SEDIMENTOLOGY AND POST-GLACIAL HISTORY
OF
LAKE MANITOBA

By

WILLIAM MICHAEL LAST

A THESIS

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ABSTRACT

Lake Manitoba is a large (4700 km^2), shallow ($\bar{z}$ = 4.0 m), brackish water lake located in south-central Manitoba. Sediment cores up to 13.5 m in length were taken at 50 offshore sites in the main South Basin of the lake. These cores were analyzed at varying intensities for over 40 physical, chemical, and mineralogical sediment parameters.

The modern offshore sediments of the South Basin are mainly silts and clayey silts, and are composed of detrital and authigenic carbonates (20-60%), clay minerals (20-50%), organic matter (15-30%), quartz (15-30%), and feldspar (2-10%). Quartz, feldspar, and dolomite are in greatest abundance around the margin of the offshore basin, whereas organic matter, calcite, and clay minerals are concentrated in the central portion of the basin. The authigenic calcite, precipitated in response to high levels of supersaturation brought about by evaporative concentration and extensive phytoplankton productivity during the ice-free season, contains an average of about 7 mole percent $MgCO_3$ in the crystal lattice.

The post-glacial sediments in the South Basin of Lake Manitoba are composed dominantly of silty clay and clayey silt except toward the extreme southern end of the basin where less clayey and more sandy sediments are common. The clay content, quartz, feldspar, and dolomite as well as K, Na, Fe, and Mg show a general increase with depth in the sediment cores, while silt, moisture content, organic matter, calcite, and Ca decrease with depth. On the basis of variations in these and other sediment parameters investigated, six lithostratigraphic units are recognized in the post-glacial record of the lake (Units A, B, C, D, E, and F from bottom to top).

Developed within this sequence and separating mostof the units are marker horizons which are recognized in the cores by a blocky to pelletal structure, comparatively low moisture content, and a contrasting gleyed, dark greenish grey color. In addition, these zones have a sharp upper contact with the overlying sediment but a gradational lower contact, and often exhibit significant changes in organic content, carbonate content and mineralogy, and grain size. These distinctive zones are interpreted to represent very low water levels of Lake Manitoba at which time complete or nearly complete drying of the lake and desiccation of the lake bottom muds occurred.

The initial phase of lacustrine deposition in the Lake Manitoba basin began about 12,000 years ago as meltwater from the retreating glacier was impounded in front of the ice to form Lake Agassiz. By 11,000 years ago, continued retreat of the ice sheet opened significantly lower outlets to the east and much of Lake Agassiz, including the Lake Manitoba basin, drained. Water levels again rose at about 10,000 years B.P. However, this final episode of Lake Agassiz sedimentation in the Lake Manitoba basin was short lived, and by about 9,000 years ago, the South Basin was again dry. For the next 4,000 years alternating wet and dry conditions prevailed in the basin in response to the interaction of a warmer and drier climate and differential crustal rebound of the basin. At about 6,000 years ago, the lake entered the final and longest period of dominantly dry conditions.

About 4,500 years B.P., a new phase of Lake Manitoba sedimentation was initiated when the Assiniboine River began to discharge into the South Basin. This added fluvial input supplied coarse-grained sediment to the

basin, and high Mg/Ca ratios in the newly developing lake resulted in the precipitation of magnesian calcite with a considerably higher $MgCO_3$ content than that of the previously deposited sediment. The Assiniboine River was diverted out of the South Basin watershed about 2,000 years ago resulting in lower sedimentation rates and deposition of slightly finer-grained material. Erosion and redistribution of the sandy deltaic sediments of the Assiniboine River by wave action has created a barrier beach separating Delta Marsh from the main lake at the south end of the basin. Except for these developments, however, there has been little change in the lake over the past 2,000 years.

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SECTION 1

INTRODUCTION

1.1 LOCATION OF STUDY AREA

Lake Manitoba is one of the largest lakes in western Canada. It is located in south-central Manitoba about 120 km northeast of Winnipeg (Fig. 1-1). The lake consists of two distinct basins, the North Basin and the South Basin, separated by the Narrows (Fig. 1-2). The size and location of the South Basin in the populated southern region of Manitoba make it an important Prairie resource in terms of recreation, fishing, hydrology and wildlife. This study is based on sediment samples taken from the southern two-thirds of the South Basin.

1.2 OBJECTIVES OF STUDY AND ORGANIZATION OF THIS REPORT

Historically, lakes have provided geologists with large-scale laboratories for the development of basic sedimentological concepts and the study of depositional processes such as shoreline and delta sedimentation (Gilbert, 1885, 1890), turbidity current flow and deposition (Forel, 1887; Grover and Howard, 1938; Gould, 1960) and chemical precipitation (Clark, 1924; Minder, 1926; Goudge, 1924; Davis, 1900). More recently, the geological study of lacustrine deposits has progressed at an unprecedented rate. These geolimnological efforts range from essentially description, monitoring, and reporting of lake sediments (e.g., Kothandaraman et al, 1977; Horie, 1974, 1975, 1976; Callender, 1969b; Dean and Gorham, 1976a) to discussions of the use and problems of lake sediments in mineral exploration (e.g., Timperley et al, 1973; Klassen et al, 1975; Klassen, 1975; Allan, 1971, 1974). Lake sediments have been shown to provide a

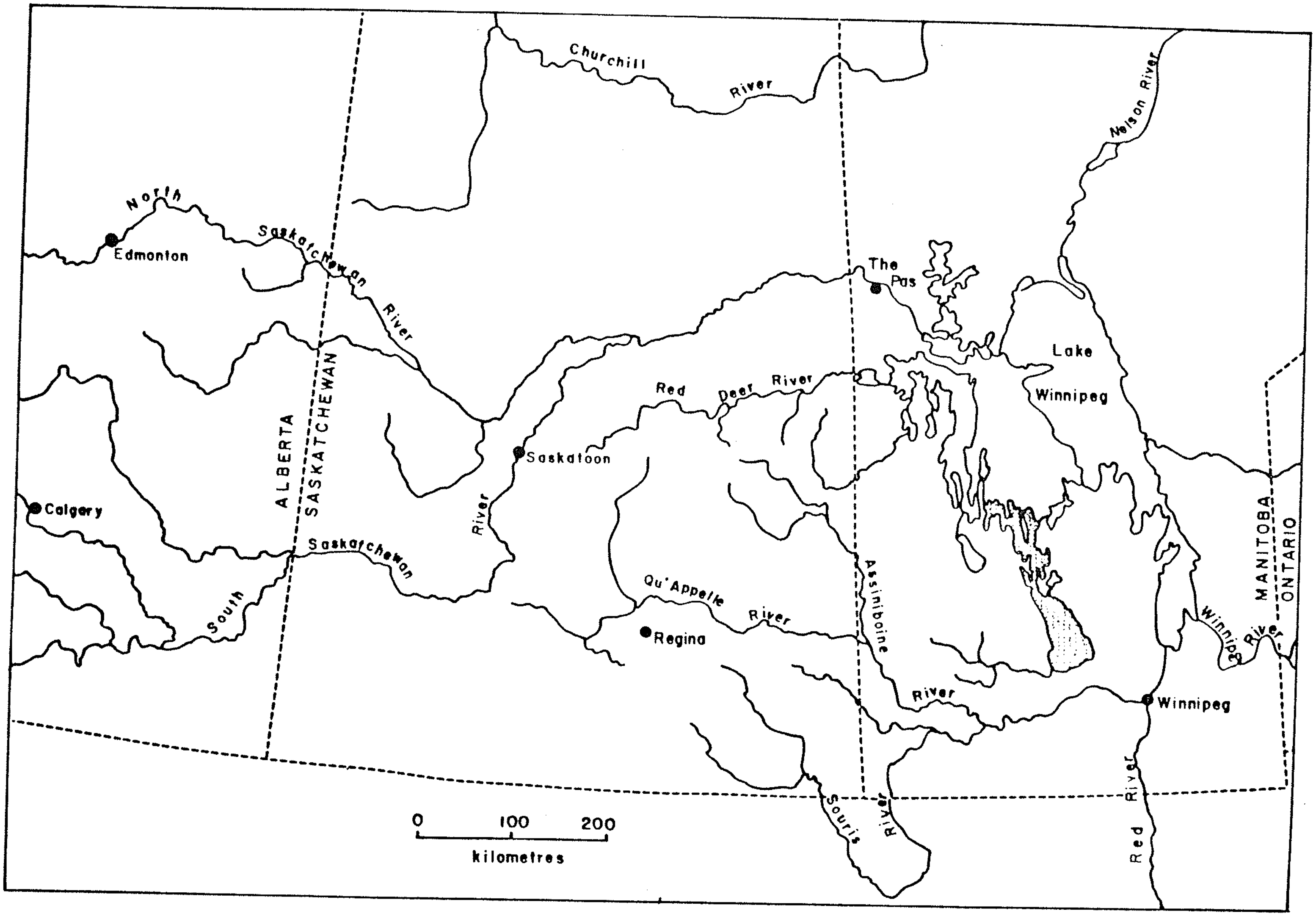


Figure 1-1. Location of Lake Manitoba (shaded) in western Canada.

