PLEISTOCENE STRATIGRAPHY OF THE WINNIPEG RIVER IN THE PINE FALLS - SEVEN SISTERS FALLS AREA, MANITOBA

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A THESIS

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- - - - - -

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ABSTRACT

The Pleistocene sediments exposed along the Winnipeg River from Lake Winnipeg to Seven Sisters Falls can be divided into four sedimentary units. These are, from oldest to youngest, a glacial till, a glacio-lacustrine clay, a glacio-lacustrine mud, and a glacio-fluvial and glacio-lacustrine sandy silt.

During Wisconsin time, ice advanced from the Keewatin ice centre situated northwest of the study area depositing a calcareous till. Most of the till was derived from the Paleozoic carbonates of Manitoba. As the ice retreated, Lake Agassiz III, a large glacial lake, inundated the area. Sedimentation in the lake resulted in the deposition of a clay unit consisting mainly of illite and montmorillonite derived from Cretaceous and Jurassic shales. Further recession of the ice opened an eastern drainage outlet and the lake level dropped subjecting the clay to subareal erosion. An ice advance from the northeast Patrician ice centre blocked eastern drainage and Lake Agassiz IV came into existence. As the lake level rose, a mud unit consisting essentially of dolomite grains, quartz grains and clay minerals derived from Paleozoic carbonates, Precambrian granites and Cretaceous shales was deposited.

Recession of the ice sheet opened eastern drainage systems and the lake level dropped gradually. A sandy silt unit was deposited in shallow water of Lake Agassiz IV as a result of delta construction and offshore processes. The sandy silt is composed mainly of quartz and dolomite grains derived from Precambrian granites and Paleozoic carbonates. Disintegration of the ice sheet in the Nelson River basin opened northern drainage. Lake Agassiz was drained to the present level of Lake Winnipeg, the sandy silt was subjected to erosion, and a soil profile developed.

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INTRODUCTION AND METHOD OF STUDY

INTRODUCTION

GENERAL STATEMENT

The study area, consisting of a portion of the Winnipeg River Valley, extends from the mouth of the Winnipeg River to Seven Sisters Falls, a distance of approximately 55 miles. The mouth of the Winnipeg River is situated approximately 60 miles north-east of Winnipeg, Manitoba (Fig. 1).

Thesis work consisted of mapping the Pleistocene sediments to determine their extent and stratigraphic relationships, as well as their physical features and mineralogy. The information obtained permitted an interpretation of the glacial history of the area.

PHYSIOGRAPHY AND GENERAL GEOLOGY

The study area is situated east of the contact between the Manitoba Lowlands and the Canadian Shield. The Manitoba Lowlands are underlain by nearly horizontal, early Paleozoic strata which overlap the Precambrian formations of the Canadian Shield. (Fig. 2). The Paleozoic strata consist primarily of limestones and dolomites and the Precambrian formations of granites and granite gneisses, with minor volcanics and basic intrusives. The Manitoba Escarpment, situated west of

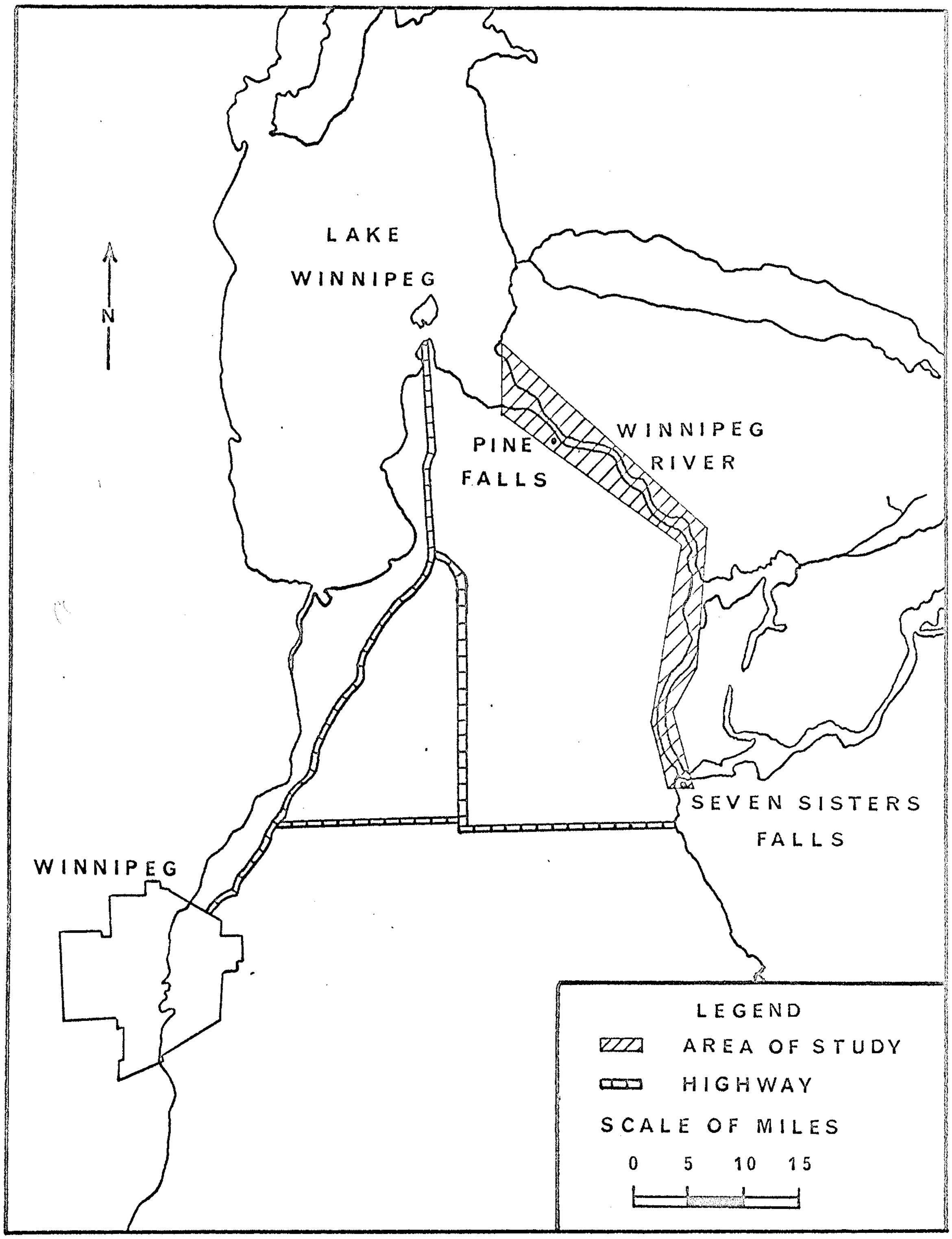

FIGURE 1. Location map.

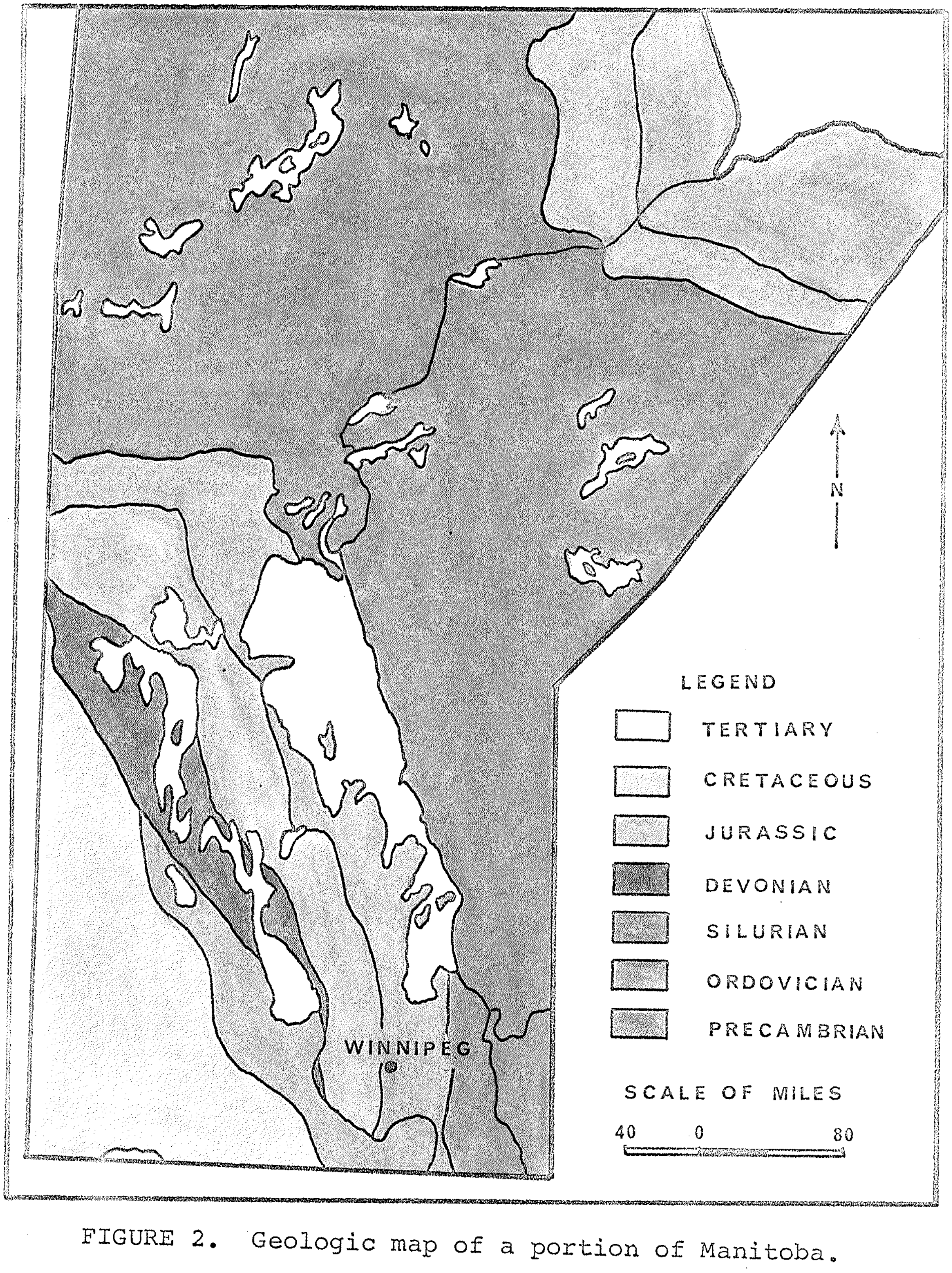

FIGURE 2. Geologic map of a portion of Manitoba.

the Manitoba Lowlands is composed primarily of Cretaceous shales.

A rocky lake country east of the Winnipeg River has a low relief of usually less than 50 feet. The relief is controlled by the character of the bedrock surface as well as by glacial and recent deposits. The area west of the Winnipeg River is mainly a lake plain of the former glacial Lake Agassiz. Locally, the relief is more pronounced where former lake beaches and highland "drift" areas are present. The elevation of the river decreases from a height of 820 feet above sea level at Seven Sisters Falls to a height of 712 feet above sea level at Lake Winnipeg.

SUMMARY OF PREVIOUS STUDIES IN THE LAKE AGASSIZ BASIN

INTRODUCTION

The pioneer explorers who recognized beach structures related to Lake Agassiz include Keating (1825), Owen (1852), Hind (1859), Palliser (1863), Warren (1868) and Dawson (1875). The earliest comprehensive studies of Lake Agassiz were published by Upham (1895), Tyrell (1896) and Leverett (1912). Johnston (1916, 1921, 1934 and 1946) found evidence for the existence of at least two stages of Lake Agassiz. Since 1946, there have been numerous papers published on various aspects of Lake Agassiz and reference to many of these may be found in the publication "Life, Land and Water" (1966). Elson (1957) correlated carbon 14 dates on moraines and beaches with glacial advances and retreats and the formation of

Lake Agassiz I and II.

