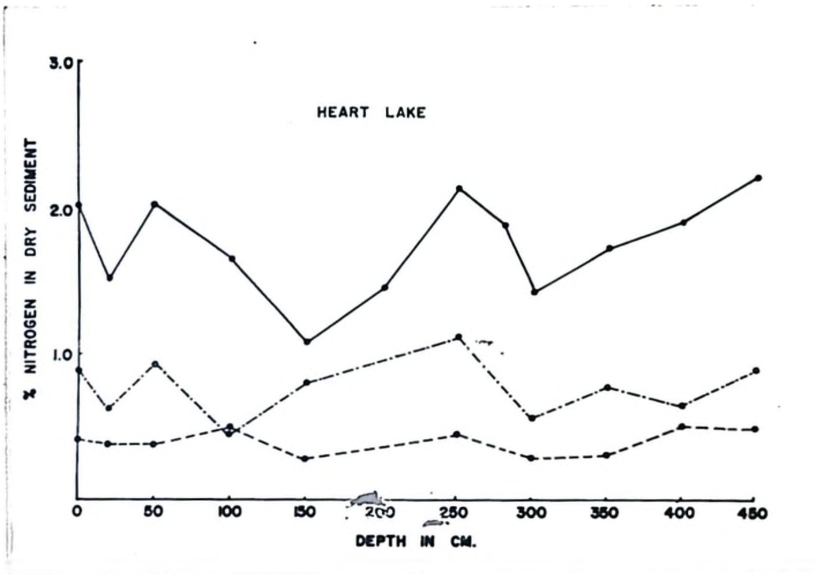


Figure 15.

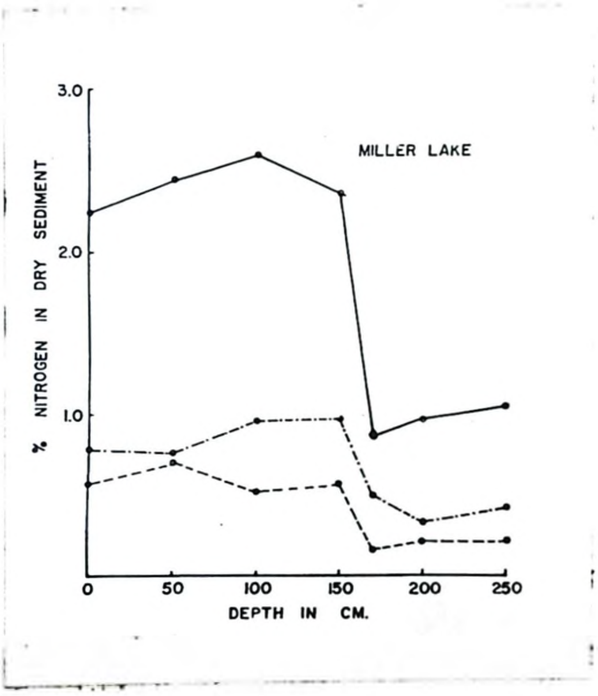


Figure 16.

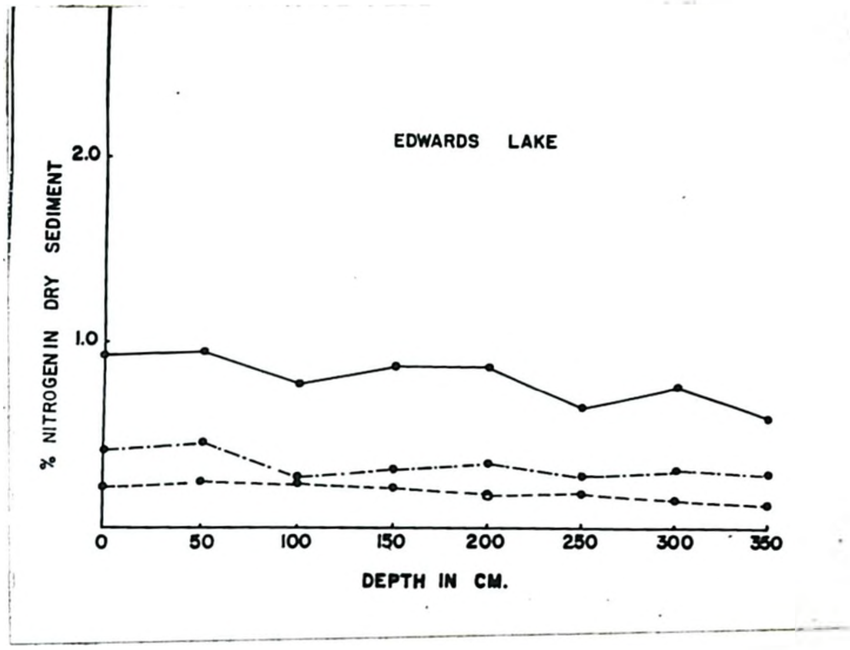


Figure 17.