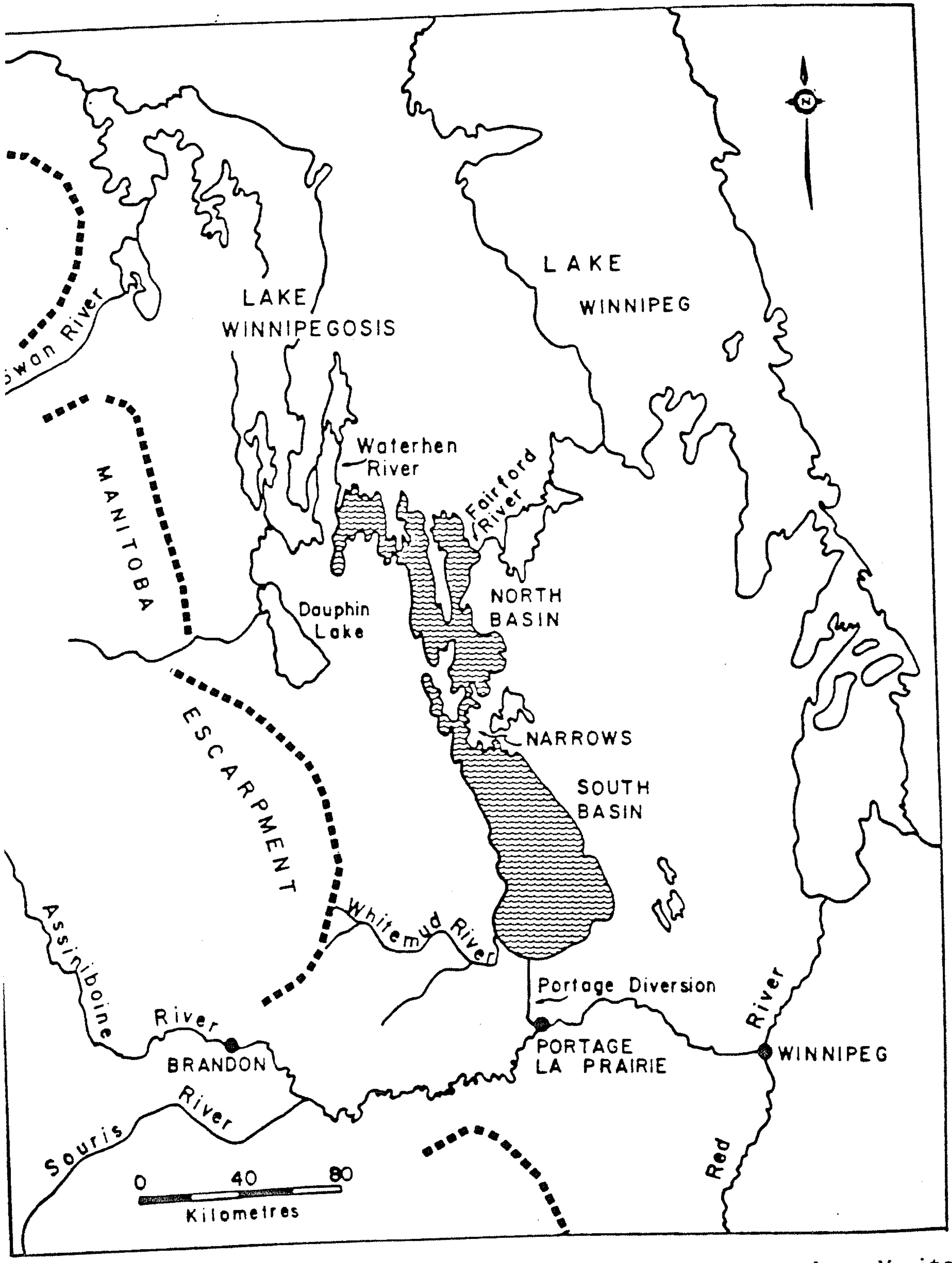


Figure 1-2. Location of Lake Manitoba (shaded) in southern Manitoba.

sensitive and valuable indicator of environmental impact of human development on the lacustrine environment, notably in terms of heavy metal and nutrient loading (e.g., Hakanson, 1977c, 1974b; Shapiro et al, 1971; Kemp et al, 1972; Kemp and Thomas, 1976; Anderson et al, 1978; Shimp et al, 1970, 1971).

The large amount of geolimnological work done within the past decade by various government organizations on, for example, the Great Lakes indicates that the results of such studies are a necessary part of environmental management schemes (see Sly, 1978a, b, 1976, 1973; Sly and Thomas, 1974; Thomas et al, 1976, 1973, 1972a, b; Kemp et al, 1977, 1976, 1974; Gross et al, 1970, 1972; Callender and Bowser, 1976; King et al, 1976). Recently published symposium volumes and texts (e.g., Matter and Tucker, 1978; Lerman, 1978; Golterman, 1977) have done much to synthesize some of the newer sedimentological work on lakes as well as publicize geolimnological efforts in the scientific community.

The basic objective of the Lake Manitoba study was to gain an understanding of the present and past sedimentary environments of the South Basin of the lake. This was accomplished by the quantitative description and interpretation of various physical, chemical, mineralogical, and, to a limited extent, biological parameters of sediment cores taken from the basin. The specific objectives of this report are to: (a) describe the present sedimentological and geolimnological environment of the South Basin of Lake Manitoba; (b) describe the late Pleistocene and Holocene sediments in the basin and identify the major spatial and temporal variations within this sediment record; and (c) interpret these changes in terms of the major depositional processes and late Quaternary history of the lake.

This thesis is subdivided into nine major sections (chapters) with supporting data and discussions located in nine appendices. Following the Introduction (Section 1), Section 2 outlines the research methodology and analytical techniques used in this study. Section 3, Lake Manitoba and its Basin, is basically a review and interpretation of what is known about the modern lake and its geological surroundings. Section 4, Description of Lake Manitoba Sediments, presents the sediment data acquired in this study. The final five sections interpret this data. Section 5 presents the lithostratigraphy of the post-glacial sediments in the basin. Section 6 discusses specific important spatial and temporal changes in the sediment record. Section 7 develops the chronological setting of this record and discusses modern sedimentation rates. Section 8 discusses the depositional environments of the major lithologic units recognized in the basin and correlates these units with the post-glacial stratigraphy outside of the present-day basin. Finally, Section 9 presents the post-glacial history of Lake Manitoba.

1.3 ACKNOWLEDGEMENTS

A large number of individuals and organizations assisted me in this research and in the preparation of this thesis. The Lake Manitoba project and my thesis research were financially supported by the Environmental Management Division of the Manitoba Department of Mines, Natural Resources, and Environment, by a grant to J. T. Teller from the National Research Council of Canada and by the University of Manitoba.

The research was conducted under the general guidance and supervision of Dr. J. T. Teller of the Department of Earth Sciences, whose devotion to the project and substantial patience with respect to

my sometimes eccentric ideas are most gratefully appreciated. My thanks also to J. Crowe, A. Beck, and R. Nowosad (Environmental Management Division) for helping to initiate this project. Drs. Teller, R. Harrison (Department of Earth Sciences), C. T. Shay (Department of Anthropology) and G. J. Brunskill (Freshwater Institute) undertook the arduous task of reading, editing, and commenting on this thesis in various stages of completion.

Drs. H. Wright and E. Cushing (University of Minnesota), Dr. P. Collinvaux (Ohio State University) and Dr. L. Gerhard (North Dakota Geological Survey) provided information and advice about winter coring equipment and techniques. Dr. J. M. Shay (Botany Department) arranged use of the University of Manitoba Field Station at Delta Marsh during the 1978 and 1979 field seasons and provided an extra Livingstone corer. Messrs. D. Garnham and E. Nast supplied invaluable navigational expertise on the lake and were especially helpful as field assistants during the coring program. The Manitoba Conservation Department in Lundar very kindly loaned the project one of their Bombardiers for part of the 1978 field season. Several pieces of field equipment were loaned by Dr. R. Hecky (Freshwater Institute) and A. Beck (Environmental Management Division). Unpublished Manitoba government data on Lake Manitoba water chemistry, hydrology, bathymetry and sediments were kindly provided by A. Beck, K. Campbell, J. Crowe, J. Little, N. Mudry, J. Ellis and E. Sorba. Dr. I. Lubinsky (Department of Zoology) kindly undertook a preliminary study of the mollusks in several of the cores.

Most of the chemical analyses were carried out in the Geochemistry Laboratory of the Department of Earth Sciences under the expert guidance of Mr. K. Ramlal. Drs. M. P. Stainton and A. Lutz (Freshwater Institute)

also analyzed selected samples. I was ably assisted in the laboratory by E. Ucakuwun, S. Sutherland and G. Jones. Drafting and photography of many of the illustrations in this thesis were done by R. Pryhitko and O. Malchenko from my often very rough original drawings.

I am especially grateful to Drs. E. M. V. Nambudiri (Department of Earth Sciences) and R. T. Carter (Anthropology Department) for use of their unpublished Lake Manitoba pollen and diatom results.

Finally, I express profound appreciation to my wife, Letty, for typing, proofreading, and offering numerous suggestions on drafts of this thesis, for being ever tolerant of the innumberable evenings and weekends taken from family responsibilities, and for encouraging me and providing the necessary financial support to abandon a "comfortable" industry position and pursue this research endeavor.

SECTION 2

METHODS AND TECHNIQUES OF ANALYSIS

2.1 FIELD METHODS

2.1.1 Coring

2.1.1.1 Core site selection and location

During January, February and March of 1978 and 1979, sediment cores and samples were collected from fifty sites in the main South Basin of the lake. In addition, cores were recovered from two inland sites: one approximately 2.5 km west of the town of Oakland and one in Cadham Bay of Delta Marsh. Figure 2-1 shows the location of these fifty-two sites relative to the present-day lake boundaries.

Bombardier travel and positioning on the ice surface was done by dead reckoning using a Brunton compass and the tracked vehicle's odometer. Core sites were further positioned by sighting from the ice surface to known geographic points on land. This latter technique was not possible, however, with locations more than 5 to 6 km offshore. Triangulation at the end of each day, and later checks on site locations indicate that the location methods used were accurate to within several hundred metres.

Coring locations were determined by consideration of the following factors:

1. Expected sediment type. Initial sites were chosen on the basis of preliminary bathymetric and surface sediment textural data (provided by the Manitoba Department of Mines, Resources and Environmental Management). Sites were selected in the offshore portion of the lake where

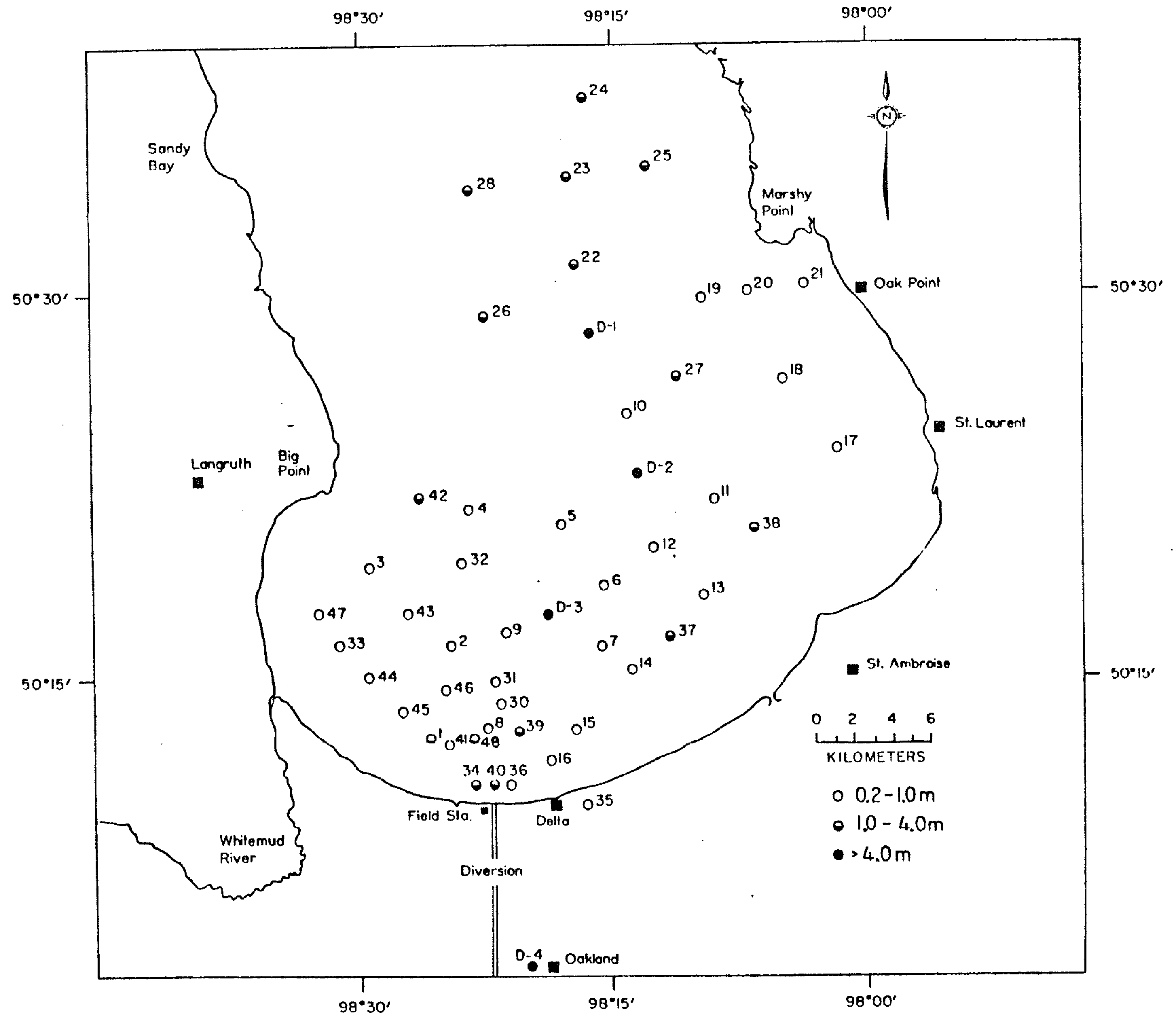


Figure 2-1. Location and approximate length of cores taken for this study.

it was anticipated that the most complete and least disturbed sedimentary record would be present. Likewise, probable areas of relatively coarse-grained surface sediment, such as sand, were specifically avoided for initial coring attempts because it was believed that sediment penetration and core recovery in coarse-grained material would be poor.

