SEDIMENTATION IN WINONA LAKE AND TIPPECANOE LAKE, KOSCIUSKO COUNTY, INDIANA, JULY 31, 1930, TO JULY 30, 1935[1]

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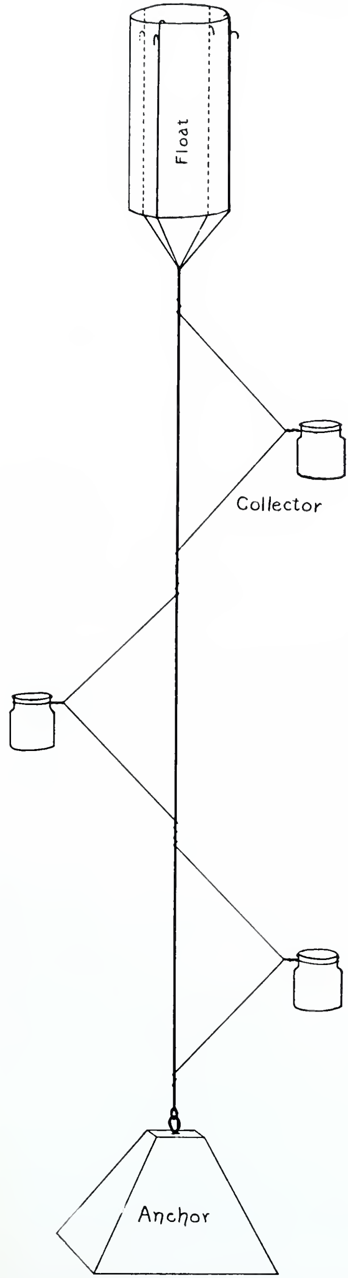

This study is an attempt to determine something of the rate and nature of the deposition on the bottoms of the lakes in northern Indiana. Lundqvist ('27) and others have shown that the deposits in many northern European lakes are laminated, and it seems pretty well established that one light band with an adjacent dark band is an annual deposit. By measuring the thickness of these bands, the rate of deposition can be determined. Welch ('35) has noted this condition in the deposits of Third Sister Lake. Fehlmann and Minder ('21) examined the sediment on the surface of a large water conduit which was submerged beneath the surface of Zurichsee and carried some distance above the bottom on a series of yokes. Below a depth of 10 meters the deposit accumulated at the rate of approximately 2 cm. per annum.

In our lakes the oligochaets and insect larvae living in and feeding on the upper part of these deposits so rework them that all traces of stratification are destroyed. The only method of attack that seemed available, therefore, was to collect the sediment at different levels in the lake as it settled out of the lake water.

A collector was designed (Fig. 1) which consisted of a wire cable with a float at one end and an anchor at the other and cylindrical glass collecting jars attached at various intervals. The weight and displacement of each

Fig. 1. Diagrammatic representation of a float with its frame and snaring hooks, an anchor, and portions of the cable with three collecting jars.

[1]Contribution 248 from the Zoology Department of Indiana University.

part of the collector had to be carefully calculated so that the collector would be held firmly to the bottom, the cable kept taut, and unnecessary weight avoided. Detailed description of the apparatus follows.

The metal floats were all made of 16-gauge galvanized ingot iron and painted with aluminum paint. Those used in Winona Lake had a displacement of six and one-third gallons; that in Tippecanoe Lake, ten gallons. Each float was enclosed in an iron framework made of half-inch rods, and to this were welded the four snaring hooks (Fig. 1). In the beginning, oak kegs, treated with asphalt, were tried but found to be unsatisfactory. During five years of use there has not been a single failure with the metal floats.

The anchors used to hold the sediment collectors to the lake bottom were built in a mold and made of concrete with an iron ring fastened at the top. Those used in Winona Lake weighed about 125 pounds in the air, while that used in Tippecanoe Lake weighed about 133 pounds.

In each collector the float was fastened to the anchor by means of a quarter-inch galvanized iron "messenger cable" of such length that the float was held submerged at a depth of about one and one-half meters in order that there might be no trouble with boats in the summer or ice in the winter.