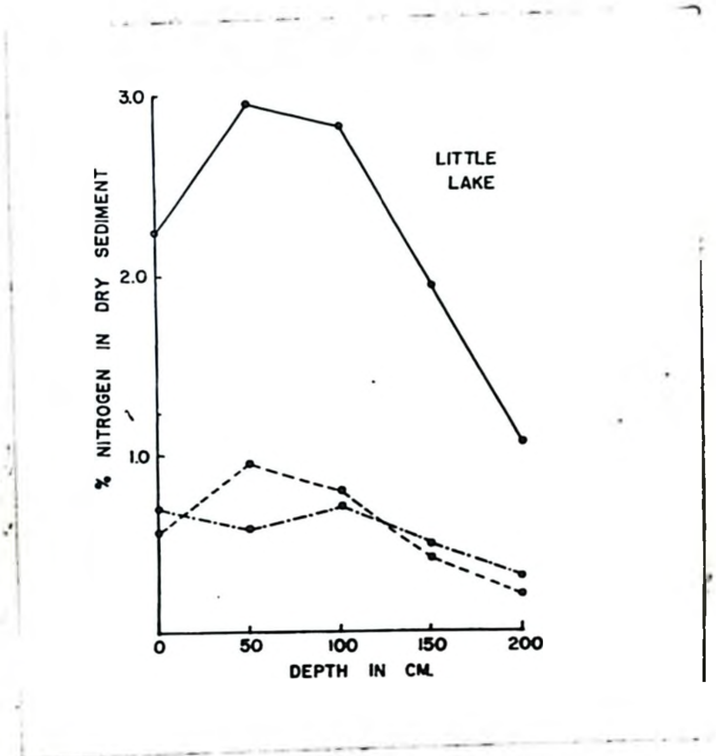


Figure 18.

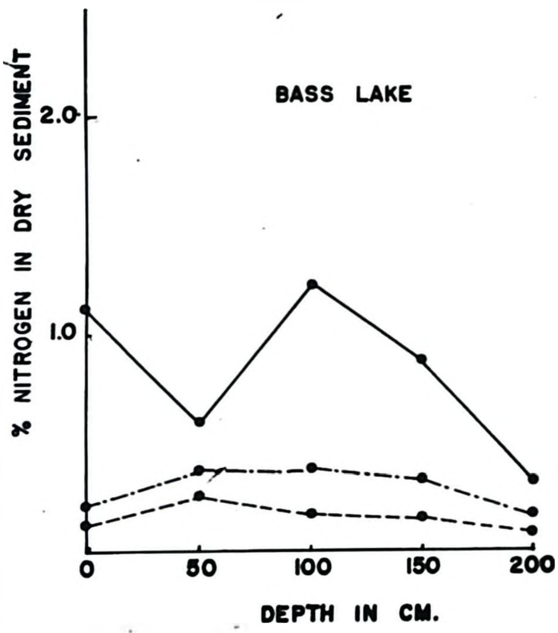


Figure 19.

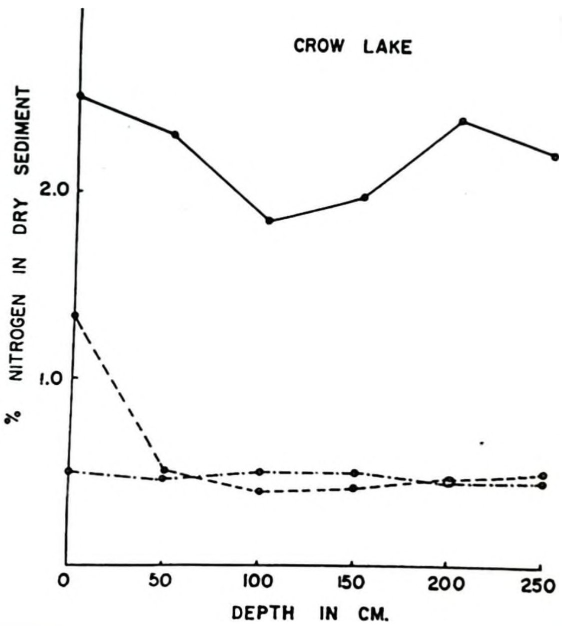


Figure 20.