2. Site distribution uniformity. Because it was expected that maps of the sedimentary facies for various horizons would be prepared, an attempt was made to obtain a fairly uniform spatial distribution of the cores. The distribution of core sites lies between a uniform and a random distribution for the southern two-thirds of the basin (nearest neighbor ratio: R = 1.28; where 0 = clustered, 1 = random, and 2.15 = uniform; Clark and Evans, 1954; Morrison, 1970).

3. Availability and daily range of transport vehicles. Core sites were, in part, controlled by the geographic location of an available tracked transport vehicle and by the maximum daily range of this vehicle. Coring operations were undertaken from two bases: the town of Delta, Manitoba, at the extreme south end of the lake, and the town of Oak Point, Manitoba, on the eastern shore of the lake (Fig. 2-1). Furthermore, when using the bombardier-mounted hollow stem auger (described in next section), the speed of travel of the rig (average of 3 to 6 km per hour) greatly limited the practical geographic extent of the deep coring program.

4. Initial stratigraphic investigation. Site locations were also determined by the results of preliminary analyses of the first cores collected and by the emerging stratigraphic relationships evident from field observations and core logging.

5. Areas of particular emphasis or interest. The maximum

density of core locations occurs in the extreme southern end of the lake. This was done to better evaluate the influence of the ancient Assiniboine River and the most recent Portage Diversion channel, and to permit an estimate of possible changes in the position of the southern shoreline.

2.1.1.2 Core acquisition

Sediment cores used in this study were collected in two ways: (a) hand-operated Livingstone coring to retrieve cores of relatively short length (4 m or less) ; and (b) Bombardier-mounted and power driven Shelby tube coring to retrieve long cores.

Livingstone coring. A total of forty-eight sites were cored using a square-rod piston sampler similar to that described by Wright et al (1965), Cushing and Wright (1965),and Wright (1967). This modified Livingstone corer was purchased from the Limnological Research Center at the University of Minnesota. Seven extra five-centimetre diameter, one-metre-long stainless steel core barrels permitted the collection of multiple cores at numerous sites without having to extrude the sediment in the field. An additional square-rod piston corer and one core barrel were made available by Dr. J. M. Shay of the Botany Department during the 1978 field season. Light-weight, high-strength, chrome-molybdenum steel alloy, seamless tubing (2 cm O.D.) was used for the connecting (drive) rods.

The sampler was pushed slowly and evenly into the sediment by two or three persons applying a downward force to the T-bar handle at the top of the drive rods. The use of a hand-held sledge to advance the corer in compact or coarse-grained sediment resulted in damage to the metal stops of the square-rod assembly and was abandoned after initial attempts. Because rod flexing (when firm sediment was encountered) was the main limiting factor of the Livingstone coring operation, no attempt was made to use a winching system like that described in Cushing and Wright (1965) to advance and extract the sampler.

Core recovery in fine-grained sediment (silt and clay) was excellent and usually exceeded 95 cm per one metre drive. Depth of coring was limited by the increased firmness of the clayey sediment with depth and by the presence of coarse-grained material. Maximum total penetration and core recovery in sand-sized sediment with the Livingstone corer was 75 cm, whereas three to four metres of silty and clayey material was routinely cored with little difficulty. A total of 56.65 m of sediment was collected from 48 core sites using the Livingstone-type sampler. A description of the field use of the coring apparatus, together with a detailed summary of required field equipment, can be found in Appendix A.

Shelby tube coring. Following the initial Livingstone coring program, a Bombardier-mounted hollow-stem power auger was used to collect core from greater depths. This Shelby tube coring work was done by Morton, Dodds & Partners Limited of Toronto. The auger was used to advance the hole and Shelby tubes were used to retrieve core through the central shaft in front of the auger bit. Although core recovery was not as complete as that of the hand-driven Livingstone operations, an average of about 85% of the section cored was recovered relatively undisturbed in Shelby tube barrels. An attempt was made to use a Shelby tube equipped with a piston assembly to improve core recovery of the upper few centimetres of high-water content sediment. However, because of cold conditions and frequent freezing of the piston rod within the drive rod, this technique was abandoned, and the upper section (0 to 3 m depth) of each deep core site was cored with the Livingstone piston corer.

New, galvanized steel Shelby tubes of diameters ranging from 5.5 to 7.3 cm were used in all deep coring operations in the lake. A total of 33.51 m of sediment was collected using the Shelby tube hollow-stem auger assembly. A more complete description of the hollow-stem auger Shelby tube coring procedure can be found in Acker (1974, p. 46-68).

2.1.1.3 Core handling

Immediately upon retrieval of the core from the lake, the ends of the core barrel were sealed (with wax in the case of the Shelby tubes and with plastic and tape in the case of the Livingstone material) and labelled with respect to site number and depth below sediment/water interface. The barrels were then placed upright in the heated Bombardier and transported to the field laboratory at the end of each work day.

Once onshore, the Livingstone material was immediately extruded from the core barrel, logged, placed in rigid PVC plastic tubing (split longitudinally), and sealed in heavy gauge plastic sheeting. The preliminary logging included determination of color (Munsell, moist), general desciption of grain size, sedimentary structures, bedding characteristics, macrofossil abundance, organic matter content, and preliminary identification of stratigraphic units within the core. After this preliminary examination, the securely wrapped and sealed cores were transported to the University of Manitoba to be logged in detail and subsampled for physical, chemical, mineralogical, and biological analyses.

The large number of cores collected required that some type of interim storage (after initial description but before detailed subsampling) be arranged. In order to prevent, or at least slow, any possible chemical reaction, some of the Livingstone cores were frozen and placed in cold storage in the Department of Mines, Resources and Environmental Management (Mines Branch) core shed at the University of Manitoba. The cores that were not frozen were further analyzed and subsampled generally within 24 to 36 hours after collection. The cores that were subjected to freezing were those from sites 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 22, 25, 26, 27, and 28.

Field handling of the Shelby tube cores was slightly different from the general procedure described above for the Livingstone material. After retrieval, marking, and sealing of the core, the Shelby tubes were stacked in a horizontal position in the heated transport vehicle to prevent freezing. Two insulated boxes were used at site D-1 and D-2, and the Shelby tubes from the uppermost fluid section of the sediment column were placed in a vertical position within the boxes to avoid possible sediment distortion and mixing during transport to shore.

Extrusion of the Shelby tube cores required special hydraulic equipment and pistons available at the University of Manitoba Department of Civil Engineering Soil Mechanics Laboratory. Therefore, the filled Shelby tubes collected each day were stored unfrozen until the entire deep drilling operation was completed, and they could be transported to the campus laboratory. It was necessary to keep the core from sites D-1, D-2, D-3 and the upper four metres of D-4 in the sealed, galvanized steel tubes for up to two weeks while coring operations continued in the field. It should be noted, however, that the results of physical, chemical, and mineralogical analyses of duplicate cored sections that were subjected to both freezing and nonfreezing conditions, and lengthy storage versus immediate subsampling and analyses, showed very little difference. It was concluded, therefore, that, for the parameters evaluated in this study, the method of storage and relative length of storage (up to several months) had no effect on the analytical results. However, freezing did adversely affect the visible sedimentary structures and bedding characteristics to the point that examination and routine logging of these features was impossible on a previously frozen core. Therefore, Shelby tube cores were never frozen.

The Shelby tube cores were extruded, by hydraulic jack, into rigid PVC plastic tubing, logged in detail, photographed, subsampled, wrapped in plastic and stored at room temperature. Due to the compact, dense nature of the material near the base of the lacustrine sediment column, it was necessary to cut several filled Shelby tubes perpendicular to the length to lessen the resistance of the sediment and facilitate extrusion. Cores from the lower two metres at site D-4 (located onshore, near Oakland) presented extreme difficulty in extrusion, and each sixty centimetre Shelby tube had to be cut up seven times before the sediment could be extruded.

2.1.2 Additional Data Gathered

The main purpose of the two seasons of field work was to collect cores of the sediment record of the South Basin of Lake Manitoba. However, in addition to the coring operations, the field crew had the opportunity to collect other types of information which could be relevant to the overall sediment study and to a better understanding of the lake. This additional data acquisition included: (a) extension of Livingstone core holes using a hand-driven soil probe; (b) collection of water samples at various depths and locations in the South Basin; (c) measurement of water temperature profiles at selected locations, and (d) collection of bathymetric data.

2.1.2.1 Supplementary soil-probe sampling

In the southwestern portion of the lake, penetration of the sediment column by the Livingstone corer was limited to generally less than one metre due to the presence of coarse-grained material. Therefore, at selected sites (41, 42, 43, 44, 45, 46, 47; Fig. 2-1) a standard 30 cm hollow cylinder soil probe (2 cm in diameter) and a 2.5 cm diameter soil auger were used to penetrate deeper than the Livingstone corer. Although totally reliable (i.e., from precise, known depths and undisturbed) core samples could not be recovered from these exploratory operations, the general sediment texture and degree of compaction at approximate depths below the sediment/water interface could be determined and recorded. In addition, the soil probe is capable of retrieving a short section of 2 cm-diameter sediment core which was used to give a rough visual indication of the type of sediment present.

2.1.2.2 Lake water sampling

As will be discussed in Section 3 of this report, a number of previous investigators have analyzed the chemistry of Lake Manitoba surface waters. Therefore, no specific effort was made to systematically collect and analyze water samples in the South Basin. However, so that this sediment study might have up-to-date information on the chemical conditions of the water column at the time of core collection, water samples were collected at various depths at core sites 22, 24, 32, 40, D-1, and D-3 (see Fig. 2-1). A single Kemmerer-style (~10 cm I.D.) brass sampling bottle (supplied by the Manitoba Department of Mines, Resources and Environmental Management) was used to collect the water. Although efforts were made to acquire a non-metallic PVC sampling bottle from various federal, provincial, and university departments, which would permit analysis of trace metal content of the waters, none was available.

