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REPORT NO. 939

A STUDY OF THE SEDIMENT IN DOUGLAS LAKE, CHEBOYGAN COUNTY, MICHIGAN

Ira T. Wilson, Heidelberg College, Tiffin, Ohio

One hundred eleven borings to the original bottom were made in the sediment of Douglas Lake. They provided the data for constructing a contour map of the original basin (Fig. 2), of a later stage called the high-level stage (Fig. 3) and of profile diagrams (Fig. 4) which show the relationship of the original, high-level and present basins to each other. The contour maps furnished the basis for determining the various morphometrical features (summarized in Table II) of the different basins as wholes as well as of the many separate depressions within the lake for which the lake is notable.

Most of the borings were exploratory in the sense that they were made rapidly with the intention only of discovering the type of sediment and the depth of the transitional zones between the various kinds of sediment encountered. However, nine borings were made in different parts of the lake from which complete cores of sediment were taken. These furnished a careful check on the conclusions based on the exploratory borings and gave material for the study of the chemical and petrographic nature of the sediment and the microfossils and laminations found in it. The fossil pollen from one boring (No. 74 in South Fish-Tail Bay, Fig. 1) has been examined and forms the subject of a separate paper already published (Wilson and Potzger, 1943). Dr. Ruth Patrick is making a study of the diatoms and Dr. Frank E. Eggleton of the invertebrates from the cores and, if warranted, separate publications will be made of this material. The laminations in the sediment have proven profitable for the construction of a post-glacial time table which will be the subject of a separate paper in the near future.

Acknowledgments

The major financial support for the field work was furnished by the Institute for Fisheries Research. The Michigan Academy of Science, Arts, and Letters, through grants-in-aid from the American Association for the Advancement of Science, contributed materially to this project. Lodging and the use of laboratory space, boats, shops and other facilities were donated by the Biological Station of the University of Michigan which is located on Douglas Lake.

The writer is indebted to John McQuate and John H. Thompson, Jr. who helped do the field work during the summer of 1942 and made many of the computations in determining the morphometrical constants, and to Philip Krause and Howard Poetter who assisted in the field work in 1943. The writer is very grateful to the staff of the Biological Station for many suggestions and much help, and especially to Dr. A. H. Stockard, who helped make the arrangements for the work, and to Drs. Paul S. Welch, Frank E. Eggleton, Frank C. Gates, and Gerald W. Prescott for many suggestions and considerable help in the interpretation of the findings. Special acknowledgment is due to Dr. A. S. Hazzard, Director of the Institute for Fisheries Research, for his keen interest in the work and for securing the means for carrying it out.

Methods

The methods used in making the borings and taking the samples of sediment are substantially those described earlier by the writer (Wilson, 1941). However, the writer would like to add that he learned that in trying to work from a float on a good sized lake where the water is rough a considerable part of the time it is essential to have a float as broad as the length of the maximum waves that occur in order to avoid rocking of the float to such an extent that work cannot be continued.

A brief history and description of Douglas Lake

I. D. Scott (1921) describes Douglas Lake (Fig. 1) as having been "a depression in an arm of a great archipelago" during the existence of Lake Algonquin and that it became isolated as a separate body of water with the subsidence of the waters of Lake Algonquin. Scott continues his description by saying that "The material surrounding the lake is all of glacial origin and is composed of sand, except at the headlands. These head lands are caused by till, which is much less readily attacked by the waves, and it will be seen from the map, (Fig. 42)* that, in general, they are opposite each other. There seem to be two small till ridges here which cause the constrictions in the outline of the lake but do not persist across the basin unless possibly in the case of the more westerly. On either side and between the ridges are heavy deposits of sand which partially filled the depressions except where the lake now lies. The eastern end of the lake is surrounded by outwash but the sands of the central and western basins, although possibly outwash, were deposited, in part at least, on the bed of Lake Algonquin which formerly covered this region."

The separate depressions found in Douglas Lake, Scott assumed to have been due to irregularities in one block of ice or to several separate blocks of ice left by the melting ice sheet that had previously covered this region. This early period as an embayment of Lake Algonquin is referred to in this report as the Algonquin Stage of the lake and the basin

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* The features referred to in this figure are also evident in Figure 1 of this paper.

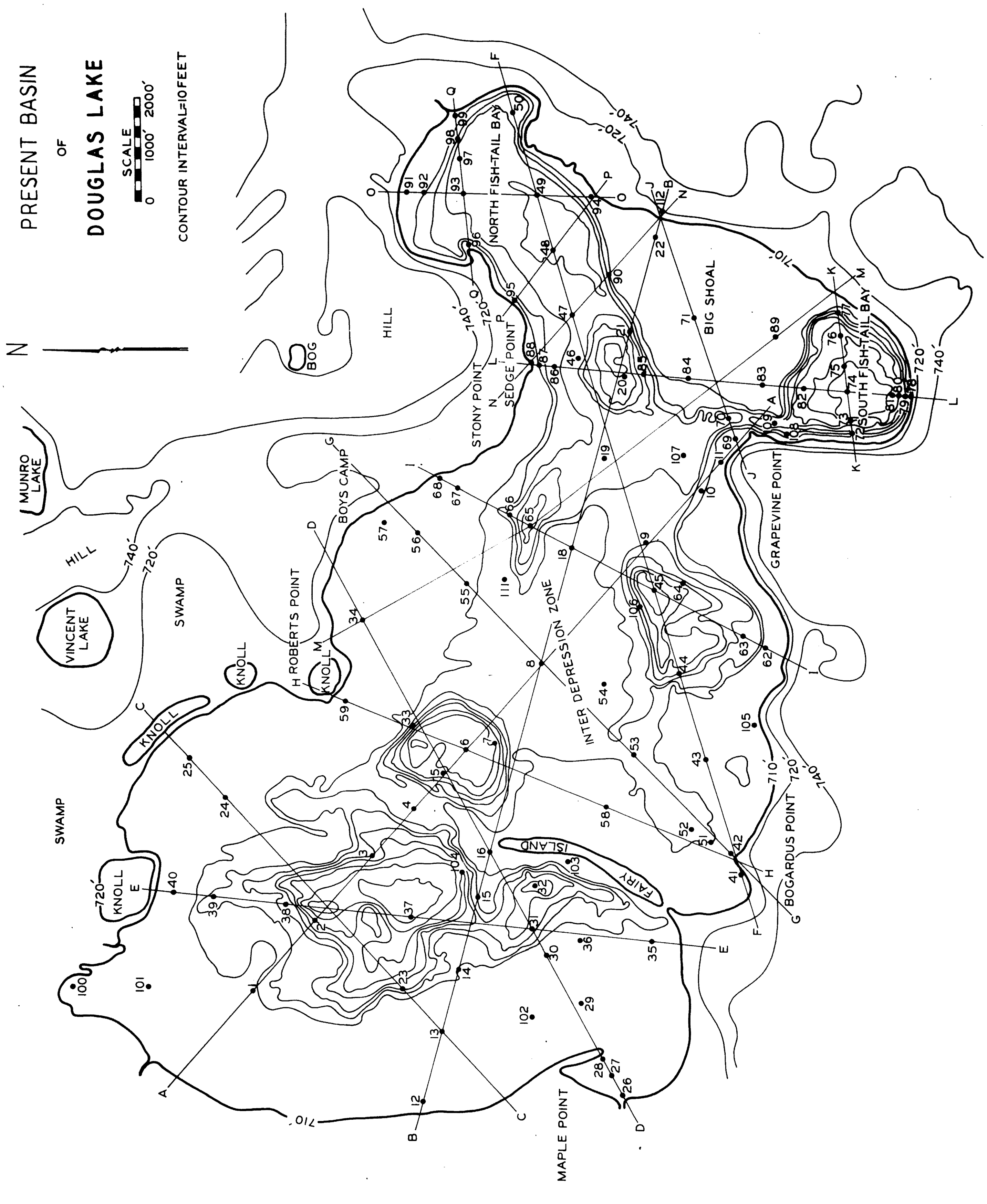

Fig. 1. Contour map of the present basin of Douglas Lake showing the location of the 111 borings that form the basis of the maps of the original (Fig. 2) and high-level (Fig. 3) basins, and the cross-section profiles (Fig. 4). It will be noted that the borings have been made along lines (with few exceptions) that cover the basin in all critical places. The lines are lettered (A-A, B-B, etc.) to correspond to the cross-section profiles in Figure 4. The names of the depressions can be determined by referring to Figure 2. The shoreline of this basin is 710 feet above sea level. The contours are taken from a map by Dr. Paul S. Welch.

it occupied at the out set as the Original Basin. It was during this early period, according to Scott, that a broad terrace was developed which still forms a conspicuous feature of the landscape around the lake at approximately the 730-foot elevation above sea leavel (about 20 feet above the present lake level). If it is assumed that 10 feet of water stood above this terrace when it was cut, then the Algonquin water level would have had an elevation of 740 feet. This is the basis on which the writer used the 740-foot contour (Figs. 1 and 2) as marking the original shoreline (Algonquin stage) of the lake.