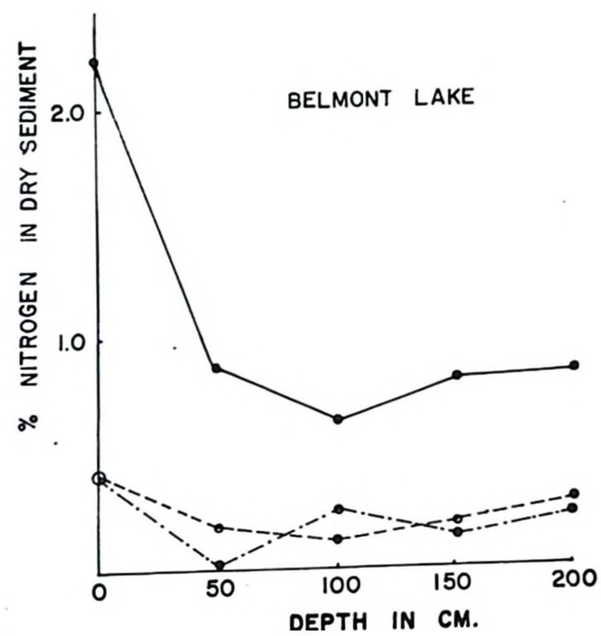


Figure 21.

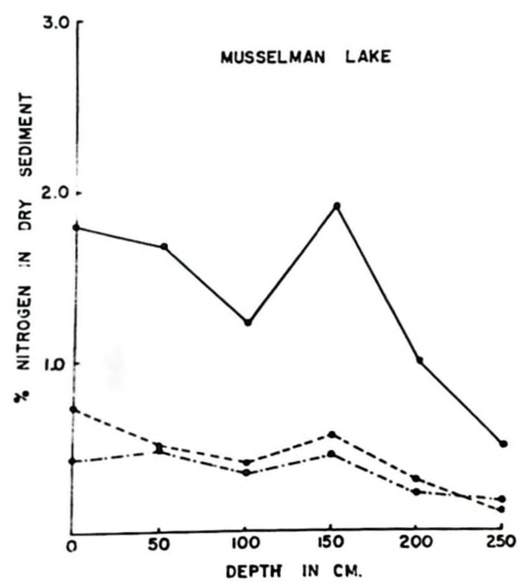


Figure 22.