2.1.2.3 Water temperature profiles

The water temperature at 0.5 m intervals was measured at sites 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 32, 38, 39, 40, D-1, and D-2 (see Fig. 2-1). A standard single channel battery operated telethermometer (accuracy of ± 0.1°C) with a 25 m lead wire and a tubular, waterproof metal thermistor probe, supplied by Dr. R. Hecky, Freshwater Institute, was used to record the temperature profiles from the ice surface to sediment/water interface.

2.1.2.4 Bathymetric data

At every core site, the depth of water was measured by sounding with a weighted nylon line. Water depth was recorded as the distance from the ice surface to the sediment/water interface.

2.2 LABORATORY METHODS

2.2.1 General Comments

The stratigraphic record preserved in the Lake Manitoba basin contains an abundance of paleolimnological data. Within the monetary and temporal confines of this study, however, there are limitations on the amount of data that can be acquired. My goal in this project was to investigate a selected number of sediment parameters which (a) are

TABLE 2-1.

Sediment parameters evaluated in this study

PHYSICAL PARAMETERS:

- Moisture Content
- Organic Matter
- Sand, Silt, Clay
- Mean Grain Size, Standard Deviation, Skewness, Kurtosis
- Bulk Density, Porosity

MINERALOGICAL PARAMETERS:

Bulk Mineralogy:	quartz, feldspar, calcite, dolomite, total clay minerals, total carbonate minerals, total soluble salts
Clay Mineralogy:	expandable clays, illite, kaolinite plus chlorite
Detailed Carbonate Mineralogy:	high Mg-calcite, low Mg-calcite, mole % $MgCO_3$ in calcite

CHEMICAL PARAMETERS:

Major Elements:	K, Na, Ca, Mg, Fe, Mn, P, Cl, S, SO_4-S, C, CO_3-C, Organic-C
Trace Elements:	Cu, Zn, Cd, Hg
Eh, pH	
Radiocarbon age	

useful in characterizing and describing the lacustrine deposits and contemporary environmental conditions, and (b) are potentially important in helping to reconstruct the developmental history of the lake and its watershed. Table 2-1 lists the three major groups of sediment parameters evaluated in this study and upon which this discussion is based.

The choice of analytical methods used to evaluate these sediment parameters was dictated by a combination of factors including: availability of equipment and technical expertise within the departmental laboratories, previous use of particular methods in other local or Manitoba regional sediment studies, and the specific objective of the analysis.

2.2.2 Sampling Interval

One of the more important considerations in any core subsampling scheme is the question of sampling interval. The number and density of a particular analysis per unit length of core controls the researcher's ability to identify changes of the parameter with depth in the sedimentary record. In general, this resolution increases with a decrease in subsample interval. However, as shown by Bortleson (1970), a point is reached at which a further decrease in subsample interval will not yield meaningful results because of such intereference factors as bioturbation, ion mobility, and turbulent mixing of the sediment.

The subsampling interval used in other lake sediment investigations is by no means standard. For example, Thomas and Soltero (1977) examined several chemical parameters of cores from Long Lake, Washington, using subsamples at every 5 mm. Because of very low sedimentation rates, Maher (1977) used a sampling interval as small as 2 mm in Lake Superior. Bortleson (1970; Bortleson and Lee,

1972) used analyses at every 3 to 5 cm for a one metre core and every 50 cm for a 10 metre core from Lake Mendota, Wisconsin. Great Lakes' sediment profile work (e.g., Kemp and Thomas, 1976) commonly uses a 1 to 2 cm interval for the first 10 cm, a 5 cm interval for the next 20 cm and a 10 cm interval for the remainder of the core.

For this Lake Manitoba study, the subsampling interval was determined by the following factors:

(1) Uniformity of subsample points. An attempt was made to maintain a certain minimum base-level subsampling interval within cores selected for detailed study. This base-level interval consisted of one subsample every 2 cm from 0 to 20 cm in core depth; one subsample every 3 cm from 20 to 100 cm; one subsample every 10 cm from 100 to 300 cm; and one subsample approximately every 20 cm for the remainder of the core.

(2) Type of sediment and frequency of fluctuation of visible sediment parameters. Sections of the core characterized by rapidly changing visual sediment parameters (such as texture, bedding, color, or moisture content) were sampled more frequently than zones of thick, monotonous, apparently similar sediment.

(3) Type of analysis. The amount of sample required, the cost, and the amount of time necessary to complete the particular analysis, in part, controlled the distribution and frequency of subsampling for certain parameters.

Finally, not all cores were subsampled and analyzed in the same detail. The three deep cores in the lake basin (sites D-1, D-2 and D-3) and selected shorter cores (sites 1, 2, 4, 7, 8, 10, 18, 19, 20, 21, 23, 24, 27, 38, 39 and 40; Fig. 2-1) received most of the detailed physical, chemical and mineralogical analytical emphasis. This was done for practical reasons so that a maximum effort could be spent on the cores in the basin that presented the best potential for historical interpretation. Figures 2-2a to 2-2c review the analytical density for each parameter in the three longest cores, and Appendix B summarizes the number and density of analyses in each core in the basin.

2.2.3 Subsampling Methods and Storage

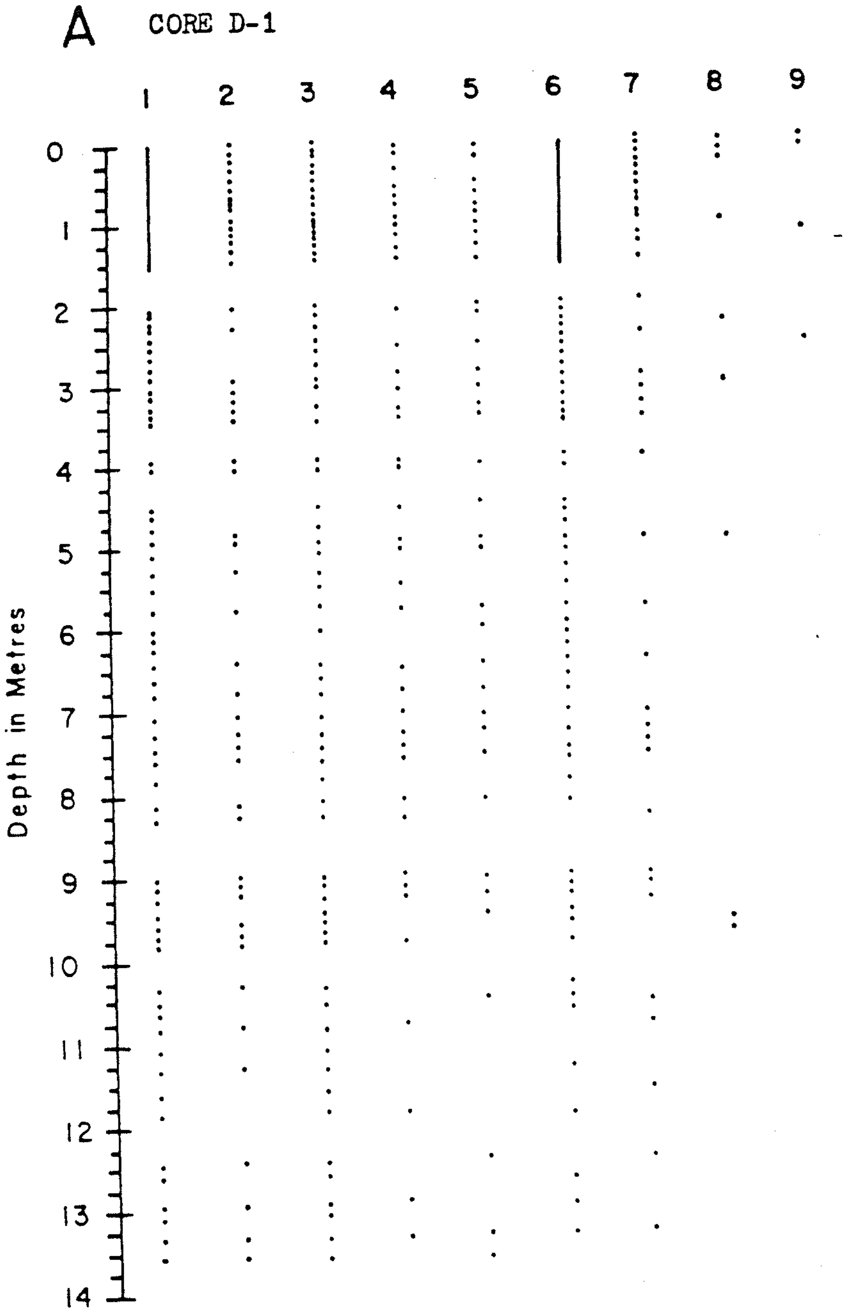
After detailed examination and logging in the laboratory, the cores were subsampled for physical, chemical, and mineralogical analyses. Figure 2-3 shows the use of various portions of a 2 cm thick section of core. Approximately 25% of the sediment disc was used to evaluate moisture content, bulk density, textural parameters, and mineralogy. Another 20% was used for chemical analysis and 5% for ash content determinations. About half of the core was retained intact to provide raw, unprocessed sediment for ^{14}C dating, biological analyses and/or additional chemical analyses.

In all subsampling procedures, care was taken to avoid or remove visible contamination. Obvious sediment smear along the edges of the cores caused by the force of the core barrel penetration and the subsequent extrusion of the sediment was removed before sampling.

All subsamples were given an identification number (ranging from 1 to 1500) at the time of sampling. Dried, disaggregated sediment not used in the mineralogical/textural analyses was stored in 7 dram (5 cm high, 3 cm in diameter) "snap-top" plastic vials (if dry) or 80 ml screw-cap Nalgene bottles (if wet). Material retained after completion

Figure 2-2 a to c.

Distribution of sample analyses in cores D-1, D-2 and D-3.