Elson (1966) described the sediments at the Pine Falls hydro plant as typical of the Pleistocene stratigraphy of the Red River basin. His description will be discussed more fully in Chapter II.

GLACIAL LAKE AGASSIZ

Evidence of Glacial Lake Agassiz is found in an area of approximately 200,000 square miles in the provinces of Saskatchewan, Manitoba and Ontario, and the states of Minnesota, North Dakota and a small portion of South Dakota (Fig. 3). Although the sediments occur within an area of 200,000 square miles, the surface areas of most phases of Lake Agassiz probably did not exceed about 80,000 square miles at any one time (Elson, 1966).

The escarpment that defines the west side of the Lake is known as the Coteau des Prairies in the United States and the Manitoba Escarpment in Canada. It has an elevation 600 to 800 feet higher than the Manitoba Lowlands. High land (approximately 1,000 feet above sea level) at Lake Traverse in Minnesota acted as a southern boundary for the lake. To the east, land with an elevation of approximately 1,300 feet above sea level extends from west of Lake Superior to the western end of Lake Saint Joseph (Zoltai, 1961). Pre-glacial and present drainage was and is to the north in the basin area. During glaciation ice blocked northern and eastern drainage and acted as a lake boundary.

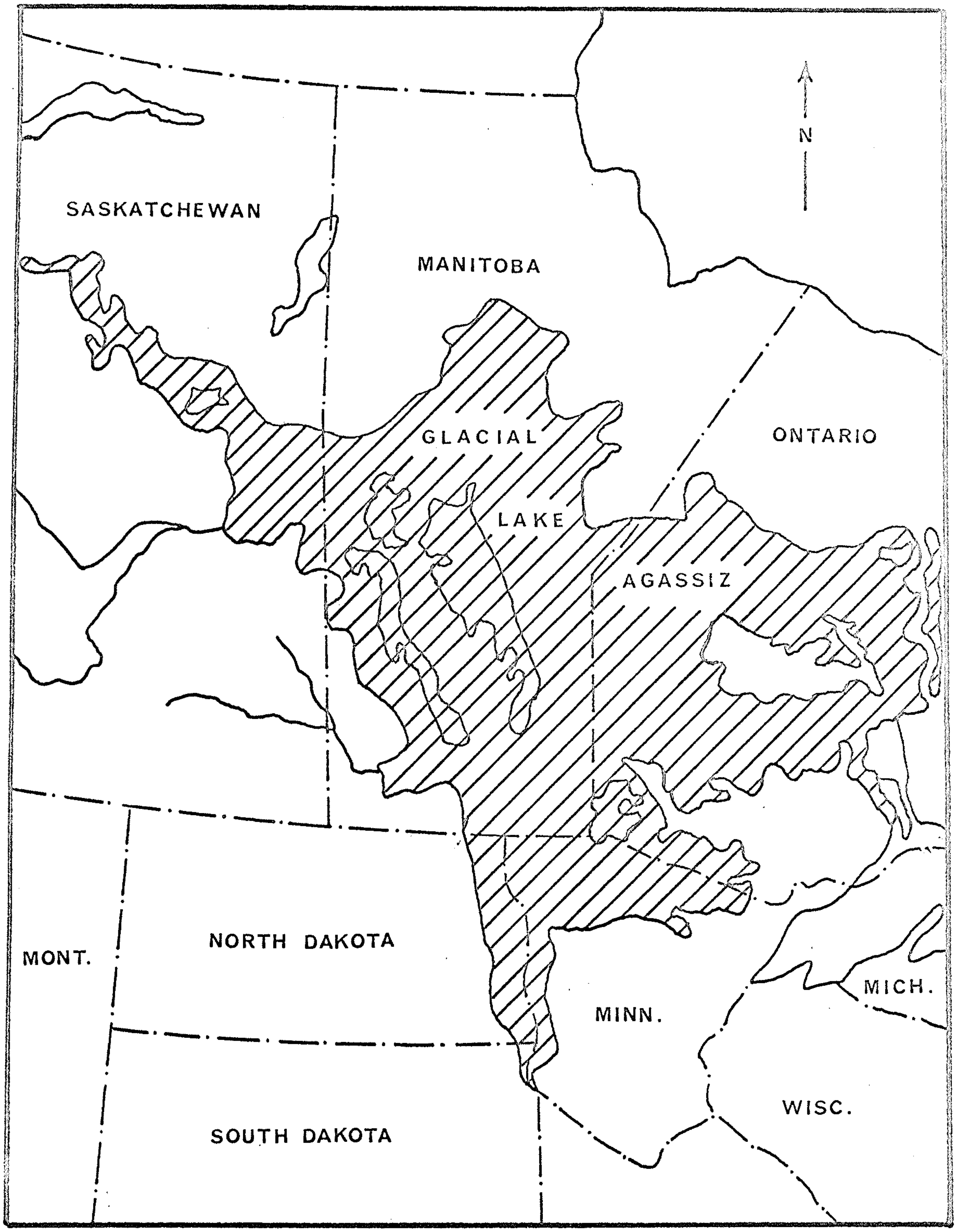

FIGURE 3. Schematic drawing, Glacial Lake Agassiz (After Elson, 1966)

The following summary of the history of Lake Agassiz is modified from Elson (1966) and is shown graphically as a succession of water levels (Fig. 4).

(a) Ice receded from the south end of the Red River basin prior to 11,700 years ago. The Herman phase (I) of Lake Agassiz formed. An increase of discharge of uncertain origin caused the River Warren to erode the southern outlet down to the Norcross level. Ice retreat in Northern Ontario opened an eastern outlet and Lake Agassiz discharged into the Lake Superior basin. The lake level fell to about the Tintah water plane.

(b) Ice readvanced and blocked the eastern outlet. Lake Agassiz rose again to the Norcross level. This phase is called Lake Agassiz II. The lake discharged through the southern outlet until a boulder armour accumulated at the Tintah level (Wright, 1965).

(c) Accelerated melting of the ice sheet caused the ice margin to retreat. The southern outlet was cut down to the Campbell water plane and Lake Agassiz expanded northward.

(d) Recession of the ice sheet north of Lake Superior opened eastern outlets into Lake Superior by way of Lake Nipigon. The level of Lake Agassiz fell to about the Burnside water plane.

(e) An important readvance of the ice margin blocked the most northerly eastern outlets and the water rose to the

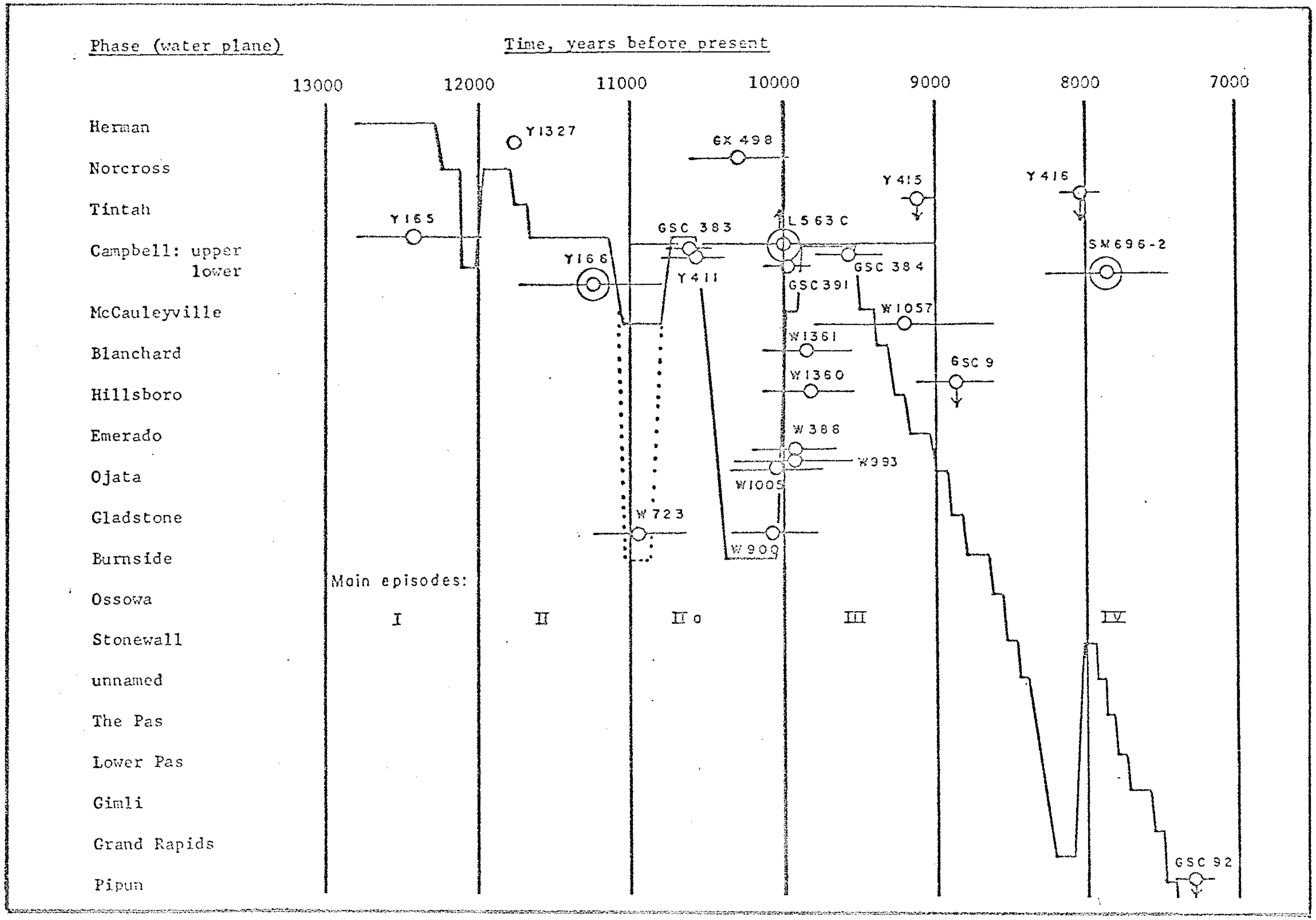

FIGURE 4. Hypothetical sequence of water levels of Glacial Lake Agassiz (after Elson, 1966). The numbers refer to radiocarbon age dates (e.g. G.S.C. 383).

McCauleyville level. Further ice margin advance blocked the remainder of the eastern outlets and the water level again rose to the Campbell strandline (the lower one), and the lake discharged southward. This, the second Campbell phase of Lake Agassiz may have been stable for 200 to 500 years. It was previously referred to as Lake Agassiz II (Elson, 1957) and is now called Lake Agassiz III (Elson, 1966).

(f) Northward retreat of the ice margin west of Lake Nipigon opened a series of successively lower outlets and the level of Lake Agassiz dropped in a series of steps to about the Grand Rapids water plane. At the end of this time, the lake was discharging eastward, probably into glacial Lake Barlow - Ojibway.

(g) An ice readvance in the northeast blocked the outlet through glacial Lake Barlow - Ojibway. Lake Agassiz rose to a level between the Stonewall and the Pas water planes. This phase is called Lake Agassiz IV.

(h) Ice retreat opened eastern outlets and the water level fell to the Gimli strandline. Disintegration of the ice sheet in Hudson Bay opened new lower outlets and the lake level fell in a series of steps to the Pipun water plane.

(i) Wastage of a remnant of the ice sheet lying across the Nelson River valley caused Lake Agassiz to drain into Hudson Bay prior to 7,300 years ago.

ACKNOWLEDGMENTS

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METHOD OF STUDY

FIELD WORK

Field work was carried out during the fall of 1966 and the spring of 1967. The exposed sections of Pleistocene sediments were described, photographed and sampled at selected intervals. The majority of the mapping was done by boat and the remainder was completed by traversing along the banks of the river.

LABORATORY STUDY

Samples from the various units were described with the aid of a hand lens, a binocular microscope and a petrographic microscope.

The qualitative mineralogy of the units was determined by analyses of selected samples. The mineralogy of the larger grain sizes (<2Ø) was determined by microscopic examination and the mineralogy of smaller grain sizes by interpretation of x-ray diffractograms.