Scott explains that when the greater Algonquin Lake lowered to the Nippissing level and Douglas Lake became an isolated body of water, the surface of this stage of the lake was considerably higher than at present and that it was during this high-level stage that most of the shore adjustments were made that characterize the lake today. A broad, wave-cut terrace was developed at this high-level stage which became exposed when the lake lowered to its present level--the terrace is about 4 feet above the present lake level. If it is assumed that 6 feet of water stood above this high-level terrace, then the 720-foot contour can be used to mark the elevation of the water and shoreline for this stage of the lake--as was done in Figures 1 and 3.

Welch (1927), Welch and Eggleton (1932), Welch and Eggleton (1935) have made a special study of the isolated submerged depressions that occur in Douglas Lake at the present time. There are seven such depressions known as Fairy Island, Maple Point, Roberts Point, Grapevine Point, Stony Point, Sedge Point, and South Fish-Tail Bay depressions (Fig. 2). The present study has revealed three additional depressions as having existed in the past which are now completely filled--they have been named Bogardus Point, Boys Camp, and North Fish-Tail Bay depressions (Fig. 2). Undoubtedly, as suggested by Scott (1921) for the depressions known to him at the time,

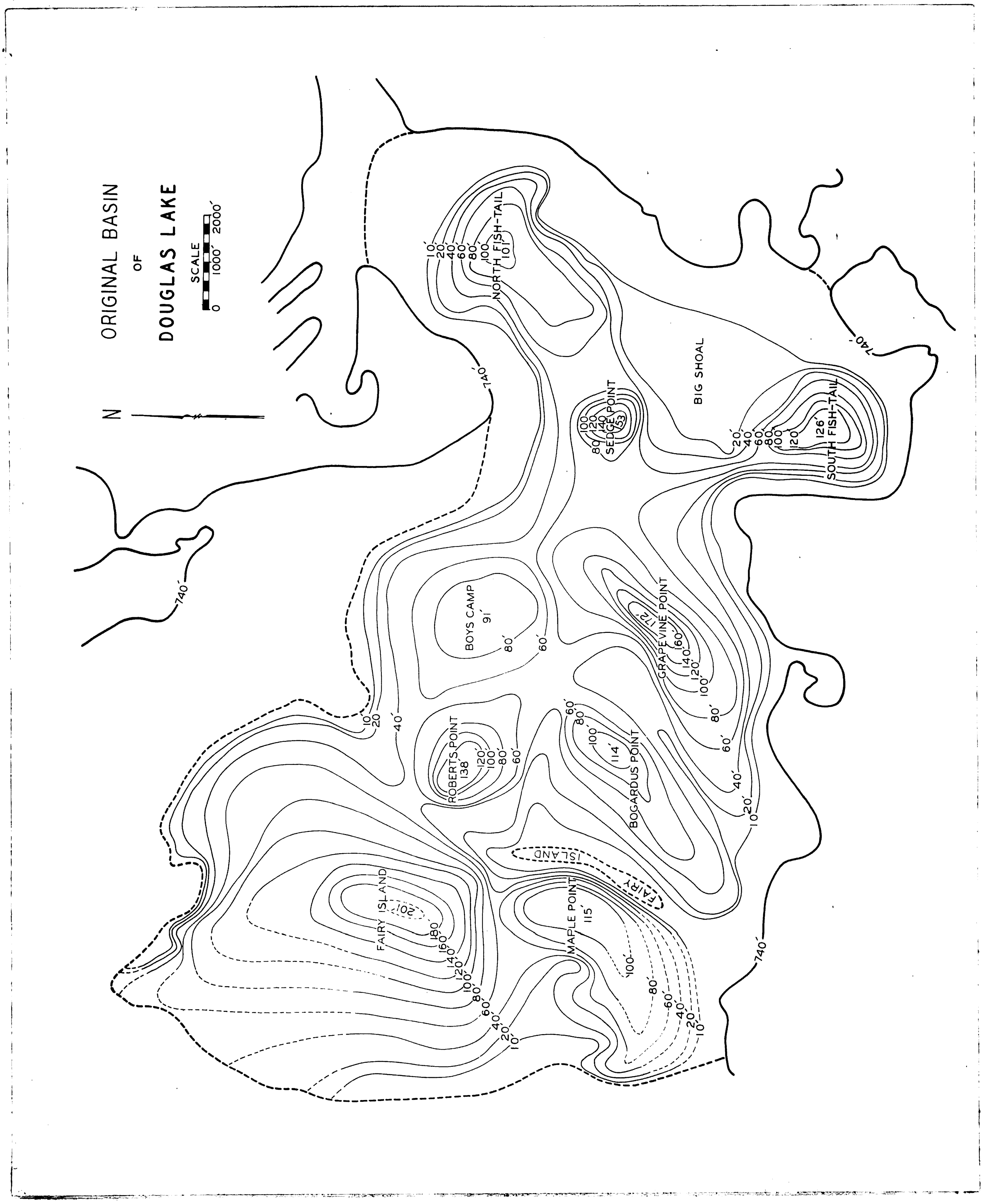

Fig. 2. Contour map of the original basin of Douglas Lake showing the names of the depressions. The shoreline (where solid) was compiled from data taken from a topographical map of the Bogardus tract (southeastern end of lake) made by the College of Engineering and the School of Forestry and Conservation of the University of Michigan and measurements and elevation (outside the Bogardus tract) made by the writer. The dotted part of the shoreline was drawn arbitrarily a little way outside the present shoreline in order to have a basis for determining the morphometrical constants of the original basin--this was necessary since it was this part of the original basin that was confluent with greater Lake Algonquin. The shoreline is 740 feet above sea level.