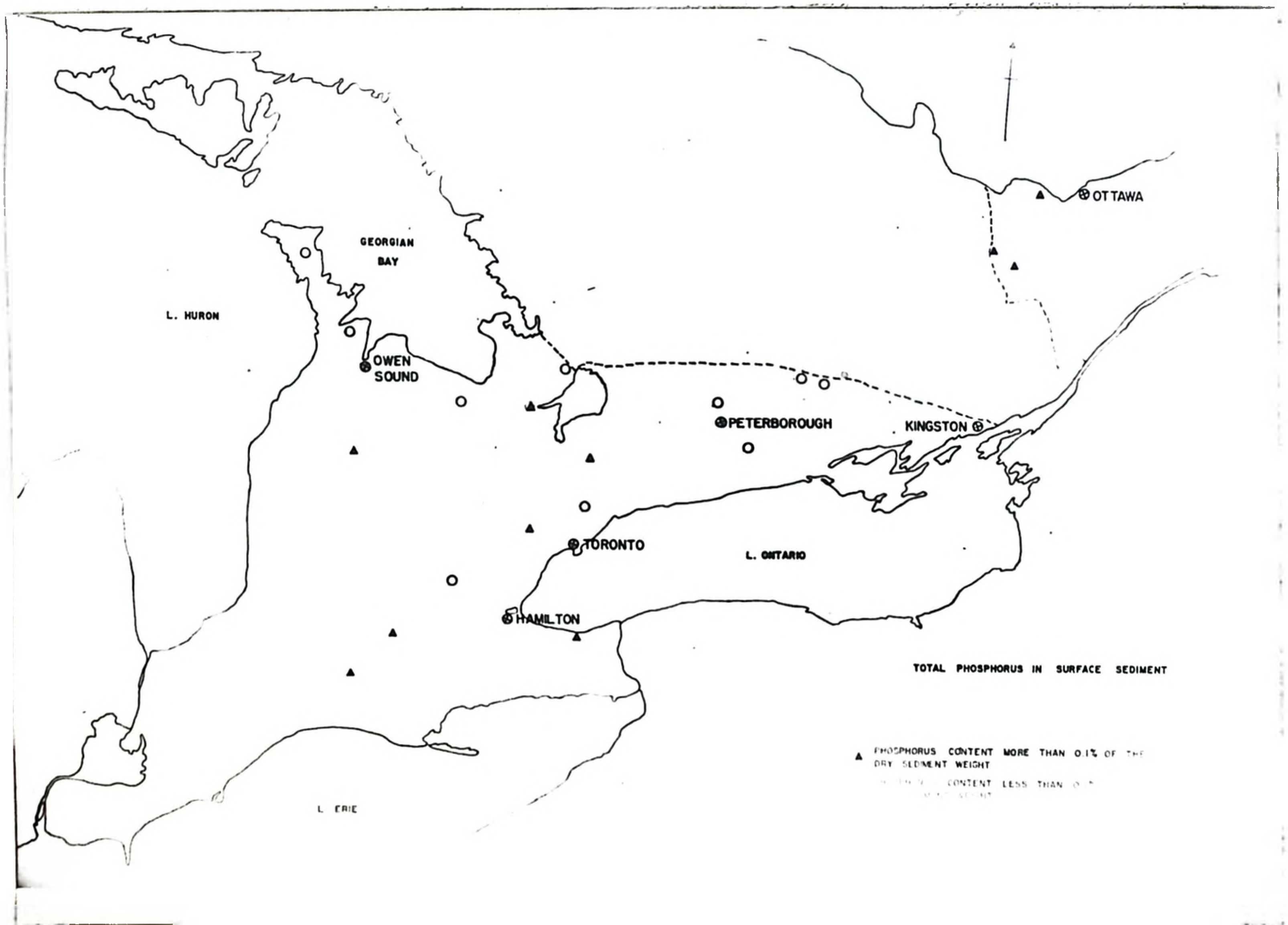

GEORGIAN BAY
L. HURON
OWEN SOUND
OTTAWA
PETERBOROUGH
KINGSTON
TORONTO
L. ONTARIO
HAMILTON
L. ERIE
TOTAL PHOSPHORUS IN SURFACE SEDIMENT
PHOSPHORUS CONTENT MORE THAN 0.1% OF THE DRY SEDIMENT WEIGHT
CONTENT LESS THAN

Figure 23.

LEGEND FOR FIGURES 24 - 26

1 LOCKHART POND
2 - WHITTAKER L.
3.1 HEART L. TOP 20 CM. OF CORE
3.2 HEART L. BOTTOM 30 CM. OF CORE
4 MILLER L.
5 EDWARDS L.
6 LITTLE L.
7 BASS L.
8 CROW L.
9 BELMONT L.
10 MUSSELMAN L.

Legend for figures 24-26.

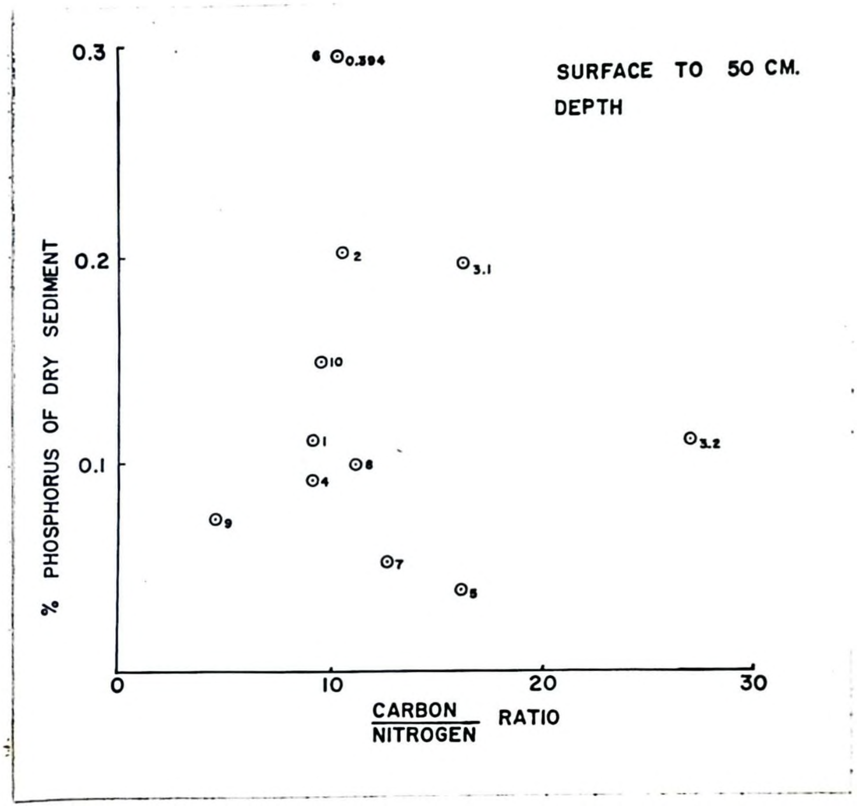

SURFACE TO 50 CM. DEPTH
% PHOSPHORUS OF DRY SEDIMENT
0.3
0.2
0.1
0
10
20
30
CARBON / NITROGEN RATIO
6
0.394
2
3.1
10
1
3.2
8
4
9
7
5

Figure 24.