The jars in which the sediment was collected were fastened at the specified depths along this messenger cable, staggered with respect to each other, and held out one foot from the cable. They were held in place by brackets of No. 9 galvanized iron wire twisted around the neck of the jar and then twisted around the messenger cable. The collecting cylinders were wide necked, pint, glass fruit jars with an opening 43 sq. cm. in area and an inside height of about nine cm.

The floats used in Winona Lake produced a tension of about 31 pounds on the top and about 18 or 20 pounds on the bottom of the cable. That used in Tippecanoe Lake produced a tension of about 54 pounds against the top and about 33 pounds at the bottom of the cable. The Winona Lake collectors rested against the bottom of the lake with a force of about 55 pounds, while in Tippecanoe Lake the collector rested against the bottom with a force of about 47 pounds.

Installation of Collectors

After soundings were made at the determined locations, the collectors were put together on the lake shore. With the help of five or six people they were then carried to the boats, the anchor being placed in one boat, the float in the other, and the cable and collecting jars dragged between them. A small secondary float was attached by a cord about ten feet long to the permanent float to mark the collector's location on the surface until it could be surveyed with a transit from two reference points on the shore. Thus prepared for installation, the boats were towed to the marked location in the lake, where the anchor and float were thrown overboard simultaneously in water about one meter shallower than the final location. Then the whole apparatus was lifted and moved to the proper depth. After the location had been recorded, the surface float was removed from the permanent float.

The locations of the collectors used in Winona Lake are shown on the map (Fig. 2), and subsequent reference to them will be made by number.

The collectors were allowed to remain in position in the lakes for various periods from 10.8 months to 60 months. See Table I.

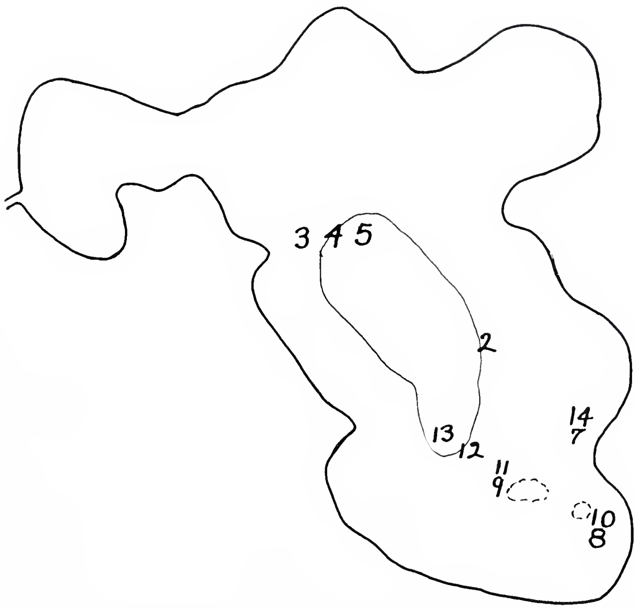

FIG. 2. Map of Winona Lake, showing locations of the collectors as numbered in the text. The sunken islands are indicated by dotted lines; the light solid line is the 22-meter contour.

Finding and Marking Collectors

When it was desired that a collector be raised for examination, its two reference lines on the shore were determined by means of the transit and marked with stakes which were visible from the lake. By rowing a boat to the point of intersection of these lines, it was possible to locate the float with a drag and to mark its position with a surface float.

Removal of the Collectors

The removal of the apparatus required a crew of at least four men. A platform was built to fit on two row boats with an open space four feet square in the center through which to raise the collectors. This apparatus was towed to the marked collector, and wires were attached to the hooks on the float. Although block and tackle was sometimes used to dislodge the weight from the bottom of the lake, it was later found that one or two men could do so without the tackle and with no great difficulty by pulling steadily. As the jars appeared at the surface, they were cut loose from the cable and covered with lids previously labeled.