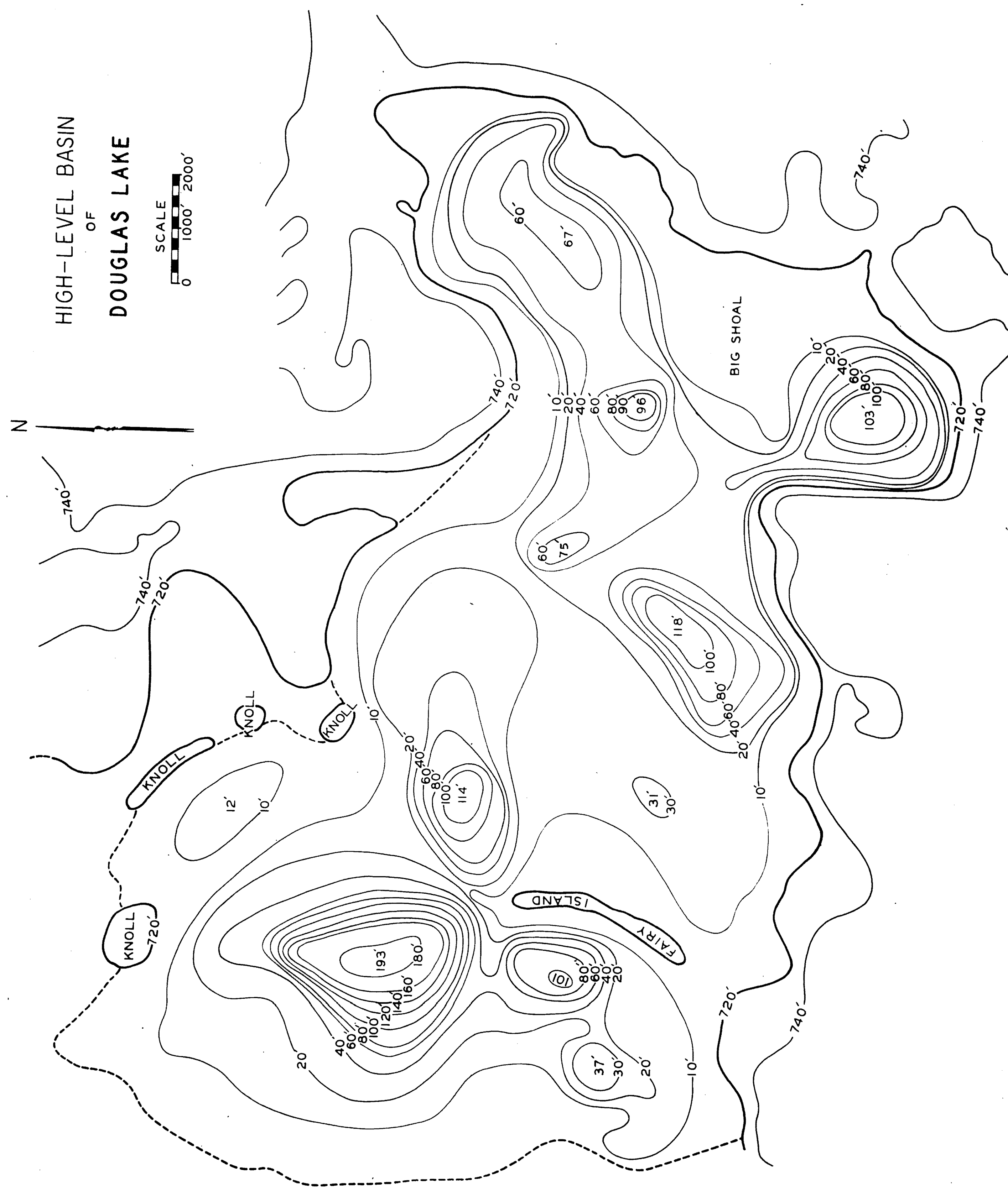

Fig. 3. Contour map of the high-level stage of Douglas Lake, i.e., the basin at the end of the Algonquin stage. The depths were taken from the point of contact of the pink clay (Algonquin deposit) and black mud or marl (warm water deposits). The shoreline is 720 feet above sea level and represents a compilation of data taken from a topographical map of the Bogardus tract (southeastern end of the lake) and measurements made by the writer. The dotted part of the shoreline was drawn arbitrarily just outside the present shoreline to form a basis for computing the morphometrical contants of the basin--this seemed desirable because at this stage of the lake water covered several square miles of low sandy ground to the west and northwest which it did not seem practicable to include in this study.

all of these depressions were caused by stranded blocks of ice from the receding Wisconsin ice sheet. Evidence will be submitted later suggesting that these dead blocks of ice remained in the several basins for varying lengths of time, thereby profoundly influencing the distribution of the sediment laid down during the early (Algonquin) stage of the lake.

Nature and distribution of the sediment

The sediment in Douglas Lake consists of four types, namely, black to brown gelatinous mud, marl, pink clay, and a brown varved clay. The black gelatinous mud is the uppermost deposit and is soft for the first few feet but is quite solid further down and is almost like horn in the bottom reaches. The marl lies immediately below the black mud and is gray in color and rich in carbonates, i.e., it is quite similar to that found at the surface in some lakes. Both the black mud and marl are thought to be warm water deposits (Fig. 4), i.e., to have been laid down after Douglas Lake had become an isolated basin in which the water warmed and stratified in summer much as it does today--this would have been during the high-level and present stages of the lake.

The pink clay is an amorphous deposit lying below the marl and is thought to have been made during the Algonquin period of the lake and, therefore, to have been a fairly cold water deposit (Fig. 4). This is inferred from the fact that the water in Lake Algonquin probably had much of its source from the melting ice sheet. The nearly complete lack of organic matter in the pink clay (Table I) and the fact that its color undoubtedly is due to the presence of iron oxide which probably came from the iron deposits further north lend themselves to this interpretation.

The brown varved clay occurs in deposits of about a foot's thickness in several localities in the lake basin below the pink clay deposit. It was found near the surface at some localities near shore but was present below 104 feet of sediment (172 feet below the present water surface) at

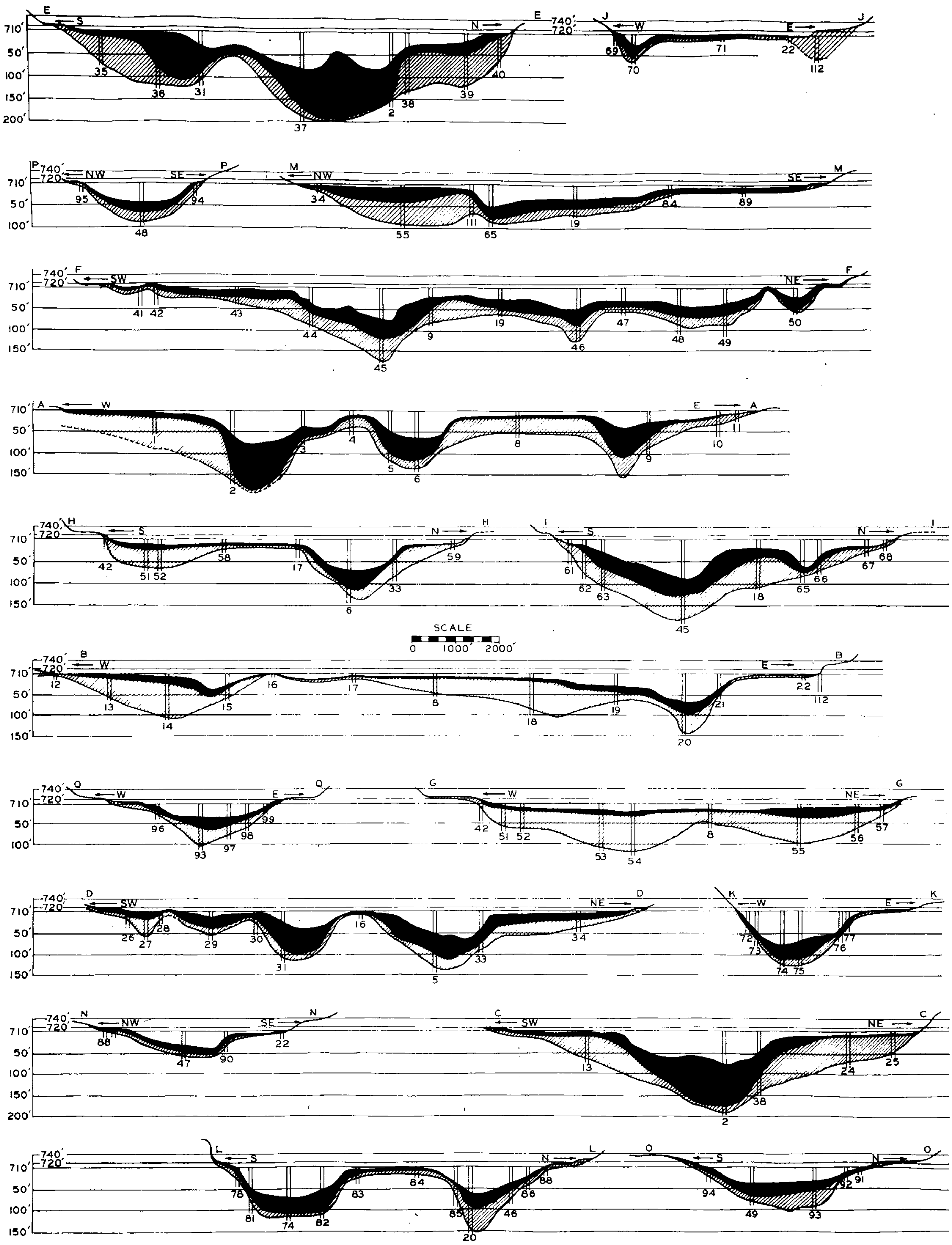

Fig. 4. Cross-section profiles showing the relationship of the basins of the three stages of Douglas Lake. The bottom line shows the original basin, the middle line (border of cross-hatched and black) shows the high-level basin, and the top line shows the present basin. The unshaded areas show the pink clay deposit of the Algonquin stage and shaded portion shows the marl (lower part--usually only a few feet) and black mud (warm water deposit) that took place during the high-level and present stages. The locations of these cross-sections are indicated in Figure 1.

boring 2 (Fig. 1) in Fairy Island depression. Since this brown clay (often quite thick deposits) is found over a wide area of this part of the State of Michigan, sometimes at levels higher than Lake Algonquin ever stood (Leverett and Taylor, 1915), it is likely that it antedates Douglas Lake. This deposit was always underlaid in Douglas Lake with very fine sand that contained enough carbonates to give a vigorous reaction to hydrochloric acid. There was 41 feet of this fine sand lying under the brown varved clay at boring 42 below which was found coarse gravel. If it should be found for certain that this brown clay layer is of earlier origin than the Algonquin stage of the lake, it could be utilized as a marker of the original bottom and remove some of the doubt expressed in the work reported here as indicated by the dotted lines on the map of the original basin (Fig. 2). In such a case the volume given here for the original basin would be somewhat reduced.