Heavy media separation was used to separate heavy minerals from the till to facilitate their identification. Sieve and pipette analyses were performed on selected samples to determine the grain size distribution of the sedimentary units. The acid soluble content of the units was determined by analyses of selected samples.

Detailed descriptions of the procedures used in performing sieve and pipette analyses, x-ray diffraction analyses, heavy media separation, and acid soluble content determinations are given in Appendix A.

CHAPTER II

THE PLEISTOCENE SEDIMENTS OF THE WINNIPEG RIVER (PINE FALLS - SEVEN SISTERS FALLS AREA)

DESCRIPTION OF THE PLEISTOCENE SEDIMENTS

INTRODUCTION

The Pleistocene sediments of the study area can be divided into four sedimentary units (Table 1 and Fig. 5). The sediments were deposited upon Precambrian granites and granite gneisses of the Canadian Shield.

TABLE I

PLEISTOCENE STRATIGRAPHY
(Pine Falls - Seven Sisters Falls Area)

UNIT	THICKNESS	DESCRIPTION
4	0 - 15'	glacio-fluvial and glacio-lacustrine sandy silt
3	0 - 25'	glacio-lacustrine mud
2	0 - 35'	glacio-lacustrine clay
1	0 - 20'	glacial till
	PRECAMBRIAN BEDROCK	

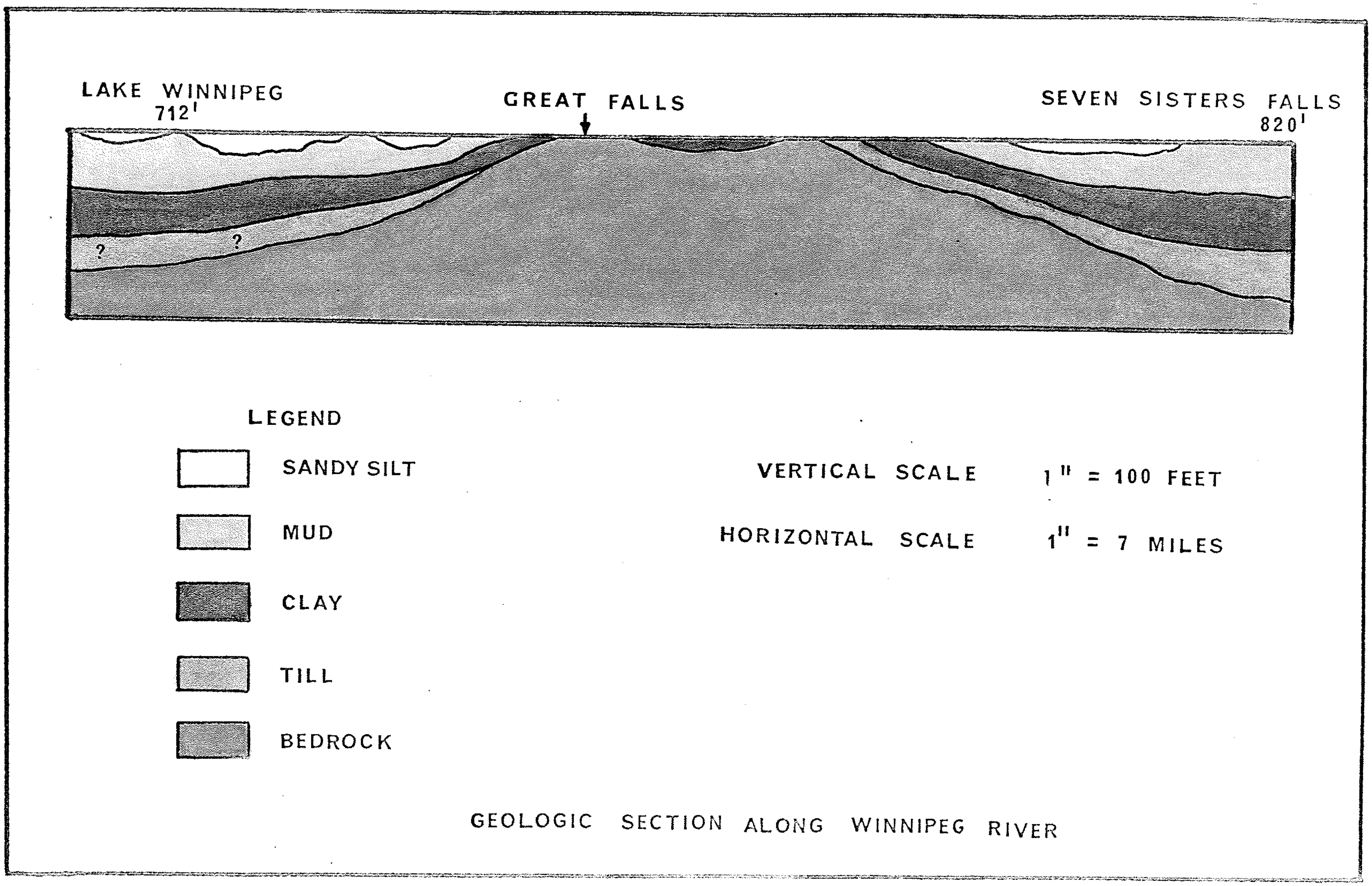

FIGURE 5. Pleistocene stratigraphy of the Winnipeg River (Lake Winnipeg to Seven Sisters Falls)

THE GLACIAL TILL UNIT

GENERAL DESCRIPTION

The extent of the till from Lake Winnipeg to Lac du Bonnet is questionable because it outcrops only in isolated localities. South-east of McArthur Falls, it outcrops in numerous localities. The till lies unconformably upon Precambrian bedrock and is overlain by lacustrine clay. (Fig. 1, Plate 1). The lower contact is exposed only where bedrock highs occur. The average thickness of the till is 10 feet although thicknesses of 20 feet are present. The till is massive and is buff coloured on the weathered surface and light grey on the fresh surface. Red granitic rock fragments are present but constitute less than 2 per cent of the unit. A glacio-fluvial deposit consisting of sandy gravel composed of quartz grains and granitic rock fragment, occurs within the till at the Pine Falls hydro plant. In section, it is approximately 1 to 2 feet thick and 10 feet long (Fig. 2, Plate 1). The till has slumped locally and has been folded and faulted but is less subject to slumping than the other units.

MINERALOGY

The minerial of grade sizes greater than 4Ø consists of carbonate (largely dolomite), and granitic rock fragments, and quartz grains. The mineralogy of the finer grade sizes was determined from x-ray diffractograms. Quartz was identified by its three largest peaks at 3.34A°, 4.26A°, and 1.82A°. Dolomite was identified

PLATE I

Figure 1. Glacial till unit overlain by glacio-lacustrine clay unit.

FIGURE 2. Glacio-fluvial deposit within the till. The till is overlain by varved clay.

by its main peak at 2.89A° and a second peak at 3.04A° and two smaller ones at 2.29A° and 2.10A°. Illite was identified by a small peak 10A° and montmorillonite by a small peak at 14A°. Either kaolin and/or chlorite is present as indicated by a small peak at 7A°. Feldspar was identified by peaks at 3.20A° and 4.04A°. The till contains less than 1 per cent heavy minerals which are in order of abundance amphibole, pyrozene, garnet, magnetite, and apatite. The till is composed mainly of carbonate rock fragments (largely dolomite), calcite and quartz grains with minor amounts of clay minerals, granitic rock fragments, feldspar and heavy minerals.

GRAIN SIZE ANALYSES

Boulders, cobbles, and pebbles constitute less than 1 per cent of the till. Grain size analyses of five samples of till (numbers 1 - 5) are presented in Fig. 6 and Table II. The location of the samples is given on Figure 7. The average statistical parameters of grain size of the till are:

Inclusive Graphic Skewness	= 0.13
Graphic Kurtosis	= 1.55
Inclusive Graphic Standard Deviation	= 2.13
Median	= 1.10
Graphic Mean	= 1.20

The method of calculating these parameters is given in Appendix B.

The till may be classified as a gravelly, muddy

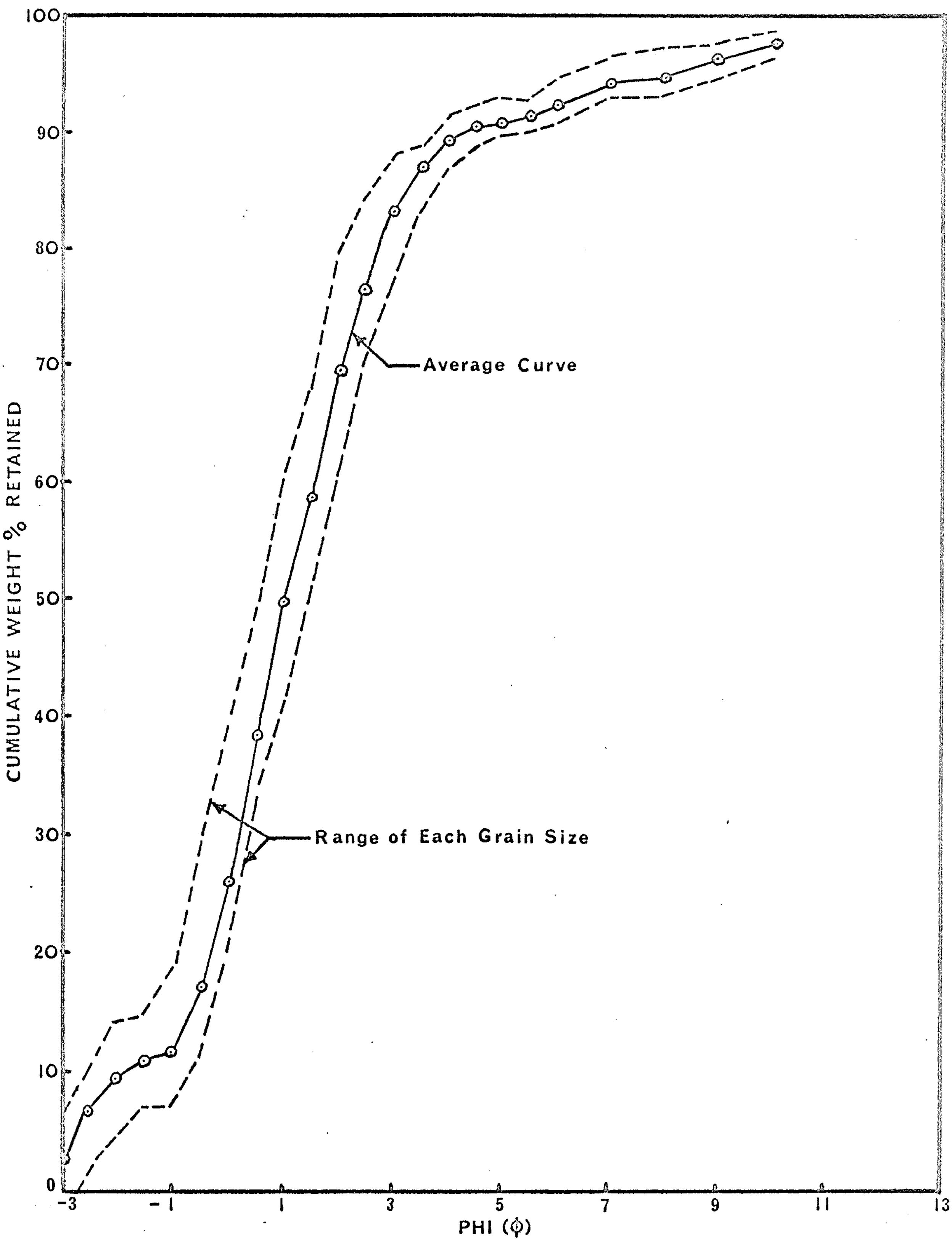

FIGURE 6. Grain size analyses of the till unit.