1 MOISTURE CONTENT, ORGANIC MATTER (L.O.I.), TOTAL CARBONATE (L.O.C.)

2 SAND, SILT, CLAY

3 BULK MINERALOGY: QUARTZ, FELDSPAR, CALCITE, DOLOMITE, TOTAL CLAY MINERALS

4 CLAY MINERALOGY: EXPANDABLE CLAYS, ILLITE, KAOLINITE + CHLORITE

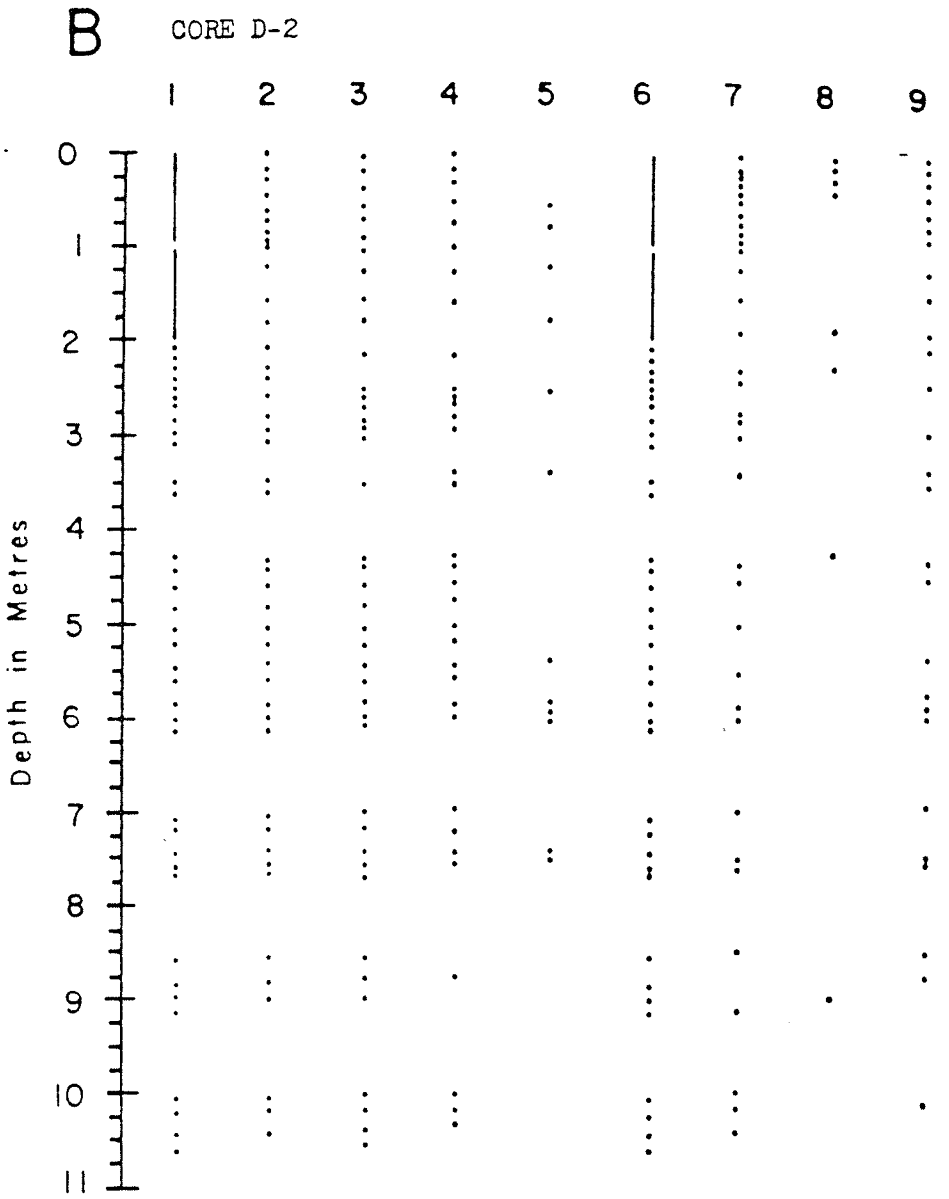
5 DETAILED CARBONATE MINERALOGY: LOW MG-CALCITE, HIGH MG-CALCITE, MOLE % MG IN CALCITE

6 pH, EH

7 ELEMENTS: K, NA, CA, MG, FE, MN, P, CU, ZN, CL

8 TOTAL ELEMENTAL C, CO_3-C, ORGANIC-C

9 HG



1 MOISTURE CONTENT, ORGANIC MATTER (L.O.I.), TOTAL CARBONATE (L.O.C.)

2 SAND, SILT, CLAY

3 BULK MINERALOGY: QUARTZ, FELDSPAR, CALCITE, DOLOMITE, TOTAL CLAY MINERALS

4 CLAY MINERALOGY: EXPANDABLE CLAYS, ILLITE, KAOLINITE + CHLORITE

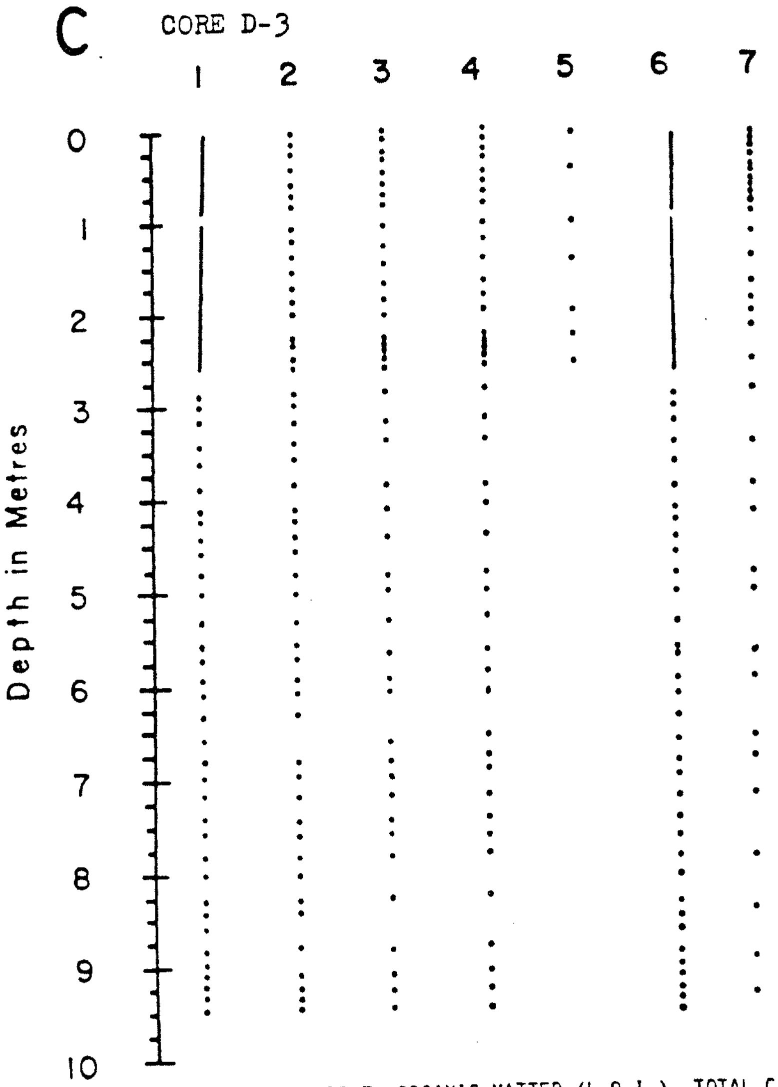
5 DETAILED CARBONATE MINERALOGY: LOW MG-CALCITE, HIGH MG-CALCITE, MOLE % MG IN CALCITE

6 PH, EH

7 ELEMENTS: K, NA, CA, MG, FE, MN, P, CU, ZN

8 TOTAL ELEMENTAL C, CO_3-C, ORGANIC-C

9 TOTAL S, SO_4-S, SOLUBLE SALT



1 MOISTURE CONTENT, ORGANIC MATTER (L.O.I.), TOTAL CARBONATE (L.O.C.)
2 SAND, SILT, CLAY
3 BULK MINERALOGY: QUARTZ, FELDSPAR, CALCITE, DOLOMITE, TOTAL CLAY MINERALS
4 CLAY MINERALOGY: EXPANDABLE CLAYS, ILLITE, KAOLINITE + CHLORITE
5 DETAILED CARBONATE MINERALOGY: LOW MG-CALCITE, HIGH MG-CALCITE, MOLE % MG IN CALCITE
6 PH, EH
7 ELEMENTS: K, NA, CA, MG, FE, MN, P, CU, ZN

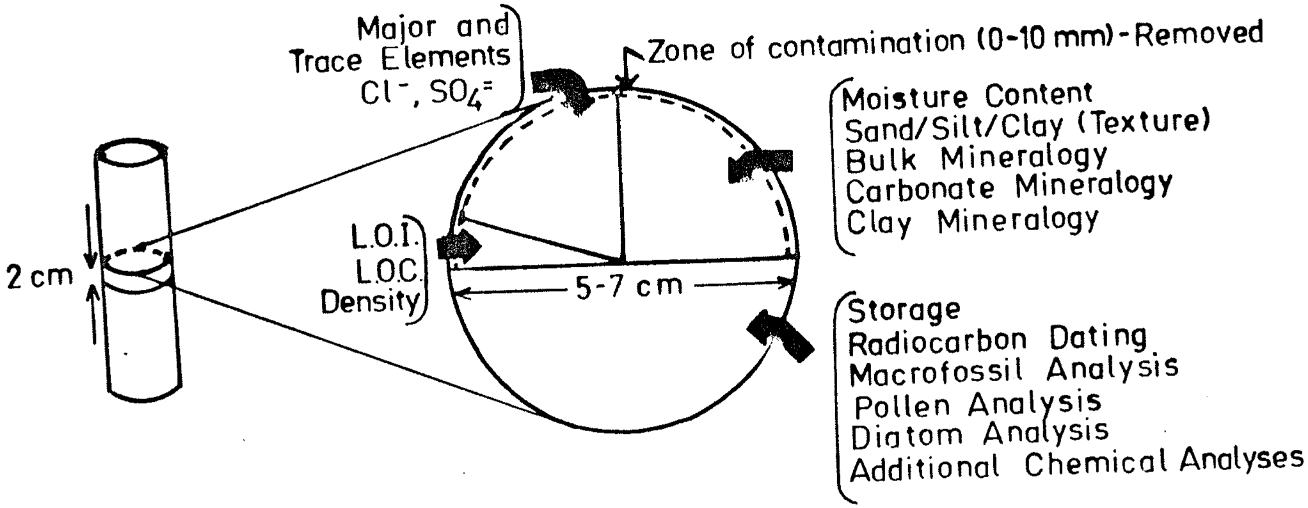


Figure 2-3. Analytical distribution of core material. Because all parameters were not measured from all subsamples, the entire subsample was not always consumed. About 40% of the core was typically retained in storage.

of chemical analyses was stored in 120 ml Nalgene screw-cap bottles.

2.2.4 Physical Parameters

2.2.4.1 Moisture content

The moisture content of the sediment was determined by heating a known weight of wet (fresh) sediment at 85° to 95°C for 24 to 36 hours and computing the weight loss. This weight loss was assumed to be due to evaporation of free pore water rather than to any loss of structural (lattice-bound) hydroxyl groups or to volatilization, oxidation or other breakdown of organic matter. The weight loss was calculated and expressed as percent of water in the wet sediment.

2.2.4.2 Unit weight, bulk density, and porosity

The mass unit weight, or the bulk density on a wet-weight basis, was obtained by filling a small plastic cylinder of known volume by inserting it into the core and then weighing the cylinder plus wet sediment. The weight of the sediment divided by the volume of the cylinder expresses the unit weight as grams per cubic centimetre.

Due to the rather labor-intensive nature of this procedure, the bulk density of the wet sediment was more routinely calculated on the basis of the relationship suggested by Axelsson and Hakanson (1971; referenced in Hakanson, 1977).

$$D = \frac{100\ D_m}{100 + (W + OM)\ (1 - D_m)}$$

where D = bulk density (g/cm^3 wet sediment);

D_m = mean density of the inorganic material;

W = water content expressed as a percent of wet-sediment weight;

OM= organic content expressed as a percent of wet-sediment weight.