Biological Analysis

Besides the materials in the jars, samples were taken from the outsides of the jars, the floats, sinkers, and supporting wires. Microscopic examinations of the fresh material were made within two to four hours after removal from the lake. In some cases, small amounts were preserved in 5% to 10% formalin, and sometimes permanent slides were made from the sediment for subsequent study.

Fresh sediment from jars at 5, 10, 15, and 20 meters in Winona Lake showed Chironomus larvae, Ciliata, creeping rotifers, moulds, rhizopods, and Algae. The Algae were given special attention, and the results are tabulated at the end of this paper.

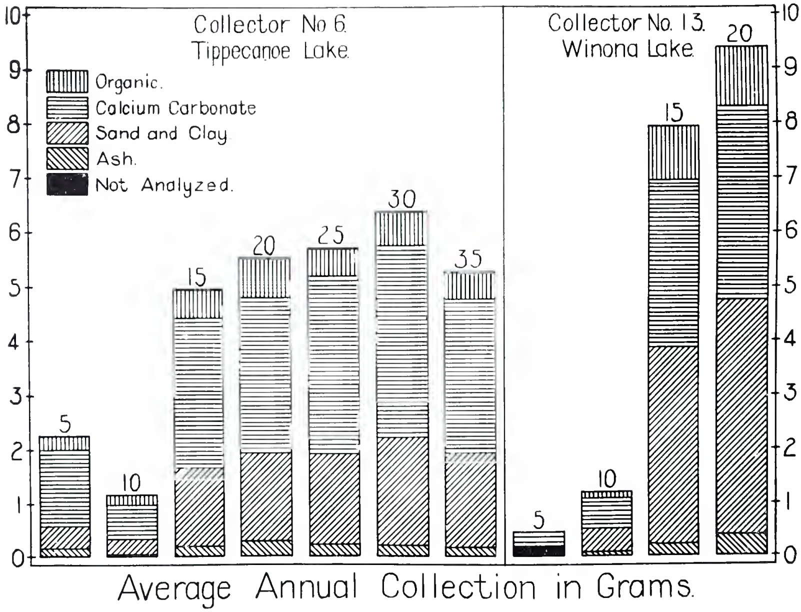

FIG. 3. See text.

Physical Analysis

After the removal of small amounts of material from the collecting jars for biological analysis, the sediment was allowed to settle for eight or ten hours. The water was then siphoned off and the sediment dried in an oven at about 60°C. for from 48 to 72 hours, when the total dry weight was determined. From this information (shown in Figure 3) Figures 4 and 5 were constructed.

Figure 4 represents a section through Winona Lake from Boys' City to Yarnell Camp, the maximum depth in this section being 22 meters. In the drawing, the depth has been exaggerated ten times. The weights of materials found at the various levels in Collectors No. 8, 9, 10, 11, 12, and 13 furnished the data for this figure.

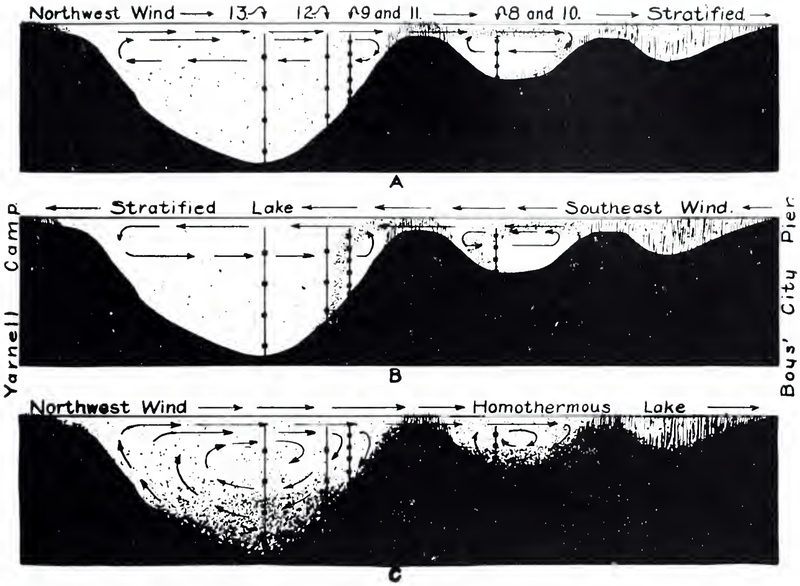

FIG. 4. Diagrams of lake circulation.