That the sequence of deposits is not quite as simple as is indicated above and by the profile diagrams (Fig. 4), due principally to the alternation of the various types of sediment at transitional zones between the major deposits, is shown by the following log of a core taken from the center of South Fish-Tail Bay depression: water, 72 feet; black soft flocculent mud, 72-74 feet; brown gelatinous laminated mud, 74-103 feet; gray marl, 103-106 feet; black tough gelatinous laminated mud, 106-107 feet; gray marl, 107-108 feet; pink clay, 108-109 feet; white sandy pink clay, 109-109.5 feet; white and pink clay alternating, 109.5-112.5 feet; fine sand, 112.5-116 feet; sandy pink clay, 116-117 feet; dark pink clay, 117-123 feet; sand, 123-123.5 feet; pink clay, 123.5-125 feet; sand, 125-126 feet; pink clay, 126-127 feet; sand, 127-127.5 feet; gray clay, 127.5-134 feet; fine sand, 134-135 feet; gray clay, 135-136 feet; fine sand, 136-137 feet; gray clay, 137-138 feet; coarse sand, 138-143 feet; as far as was penetrated.

Table I gives a chemical and petrographic analysis for the four types of sediment listed above, namely, black gelatinous mud, gray marl, pink clay, and brown clay. The analyses were made by the Basic Refractories, Inc. Research Laboratories of Tiffin, Ohio, to whom the writer is indebted. The method of chemical analyses was that ordinarily used in limestone work. Miss Elizabeth Haley of the laboratory did the petrographic analyses. She found it impossible to separate the material by the usual methods due to the large amount of calcite and organic matter present. She says, "No attempt was made to distinguish the various clay minerals--kaolin, dickite, sericite, etc.--and a complete identification of all minerals present was not undertaken." The analyses give a good idea, however, of the relative abundance of the principal minerals present.

The analyses of the black gelatinous mud show it to be mostly water (75 per cent). This is due to its gelatinous nature because most of this water is an integral part of the jelly and cannot be removed by dehydration with alcohol. A sample taken from nearer the surface would have shown an even higher percentage of water. Exclusive of the water most of this sediment is organic matter (30 per cent) in which pollen grains and fragments of plants can be recognized. Silicon dioxide makes up 48.80 per cent of this sediment (dry weight)--it is mostly the tests of diatoms. Quartz, calcite, and limonite were recognized in the petrographic analysis, their importance being in the order named.

The marl sample analyzed, although appearing to be no more firm than the gelatinous sediment, contained only 47.99 per cent water. On the basis of dry weight, as in the case of the black gelatinous mud, there are considerable quantities of organic matter (11.30 per cent) and silicon dioxide (27.20 per cent). The carbonates (mostly calcium and magnesium) form a large proportion of the sediment (approximately 50 per cent) mostly in the form of calcite and dolomite. There was a small quantity of kaolins present, also.

TABLE I

ANALYSES OF SELECTED SAMPLES FROM BORING 74 IN

SOUTH FISH-TAIL BAY DEPRESSION

Sample composition	Black gelatinous mud	Marl	Pink clay	Clay bank (near Burt Lake)
Depth of water (feet)	69	69	69	15 (above surface)
Depth below water surface (feet)	77-94	98-99	109-110	15 (above surface)
Chemical constituents (Percentage--dry weight)				
SiO_2	48.80 (Diatoms)	27.20	48.20 (Quartz)	38.34
R_2O_3	6.00	6.00	12.36	10.85
CaO	4.20	24.00	9.55	15.35
MgO	1.30	3.80	7.84	8.14
Loss on ignition	35.00	34.35	16.60	21.68
Calculated organic matter	30.00	11.30	1.00	None
Petrographic analyses				
Color of wet samples	Black	Greyish-green	Brown	Pinkish-tan
Color of dry samples	Grey-green	Grey	Tan	Pinkish-tan
Color after leaching with HCL	Brownish-grey	Dark olive green--brown when dried		Blue-grey
Loss of water on drying	75.00%	47.99%	34.24%	Large quantity
Names of minerals	Quartz* Calcite Limonite	Calcite* Dolomite Kaolins Quartz Limonite Feldspar	Dolomite* Clay Quartz Feldspar Iron oxide Titanite (?) Zircon (?)	Dolomite* Calcite Kaolin Quartz Limonite Feldspar Titanite (?) Zircon (?)

* In order of abundance

The pink clay by dry weight is 48.20 per cent silicon dioxide nearly all in the form of quartz. The percentage of magnesium oxide is higher than in the marl and calcium oxide lower--they occur mostly in the form of dolomite. The R_2O_3 compounds are more abundant probably due to the increase in alumimum oxide found in the higher proportions of clay and feldspar present. It is to be noted that some iron oxide is present as contrasted to the other kinds of sediment which undoubtedly accounts for the pink color so characteristic of this sediment. The large amount of clay present causes the physical appearance of the sediment. Organic matter is almost entirely absent from this material (1 per cent)--it is made up to some extent of pollen grains.

The brown varved clay is much like the pink clay except that considerable calcite is present as well as limonite, the latter accounting for the brown color. The varves vary from 10 to 30 per inch and indicate that the deposit was laid down in cold water since varves do not form in water over 10 degrees centigrade.

The distribution of the warm and cold water types of sediment are indicated on the profile drawings (Fig. 4). The black shaded portions of the profiles represent the black gelatinous mud and the marl--the marl portion makes up only a few feet of this part of the deposit near the bottom. The cross-hatched portion of the profiles indicate the pink clay deposit. Figure 5 shows the distribution of the sediment in the various separate depressions and the lake as a whole plotted as graphs. The graphs give a good idea of the average distribution of sediment.

Morphometrical changes in the basins

1. Introduction

Reference has been made to the fact that Douglas Lake has had three stages, namely, the Algonquin at which time it formed an embayment in the