Using 2.66 g/cm^3 as an approximation of D_m, the calculated bulk density showed a good correlation with the laboratory derived values (Fig. 2-4). Bulk density on a dry weight basis (that is, grams dry weight per unit volume of fresh sediment) was computed for selected samples after oven drying.

An approximation of the porosity of the sediment was calculated according to Rieke and Chilingarian (1974):

$$\emptyset = \frac{D_m - D}{D_m - D_w} \times 100$$

where D_w = density of the interstitial water (assumed to equal 1.0).

2.2.4.3 Organic matter

A rough indication of the amount of organic matter present in the sediment was obtained by heating a portion of the oven-dried sediment to 450° to 500°C for one hour (modified after Dean, 1974). The resulting weight loss, expressed as a percentage of the oven-dry weight was taken to represent the loss due to ignition of organic material. From this loss on ignition value (L.O.I.), a rough estimate of the organic carbon content can be determined by applying the appropriate conversion factor (organic carbon/L.O.I. = 1/2.54; see Section 2.2.6).

2.2.4.4 Textural analysis

Lake Manitoba sediment samples were analyzed using standard laboratory sieve and pipetting techniques as outlined by Folk (1968). After disaggregation and pretreatment with 3% hydrogen peroxide to

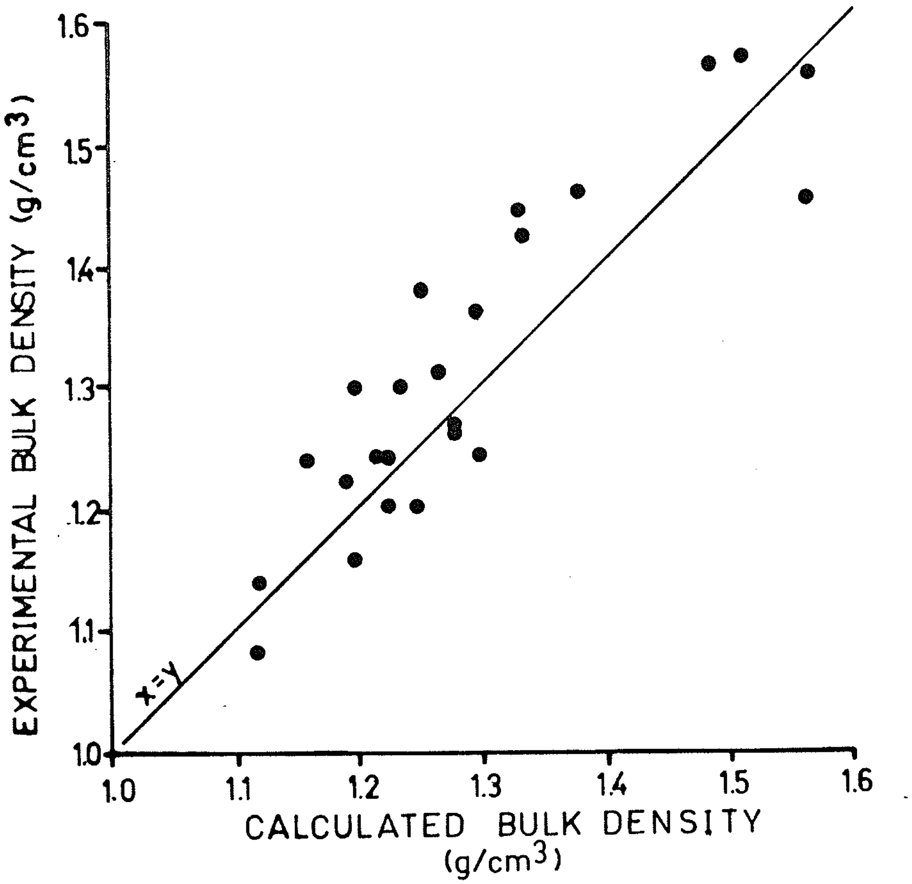


Figure 2-4. Relationship between experimentally determined wet bulk density (unit weight) and calculated wet bulk density.

remove organic matter, a 3 to 10 g subsample was wet-sieved through a 62 micron (4 phi) sieve using 10% Calgon (sodium hexametaphosphate) as a dispersion agent. The material passing through the 62 micron sieve was transferred to a 1000 ml graduated cylinder, stirred and subsampled at appropriate times and depths (Folk, 1968). The sand fraction retained on the 62 micron sieve was flushed with distilled water, air dried and weighed to determine the amount of sand in the sample. In the few cases where the 62 micron fraction was large enough (more than about 5%), it was dry-sieved at 1 phi intervals using a Ro-tap sieve shaker.

Data was obtained for each phi interval of the silt and clay sizes between 4 phi and 9 phi for all surface sediment (i.e., core depths of 0 to 2 cm) samples. In addition, twenty samples were analyzed for the 11 phi and 12 phi size fractions to substantiate Folk's (1968) suggestion for the linear approximation of the cumulative grain size between 10 phi and 14 phi.[1] For all subsurface sediment, only the percentages of sand, silt, and clay were determined. In this study, the following grain size subdivisions were used:

Clay: material finer than 3.9 microns (1/256 mm, 0.00016 inches, or 8 phi units);

Silt: material having a diameter in the range of 3.9 to 62.5 microns (1/256 to 1/16 mm, 0.00016 to 0.0025 inches, or 8 to 4 phi units);

Sand: material having a diameter in the range of 62.5 to 2000 microns (1/16 to 2 mm, 0.0025 to 0.08 inches, or 4 to -1 phi units);

Gravel: material coarser than 2000 microns (2 mm, 0.08 inches, or -1 phi units).

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[1] This essentially linear approximation of the size distribution between 10 phi and 14 phi was also confirmed by Last (1974, p. 119) in fine-grained Lake Agassiz sediment of southern Manitoba.

A 60 ml aliquot of the clay-sized material was retained from the textural analysis procedure in a 125 ml Nalgene bottle for clay mineral analysis.

2.2.5 Mineralogical Parameters

2.2.5.1 Clay mineralogy

Qualitative and semi-quantitative clay mineral analyses were conducted on the finer than 8 phi size fraction of the sediment using X-ray diffraction techniques. Initial semi-quantitative experiments suggested that there is very little difference between the finer than 8 phi, finer than 9 phi, and finer than 10 phi size fractions. The finer than 8 phi fraction was chosen for routine evaluation because of the relative speed with which it was separated from the coarser, non-clay fraction, and the convenience of this separation in the general scheme of textural/mineralogical analyses.

Oriented clay mineral mounts were prepared by allowing an aliquot of the aqueous clay solution to settle and dry on a glass slide. Although numerous authors (Gibbs, 1965, 1967; Stokke and Carson, 1973) have suggested that this sedimentation technique can lead to erroneous results due to an inherent size segregation (and, hence, a mineral segregation) of the clay film, it can be argued that any one mounting method, if used singly and consistently throughout a study, will show the relative variation and trends in clay mineral content of the stratigraphic sequence being evaluated.

The sedimentation-on-glass-slide technique was chosen for the Lake Manitoba study because this method (a) is considerably less time consuming than other techniques, (b) requires no specialized mounting equipment, (c) has been shown to maintain high levels of reproducibility (Last, 1974), and (d) has been the most commonly used mounting technique in other clay mineral studies within the Lake Manitoba region (e.g., Moran, 1972; Last, 1974; Kushnir, 1971; McPherson, 1970).

Diffractograms of the clay slides were irradiated on a Philips powder diffractometer using nickel-filtered CuK alpha radiation generated at forty kilowatts and twenty milliampheres. Further pertinent equipment settings included: 1^{o} beam slit, 0.006 inch detector slit, 400 range counts per second, and two seconds times constant with the zero supressor at zero. Traces were initially run from 2^{o} two theta to 30^{o} two theta. The slides were scanned in one direction only at a rate of 1^{o} X two theta per minute. After an initial reconnaissance survey of fourteen samples to determine the main types and relative abundances of clay minerals present in the Lake Manitoba sediment, the angles scanned were decreased to 3^{o} two theta to 15^{o} two theta. Other than this change, all clay samples were analyzed at the same instrument settings and chart speeds throughout the study.

Two slides for each sample were prepared from the solution of size fractionated clay. Diffractograms were obtained from one which had been glycolated (by placing in an ethylene glycol environment for at least forty-eight hours; Brunton, 1955) and one heated at 300^{o} to 375^{o}C for one hour (Carroll, 1970). Frosted petrographic slides were used throughout this project to prevent the clay film from curling and cracking.

These two X-ray diffraction patterns were used to make semi-quantitative estimates of the relative amounts of the major clay mineral groups present: illite, expandable-lattice clay minerals (which include minerals of the montmorillonite group, vermiculite, expanding chlorites, and various mixed-layer species), and kaolinite plus chlorite.

Illite was defined on the diffractograms by a sharp peak at 10 Å (8.8° two theta) which was not affected by glycolation or heating. The expandable clay group was identified on the basis of its expanding lattice. When dry, the material has a basal spacing of about 12.5 Å (7.05° two theta; variable peak depending on the exact compositions of the expandable lattice material). After glycolation the material expands to a 17 Å (5.19° two theta) peak. Unfortunately, because this peak is often very broad and occurs at a low two theta angle, accurate baseline positioning is very difficult, and, therefore, the peak becomes unusable even in rough semi-quantitative clay mineral work. However, heating at over 300°C will cause a shift in the peak position from 17 Å to 10 Å peak (Carroll, 1970). Because this heating does not affect the illite contribution to the 10 Å peak, the difference in intensities between the 10 Å peak from the glycolated slide and the heated slide reflects the relative amount of expandable clay minerals in the sample.

The kaolinite and chlorite groups were identified by their combined, overlapping reflection at 7 Å (12.4° two theta) from the glycolated slide. No attempt was made to separate and quantitatively evaluate these two components.

Semi-quantitative calculation of the three main clay mineral groups was made using a method similar to that described by Teller (1970), Ettensohn (1971), and Last (1974). Basically, this procedure is a modification of that originally suggested by Johns et al (1954) and uses the 10 Å illite peak as an internal standard. No additional weighting factors are employed, however. The relative abundances of the clay mineral groups, as determined by their peak heights, are related to the illite peak, summed and equated to 100%. This calculation procedure is also used for routine work by the North Dakota Geological Survey (M. Arndt, personal communication, 1974).

It is fully recognized that some error may be introduced by this computational procedure, particularly with respect to weighting versus direct comparison of peak intensities (Pierce and Siegal, 1969), and with regard to the use of the 10 Å illite peak as an internal standard (Austin and Leininger, 1976). However, as discussed by Last (1974), in light of the variety of weighting schemes suggested in the literature (e.g., Hathaway and Carroll, 1954; Schultz, 1964; Johns et al, 1954; Pierce and Siegal, 1969) and the semi-quantitative nature of the clay mineralogy study in general, additional precision enhancement in the area of calculation and computation techniques probably represents an unnecessary and time consuming refinement.