The distribution of sediment in these collectors indicates three types of condition depending on the direction of the wind and the temperature of the lake. In Figure 4, A and B indicate the way in which sediment drifts with the currents across the sunken islands, where there is much vegetation, when the lake is stratified in warm weather; C shows what seems to happen during the homothermous condition of the vernal and autumnal overturns, when the organic material and carbonates produced in the littoral are distributed generally over the lake. It must be remembered that no jars, with the exception of those on Collectors No. 7 and 14, were more than about one-fourth filled. The graphs show relative weights of material and do not give a true picture of how well filled the jars were.

Check of a Possible Error

In order to determine the probability of a loss of material from the collectors at the time of removal from the lake, the following experiment was performed. A collector jar containing 20 grams of dry sediment, and provided with a removable lid, was lowered into 40 feet of water, and the lid was removed. After one hour the jar was raised in a manner simulating the raising of one of the collectors, the water was siphoned off, and the sediment was dried and weighed. The loss was so small that it was not perceptible on a balance sensitive to 0.1 g. It is our opinion, however, that the loss from a jar of naturally deposited, flocculent sediment might be significant, especially if the total amount in the jar was less than three grams.

TABLE I

Collector Numbers	Depths of Jars	Depths of Anchors	Summer Installed	Summer Removed	Months in Water	Total Collection in Grams	Average Annual Collection	Per Cent of Carbonate	Per Cent of Organic	Per Cent of Sand and Clay	Per Cent of Ash
2	5	13.8	1930	1931	10.8	0.14	0.16	....	19.75	....	......
2	12	13.8	1930	1931	10.8	3.4	3.78	34.6	17.5	....	......
3	5	16	1930	1933	36.3	13.55	4.48	24.92	23.9	....	......
3	10	16	1930	1933	36.3	24.7	8.16	29.10	28.9	....	......
3	15	16	1930	1933	36.3	31.4	10.4	25.23	20.3	....	......
4	5	22	1930	1933	36.3	12.14	4.02	16.93	22.1	....	......
4	10	22	1930	1933	36.3	23.6	7.8	26.2	21.1	....	......
4	15	22	1930	1933	36.3	30.3	10.01	32.62	22.6	....	......
4	20	22	1930	1933	36.3	33	10.94	30.39	23.7	....	......
5	5	22.5	1930	1931	10.8	1.03	1.15	....	21.25	....	......
5	10	22.5	1930	1931	10.8	3.36	3.74	45.15	19.65	....	......
5	15	22.5	1930	1931	10.8	7.02	7.8	....	19.85	....	......
5	20	22.5	1930	1931	10.8	6.1	6.78	42.15	18.95	....	......
6	5	36	1930	1935	60	11.3	2.26	63.45	11.2	19.2	6.15
6	10	36	1930	1935	60	5.8	1.16	54.7	15.17	26.5	3.63
6	15	36	1930	1935	60	24.75	4.95	55.7	10.4	29.4	4.5
6	20	36	1930	1935	60	27.7	5.54	51.55	13.0	29.95	5.5
6	25	36	1930	1935	60	28.55	5.71	57.45	8.6	29.85	4.1
6	30	36	1930	1935	60	31.85	6.37	55.55	9.65	31.25	3.55
6	35	36	1930	1935	60	26.3	5.26	53.7	9.3	33.6	3.4
7	1	1	1930	1931	10.5	46.5	53.15	34.65	10.01	....	......
7	1	1	1930	1931	10.5	50.14	57.3	41.2	8.5	....	......
8	2½	8.5	1931	1933	25.1	23.5	11.25	44.0	18.7	....	......
8	4½	8.5	1931	1933	25.1	12.3	5.88	32.2	19.5	....	......