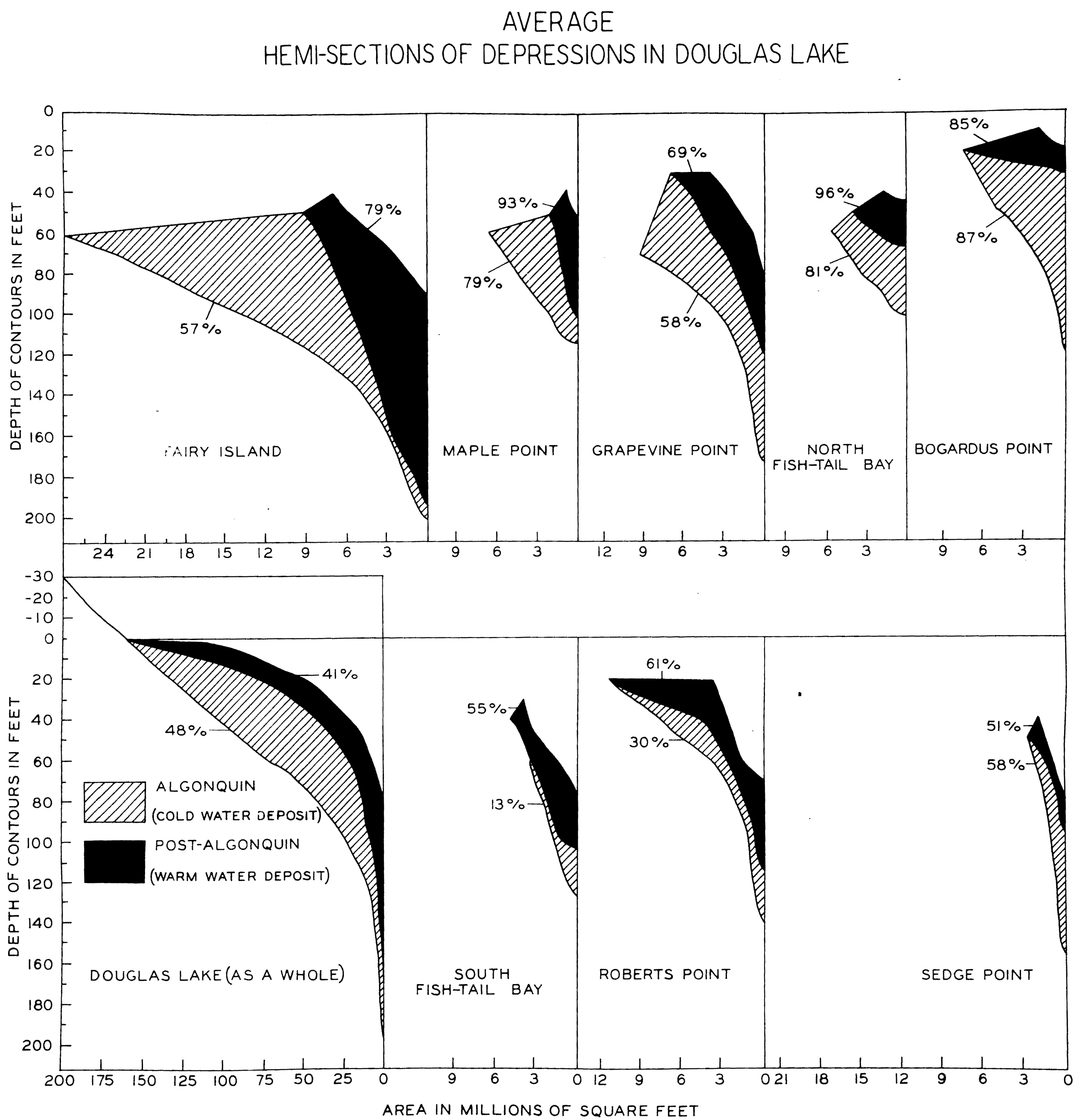

Fig. 5. Graphs made from the areas within the various contours of the different stages of the depressions and the lake as a whole plotted against their depths. They can be taken to represent average half cross-sections of the depressions. The areas of the graphs between the curves for the different basins represent sediment. The graphs help to visualize the part of the basins in which the sediment accumulated at different stages as well as the changes in slope, maximum depths, etc. that took place. The percentage figures indicate the amount of filling of the basin in which they occur.

great post-glacial Lake Algonquin, the high-level stage which began when Lake Algonquin receded to the Nipissing level and isolated the Douglas Lake embayment, and the present stage which is approximately 10 feet lower than the high-level stage. There is no way to distinguish between the sedimentary deposits laid down during the high-level and present stages, consequently the comparisons between stages are between the basins as they existed at the beginning of the Algonquin stage (original basin), at the beginning of the high-level stage (high-level basin), and the basin as it exists today (present basin). The present study of the morphometry of the original and high-level basins has been limited to the region of the present basin of the lake at the west end in spite of the fact that there is a broad plain extending several miles west of the present lake basin that formed a part of the Algonquin and high-level stages. This is done partly for convenience but also because the character of the deposit over this plain is so different from that in the region of the present basin that apparently entirely different forces were involved in their deposition.

In this section of the report the three stages of each depression will be described first and a comparison of similar morphometrical features between them attempted. Second, the three stages of the lake as a whole will be considered. Third, certain boulder belts will be described. Finally, unusual sand deposits found in some depressions will be described. The morphometrical data for all the depressions and for the lake as a whole are tabulated in Table II together with the percentages of change that took place between the stages. It should be kept in mind that in the morphometrical computations each depression was considered as if the topmost complete contour (isolation contour) was its shoreline and marked the surface level of the depression. Obviously, all the depressions from this point of view were submerged many feet below the general surface water of the lake and were consequently removed from the influences of wave action. This method of considering the depressions seemed the only feasible way to work out the morphometrical features for purposes of comparison.

2. Descriptions of the depressions and comparison of the morphometrical features of the three stages

Fairy Island Depression. This depression (Figs. 1, 2, and 3) is by far the largest of all the depressions in Douglas Lake at all three stages as indicated by the areas at the various isolation contours (60-ft. for the original basin; 50-ft. for the high-level; and 40-ft. for the present basin). The original Fairy Island Depression has an area of 27,590,000 sq. ft., the high-level stage 9,063,000 sq. ft., and the present basin 7,042,000 sq. ft. This is a decrease of 67.15 per cent from the original to the high-level stage and of 22.30 per cent from the high-level to the present stage. This marked decrease in area from the original to the high-level basin indicates a tremendous accumulation of sediment around the periphery of the basin during the Algonquin stage. The data above and all other data referred to in this section will be found in Table II unless otherwise stated.

The maximum depth of Fairy Island Depression increased from 141 to 143 feet from the original to the high-level stage and the mean depth from 46.44 to 69.35 feet showing that scarcely any of the sediment settled out in the center of the basin during Algonquin time. In great contrast there was a decrease of 66.72 per cent (from 69.35 to 23.08 feet) in mean depth after the beginning of the high-level stage--these changes, together with the rather small decrease in area (22.30 per cent), show that practically all the sediment settled in the center of the basin during this time. These changes can be visualized by looking at the graph (Fig. 5) showing the areas of the contours at the three stages.

Name of depression	AREA (sq. ft. in thousands) Original	High-level	Present	MAXIMUM DEPTH (Feet) Original	High-level	Present
Fairy Island	27,590,000	9,063,000	7,042,000	141	143	49
% of change		-67.15*	-22.30*		+1.42	-65.73
		-74.46*			-65.25	
Grapevine Point	9,192,000	6,799,000	3,936,000	102	88	51
% of change		-26.03	-42.04		-13.72	-42.05
		-57.17			-50.00	
Boys Camp	6,737,000	0	0	31	0	0
% of change		-100.00	0.0		-100.00	0.0
		-100.00			-100.00	
Maple Point	6,412,000	1,886,000	637,000	55	51	11
% of change		-70.57	-66.25		-7.27	-78.43
		-90.06			-80.00	
North Fish-Tail Bay	5,473,000	3,732,000	1,503,000	41	17	4
% of change		-31.81	-59.73		-58.54	-76.47
		-72.54			-90.24	
Bogardus Point	4,859,000	7,459,000	1,920,000	64	11	9
% of change		+74.09	-74.26		-82.81	-18.18
		-60.49			-85.94	
Roberts Point	3,906,000	11,897,000	3,880,000	78	94	52
% of change		+204.66	-67.38		+20.51	-44.68
		-0.64			-33.33	
South Fish-Tail Bay	2,663,020	4,522,000	3,926,000	56	63	43
% of change		+69.78	-13.17		+12.50	-31.75
		+47.40			-23.21	
Sedge Point	1,681,000	2,426,000	1,835,000	83	46	39
% of change		+44.31	-24.37		-44.58	-15.22
		+9.13			-53.01	
Stony Point	0	725,000	701,000	0	25	19
% of change		0.0	-3.24		0.0	-24.00
		0.0			0.0	
Whole Lake	199,465,000	173,458,000	160,088,000	201	193	89
% of change		-13.04	-7.71		-3.98	-53.89
		-19.74			-55.72	

* These figures and others in the same relative position represent the percent of change for the figures between which they lie.

MEAN DEPTH (Feet)			VOLUME (cu. ft. in thousands)**		
Original	High-level	Present	Original	High-level	Present
46.44	69.35	23.08	1,281,430,000	628,599,000	162,567,000
+49.33	-66.72		-50.94	-74.14	
	-50.30			-87.31	
29.18	35.73	18.80	268,235,000	242,918,000	74,037,000
+22.45	-47.38		-9.44	-69.52	
	-35.57			-72.40	
16.65	0.0	0.0	112,248,000	0	0
-100.00	0.0		-100.00	0.0	
	0.0			-100.00	
27.76	25.83	5.86	188,022,000	48,736,000	3,739,000
-6.95	-77.31		-74.08	-92.33	
	-78.89			-98.01	
21.45	15.35	1.33	117,428,000	31,107,000	2,004,000
-28.45	-91.33		-73.51	-93.56	
	-93.80			-98.29	
20.01	5.26	7.59	107,278,000	39,242,000	14,578,000
-73.71	+44.30		-63.42	-62.85	
	-62.07			-86.41	
29.02	25.26	29.92	113,361,000	300,599,000	116,167,000
-12.96	+18.49		+165.17	-61.35	
	+3.08			+2.47	
32.00	37.17	24.25	85,260,000	168,099,000	95,223,000
+16.16	-34.76		+97.16	-43.35	
	-24.22			+11.68	
33.50	16.76	16.45	56,326,000	40,660,000	30,186,000
-49.97	-1.84		-27.81	-25.76	
	-50.90			-46.41	
0.0	10.19	6.93	0	7,386,000	4,859,000
0.0	-32.00		0.0	-34.21	
	0.0			0	
47.87	31.02	18.17	14,942,574,000	6,634,224,000	2,908,403,000
-35.20	-41.44		-55.60	-56.16	
	-62.03			-80.54	

** The detailed tables showing the volumes by frustra are on file in the Institute for Fisheries Research at Ann Arbor, Michigan.