2.2.5.2 Bulk mineralogy

X-ray diffractometry was also used to qualitatively and semi-quantitatively examine the mineralogy of the non-size fractionated sediment of Lake Manitoba. Randomly oriented samples were prepared by mounting a finely-powdered sediment subsample on a standard frosted glass slide (Klug and Alexander, 1974). One slide per sample was prepared and irradiated in one direction from 4^{o} two theta to 35^{o} two theta. Scanning speed was generally at 2^{o} two theta per minute and range C.P.S. was set at 200 counts per second. All other instrument settings were as described for the clay mineral evaluation.

Whole-sediment mineral identification was done on the basis of d-spacing values using standard indices (A.S.T.M. X-ray Powder Diffraction File; Chen, 1977). The abundance of the various minerals were interpreted from the diffractograms using the intensity of the strongest peak for each mineral as outlined by Schultz(1964). Basically this technique involves comparing the mineral's peak intensity in the naturally occurring mixture to the intensity of a pattern run on a sample of the pure mineral. That is, in effect an "intensity factor" is applied to the mineral peak height. The intensity factors used in this study (shown in Table 2-2) were derived from duplicate diffractometer traces of slides of the pure minerals. Where possible, the minerals in the prepared slides were obtained from local or regional bedrock sources. These intensity factors agree very well with those used by Schultz (1964) and Callender (1968).

Using this method, the sums of all the mineral constituents in over 200 samples varied between 84 and 122% ($\bar{x}$ = 103%). The sums were normalized to 100%. Replicate analyses suggest that the precision of any individual mineral determination is ± 8%. This quantitative evaluation technique has also been successfully used by Hower et al (1976) and Callender (1968).

It is important to note that this procedure is designed to derive relative percentage estimates of each mineral independently. That is, none of the individual mineral components were derived by taking the difference between the sum of the constituents and 100%. This, of course, is not the case with the previously described semi-quantitative estimates for the individual clay mineral components. Nevertheless, the fact that the bulk mineral component data does constitute a closed data set (that is, the sum of all parameter values is equal to 100%), places some restraint on the interpretation of individual component trends and statistical analysis. However, because of the greater number of components in this data set compared to, for example, the clay mineralogy or textural (percent sand,

TABLE 2-2

Factors used for quantitative interpretation of bulk mineralogy in Lake Manitoba sediments

Mineral	Identification Peak(s) (°2 theta, CuK alpha)	Peak Units per 100% of Mineral	Intensity Factor*
Quartz	26.7	22.2	0.045
Plagioclase	27.8 - 27.9	17.0	0.058
Potassic feldspar	27.4 - 27.5	13.3	0.075
Calcite (total)	29.4 - 29.8	20.0	0.050
Dolomite	30.9	19.0	0.052
Total Clay Minerals	19.9 - 20.1	2.0	0.500
Aragonite	26.2	16.5	0.060

*The intensity factor is used by multiplying the mineral peak, height (in graph units) by the particular factor. For example, if in the unknown sediment mixture the 26.7° quartz peak is 6.2 units, the abundance of quartz in the sample is 6.2 X 0.045 or 27.9%. The calculated percentages for each mineral present in the mixture are thus determined and then normalized to equal 100%. More details regarding the derivation of the intensity factors can be found in Schultz (1964).

silt, clay) parameters, the severity of these restraints is lessened.

2.2.5.3 Detailed carbonate mineralogy

X-ray diffractometry was used to examine the detailed carbonate mineralogy of selected surface (i.e., 0 to 2 cm depth) and subsurface samples. Randomly-oriented, powdered mounts of these samples were irradiated from 25° two theta to 32° two theta at a scanning speed of 1/8° two theta per minute. All other instrument settings and speeds were as reported under the bulk mineralogy section.

This detailed X-ray diffraction analysis revealed the presence of a disordered calcite in the sediment of Lake Manitoba. The disordered species of calcite is recognized by a shift in the mineral's X-ray reflections toward higher diffraction angles (corresponding to smaller lattice spacing).

An estimate of the amount of Mg^{2+} incorporation into the calcite lattice (mole percent $MgCO_3$) was made on the basis of the amount of this shift in the X-ray diffraction peak of the strongest calcite reflection (104) using the curves presented by Goldsmith and Graf (1958). The 3.34 Å (101) quartz reflection was used as an internal standard. Because both "normal" (3.03 Å) calcite and high-Mg calcite were usually present in the bulk samples, an approximation of the relative abundance of the two varieties was made according to Berner (1966).[1] This technique basically is a comparison of areas under the two peaks (i.e., area under

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[1] In this report, the calcite phase with less than 2 mole percent $MgCO_3$ in solid solution will be referred to as "calcite," "normal calcite," or "low-Mg calcite." The calcite phase with more than 2 mole percent $MgCO_3$ is termed "high-Mg calcite," "Mg-calcite," or "disordered calcite."

3.03 Å peak + area under the higher angle peak = unity). This ratio was then applied to the percent total calcite derived from the fast scan to approximate the percentage "normal" calcite and the percentage high-Mg calcite in the bulk sample. Although, as pointed out by Berner (1966) and Graf and Goldsmith (1963), this technique is not strictly reliable because of differences in diffraction efficiency, crystallinity, preferred orientation, and absorption characteristics, it is, nonetheless, the most commonly used non-chemical procedure for approximating percentages of the various species of calcite (Callender, 1968; Lippman, 1973; Chen, 1977; Müller and Wagner, 1978; Magaritz and Kafri, 1979). Hein et al (1979) indicate that this technique has an accuracy of about 1 mole percent.

2.2.5.4 Total carbonate minerals

The total amount of all carbonate minerals in the sediment was, in addition to the above X-ray techniques, also approximated using the combustion method outlined by Dean (1974). This technique, utilizing the weight lost on combustion (L.O.C.) of the sample when heated from 500° to 1000°C, has been shown to generate results that are comparable in terms of precision and accuracy to other methods, providing the total carbonate contents are greater than about 5 to 10% (Dean, 1974). In this study, there are good correlations between the total carbonate mineral content as determined by the L.O.C. method and the amount of calcite plus dolomite determined by X-ray diffractometry (Fig. 2-5), as well as with the total carbonate carbon determined by a LECO carbon analyzer (Fig. 2-6).

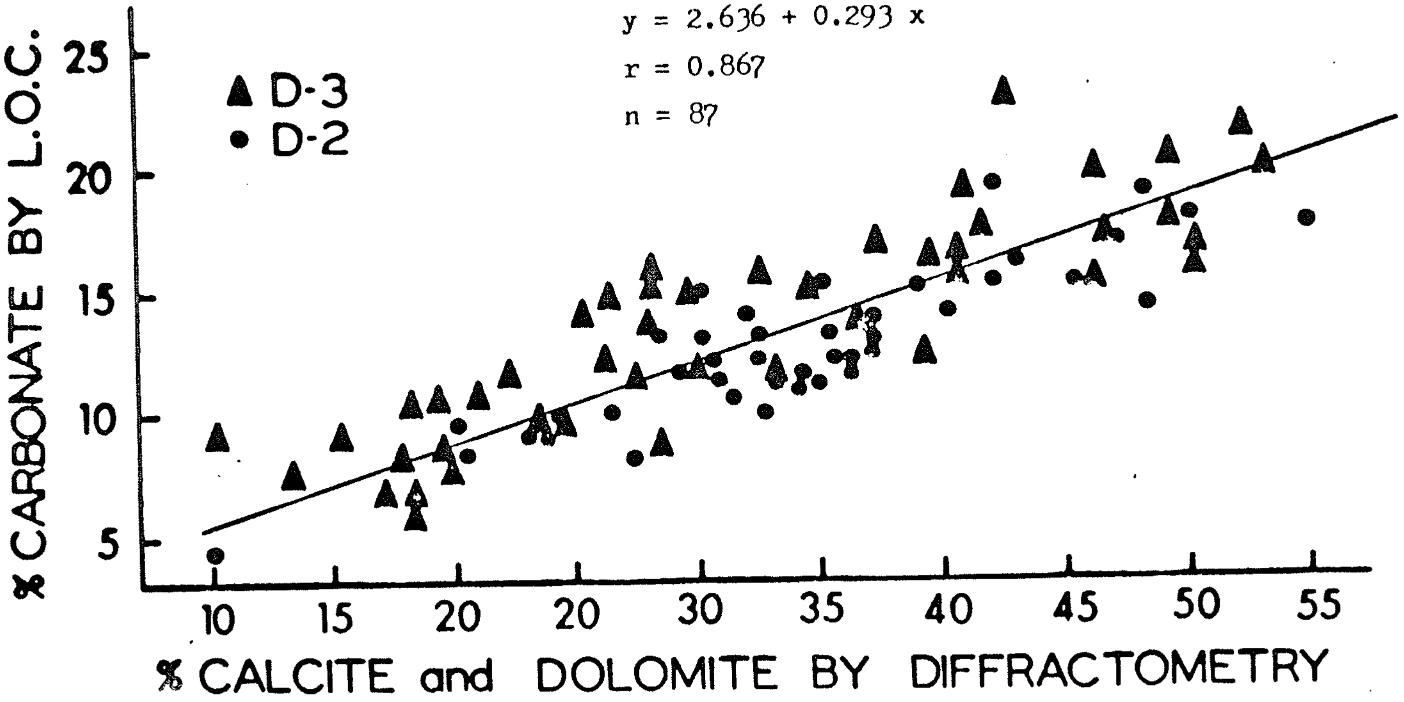

Figure 2-5. Relationship between weight percent loss on combustion (L.O.C.) and the sum of the percent calcite plus percent dolomite determined by X-ray analysis of bulk samples from cores D-2 and D-3.