8	6½	8.5	1931	1933	25.1	21.6	10.33	41.4	17.1	....	......
8	8¼	8.5	1931	1933	25.1	47.1	22.6	40.65	18.6	....	......
8	8¼	8.5	1931	1933	25.1	40.3	19.3	38.0	18.25	....	......
9	2½	12	1931	1933	25.2	22.05	10.5	14.5	21.5	....	......
9	4½	12	1931	1933	25.2	29.6	14.1	14.25	5.5	....	......
9	6½	12	1931	1933	25.2	12.65	6.02	23.43	9.1	....	......
9	8½	12	1931	1933	25.2	8.0	3.81	24.75	21.9	....	......
9	10½	12	1931	1933	25.2	22.4	10.68	33.92	18.7	....	......
9	12	12	1931	1933	25.2	50.65	24.2	47.1	18.9	....	......
10	2½	8.5	1933	1935	22.2	13.7	7.4	51.9	15.55	28.4	4.15
10	4½	8.5	1933	1935	22.2	1.28	0.69	93.75	....	....	......
10	6½	8.5	1933	1935	22.2	0.15	0.08	....	....	....	......
11	2½	12	1933	1935	22.5	14.7	7.84	57.5	9.7	29.2	3.6
11	4½	12	1933	1935	22.5	1.45	0.77	71.7	....	....	......
11	6½	12	1933	1935	22.5	0.55	0.29	90.0	....	....	......
11	8½	12	1933	1935	22.5	1.65	0.88	67.8	....	....	......
11	10½	12	1933	1935	22.5	7.5	4.0	47.6	7.95	38.4	6.05
12	5	16	1933	1935	22.4	1.64	0.88	53.8	....	....	......
12	10	16	1933	1935	22.4	1.75	0.94	57.1	....	....	......
12	14½	16	1933	1935	22.4	8.51	4.55	40.5	11.4	44.2	3.9
13	5	22	1933	1935	22.6	0.85	0.45	56.0	....	....	......
13	10	22	1933	1935	22.6	2.3	1.22	45.5	9.05	35.1	10.35
13	15	22	1933	1935	22.6	14.95	7.93	38.55	12.4	45.9	3.15
13	20	22	1933	1935	22.6	17.75	9.4	37.65	11.6	46.35	4.4
14	1	1	1931	1935	47.5	113.94	28.7	30.75	5.05	59.0	5.2

Indicated depths of jars and anchors are expressed in meters.
Collector number 6 was in Tippecanoe Lake, the others in Winona Lake

TABLE II. KINDS AND RELATIVE ABUNDANCE OF ALGAE IN THE COLLECTING JARS

Collector Numbers.	2		5				7		6						
Jar depths in meters	5	12	5	10	15	20	1	1	5	10	15	20	25	30	35
No. of kinds of algae	4	5	6	6	7	9	8	11	9	8	6	9	7	8	5
Approximate abundance	7	15	8	12	18	19	13	17	16	15	13	18	16	18	14
Diatoms—															
Amphiprora												1			
Amphora									1		1	1		1	
Asterionella												1			
Cocconeis					1				2			2	1	1	2
Cocconema															
Cyclotella															
Cymatopleura							1	1			1			1	
Cymbella								1							
Diatoma													1	2	
Epithemia															
Fragilaria		3		1	3	3	1	1	1	1	1	2	3	3	2
Gomphonema															
Melosira	2	5	2	4	5	5	3	4	3	4	5	5	5	5	5
Navicula			1			1	1	1	2	1			1	1	1
Nitzschia		1		1	1	1	2	1							
Pleurosigma			1					1		1		1			
Stephanodiscus	1	4	1	3	4	4	2	3	2	3	4	4	4	4	4
Synedra									1						
Tabellaria		2			3	2	2	1							
Blue Greens—															
Anabaena															
Aphanizomenon															
Chroococcus										2		1			
Coelosphaerium															
Gloeothece															
Gomphosphaeria															
Lyngbya				1	1	1			2						
Merismopedia							1		2						
Microcystis	3		2										1		
Oscillatoria	1		1	2		1				2					
Greens, etc.—															
Ankistrodesmus										1					
Ceratium						1									
Chlorococcum															
Cladophora															
Closterium															
Coelastrum															
Cosmarium															
Crucigenia															
Mougeotia															
Oedogonium															
Pediastrum								1							
Scenedesmus								2			1				
Spirogyra															
Staurastrum															
Trachelomonas															