TABLE II

GRAIN SIZE ANALYSIS OF THE GLACIAL TILL UNIT

(Based on an average of 5 samples)

PHI UNITS	WEIGHT COARSER (GRAMS)	PERCENT COARSER	CUMULATIVE PERCENT COARSER
- 3.0	1.04	1.91	1.91
- 2.5	2.34	4.27	6.18
- 2.0	1.76	3.21	9.39
- 1.5	0.53	0.98	10.37
- 1.0	0.75	1.38	11.75
- 0.5	3.05	5.58	17.33
0	4.93	9.01	26.34
+ 0.5	6.57	12.02	38.36
+ 1.0	6.33	11.58	49.94
+ 1.5	4.74	8.64	58.58
+ 2.0	5.95	10.88	69.46
+ 2.5	3.68	6.75	76.21
+ 3.0	4.18	7.65	83.86
+ 3.5	2.25	4.12	87.98
+ 4.0	0.86	1.58	89.56
+ 4.5	0.62	1.14	90.70
+ 5.0	0.06	0.10	90.80
+ 5.5	0.55	1.00	91.80
+ 6.0	0.44	0.80	92.60
+ 7.0	1.59	2.90	95.50
+ 8.0	0.22	0.40	95.90
+ 9.0	0.27	0.50	96.40
+10.0	0.55	1.00	97.40
+10.0	1.42	2.60	100.00
TOTAL	54.68	100.00	100.00

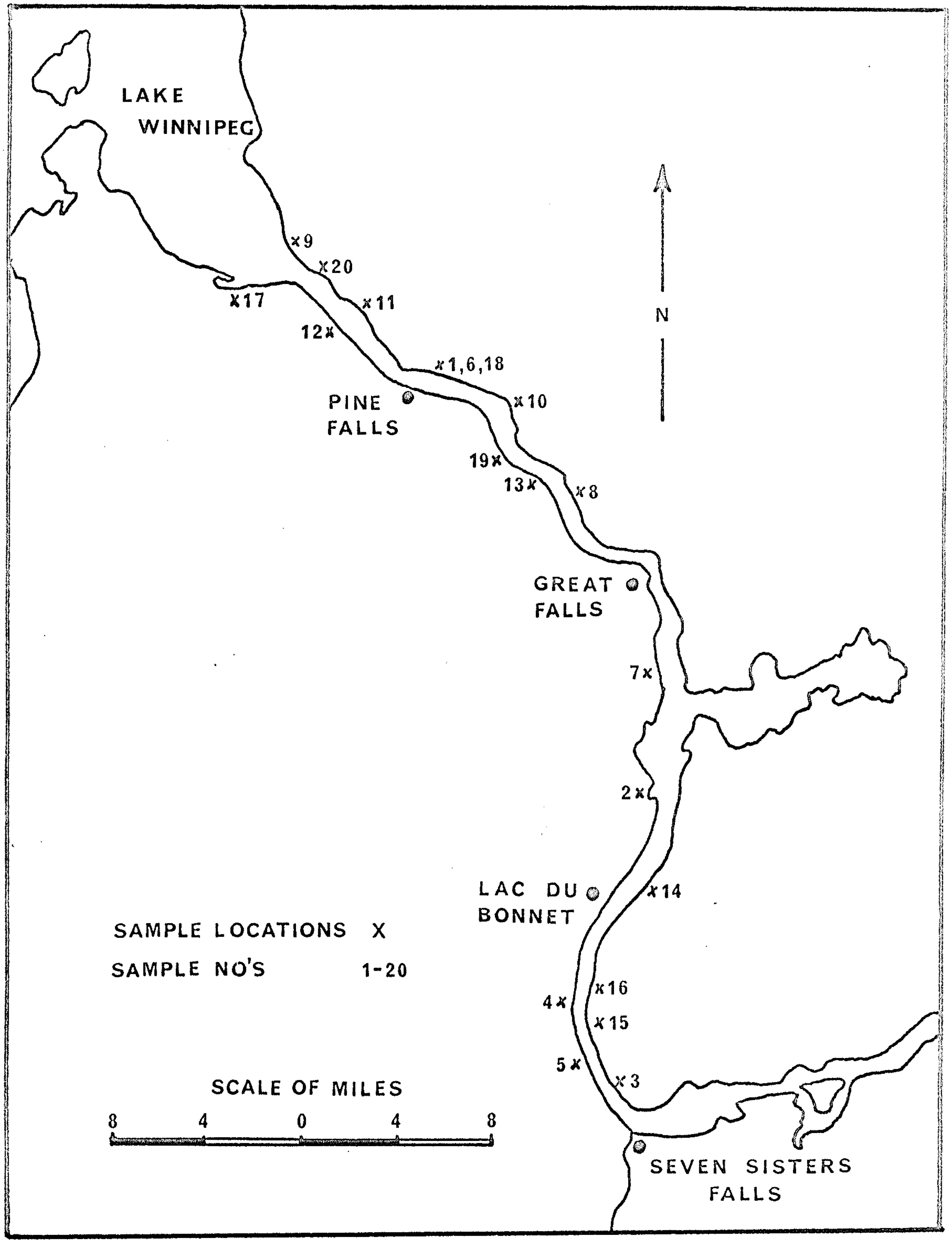

FIGURE 7. Sample locations map.

sand (Folk, 1965). The grain size curve is finely skewed indicating an excess of fine material and very leptokuric indicating that the material in the central portion of the curve is better sorted than the material in the tails, The till may be described as very poorly sorted (Folk, 1965).

ACID SOLUBLE CONTENT

The acid soluble content of the till, based on an average of the five samples is 11.4 per cent.

THE GLACIO-LACUSTRINE CLAY UNIT

GENERAL DESCRIPTION

Except for areas where bedrock highs occur, the clay is present in exposed sections from the mouth of the Winnipeg River to Seven Sisters Falls. The clay has been deposited on the glacial till unit and is overlain by glacio-lacustrine mud. The upper contact of the clay unit is an erosional surface marked by numerous cut and fill structures (Fig. 1, Plate II). Former stream channels have been cut down into the clay and mud has filled the channels. The channels range in size from 6 feet to approximately 250 feet in length and 2 to 5 feet in depth. The clay unit has a maximum thickness of approximately 25 feet but is usually 10 to 15 feet thick. The lower 1 to 2 feet of the clay unit is a glacio-lacustrine deposit consisting of alternating layers of sandy silt and silty clay, each layer having a thickness of 1/2 to 2 inches. The deposit was derived mainly from the till and hence has the

PLATE II

FIGURE 1. Erosional contact between clay unit and overlying mud unit.

FIGURE 2. Silt "pockets" within varved clay.

same mineralogy. The overlying 1 to 2 feet of the clay consists of layers ranging in thickness from 1 to 2 m.m. at the base to 5 m.m. at the top. The layers are alternately grey-brown clay and buff grey silty clay. Above this finely laminated bed is a bed that usually constitutes one-half the thickness of the total unit (0 - 15 feet). Individual layers within this bed number 2 to 3 per inch and consist alternately of buff silty clay and grey-brown clay. The silty layers are usually slightly thinner than the clay layers, are frequently sublaminated, and in isolated localities exhibit vertical graded bedding. The clay layers contain numerous granules and quartz grains. A clayey silt stratum, one-half foot in thickness is present at the Pine Falls hydro plant, but it could not be traced for any appreciable distance. In the bottom half of the clay unit, "silty pockets" or concretions frequently occur which in certain instances constitute up to 5 per cent of the unit. The laminations are deformed or bent around the "silt pockets" (Fig. 2, Plate II). Locally, silt fragments form horizontal lenses of silt breccia with a clay matrix (Elson, 1966). Granitic and carbonate ice rafted erratics are present in the lower portion of the clay unit and usually deform the bedding. The upper half of the clay unit (0 - 15 feet) is usually finely varved with individual laminations of clay and silty clay numbering 10 - 20 per inch (Fig. 8)

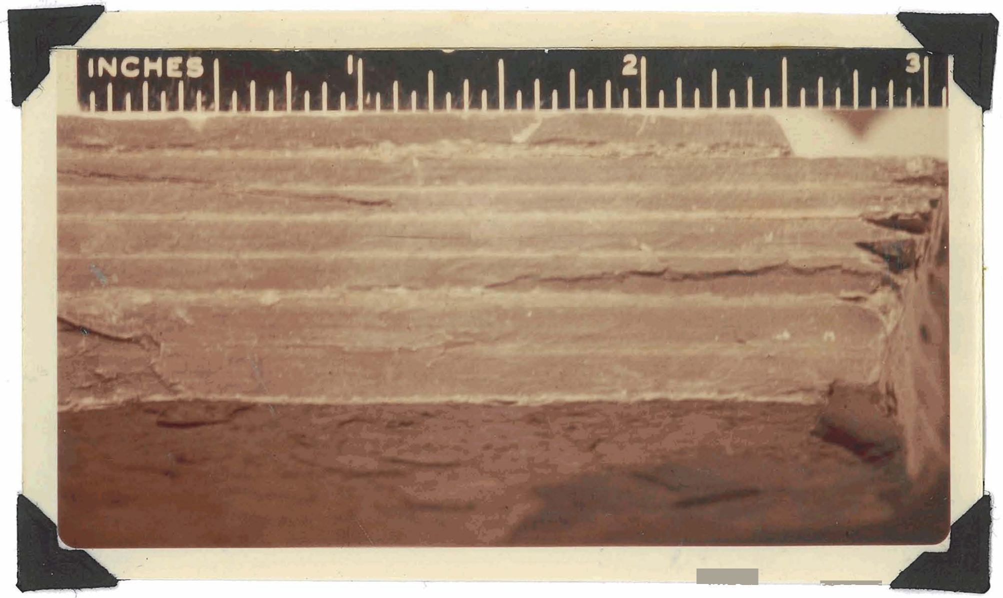

Figure 8. Finely laminated varved clay.

In many places the laminations are so thin that they are impossible to measure. Locally the upper portion of the clay unit appears massive.

MINERALOGY

The only particles that are large enough to identify without x-ray diffraction are boulders, cobbles, and pebbles of granitic and carbonate composition.

Quartz was identified on x-ray diffractograms by its three strongest peaks at 3.34A°, 4.26A°, and 1.82A°. Dolomite was identified by its strongest peak at 2.89A°. Montmorillonite was identified by a broad diffuse peak at approximately 15A°, and possibly a smaller peak at 4.5A°. Illite was identified by a small peak at 10A°. Either Kaolin and/or chlorite is present as indicated by a small peak at 7.17A°. Very small peaks at 1.49A° and 3.58A° also indicate the possibility of kaolin. A very small peak at 3.20A° indicates the presence of a minor amount of feldspar.

The unit is composed mainly of montmorillonite and illite or possibly interlayered montmorillonite illite, dolomite, and quartz, with minor kaolin and/or chlorite, and perhaps minor feldspar. Quartz and dolomite predominate in the silty layers and clay minerals in the clay strata or laminations. The "silt pockets" are composed mainly of dolomite, with minor quartz and clay minerals.

GRAIN SIZE ANALYSES

Grain size analyses were performed on five samples (numbers 5 - 10) of the clay unit. The sample locations are given in Figure 7, and the analyses in Figure 9 and Table III. The samples analyzed contained both silty clay and clay because the individual layers could not be separated accurately. Because of the difficulty in obtaining accurate grain size analyses of clay size particles, the grain size parameters were not calculated. The only purpose the analyses serve, therefore, is to indicate the approximate percentages of silt and clay. The unit is classified as a clay (Folk, 1965). It was estimated that 10 - 25 per cent of the clay is colloidal.

ACID SOLUBLE CONTENT

The acid soluble content of the clay based on an average of the 5 samples is 2.1 per cent.