TABLE II

DOUGLAS LAKE

SUMMARY OF ALL MORPHOMETRICAL DATA

(All morphometrical computations for the depressions were made as if the topmost complete contour of a depression was the "surface" of the basin. This was true for computations for the whole lake.)

VOLUME DEVELOPMENT						MEAN SLOPE (Percent)					
Original	High-level	Present				Original	High-level	Present			
1.0	1.4	1.4	+40.00	0.00	+40.00	5.19	11.95	5.92	+130.25	-50.46	+14.02
0.9	1.2	1.1	+33.33	-8.33	+22.22	7.08	7.99	6.07	+12.85	-24.03	-14.26
1.6	0.0	0.0	-100.00	0.0	-100.00	2.32	0.0	0.0	-100.00	0.0	-100.00
1.5	1.5	1.6	0.00	+6.67	+6.67	6.25	8.05	2.78	+28.80	-65.46	-55.52
1.6	2.7	1.0	+68.75	-62.96	-37.50	4.50	1.78	0.99	-60.44	-44.32	-78.00
0.9	1.4	2.5	+55.56	+78.57	+177.78	6.34	0.51	1.87	-91.89	+264.78	-70.23
1.1	0.8	1.7	-27.27	+112.50	+54.54	7.93	4.77	6.84	-38.85	+43.40	-13.73
1.7	1.8	1.7	+5.88	-5.65	0.00	8.92	8.01	6.55	-10.20	-18.23	-26.57
1.2	1.1	1.3	-8.33	+18.18	+8.33	13.49	5.49	6.55	-59.30	+19.31	-51.44
0.0	1.2	1.1	0.0	-8.33	0.0	0.0	5.72	4.55	0.0	-20.45	0.0
0.7	0.5	0.6	-28.57	+20.00	-14.29	5.89	3.72	2.81	-36.86	-24.44	-52.29

LENGTH OF SHORELINE (Feet) (Isolation contours)					SHORELINE DEVELOPMENT				
Original		High-level		Present	Original		High-level		Present
21,250		11,750		13,300	1.1		1.1		1.4
	-44.70		+13.19			0.00		+27.27	
		-37.41					+27.27		
14,100		10,450		9,000	1.3		1.1		1.3
	-25.89		-13.87			-15.38		+18.18	
		-36.17					0.00		
9,800		0.0		0	1.1		0.0		0.0
	-100.00		0.0			0.0		0.0	
		-100.00					0.0		
11,850		5,100		4,950	1.3		1.0		1.7
	-56.96		-29.41			-23.08		+70.00	
		-58.23					+30.77		
10,100		9,100		7,450	1.2		1.3		1.7
	-9.90		-18.13			+8.33		+30.77	
		-26.24					+41.67		
10,250		11,500		8,000	1.3		1.2		1.6
	+12.19		-30.43			-7.93		+33.33	
		-21.95					+23.08		
7,400		14,600		8,300	1.1		1.2		1.2
	+97.30		-43.15			+9.09		0.00	
		+12.16					+9.09		
6,300		10,300		9,100	1.1		1.4		1.3
	+63.49		-11.65			+27.27		-7.14	
		+44.44					+18.18		
5,300		5,900		5,800	1.2		1.1		1.2
	+11.32		-1.69			-8.33		+9.09	
		+9.43					0.00		
0		3,800		4,400	0.0		1.3		1.5
	0.0		+15.78			0.0		+15.38	
		0					0.0		
***		***		74,400	***		***		1.6
	0.0		0.0			0.0		0.0	
		0					0.0		

*** The lengths of the original and high-level shorelines are so arbitrary as to make a computation of shoreline development futile.

AVERAGE DEPTH OF SEDIMENT**** (Feet)			ISOLATION CONTOUR		
Original-high-level	High-level-present	Original-Present	Original	High-level	Present
30.30	60.30	53.10	60	50	40
37.55	24.84	49.68	70	30	30
15.18	0.0	15.18	60	0	0
28.19	30.53	39.73	60	50	40
24.18	29.30	33.83	60	50	40
52.03	11.56	59.08	50	20	10
32.98	15.50	39.15	60	20	20
9.36	25.46	45.74	70	40	30
33.75	13.10	46.91	70	50	40
0.0	13.32	0.0	0	50	40
22.97	11.86	33.29	-30	-10	0

**** The volume of sediment in each depression was computed as if the lower basin of any two lake stages, e. g., original and high level, included a special frustrum extending from the topmost contour of the lower to the level of the topmost contour of the upper basin. In computing the AVERAGE DEPTH OF SEDIMENT the total value for the quantity of sediment was always divided by the area of the topmost contour of the lower of the two basins being considered.

The reduction in volume from the original (1,281,430,000 cu. ft.) to the high-level (628,599,000 cu. ft.) stage is 50.94 per cent as contrasted to a reduction of 74.14 per cent from the high-level to the present stage (162,567,000 cu. ft.). The absolute amounts of the reductions in volumes were 652,831,000 and 466,032,000 cubic feet, respectively.

In view of the contrasting changes in area and maximum and mean depths during the Algonquin and subsequent stages of the lake, it is not surprising to find that the mean slope increased from 5.19 per cent to 11.95 per cent during the former and decreased from 11.95 per cent to 5.92 per cent during the latter periods.

There was an increase in volume development of 40.00 per cent from the original (1.0) to the high-level (1.4) basins. In contrast to this there was no change from the high-level (1.4) to the present (1.4) basins.

The length of the shoreline decreased from the original (21,250 ft.) to the high-level (11,750 ft.) basin by 44.70 per cent but increased by 13.19 per cent from the high-level to the present (13,300 ft.) basin. Shore development did not change during the Algonquin stage but increased 27.27 per cent (1.1 to 1.4) during the subsequent period. These figures are significant so far as the original to high-level changes are concerned but are not so dependable when comparing the high-level to the present basins because the "shoreline" (isolation contour) of the present basin was determined from so many more soundings than was the case in the other two basins that it shows many irregularities overlooked in the two earlier basins.

The volume of sediment (Table III) laid down during the Algonquin stage was 836,101,000 cu. ft. and that laid down subsequently, i.e., since the beginning of the high-level stage is 546,560,000 cu. ft. Comparison of tables showing the volume of sediment by frustra (on file at the office of the Institute for Fisheries Research, Ann Arbor, Michigan) shows that 50 per cent of the sediment lies above the base of frustrum 3 (30-feet contour) in the case of that laid down during the Algonquin stage, whereas 50 per cent of that laid down afterwards (high-level and present stages) lies above the base of the sixth frustrum (60-foot contour). This difference follows from the fact that most of the sediment was laid down in the shallow periphery of the basin during the Algonquin stage but in the center during the later stages.

Maple Point and Grapevine Point Depressions. These two depressions resemble Fairy Island Depression in that most of the pinkish clay sediment characteristic of the Algonquin period of the lake settled out around the periphery of the basin while the reverse process (filling in the center) prevailed during the high-level and present stages of the lake. This sequence of filling caused changes in the morphometrical features from the original to the high-level stage on the one hand and from the high-level to the present stage on the other to be about the same as for the corresponding periods in Fairy Island Depression. These resemblances can be verified by consulting Table II. Figure 5 shows the similarities graphically.

The three basins described so far, namely: Fairy Island, Maple Point, and Grapevine Point, at the outset were the largest in area, maximum depth, and volume of all the ten depressions in the original basin of Douglas Lake. They must have resulted from having been occupied by the largest blocks of ice. This fact, as will be shown later, probably is responsible for their peculiar manner of filling as contrasted to the other basins.

Bogardus Point Depression. This depression differs radically from those already described in that it was almost completely filled with pink clay during the Algonquin stage of the lake. This difference is reflected to some extent in differences in changes that have taken place in morphometrical features (Table II). Sediment in this basin settled in the center of the basin more rapidly than around the periphery during the Algonquin stage (Fig. 5). This is shown by the reduction in maximum depth from 64 feet in the original basin to 11 feet in the high-level basin and by a reduction in mean depth from 20.01 feet to 5.26 feet, respectively. An increase in area by 74.09 per cent (from 4,859,000 sq. ft. to 7,459,000 sq. ft.) from the original to the high-level basin emphasizes the fact that there was relatively little filling in of sediment around the edges of the basin. This is shown, also, by the fact that 84 feet of sediment accumulated in the center of the depression (boring 53) while the topmost contour (isolation contour) was raised only 30 feet during the Algonquin period. Also, the reduction in volume (63.42 per cent) was considerably greater than in the case of Fairy Island Depression where the filling was largely around the periphery during the same period. A reduction of 91.89 per cent in mean slope (from 6.34 to 0.51 per cent) during this period follows from the increase in area and reduction in depth. Some decrease in irregularity in the shoreline is shown by the decrease in shoreline development from 1.3 to 1.2.