1, rare; *2*, occasional; *3*, common; *4*, abundant; *5*, very abundant. Approximate abundance consists merely of the totals of the columns below.

Rusting of Wires and Cables

The collectors in Winona Lake showed very little rusting above five meters, the region ordinarily in the epilimnion. Below that the apparent rust increased slightly with the depth until within two meters of the bottom below which there was an enormous increase in the rusting.

In Tippecanoe Lake the rusting was very slight in the upper ten meters, the region ordinarily included in the epilimnion of that lake. Below that point the increase in rusting was about uniform all the way to the bottom, where it was almost as prominent as in Winona Lake. It

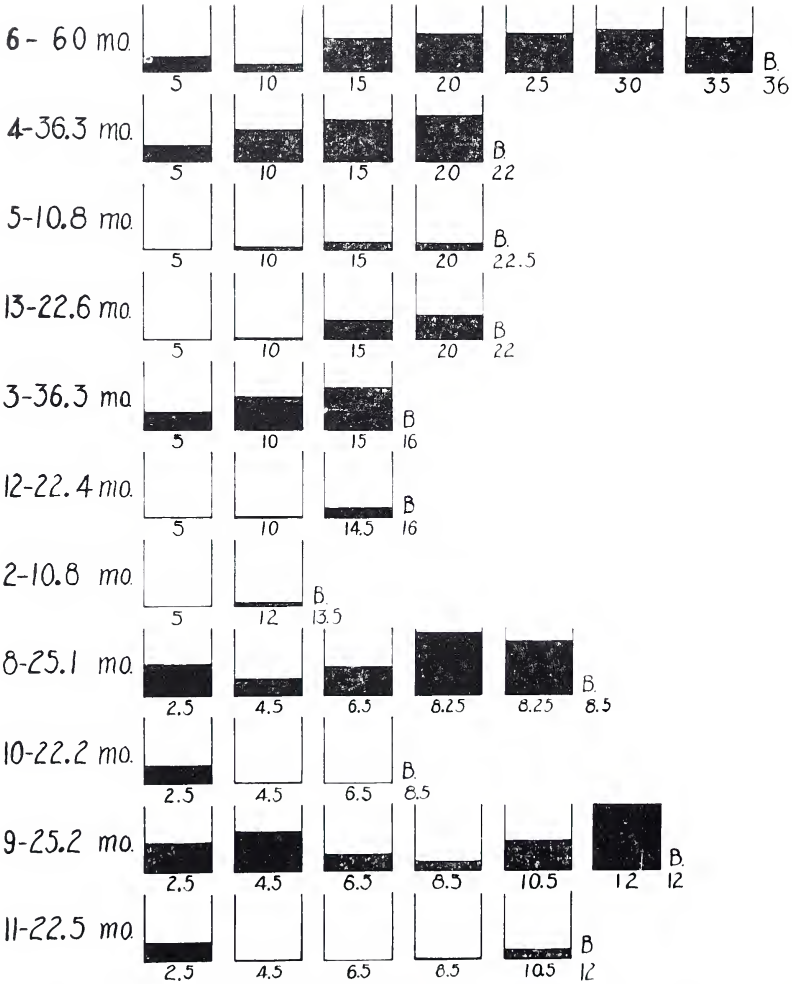

FIG. 5. Graphic representation of total weights of sediment collected. On the extreme left are the collector numbers, followed by the number of months the collector was in the lake. Under each jar is its depth in meters below the surface; under *B*, at the end of each series, is indicated in meters the depth of the lake at that point.

was noted that there was no sudden increase in the rust in the last two meters in Tippecanoe Lake.