THE GLACIO-LACUSTRINE MUD UNIT

GENERAL DESCRIPTION

The mud unit is exposed in most localities but

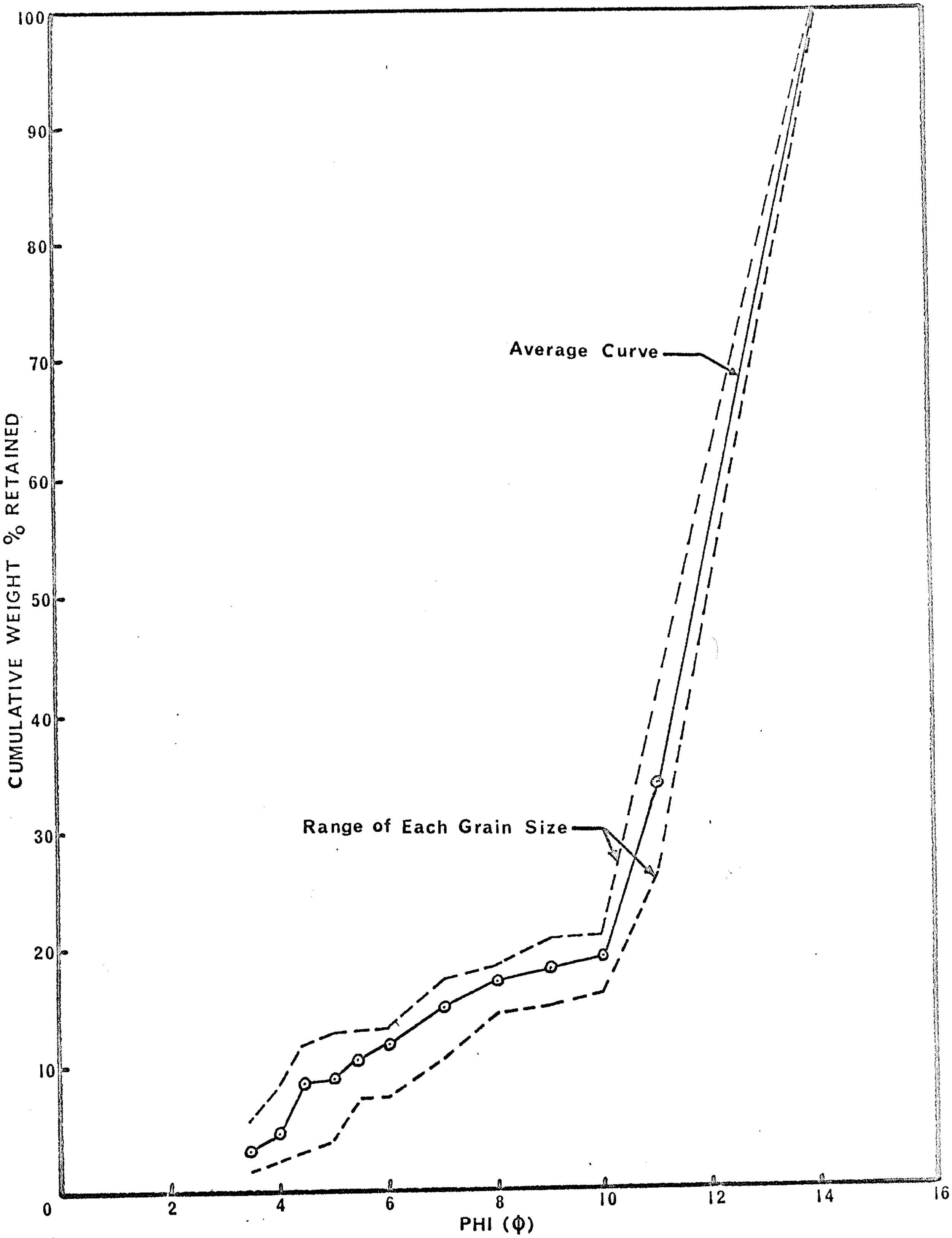

FIGURE 9. Grain size analyses of the clay unit.

TABLE III

GRAIN SIZE ANALYSIS OF THE CLAY UNIT
(Based on an average of 5 samples)

PHI UNITS	WEIGHT COARSER (GRAMS)	PER CENT COARSER	CUMULATIVE PERCENT COARSER
ϕ 3.5	0.50	3.01	3.01
ϕ 4.0	0.21	1.26	4.27
ϕ 4.5	0.74	4.47	8.74
ϕ 5.0	0.03	0.17	8.91
ϕ 5.5	0.21	1.28	10.19
ϕ 6.0	0.33	1.99	12.18
ϕ 7.0	0.45	2.74	14.92
ϕ 8.0	0.29	1.78	16.70
ϕ 9.0	0.28	1.72	18.42
ϕ10.0	0.17	1.00	19.42
ϕ11.0	2.50	14.91	34.33
ϕ11.0	10.88	65.67	100.00
TOTAL	16.79	100.00	100.00

is absent locally due to erosion on bedrock highs. The mud was deposited upon the undulatory drying surface of the clay. The mud is overlain by the sandy silt unit in certain localities (Fig. 1, Plate III) and by the soil profile in other localities (Fig. 2, Plate III). In certain areas, the upper contact is an undulatory erosion surface with 2 to 5 feet of relief and in others it is essentially flat lying and does not appear to have undergone extensive erosion. Where the relief on the contact is greatest, cut and fill structures formed by former streams are present. The mud unit is 25 feet thick locally but the average thickness is approximately 10 feet.

The basal 1 to 5 feet of the mud unit consists of alternating layers of grey mud and buff fine sand. The mud layers are 1 to 2 inches thick and the sand layers less than 2 m. m. The central portion of the mud unit (2 - 15' thick) consists of alternating layers of silt and silty clay usually 0.5 to 1 inches in thickness. The upper portion of the unit (2 - 10 feet) appears massive in most localities but has a faint indication of bedding. It consists of a buff coloured mud. The mud exhibits a good parting parallel to the bedding and weathers with a characteristic blocky structure that has been called a "nuggety structure" by Wicks (1965) (Fig. 1, Plate IV). Slumping of the river banks has folded and faulted the mud in numerous localities.

Concretions occur in the coarse grained layers of

PLATE III

FIGURE 1. The mud unit overlain by the sandy silt unit.

FIGURE 2. The mud unit overlain by the soil profile.

the laminated portions of the mud unit. Their longest dimension is always parallel to the bedding. The concretions, consisting mainly of dolomite and minor amounts of calcite, are generally a combination of ring and septarian concretion, although irregular shaped ones are not uncommon. (Fig. 2, Plate IV). They are seldom greater than 2 inches in diameter and average approximately 1 inch in diameter.

MINERALOGY

All the mineralogy was determined by x-ray diffractograms because of the fine grain size of the sediment. Quartz was identified by its main peaks at 3.34A°, 4.26A° and 1.82A°. In addition four small quartz peaks were identified. Dolomite was identified by its main peaks at 2.89A°, 2.19A° and 1.97A°. Montmorillonite was identified by a small peak at 15A° and illite by a small peak at 10A°. Kaolin and/or chlorite is present as is indicated by a small peak at 7.19A°. Feldspar, likely andesine, was identified by peaks at 3.18A°, 3.12A° and 4.04A°. The unit consists mainly of dolomite and quartz grains but also contains minor amounts of feldspar and clay minerals. The clay mineral content is highest where the unit is well laminated. It should be noted that diffractograms of samples from the massive portion of the unit from widely separated localities are similar in appearance. This indicates that except where the unit is laminated, it has a uniform mineralogy and the minerals are in the same relative proportions.

PLATE IV

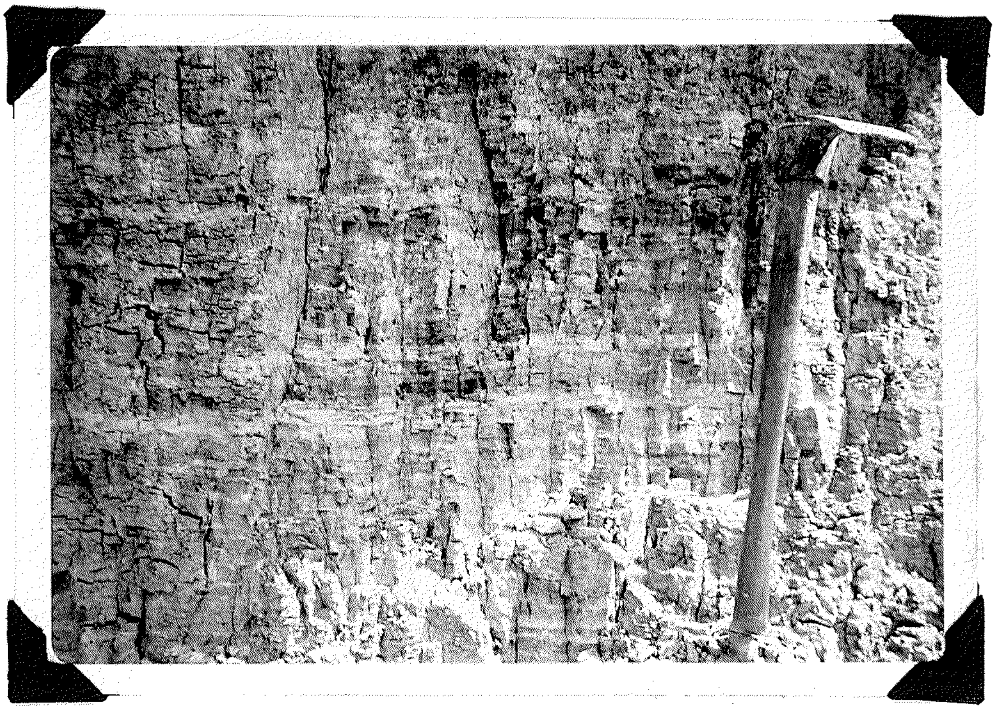

FIGURE 1. "Nugget structure" on the weathered surface of the mud unit.

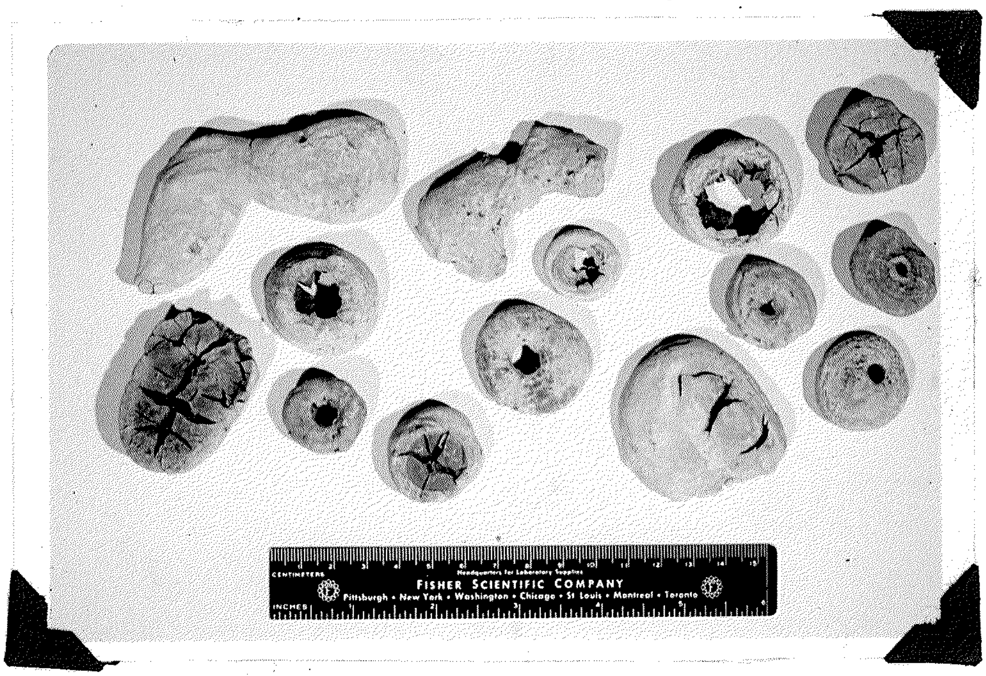

FIGURE 2. Concretions from the mud unit.