The morphometrical changes in this depression during the time subsequent to the Algonquin period (during the period of the high-level and present basins) are of a diametrically opposite kind to those that took place from the original to the high-level basin due to the fact that the sediment has accumulated more rapidly around the periphery than in the center of the basin. This is shown by the reduction of 74.26 per cent in area and the relatively slight reduction in maximum depth of 18.18 per cent. The volume was reduced by 62.85 per cent. The faster rate of reduction in area than in maximum depth caused an increase in mean slope from 0.51 per cent to 1.87 per cent.

The present basin of Bogardus Point Depression is in reality only an embayment but the mouth of the bay was arbitrarily taken as the limit of the lakeward side of the basin.

It is evident that Bogardus Point Depression has filled in a fashion exactly opposite to that which took place in Fairy Island, Maple Point and Grapevine Point depressions at corresponding periods.

Boys Camp Depression. This depression was completely obliterated during the Algonquin stage of the lake so it is impossible to know whether or not the filling of the basin took place more rapidly around the periphery than in the center but it, undoubtedly, did fill in the center at a rapid rate which puts the basin in the same class as Bogardus Point Depression during the Algonquin period. No filling has occurred in this depression since the Algonquin stage.

South Fish-Tail Bay Depression. This depression is unique in that no appreciable amount of sediment settled around the periphery of the basin in the Algonquin stage and very little in the center (Fig. 5). The change in the isolation contour from 70 to 40 feet between the original and high-level stages makes a deceiving situation since it suggests considerable filling around the edge but the 30-foot elevation is due to the plugging of a narrow channel connecting the depression to the main body of the lake (compare Figs. 2 and 3) and not to deposition within the basin itself. This elevation of the isolation contour is chiefly responsible for the increase in area (69.78 per cent), maximum depth (12.50 per cent), mean depth (16.16 per cent), and in volume (97.16 per cent). Since the area increased more than the maximum depth, the mean slope shows a decrease (10.20 per cent). Volume development, length of shoreline, and shoreline development increased, also. The mean depth of sediment which accumulated during this period was only 9.36 feet, which is less than one-third of the average amount that accumulated in the other nine basins during the same time (Table II).

In sharp contrast to the morphometrical changes that took place during the Algonquin stage, every morphometrical feature shows a decrease in value from the beginning of the high-level stage on. The average depth of sediment accumulated during this later period has been 25.46 feet. Most of it settled in the central deep part of the depression (Fig. 5) which is shown by the fact that there was only a 10-foot elevation in the isolation contour and the maximum depth decreased 31.75 per cent.

North Fish-Tail Bay Depression. This depression might be taken as the mean of the 10 depressions for it has filled about the same amount around the periphery as in the center both during the Algonquin stage and subsequently (Fig. 5). This fact is reflected in the morphometrical changes (Table II) that took place during the two periods--they are all negative except volume development and shoreline development both of which increased between the original and high-level stages. For example, between the original and high-level stages the area decreased 31.81 per cent, maximum depth 58.54 per cent, mean depth 28.45 per cent, volume 73.51 per cent, mean slope 60.44 per cent, and length of shoreline 9.90 per cent. The average depth of sediment that accumulated is 24.18 feet. The corresponding figures for the changes from the high-level to the present stage are considerably greater, showing acceleration in the same trends which is undoubtedly due to the greater relative quantity of sediment that accumulated during this time, namely, an average of 33.83 feet.

Stony Point Depression. This depression formed an arm of Grapevine Point Depression during the Algonquin period (Fig. 2) but was cut off as an independent depression at least by the time of the high-level stage by a ridge of sediment that formed across the base of the arm (Fig. 3). During the high-level and present stages of the lake there has been a fairly uniform accumulation of sediment over the entire basin which has reduced moderately the area, maximum depth, mean depth, volume, slope, and volume development (Table II). The length of shoreline and shoreline development increased slightly. These changes are very much like those that occurred in North Fish-Tail Bay Depression during the same period. The average depth of sediment deposited has been 13.32 feet.

Roberts Point Depression. This depression is striking in that between the original and high-level basins it shows, among all the depressions, the greatest change in elevation of its isolation contour (from the 60- to 20-ft.) due to a damming of the basin at the southeastern and northwestern corners rather than to an accumulation of sediment around the periphery (compare Figs. 2 and 3). The above changes caused the greatest increase in area relatively of any depression (204.66 per cent). This was partly because most of Boys Camp Depression was thrown into it by the time the high-level stage was reached. There was an increase in maximum depth of 20.51 per cent, which is the greatest increase that took place in any depression in this respect. The fact that the area increased more than the volume and maximum depth caused a decrease in mean depth (12.96 per cent) and of mean slope (38.85 per cent). The volume increased by 165 per cent. The volume development decreased 27.27 per cent. This gave the high-level basin the lowest value in volume development (0.8) of any depression at any stage. Length of shoreline and shoreline development both increased (97.30 per cent and 9.09 per cent, respectively). About an average amount of sediment (23 feet at boring 6) settled out in the center of the basin during the Algonquin stage.

From the high-level to the present basin every morphometrical feature changed in a manner opposite to that noted above for the changes from the original to the high-level stage (Table II). Fifty-one feet of sediment accumulated during this period at boring 6. That most of the sediment accumulated in the center of the depression during this period is shown, also, by the fact that there was no elevation in the isolation contour.

Sedge Point Depression. Of all the depressions this one was the smallest originally in area, volume, and length of "shoreline" but it was one of the deepest (83 feet maximum depth from the isolation contour). The small area and great depth account for the fact that its mean slope was the greatest (13.49 per cent). It filled moderately around the periphery but rapidly in the center during the Algonquin stage (Fig. 5). The depression increased in area (44.31 per cent) and decreased in maximum depth (44.58 per cent) and mean slope (59.30 per cent). The length of shoreline increased 11.32 per cent. Volume decreased (27.81 per cent) as did volume development (8.33 per cent) and shoreline development (8.33 per cent).

During the high-level and present stages of Sedge Point Depression sediment settled slightly faster around the edges than in the center since there was a decrease in area of 24.37 per cent and in maximum depth of only 15.22 per cent. These changes caused an increase in mean slope of 19.31 per cent. Volume development increased by 18.18 per cent. Except for volume development between the original and high-level stages, Sedge Point Depression shows the same trends of change in morphometrical features (but to a less degree) as Bogardus Point Depression at corresponding stages. This is probably due to the fact that both basins filled in the center faster than around the edges during the Algonquin stage and faster around the edges than in the center during the high-level and present stages.

3. Comparison of the morphometrical changes in the lake basin considered as a whole

When the lake is considered as a whole, it is found that the area decreased 13.04 per cent from the Algonquin to the high-level stage and 7.7 per cent from the high-level to the present time. Maximum depth decreased little (3.98 per cent) from the Algonquin to the high-level stage because of so little filling in Fairy Island Depression (the deepest place) but maximum depth decreased 53.89 per cent during the high-level and present stages because Fairy Island Depression filled absolutely more than any other depression (104 feet). Mean depth decreased 35.20 per cent during the Algonquin stage and 41.44 per cent subsequently. Decrease in volume was 55.60 per cent and 56.16 per cent, respectively. Mean slope decreased 36.86 per cent and 24.44 per cent, respectively. Volume development decreased during the Algonquin stage 28.57 per cent but reversed this trend and increased in the subsequent stage by 20.00 per cent.

The above morphometrical data indicate that during the Algonquin period the lake (as a whole) filled around the edges faster than in the deeper parts but filled almost exclusively in the depressions during the high-level and present stages. Comparison of Figures 1, 2 and 3 (contour maps of the original, high-level and present stages, respectively), examination of Figure 4 (cross-section profiles), and of Figure 5 (graph of areas of contours) will make this generalization evident.

4. Boulder belts

Boulders of considerable size (up to 2 feet in diameter) are found at several places around the edges of Douglas Lake. Some of them lie on deposits of sand of many feet in depth. They were noted at borings 11, 21, 22, 38, 40, 49, 59, 71, 102, and 105 (Fig. 1). The texture of the material that makes up the shore in most localities mentioned is not such as to suggest that the shore is their source.