Chemical Analysis

The following procedure was used in analyzing the sediment from all the jars on Collectors No. 6, 10, 11, 12, 13, and 14: 1. Weigh the crucible. 2. Weigh out the sample, which has been dried at about 60°C. for 24 hours. 3. Treat the sample with cold hydrochloric acid. 4. Filter and wash three times with distilled water. 5. Dry the sample in the oven for 16 hours. 6. Weigh. 7. Ash. 8. Cool and weigh. 9. Boil in hydrochloric acid for three minutes, and then boil in distilled water for three minutes. 10. Filter. 11. Dry for 20 hours, and weigh. No. 2 minus No. 6 is the weight of calcium carbonate. No. 8 is the weight of silicon dioxide and ash. No. 8 minus No. 11 is the weight of ash.

The following procedure was used in analyzing the sediment from all the jars on Collectors No. 2, 3, 4, 5, 7, 8, and 9: 1. Weigh the crucible. 2. Weigh out the sample, which has been dried at about 60°C. for 24 hours. 3. Ash. 4. Cool and weigh. 5. Boil for three minutes in hydrochloric acid. 6. Filter and wash three times with distilled water. 7 Dry in oven for 16 hours. 8. Weigh. No. 4 minus No. 8 is the weight of calcium carbonate. No. 8 is the weight of silicon dioxide and clay.

It will be noted that no account was taken of magnesium, aluminum, iron, etc. It was felt that the accuracy of collection and other methods used did not justify a determination of such salts.

Comparisons of Winona Lake with Tippecanoe Lake

There seems to be quite a difference in the method of sedimentation in these two lakes. The collections out in the pelagic regions of Winona Lake seem to indicate that there is a general mixing of sediment at some time during the year. In Figure 5, Collectors No. 4, 5, 13, 3, 12, and 2 show this rather steady increase in amount of sediment with the depth of the jar. Collector No. 6, however, shows that in Tippecanoe Lake there was only a slight increase in sediment as the depths increased. It seems that most of the sediment is formed in the epilimnion and then falls into the jars in the hypolimnion. This is also shown very well by Figure 6, which is a photograph of the jars a few hours after they were removed from Collector No. 6 in Tippecanoe Lake and before the water was siphoned off. These jars were located at depths of 5, 10, 15, 20, 25, 30, and 35 meters, starting with the left side of the photograph. They were in the lake for five years.

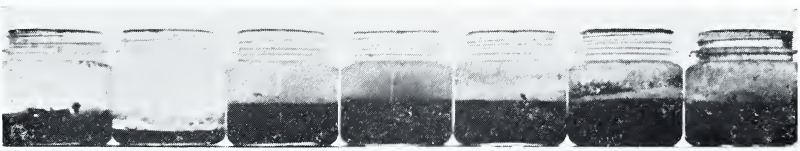

FIG. 6. See text.

This regular increase in sediment with the depth did not occur in Collectors No. 8, 9, 10, and 11 (Fig. 5). This was because they were located near the sunken islands in Winona Lake, and the currents around and over these islands brought sediments in a way that did not occur in the pelagic regions (Fig. 4).

Yearly Variations in Sedimentation in Winona Lake

Collectors No. 3, 4, and 5 were located at about one-third of the length of the lake from the north end, straight west of the center of McDonald Island and as close to the west shore as they could be to get the indicated depths. Nos. 4 and 5 were put in at the same time in almost the same depth of water and were about ten meters apart. No. 5 was removed at the end of 10.8 months. No. 4 was allowed to remain 25.5 months longer. While No. 4 was in the lake about three and one-third times as long as No. 5; its collecting jars were found to contain between five and ten times as much sediment.

This would seem to indicate that more sediment was deposited in the north part of the lake in one or both of the last two years than in the first year. The influence of the organisms growing in the sediment collected in the glass jars has not been determined. Some organisms may increase slightly the amount of sediment, while others may decrease it. An attempt is being made to eliminate this factor.