GRAIN SIZE ANALYSES

Grain size analyses of five samples (numbers 0 - 15) of the massive portion of the unit are given in Fig. 10 and Table IV. Sample locations are given in Fig. 7. The statistical parameters of grain size are:

Inclusive graphic Skewness	= 0.55
Graphic Kurtosis	= 1.27
Inclusive Graphic Standard Deviation	= 1.48
Median	= 6.30
Graphic Mean	= 6.35

TABLE IV

GRAIN SIZE ANALYSIS OF THE MUD UNIT
(Based on an average of 5 samples)

PHI UNITS	WEIGHT COARSER (GRAMS)	PERCENT COARSER	CUMULATIVE PER CENT COARSER
ϕ 3.0	0.04	0.23	0.23
ϕ 3.5	0.21	1.41	1.64
ϕ 4.0	0.79	5.16	6.80
ϕ 4.5	0.98	6.40	13.21
ϕ 5.0	0.47	3.07	16.28
ϕ 5.5	0.52	3.44	20.72
ϕ 6.0	1.29	8.40	29.20
ϕ 7.0	4.85	31.70	60.90
ϕ 8.0	0.84	5.50	66.60
ϕ 9.0	1.49	9.80	76.40
ϕ10.0	1.97	12.90	89.30
ϕ10.0	1.65	10.70	100.00
TOTAL	15.10	100.00	100.00

The unit is poorly sorted mud but is close to the boundary between mud and silt (Folk 1965). The average grain size curve is strongly, fine skewed indicating an excess of fine material, and leptokurtic indicating the material in the central portion of the curve is better

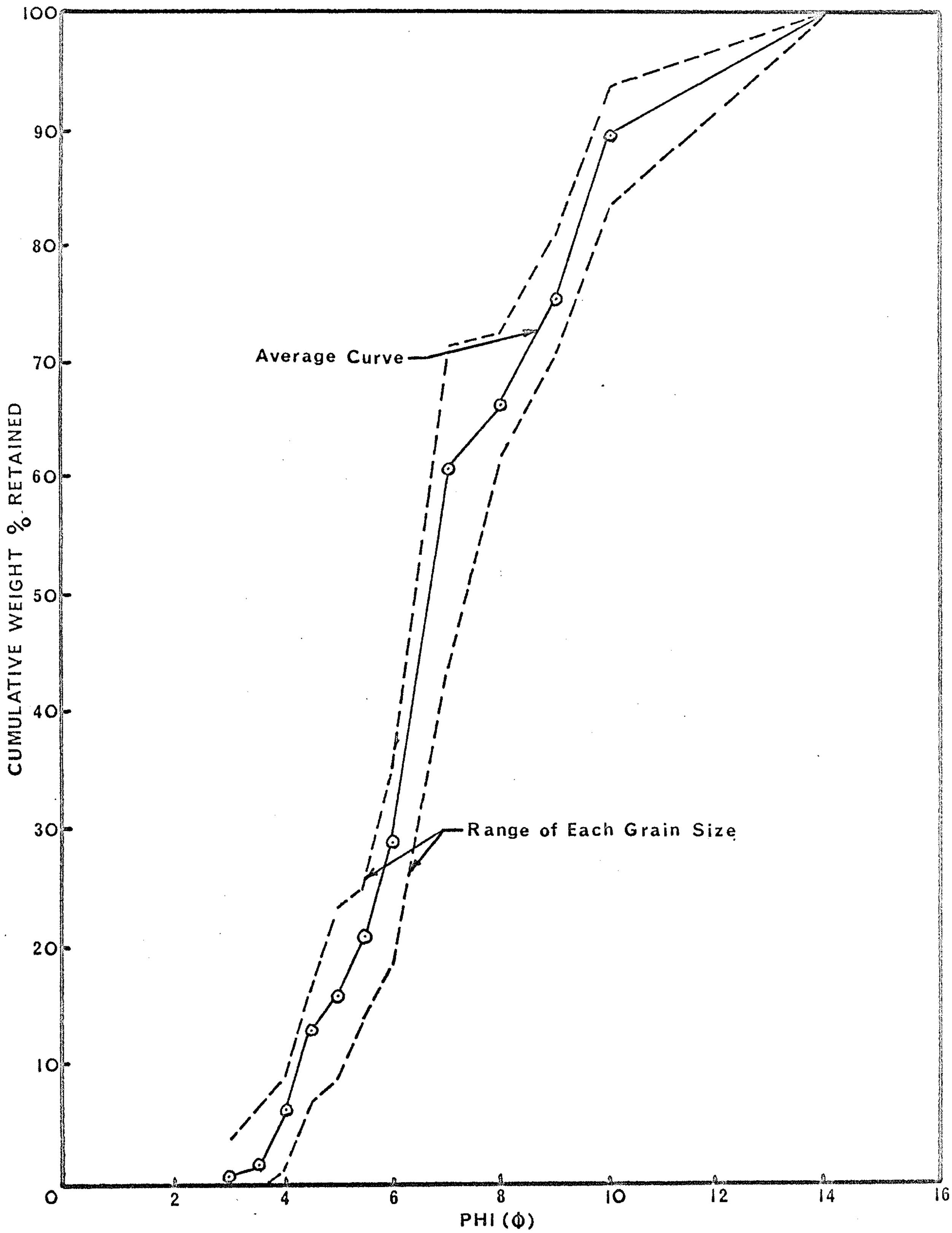

FIGURE 10. Grain size analyses of the mud unit.

sorted than the material in the tails.

ACID SOLUBLE CONTENT

The acid soluble content of the mud unit based on an average of the 5 samples is 6.5 per cent.

THE GLACIO FLUVIAL AND GLACIO-LACUSTRINE SANDY SILT UNIT

GENERAL DESCRIPTION

The sandy silt unit occurs from Lake Winnipeg to Pine Falls and from Lac du Bonnet to Seven Sisters Falls but is not as widely distributed as the other units. The sandy silt was deposited upon the mud unit and the contact between the two is undulatory. There appear to be former stream channels or cut and fill structures along the contact in certain localities. The upper surface of the sandy silt is an erosion surface that is covered by a soil profile which is approximately 1 foot thick. The sandy silt is commonly less than 3 feet thick but in depressions is 10 to 15 feet thick. It is massive where it is thinnest (Fig. 1, Plate V) but exhibits bedding in thicker sections. When bedding is present, it consists of alternating layers of brown silty clay and buff silty sand. The layers number from 1/2 to 10 per inch but average 2 per inch. One particular layer in isolated localities is approximately 1 1/2 feet thick and consists of cross-bedded silty sand (Fig. 2, Plate V). Cross-bedding and vertical graded bedding is present in many of the thinner sandy layers as well. The direction of the cross bedding in different sections is variable and no definite trends

PLATE V

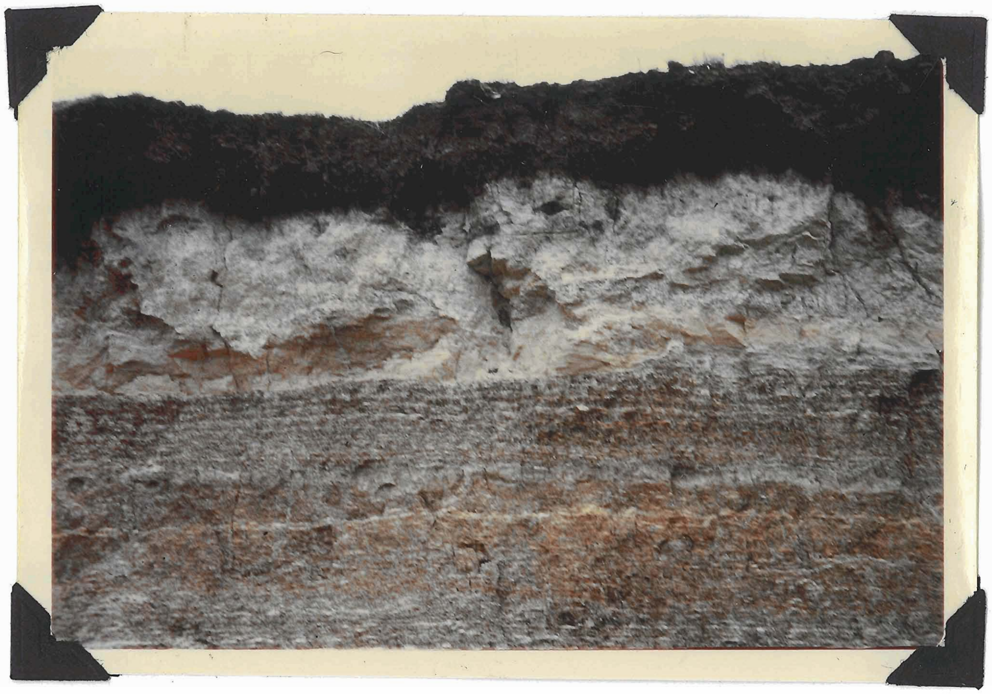

FIGURE 1. Massive sandy silt overlying the mud unit.

FIGURE 2. Cross bedding in the sandy silt unit. (Engineer's scale 1 foot long)

could be determined.

MINERALOGY

Sand grains, identified by microscopic examination are composed of quartz and dolomite. The remainder of the sediment was identified by x-ray diffraction. Quartz was identified by its main peaks at 3.34A°, 4.26A° and 1.82A°, although several smaller peaks were observed. Dolomite was identified by its three main peaks at 2.09A°, 2.19A°, and 1.79A°. Calcite was identified by peaks at 3.04A°, 2.29A°, and 2.10A°. Feldspar was identified by a small peak at 3.04A°. A small peak at 14A° indicates the presence of a minor amount of montmorillonite. A peak at 7.10A° is due to Kaolin and/or chlorite. The sandy silt consists mainly of dolomite and quartz and contains minor amounts of calcite, feldspar and clay minerals.

GRAIN SIZE ANALYSES

Grain size analyses of 5 samples (numbers 15 - 20) from the massive portion of the unit are given in Fig. 11 and Table V. The locations of the samples are given in Fig. 7.

The statistical parameters of grain size are:

Inclusive Graphic Skewness	=	-0.05
Graphic Kurtosis		4.09
Inclusive Graphic Standard Deviation	=	0.10Ø
Median	=	4.20Ø
Graphic Mean	=	4.17Ø