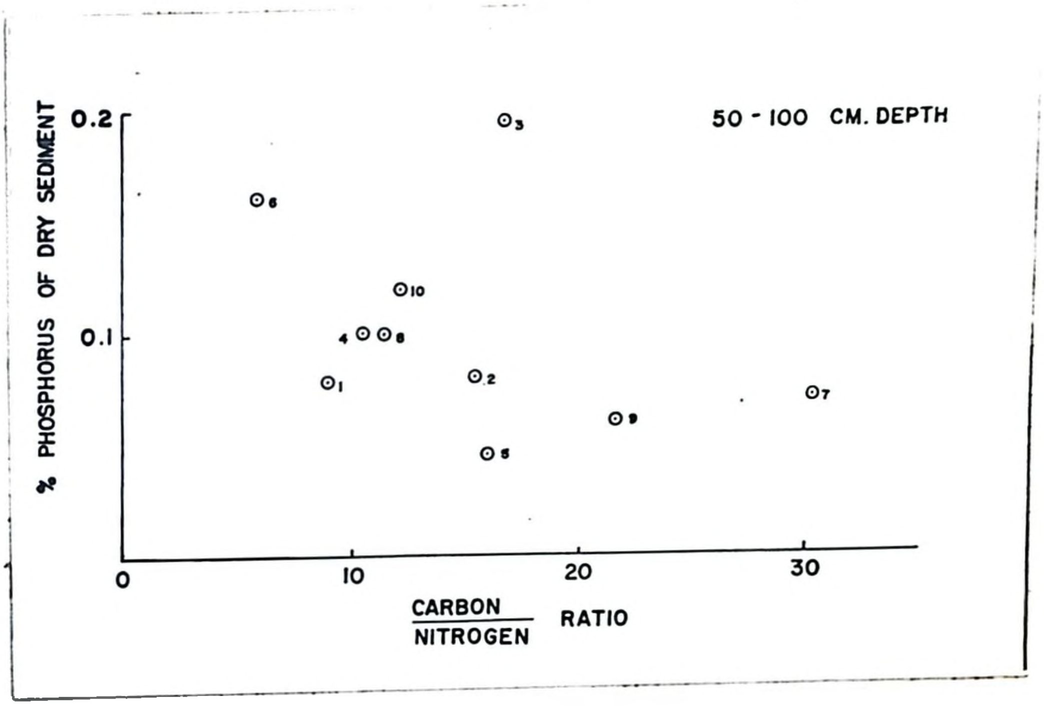


Figure 25.

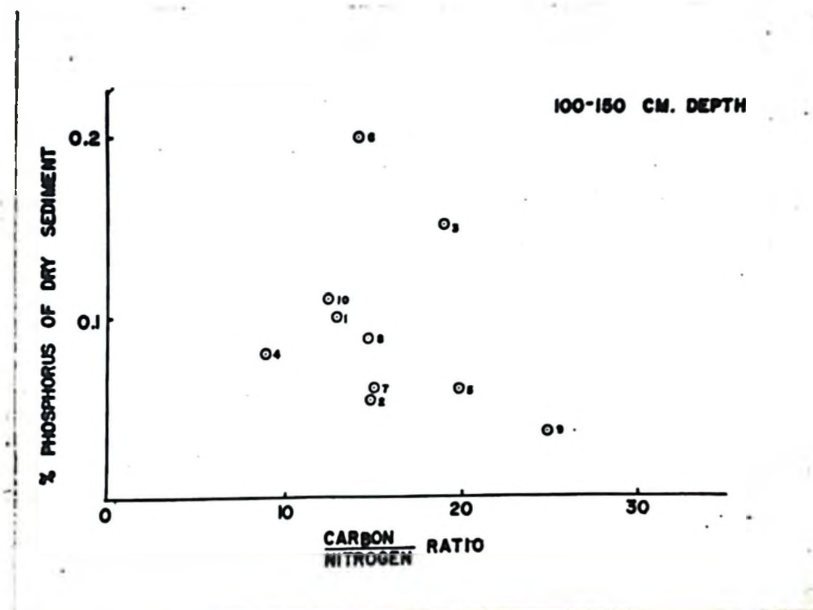


Figure 26.