Collectors No. 8 and 10 were in practically the same location, on the southeast side of the sunken island in the south part of the lake, for approximately equal lengths of time, No. 8 being there 25.1 months and No. 10, 22.2 months. No. 10 was installed during the two years following the removal of No. 8. No. 8 collected from two to ten times as much sediment as No. 10. The same sort of comparison can be made with Collectors No. 9 and 11 on the northwest side of the same sunken island. More sediment was deposited on both sides of the sunken island during the first two years than during the last two years (Fig. 2).

The average weather conditions might cause some change in the productivity of the lake and the resulting production of sediment, but it seems that such great differences as are observed are more apt to be due to the amount, direction, and duration of the wind at certain important times of the year. For example, if, on the days when the lake happens to be homothermous, the wind does not blow, the sediment is likely to stay close to where it is formed instead of being circulated all over the lake. If there is wind at such times, its direction and strength will be important in determining the amounts deposited in various parts of the lake.

Chemical Comparisons

In Collector No. 4 the percentage of carbonate tends to increase with the depth, whereas in Nos. 12 and 13 it tends to decrease with the depth. The jars near the sunken island, with the exception of No. 9, show an irregularity in the percentage of carbonate, apparently caused by the currents coming from the island. No. 9 shows an increase in carbonate with the depth. In Collector No. 6 the percentage of carbonate collected at five meters was 63.45. Below that level the carbonate was quite uniform, averaging about 54.8%, or a decrease in percentage of about 8.65. In Winona Lake there seemed to be a large difference in the percentage of carbonate collected at the same location from one year to the next, as is shown by Collectors No. 9 and 11. The collectors located in the north part of the lake tend to show a smaller carbonate percentage than those in the south part, but more work must be done on this point to verify this tendency. It would be more significant if exactly the same method of chemical analysis had been used on the collections in both parts of the lake. The collection from Tippecanoe Lake (No. 6) shows a higher percentage of carbonate than the average of those in Winona Lake.

The percentage of organic material collected was, on the average, lower in Tippecanoe Lake than in Winona Lake. In Collectors No. 7 and 14 there was noted a relatively small percentage of organic material and a large percentage of sand and clay. The percentage of sand and clay seems to average higher in Winona Lake than in Tippecanoe Lake. In Tippecanoe Lake the percentage of sand and clay increased with the depth.

Discussion and Conclusions

The middle basin of Tippecanoe Lake, where Collector No. 6 was placed, is especially productive in plankton, with a minimum of marginal plants, due to its very steep slope. Winona Lake has a more gradual slope with dense growth of littoral plants along much of its shore line.

Our results indicate that most of the deposit in Tippecanoe Lake is formed in the epilimnion and falls directly to the bottom, with currents playing a small part in its deposition. In Winona Lake, on the other hand, much of the deposited material is derived from the littoral. If this disintegrating organic material were evenly distributed through the water of the lake during the fall overturn and then allowed to settle during the winter stagnation period, the results would be similar to those obtained in the deeper part of the lake. The results obtained near the marl shoals known locally as "sunken island" were complicated by currents carrying marl from this shoal to the adjacent deep water.

In the deepest parts of Winona Lake the sediment is being deposited at the rate of about 2.32 kg. per square meter per year, but near the sunken island the rate of deposit is about twice as great; the depth of the sediment seems to be increasing at the rate of about one-third of an inch a year in the deepest parts. These statements assume that sediment once laid down is not subsequently picked up and deposited elsewhere.

In Winona Lake there is a great deal of variation in the quantity and quality of the sediment collected at a given location from one year to the next. This seems to be correlated with the force of the wind during the periods of complete circulation.

In the deep part of Tippecanoe Lake the sediment is being deposited at the rate of about 1.4 kg. per square meter per year.

The study is being continued both in Winona Lake and lakes of different types. The apparatus here described might be adapted to the study of lake currents.

Acknowledgments

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