5. Sand strata in depressions

Fairy Island Depression had a layer of washed sand and gravel (up to 5 mm. in diameter) of 20 feet thickness at boring 2 and an estimated thickness of 35 feet at boring 37 which lies between the marl of the warm water deposit and the pink clay of the Algonquin (cold water) deposit.

Roberts Point Depression had an 18-foot deposit of washed sand at boring 7 overlying the original bottom.

The depressions mentioned above had very little deposit in their centers during the Algonquin stage and consequently had their maximum depths reduced the least. They are the basins that had the largest volumes at the end of the Algonquin stage as well as the steepest slopes. These facts make it seem likely that they were occupied longest by blocks of ice.

Volume of sediment and percentage of filling of basins

Table 3 shows the volumes of sediment of the various basins and the percentage of their filling. Although, with the exception of Roberts Point and South Fish-Tail Bay depression, the absolute volumes of sediment that settled in the original depressions during the Algonquin stage of the lake (original to high-level in the table) were greater than that which acumulated subsequently (high-level to present in the table), the reverse is true on a percentage basis with the exception of Sedge Point Depression. More than twice as much sediment settled in the lake as a whole during the first period as subsequently (4,582,776,000 and 2,058,089,000 cubic feet, respectively).

The average depth of sediment (Table II) that settled in the various depressions at different periods shows the differences in the rate of sedimentation that have taken place. For the lake as a whole (exclusive of the basin lying above the present water level) on the average 22.97 feet of sediment settled out during the Algonquin period and 11.86 feet during

TABLE III

VOLUMES OF SEDIMENT (IN THOUSANDS OF CUBIC FEET)

AND PERCENTAGE OF FILLING OF BASINS

Names of depressions	Original to high-level: Volume of sediment	Original to high-level: Percentage of basin filled	High-level to present: Volume of sediment	High-level to present: Percentage of basin filled	Original to present: Volume of sediment	Original to present: Percentage of basin filled
Fairy Island	836,101	57.08	546,560	77.07	1,465,188	90.00
Grapevine Point	345,135	58.69	168,880	69.52	456,768	86.05
Maple Point	180,782	78.77	57,615	93.90	254,745	98.55
North Fish-Tail Bay	132,349	80.97	55,279	96.50	185,185	98.93
Bogardus Point	252,813	86.56	86,256	85.54	287,069	98.55
Roberts Point	128,816	30.00	184,432	61.35	152,915	56.77
South Fish-Tail Bay	24,945	12.92	115,119	54.73	121,836	56.13
Sedge Point	56,738	58.25	31,778	51.28	78,877	72.33
Stony Point			9,657	66.50		
Boys Camp	112,248	100.00				
Lake as a whole	4,582,776	47.99*	2,058,089	41.44*	6,640,865	69.54*

* Exclusive of that part of the basin above the present water level.

the subsequent periods. Conspicious differences occur between the Algonquin and subsequent periods among the depressions. For example, in Fairy Island Depression an average of 30.30 feet settled in the first period and 60.30 feet subsequently; in Bogardus Point Depression the figures are 52.03 and 11.56 feet, respectively. The figures for the other basins range somewhere between these extremes.

Comparison at corresponding periods among the depressions of the average depths of sediment reveals striking differences. For example, in Fairy Island Depression during the high-level and present periods there were 60.30 feet deposited, in Grapevine Point Depression, 24.84 feet, in Roberts Point Depression, 15.50 feet, and in Sedge Point Depression 13.10 feet. These figures are in great contrast to those the writer found in the several depressions (much shallower) in Winona and Tippecanoe lakes in Indiana (Wilson, 1936 and 1938, respectively) where the average depths of sediment were much the same. Examination of the locations of the depressions in Douglas Lake (Fig. 2) shows that those in the most wind-exposed positions have the least average depth of sediment for the warm water period--they are Sedge Point, Stony Point, and Roberts Point depressions. Fairy Island Depression is in an exposed position and at the same time has the greatest average depth of sediment for the warm water period (60.30 feet) but it lies at the lee end of the lake. It seems likely that swift currents over the wind-exposed basins do not give time for sediment to settle into them, whereas, in Fairy Island Depression less swift currents and the fact that considerable quantities of sediment may be carried ultimately to that part of the lake by return currents could account for the great quantity of sediment that has settled there.

Discussion

To explain satisfactorily the diverse types of morphometrical changes that took place in the different depressions of Douglas Lake, especially during the Algonquin period, to understand the deposition of boulders over deep sand deposits and the interpolation of sand and gravel layers between the Algonquin and subsequent deposits that occur in some depressions, and to find a logical explanation of the thick deposits of pink clay (Algonquin deposits) around the margins of some depressions where there is scarcely any such deposit in the center, it is only necessary to assume that the great ice blocks that occupied the depressions at the outset of the Algonquin period persisted varying lengths of time in different depressions and did not disappear in Fairy Island Depression until near the close of the Algonquin period. Such a theory implies that where the ice blocks were thin as around the margins of depressions, in the relatively shallow interdepression zones, and in shallow depressions, the ice blocks melted early and such localities became the first repositories of sediment and, therefore, accumulated the deepest deposits of cold water sediment. Conversely, the deepest and most voluminous basins (at least in their centers) would be expected to have become free of ice last and would have accumulated the least deposit of cold water sediment. After all of the glacial ice had melted it would be inferred that deposition of sediment would take place according to the intrinsic factors inherent in the lake as a whole and in the individual depressions.

The above expectations are verified amply by the evidence. For example, it has been shown that during the Algonquin stage the very large Fairy Island Depression filled almost exclusively around the margin where the original block of ice was thin and undoubtedly melted early, whereas, at the opposite extreme, stand Boys Camp and Bogardus Depressions (that were originally shallow depressions) in which the ice undoubtedly melted early and which filled almost entirely with pink clay deposit. South Fish-Tail Bay Depression had very steep sides and was deep and well protected by Grapevine Point and apparently had scarcely any melting of its ice block until late in the Algonquin period and consequently has relatively little pink clay deposit. The other depressions are intermediate between those already discussed and vary in a general way inversely in the quantity and distribution of their pink clay deposit with their depth and volume.

That ridges on the original bottom of the lake began deposition early due to becoming free of ice seem well illustrated at boring 4 between Fairy Island and Roberts Point Depressions where the original depth was only 42 feet ~~(from the~~ (from the surface of the present basin) and there ~~is~~ are only 25.5 feet of pink clay deposit and one-half foot of recently deposited sandy organic matter. A similar example occurs at boring 8 in the inter-depression zone where there is a 42-foot pink clay deposit that reaches to the base level of wave action and over which only one-half foot of sandy organic matter lies.

According to the general theory presented above the boulder belts superimposed on sand could be explained by assuming that the sand deposits over which the boulders lie were made around the margins of the depressions while the ice blocks in the centers of the depressions were anchored to the bottom. During such a time wave action and currents may be presumed to have been adjusting the shoreline and carrying sand into the water near shore. The melting block of ice may have contributed some sand to this zone. Finally, when the ice block in a depression freed itself from the bottom and floated, it may be presumed to have drifted toward the shore and melted and thus dropped its boulders on top of the previously deposited sand.

The presence of the sand and gravel layers interpolated between the cold and warm water deposits in the deepest depressions can be explained in two possible ways. First, one might assume that after the ice blocks had melted the increased wave action caused violent shore adjustments in which considerable sand was carried to the center of the depressions where it settled before the deposition of warm water sediment began. Second, the ice block could have dropped its burden of sand and gravel directly into the depressions as it melted, after it became detached from the bottom and was floating.

The place of deposition of sediment during the Algonquin period was controlled to a large extent by the blocks of ice that occupied the depressions and as has been shown, most of the sediment settled around the periphery of the depressions during that time. During the high-level and present stages of the lake the controlling factors in distribution of sediment have been the factors inherent in the shape and form of the basin itself. In these latter periods nearly all of the sediment has settled in the centers of the depressions and very little around the periphery of the lake. This is what is to be expected in a lake as large as Douglas Lake, the long axis of which lies in the direction of the prevailing winds. That is, wave action is so vigorous that the shore out to the base level of wave action is being eroded and the abraided material carried away to settle in the depressions. Undertow and return currents down to the level of the thermocline and currents below that level at the spring and autumnal overturns probably keep the fine sediment suspended until it reaches the depressions where it can settle to the bottom permanently.

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INSTITUTE FOR FISHERIES RESEARCH

Ira T. Wilson

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