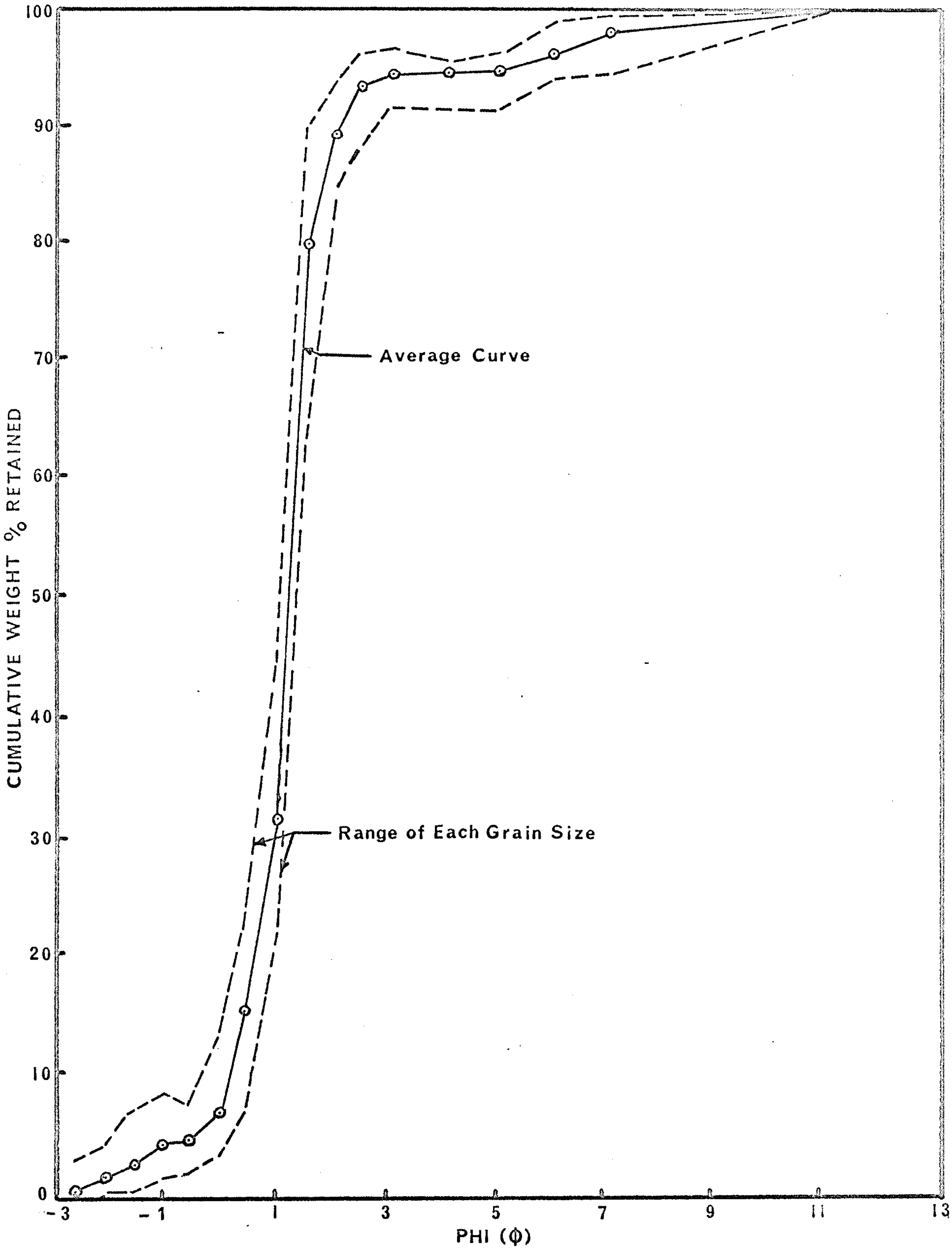

FIGURE 11. Grain size analyses of the sandy - silt unit.

TABLE V

GRAIN SIZE ANALYSIS OF THE SANDY SILT UNIT
(Based on an average of 5 samples)

PHI (Ø)	WEIGHT COARSER (GRAMS)	PERCENT COARSER	CUMULATIVE PERCENT COARSER
+ 0.5	0.07	0.39	.39
+ 1.0	0.20	1.19	1.58
+ 1.5	0.21	1.28	2.86
+ 2.0	0.20	1.17	4.03
+ 2.5	0.12	.74	4.77
+ 3.0	0.47	2.80	7.57
+ 3.5	1.31	7.78	15.35
+ 4.0	2.78	16.70	32.05
+ 4.5	8.01	47.95	80.00
+ 5.0	1.51	9.00	89.00
+ 5.5	0.47	4.40	93.40
+ 6.0	0.15	0.90	94.30
+ 7.0	0.02	0.10	94.40
+ 8.0	0.03	0.20	94.60
+ 9.0	0.39	2.30	96.90
+10.0	0.10	0.60	97.50
+10.0	0.42	2.50	100.00
TOTAL	16.73	100.00	100.00

The unit is a moderately sorted sandy silt (Folk, 1965). The grain size curve is nearly symmetrical and extremely leptokurtic indicating that the material in the central portion of the curve is better sorted than the material in the tails.

ACID SOLUBLE CONTENT

The acid soluble content of the unit based on an average of the 5 samples is 3.6 per cent.

SEDIMENTOLOGY OF THE PLEISTOCENE SEDIMENTS

INTRODUCTION

In this section, observable features such as the colour of the sediments, "silt pockets", concretions "nugget structure", glacio-fluvial deposits and varves will be discussed. This will be followed by a discussion of each of the four sedimentary units.

OBSERVABLE FEATURES IN THE SEDIMENT

COLOUR

Weller (1960) states that the colour of a sediment is controlled by several factors. The intrinsic colour of the minerals and rock fragments of which the sediment is composed affects its colour. The finer the grain size, the closer the packing of grains and the greater the abundance of organic matter the darker the colour of the sediment. The oxidation state of the iron content in a sediment controls its colour; ferrous iron producing a blue to grey colour, and ferric iron a yellow or brown. The Tyndall limestone of Manitoba exhibits a blue colour due to ferrous iron and a buff colour due to ferric iron (Shephard, 1931).

The buff colour of the glacial till on the weathered surface and the grey colour of the fresh surface is believed due to the presence of ferric and ferrous iron respectively. The high carbonate content of the till contributes to its light colour as does the low organic matter content, the variable grain size, and the "loose" packing.

The varved clay unit is lighter grey on the weather surface than the fresh surface due to the oxidation of ferrous iron to ferric iron. Increased carbonate content and the coarser grain size of the silty layers of the varves produces a lighter colour than is exhibited by the clayey layers. Organic matter in the clay tends to darken its colour.

The buff yellow colour of the silt mud unit is controlled primarily by the abundance of dolomite which likely contains ferric iron. In describing a similar type of sediment near Fargo, Dennis, Akins and Worts (1949) stated "the yellow to buff colour is believed to be the product of weathering wherein the iron compounds in the deposit have been oxidized". The coarser grain size, the lesser the degree of compaction, and the lack of an appreciable amount of organic matter tend to lighten the colour of the mud as compared to the varved clay.

The yellow to buff colour of the sandy silt unit is controlled mainly by the intrinsic colour of the dolomite and quartz grains. The larger grain size and loose packing tends to lighten the colour as does the low percentage of organic matter. The presence of clay minerals darkens the sandy silt locally to a grey brown.

THE "SILT POCKETS"

There appear to be two possible origins for the "silt pockets" found in the varved clay. Wicks (1965) believes that they were frozen particles of till that were carried out into Lake Agassiz by streams or ice rafting. The till settled and was embedded in the soft clay of the lake bottom and maintained its shape upon thawing. Penecontemporaneous differential compaction would result in the overlying clay layers being bent around the "pockets" (Hills, 1963). It is also possible that the silt pockets are concretionary. Weller (1960) states that these types of concretions are quite common in shales and muds. He believes that they originate fairly early in the history of the sediment when it has a high porosity. The concretions form from solutions and become surrounded by compacted laminae that bend sharply and completely around them. This is observed to be the case (Fig. 2, Plate III). The writer prefers the first origin because similar types of clastic particles form a silt breccia with a clay matrix in certain localities within the clay unit (Elson, 1966).

CONCRETIONS

It is not known whether the dolomite concretions were formed prior to deposition of the mud unit and were carried into the lake as clastic particles, or whether they were formed within the mud unit. They are always found in the most permeable layers which would allow solutions to move more freely. However, the most permeable layers also contain the largest grain size material and if concretions were carried into the lake with the sediment, they would tend to concentrate in the coarse grained layers. The ring type concretions may have originally formed around tree stems. The cracks in the septarian type concretions are believed to develop at an early stage as a result of partial dehydration of material in the colloidal state

(Weller, 1960). Similar types of concretions are quite common in varved sediments but usually have an abundance of calcite with respect to dolomite (Warkentin, 1967). Burwash (1983) believes that the irregular shaped concretions form around nucleii when carbonate precipitates as a result of increased temperature of the water during the summer.

"NUGGET" STRUCTURE

The "nugget" structure or blocky weathering of the mud unit is thought to be the result of the dehydration of clay minerals with the subsequent formation of small scale columnar jointing either by evaporation and/or freezing (Wicks, 1965).

THE GLACIO-FLUVIAL DEPOSITS WITHIN THE TILL

The glacio-fluvial deposits in the till are believed to have been deposited by streams emerging from crevasses in the face of the ice sheet (Dennis, Akins and Worts, 1949). Similar features found within Lake Agassiz sediments in Minnesota are ice contact and outwash deposits (Winter, 1966).

VARVES

DeGeer (1912), the initiator of varve studies, suggested that varves were deposited by meltwater bottom-flows in glacial lakes. In North America, however, the view that the transportation of sediments took place near the surface of the water has been advocated by Antevs (1925, 1951) and Flint (1957). Kuenen (1951) proposed turbidity currents as the cause of glacial varves by pointing out that the sediment laden meltwater issuing from waning glaciers must have been heavier than the clear lake water and consequently must have followed the bottom of glacial lakes and did not rise to the surface. This hypothesis is further supported by the fact that field observations of stream flow into Lake Mead (Gould 1951) and Lake Hazen (Deane, 1958) demonstrates that sediment laden streams do plunge beneath the surface of the lake and continue along the bottom as turbid bottom flows.

Advocates of the hypothesis that the sediment flows out along the water surface believe that this phenomenon is due to the stream water being warmer and hence less dense. This causes it to flow out over the denser colder lake water facilitating the spreading of the sediment. This would not be true if the streams were carrying glacial meltwater from a near ice mass. Burwash (1938) suggested that the CO_2 content of the water is important by pointing out that cold water has a greater capacity for the solution of gases. Thus a cold lake could hold more CO_2 in solution than a warm lake. During the winter months, a lake would be more acidic and be able to hold carbonates in solution; however, as the lake warmed in the summer, CO_2 would be released and calcium carbonate would be precipitated. Depth of water is believed to control the formation of varves. If the water is shallow and subjected to wave action any varves that may be forming would be destroyed. Lake Louise, Alberta, where varves are forming at the present time is approximately 180 feet deep (Flint 1957). Lake Agassiz I sediments at Winnipeg that were deposited in water greater than 150 feet deep are not varved (Wicks 1965). Lake Agassiz II (Elson's Agassiz IV) sediments that are varved were deposited in water approximately 350 feet deep (Wicks, 1965).

Another factor that may effect varve formation is unusual concentrations of salts which would act as electrolytes, causing grains to flocculate.

Flint (1957) states that varves consist of a coarse grained member, dominantly silt, and a finer grained member, dominantly fine silt and clay, and that graded bedding and sublaminations frequently occur in the coarse grained member. This was observed to be the case in the varved sediments studied. The sublaminations are due to sudden influxes of sediment. The carbonate content was higher in the coarse grained members but this is due to the coarse grained members being mainly carbonate rock fragments or grains. The coarser varves are believed to form when the ice margin is relatively nearby and is capable of supplying large amounts of sediment. The finer varves likely form in deep water at a time when the ice margin is father from the sedimentary area.

Because of the uncertainty of the mechanism of varve formation, and whether each couplet represents one year of sedimentation or only a sudden influx of sediment, no attempt was made to correlate varves. In addition, the lake sediments are time transgressive because they are at considerably different elevations in different parts of the area and were deposited in both transgressing and regressing states of Lake Agassiz.

THE GLACIAL TILL UNIT

The till is believed to have been deposited by ice which advanced from the north-west or west of the area, passing over Paleozoic carbonates (Fig. 2) because it contains an abundance of dolomitic and limestone rock fragments. The quartz grains and granitic rock fragments are of local provenance having been derived from Precambrian rocks and possibly the Winnipeg Sandstone. The source of the clay minerals is likely the Cretaceous and Jurassic shales with minor contributions coming from shale at the top of the Winnipeg Formation and weathering of Precambrian rocks. The till unit is similar to the deposits of till in the Winnipeg area (Wicks, 1965) but contains more granitic rock fragments.

The 1 to 2 foot gradational contact between the till and the overlying clay unit is a glacio-lacustrine deposit of Lake Agassiz III that formed when the ice mass was nearby and supplied abundant till as source material.

THE GLACIO-LACUSTRINE CLAY UNIT

This unit was originally thought to have been deposited in Lake Agassiz I (Wicks 1965). Elson (1966) proposed a new classification scheme which divides Lake

Agassiz into 5 stages (Fig. 4) the varved clay being a Lake Agassiz III deposit.

The source of the clay minerals was likely the Cretaceous and Jurassic shales with minor contributions coming from the Winnipeg Formation and weathering of Precambrian rocks. There is a marked similarity between the mineralogy of the Cretaceous shales and the varved clays in Winnipeg (Wicks, 1965). Minor contributions from the Paleozoic and Precambrian rocks explain the presence of dolomite, feldspar and quartz.

Several ice margin advances and retreats may be inferred from the character of the varved clay unit. The lower 1 - 2 feet of finely laminated clay suggest a remote source or a small supply of sediment, probably an ice margin retreat. A long episode of abundant sediment followed which deposited the coarsely layered portion of the unit. This period of abundant sediment may have been caused by a decrease in water level which permitted shore erosion to take place. The silty clay stratum found within the lower half of the clay unit at the Pine Falls hydro plant that is approximately 1/2 foot thick was likely deposited by a turbidity current of local extent. The upper portion of the unit which is finely varved and almost massive in certain localities was deposited in deep water at a time when the ice margin was remote. After deposition of the clay unit, the water level declined rapidly and the surface of the clay unit was eroded either subaerially or in shallow water by stream and wave action.

Erosion is indicated by the numerous cut and fill structures along the contact. A subaereal erosion episode is preferred by the writer because consolidation tests on the varved clay in the Winnipeg area indicate a previous drying interval (Baracos, personal communication)[1]

THE GLACIO-LACUSTRINE MUD UNIT

The main source of the carbonate mud was the Paleozoic carbonates with minor contributions of quartz and feldspar coming from the Precambrian rocks, and clay minerals from the Cretaceous and Jurassic shales.

An initial rise of water level with the subsequent formation of Lake Agassiz IV occurred after the period of erosion of the varved clay unit. Water level rise was likely caused by an advance of ice which blocked eastern outlets. The lower sandy portion of the unit was deposited in shallow water and as the water level rose the mud and silty clay was deposited.

The almost massive nature of the upper portion of the mud unit suggests a remote ice margin.

THE GLACIO-FLUVIAL AND GLACIO-LACUSTRINE SANDY SILT UNIT

The major source areas for the sandy silt were the Paleozic carbonates, the Precambrian granites and the sandstones from the Winnipeg Formation. Minor amounts of clay minerals were derived from Cretaceous and Jurassic shales. The low contact is an erosion surface indicating that after the deposition of the mud unit the water level

1 A. Baracos, Civil Engineering Department, The University of Manitoba.

dropped considerably subjecting the mud to either wave action or subareal erosion. The sandy silt unit was deposited in relatively shallow, quite water, possibly due to delta construction and/or offshore processes. Evidences to suggest this are numerous stream channels that are filled with sand and the variable trend of cross bedding. Elson (1966) suggested the possibility of a minor rise in water level at the end of the deposition of sandy silt to account for the relatively flat lying upper surface of the unit. As northward drainage was instituted the level of Lake Agassiz IV dropped and a soil profile was developed upon the sandy silt.

CHAPTER III

GEOLOGIC HISTORY OF THE PLEISTOCENE SEDIMENTS

INTRODUCTION

During the Pleistocene Epoch, there were four major stages of glaciation in North America. These were from oldest to youngest, the Nebraskan, Kansan, Illinoian, and Wisconsin stages (Flint, 1957). Glacial deposits in the study area are indicative only of the Wisconsin stage (Elson, 1966). The Wisconsin stage may be subdivided as follows:

WISCONSIN STAGE	(Valders glaciation? (Mankato glaciation? (Two Creeks interstadial (Cary glaciation (Tazewell glaciation (Peorian interstadial (Iowan glaciation

The four major centres of ice accumulation during Pleistocene time were the Cordilleran, the Labradorian, the Keewatin and the Patrician. Ice advances in the study area originated from the Keewatin centre, situated north west of the area, and the Patrician centre, situated north east of the area.

CORRELATION OF GLACIAL ADVANCES AND RETREATS WITH LAKE AGASSIZ SEDIMENTS IN THE STUDY AREA

Little work has been done in the immediate area to determine the extent of advances and retreats of ice. However, much of the evidence of earlier advances has been destroyed by later advances of ice. In the upper Whitemouth River area, Johnston (1921) noted evidence of two till sheets, the older being deposited by an ice advance from the northeast and the younger by an advance from the west or northwest. The till exposed along the Winnipeg River is believed to be associated with this second advance. A large moraine near the southeast shore of Lake Winnipeg composed mainly of granitic material is likely associated with a north-easterly advance of ice. It could possibly be an interlobate moraine associated with the confluence of northwesterly and northeasterly advancing ice lobes. Striations at Great Falls and Lac du Bonnet trend approximately N45°E indicating an ice advance from the northeast. It is believed that they are associated with the same advance that deposited the large granitic moraine. If they were formed by a later ice advance from the northeast there should be evidence of over-riding of the sediments along the river and at least scattered evidence of a second granitic till sheet. Zoltai (1961) determined the glacial history of a part of Northwestern Ontario situated immediately east of the study area. He concluded that in that area, the first advance came from the Northwest (Keewatin centre). Evidence for this advance consists of calcareous oxidized till and glacial striae. The second advance of ice came from the northeast (Patrician centre). This advance is indicated by glacial striae and granitic till termed "red drift". The third advance of ice came from a westerly direction spreading calcareous till over the area. The final advance of ice came from the northeast (Patrician Centre). It is not known whether the ice front reached as far south as the Winnipeg River.

Based on the evidence presented above, Elson's history of Lake Agassiz (1966), and the study of the sediments along the Winnipeg River, the following sequence of events is suggested as a possible glacial history of the area:

(a) Ice advanced into the area from the northwest (Zoltai, 1961).

(b) Ice advanced from the northeast depositing the granitic moraine near Lake Winnipeg. It should be noted that between advances early stages of Lake Agassiz were present in the area but all evidence of them was destroyed by later ice advances. Evidence for these earlier stages of Lake Agassiz is present in adjacent areas (Elson, 1966).

(c) Ice advanced from the west or northwest depositing the carbonate till found along the river.

(d) Lake Agassiz III (Elson 1966) formed upon the till and 1 to 2 foot thick glacio-lacustrine deposit which constitutes the gradational contact between the till and clay units was deposited.

(e) As the ice margin retreated, the lower 1 to 2 feet of finely laminated varved clay was deposited. A fluctuation of lake level caused a more rapid influx of sediment and the coarsely laminated portion of the varved clay unit was deposited. As the ice margin retreated the finely laminated varved clay was deposited.

(f) As the ice retreated still further, eastern outlets were opened and Lake Agassiz drained considerably, subjecting the varved clay to erosion.

(g) An ice advance, likely from the northeast blocked eastern outlets and Lake Agassiz IV (Elson, 1966) was initiated. The lake level rose gradually depositing the mud unit upon the varved clay.

(h) Ice margin retreat opened eastern and possibly northern outlets and Lake Agassiz IV water level dropped. The sandy silt unit was deposited in shallow water as a result of delta construction and/or offshore processes. Numerous streams eroded into the mud unit producing an undulatory erosion surface on the mud. A minor rise of water level may have occurred to produce the flat lying upper surface of the sandy silt unit (Elson, 1966).

(i) Ice retreat opened northern drainage systems and Lake Agassiz dropped to the present level of Lake Winnipeg and a soil profile developed upon the sandy silt.

In conclusion, it should be stressed that the above history contains considerable speculation. Further work is needed in adjacent areas to delineate the extent of the various advances and retreats of ice and to correlate these advances and retreats with various stages of Lake Agassiz and eastern and northern outlets.

APPENDIX A

LABORATORY ANALYSIS OF SAMPLES

INITIAL SAMPLE PREPARATION

Before any tests could be preformed on the samples, they had to be disaggregated. The samples of sandy silt were unconsolidated and contained only a minor number of aggregates which were crushed with the fingers. A binocular microscope was used to examine the samples to ensure that all the particles of the aggregates had been separated. Samples of glacial till and glacio-lacustrine mud were air dried and placed on a large sheet of paper. As many lumps as possible were crushed with a wooden stick and the fingers. The smaller aggregates were crushed with a rubber cork in a porcelain mortar. Samples of varved clay were placed in a dish containing distilled water. With the aid of rubber gloves, the sample was "muddled" until all the lumps had been crushed. The samples were air dried and disaggregated with a porcelain mortar and a rubber cork.

SIEVE AND PIPETTE ANALYSES

Samples of till, sandy silt, and mud were dry sieved, utilizing phi (Ø) grade scale screens. All samples were sieved for 15 minutes. Material finer than 4Ø was caught in the pan and pipetted. The samples of clay had to be wet sieved because the fine grain sized material tended to blind the screens. The sample to be sieved was placed in a small bottle containing distilled water to which a dispersent (Calgon, with a concentration of 0.5 grams per liter) had been added. The bottle was shaken vigorously. The sample was poured from the bottle onto a wet 4Ø mesh screen which was held over a pan. The sediment finer than 4Ø was washed through the screen using a wash bottle filled with distilled water and dispersent. The material finer than 4Ø was placed in a 1000 ml. cylinder and was ready for pipette analysis. The material retained on the screen was dry sieved.

Pipette analyses were performed according to the method outlined by Folk, 1965, p. 37 - 40. 10Ø was used as the lower limit for analysis. Calgon with a concentration of 0.5 grams per liter of distilled water was used as a dispersent. A small amount of hydrogen peroxide was used to destroy organic matter in the samples. The clay is partially colloidal and it was difficult to obtain accurate analyses. The weight percentage of material in the various grade sizes was calculated, and cumulative curves plotted. Statistical parameters of grain size were calculated according to the method outlined in Appendix B.

X-RAY DIFFRACTION ANALYSES

Large grains were identified by microscopic examination. The grains finer than 2Ø were crushed in a mortar and pestle. The material was loaded in a Philips rotary specimen holder and analyzed on a Norelco X-Ray diffractometer. Copper-nickel was used as an internal standard and all samples were analyzed through the range of 5° - 80° 2Ø. The minerals present in the samples were identified by interpretation of the diffractograms.

HEAVY MEDIA SEPARATION

Tetra-bromo-ethane, with a specific gravity of 2.96 at 20°C., was used as a heavy media.

The apparatus consisted of a separatory funnel, a metal stand, a funnel lined with filter paper and a beaker. The following procedure was used:

1. The apparatus was washed with acetone.
2. The separatory funnel was partially filled with tetra-bromo-ethane.
3. A small portion of the sample was placed in the separatory funnel and the heavy minerals were allowed to settle to the bottom. The heavy media was stirred gently to aid the settling process. This procedure was followed until all of the heavy minerals had been separated.
4. The heavy and light minerals were collected and reprocessed, separately.
5. The tetra-bromo-ethane was filtered off the heavy and light mineral fractions.
6. The heavy and light minerals were washed with acetone and allowed to dry.
7. The heavy minerals were identified with the aid of binocular and petrographic microscopes.

ACID SOLUBLE CONTENT

Approximately 20 grams of sample was used for each analysis. After weighing, a sample was placed in 1:7 HCL and was allowed to remain until all the soluble material had been dissolved. The acid was decanted. The sample was washed in distilled water three times. Each time the mineral was allowed to settle before the water was decanted. The sample was air dried and weighed. The acid soluble content was calculated using the formula.

$$\% \text{ Acid Soluble Content} = \frac{WB - WA}{WB} \times 100$$

where

W.B. = weight of sample before dissolving in acid.

W.A. = weight of sample after dissolving in acid.

APPENDIX B

STATISTICAL PARAMETERS OF GRAIN SIZE

The parameters are those defined by Folk, 1965. In the formulas, numbers such as 16Ø and 84Ø, represent the Ø values corresponding to a particular percentage (16% and 84%) on the cumulative curves.

INCLUSIVE GRAPHIC SKEWNESS (SKI) measures the degree of asymmetry of the cumulative curve as well as the "sign" i.e., whether a curve has an asymmetrical tail on the left or right. It is given by the formula:

$$Ski = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

GRAPHIC KURTOSIS (K.G.) is a measure of the ratio between the sorting in the "tails" of the cumulative curve and the sorting in the central portion of the curve. It is given by the formula:

$$K.G. = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$$

INCLUSIVE GRAPHIC STANDARD DEVIATION (σ) is a measure of the sorting of the sample and is given by the formula:

$$\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

MEDIAN (Md) is the particle diameter corresponding to the 50% mark on the cumulative curve.

GRAPHIC MEAN (M.z.) is the particle diameter given by the formula:

$$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

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