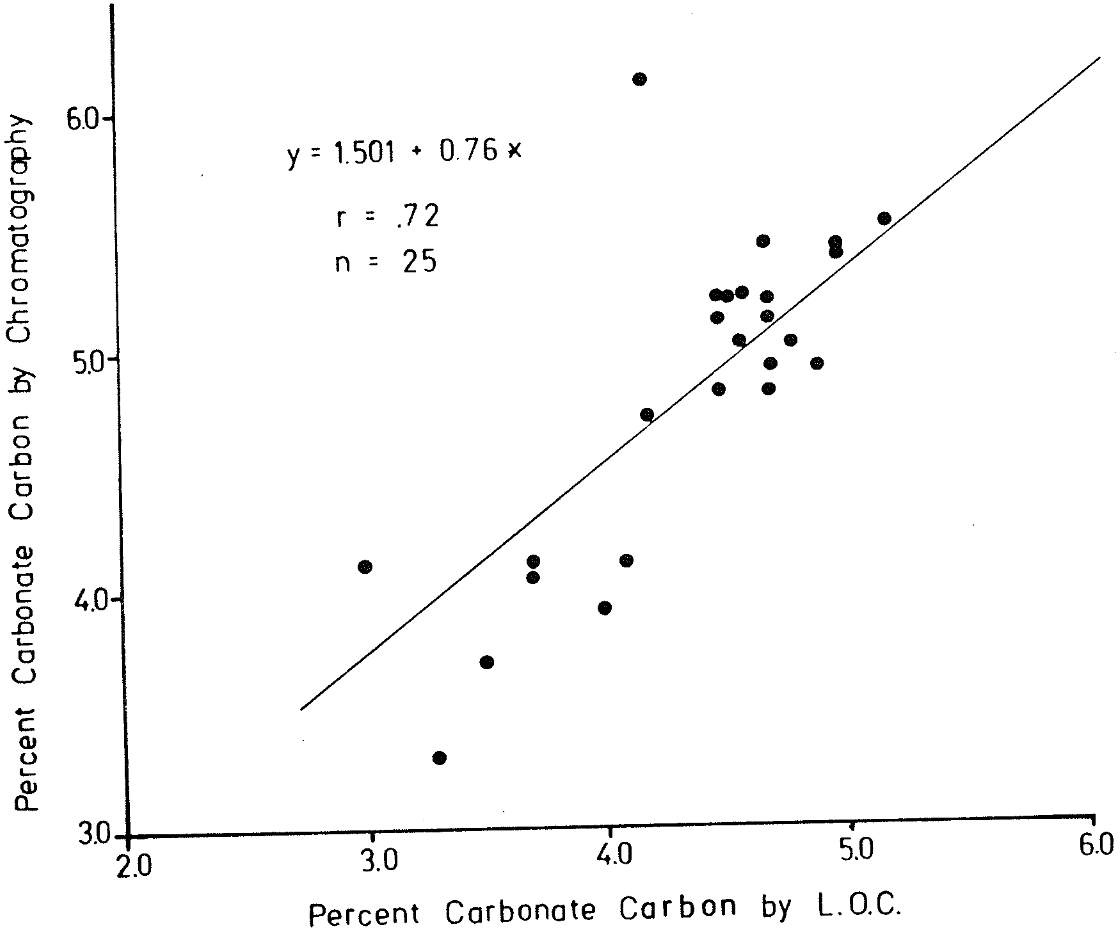

Figure 2-6. Relationship between weight percent loss on combustion (L.O.C.) and percent carbonate carbon determined by gas chromatography.

2.2.6 Chemical Parameters

2.2.6.1 Hydrogen ion concentration and redox potential

Measurements of wet sediment pH and Eh were made during the detailed laboratory logging of the cores. A Fisher Accumet (Model 120) pH meter and a Radiometer (Model 29) pH meter were used to make the determinations.

Measurements of pH were made by inserting a standard glass-reference combination electrode (Radiometer GK2311C) directly into the wet sediment. After a short equilibrium period (2-4 minutes), the pH was read to the nearest 0.1 unit. The electrode was rinsed clean and standardized before each reading.

Oxidation-reduction potential measurements were made by inserting a platinum wire electrode (Fisher 13-639-115) directly into the wet sediment. The Eh was read to the nearest 5 millivolts.

2.2.6.2 Elemental concentrations

For determination of total elemental concentrations in the sediment, a 0.5 g (approximate dry weight) subsample was oven dried (85 to 95°C), crushed, and digested overnight in an 18 ml mixture of concentrated hydrofluoric, nitric, and sulfuric acid (10:5:3; modified after Shapiro and Brannock, 1956). Teflon ware was used throughout the digestion and solution preparation procedures. After overnight digestion at 90°C, the solution was brought to fumes of $SO_3^=$ and the volume reduced to approximately 2 to 4 ml. After cooling, the solution was made up to volume with deionized, distilled water and stored in 120 ml Nalgene bottles for chemical analysis.

Concentrations of calcium, magnesium, sodium, potassium, iron, manganese, copper, lead, zinc and cadmium in this solution were determined by atomic absorption spectrophotometry. Lanthanium chloride solution was added to nullify possible interference in the calcium and magnesium determinations. Standard stock solutions were prepared according to Ward et al (1969).

Colorimetric analysis was used to determine total phosphorous concentrations by measuring the light transmitted at 430 mu by the solution with molybdovanadophosphoric acid complex added to develop the color (Shapiro and Brannock, 1962).

Sulfur (as total sulfur) was determined titrimetrically after combustion of a separate sediment sample in oxygen at approximately 1450°C (Maxwell, 1968). Sulfate sulfur was determined gravimetrically by the precipitation of barium sulfate from an HCl extract of the sediment (Hesse, 1971).

A Hewlett-Packard C-H-N analyzer was used to evaluate the total carbon and carbonate carbon in selected sediment samples (Stainton et al, 1977). From these values the difference was taken to represent organic carbon. The relationship between organic carbon and organic matter (as determined by L.O.I.) is shown in Fig. 2-7.

Total mercury in the sediment was determined by a commercial laboratory (X-Ray Assay Laboratories, Limited, Don Mills, Ontario) according to procedures outlined by Hatch and Ott (1968). The analyses were done on a Pharmacia Mercury Monitor Model 100M analyzer after digestion in $KMnO_4/HNO_3/H_2SO_4$ (T. Eagles, X-Ray Assay Laboratories Limited, written communication, 1979).

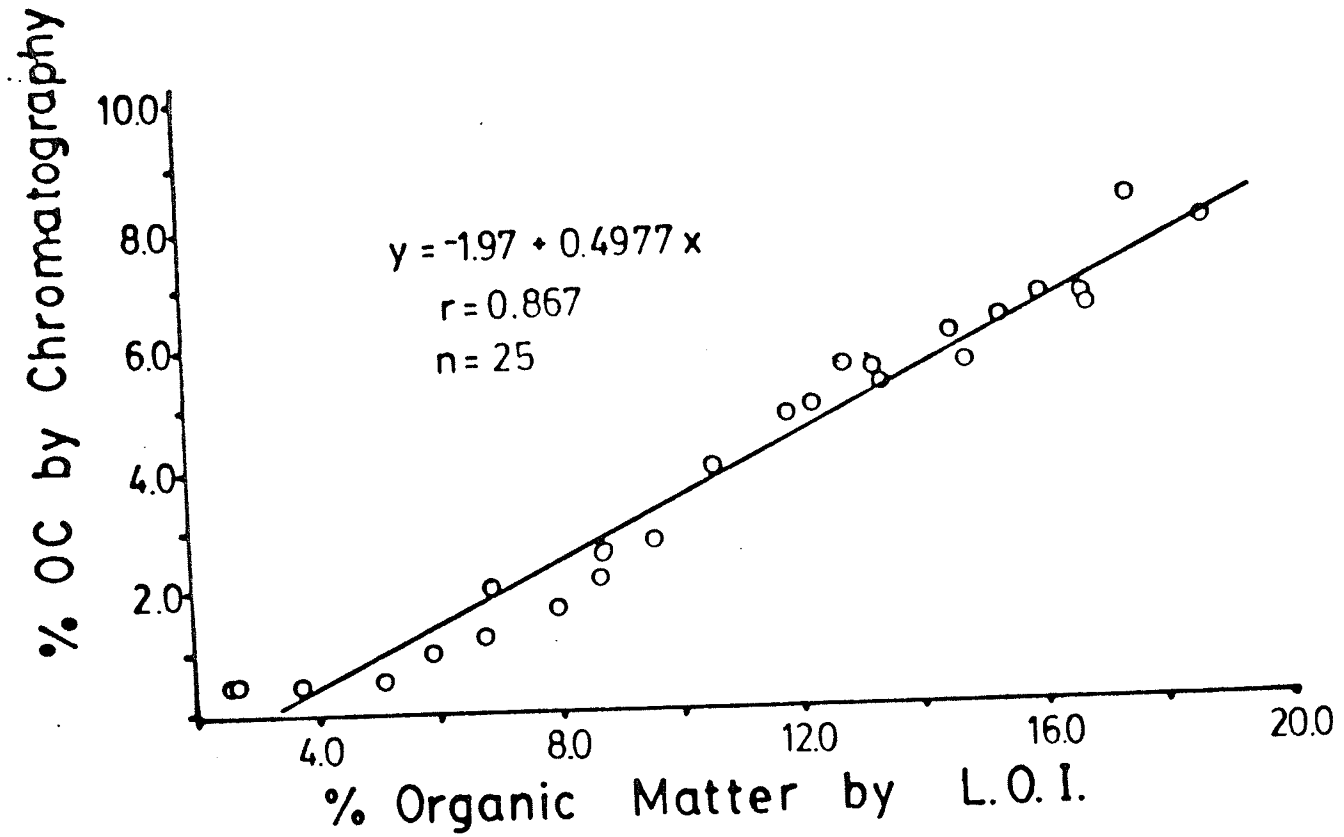

Figure 2-7. Relationship between percent organic matter determined by loss on ignition (L.O.I.) and percent organic carbon (OC) determined by gas chromatography.

2.2.6.3 Total soluble salt

Total soluble salt content of selected samples was determined by leaching a sediment subsample with 1.0 N ammonium acetate at pH 5.2 and computing the percent weight lost (Dean and Gorham, 1976; Wangersky and Joensuu, 1967).

2.2.6.4 Water sample analyses

Water samples collected from Lake Manitoba were filtered through a Whatman No. 42 filter and analyzed for major cations (calcium, magnesium, potassium and sodium) by atomic absorption as outlined above. Chloride content was determined by titration with 0.1 N silver nitrate solution using potassium chromate as an endpoint indicator (Kolthoff and Sandell, 1952). Sulfate was precipitated as barium sulfate and measured gravimetrically (Stainton et al, 1977). Total alkalinity was determined by titration with 0.01 M hydrochloric acid with methyl orange as the endpoint indicator. Total dissolved solid content was determined by evaporation of a known volume of filtered solution and weighing the residue.

2.3 METHODS OF ABSOLUTE AGE DETERMINATION

2.3.1 Introduction

Two methods were used in an attempt to establish the absolute age of the Lake Manitoba sediment cores. These methods are: (1) carbon-14 age dating of organic matter in the sediment, and (2) the rise in concentration of *Ambrosia* (ragweed) pollen.

2.3.2 ^{14}C Dating

The organic matter from ten core subsamples was radiocarbon dated by commercial laboratories (Krueger Enterprises, Inc., Cambridge, Massachusetts, and Brock University Geological Science Radiocarbon Lab, St. Catherines, Ontario). In addition to these ten dates, four samples submitted to the Brock Laboratory were found to generate an insufficient amount of carbon dioxide necessary to obtain a reliable date (M. Melville, personal communication, 1979). In all cases, the laboratories oven dried the core samples and then dispersed them in water. The finely disseminated organic matter and clay-sized material were separated from sand and silt and treated with hot dilute hydrochloric acid by the dating labs to remove all carbonates prior to combustion and counting. A listing and critical assessment of these dates and a description of the method of correcting anomalous dates are discussed in Section 7.

2.3.3 Ambrosia Rise

The presence and rise of Ambrosia (ragweed) pollen in recent lake sediments over much of North America is generally interpreted as an indication of physical disturbance of the watershed soils associated with European settlement, land clearing, and large scale agricultural development. As such, this stratigraphic marker horizon is probably time transgressive over North America as pointed out by Maher (1977). The horizon has been dated at 1775 in Maine (Davis, 1967), 1830 in southern Michigan (Davis et al, 1971), 1840 in deposits of southern Lake Michigan (King et al, 1976), 1850 in sediments of Lake Ontario and other lake deposits of southern Ontario (McAndrews, 1976; McAndrews and Boyko, 1972), 1870 in Lake Huron sediments (Kemp and Harper, 1977), 1888 in northern Minnesota (Bradbury and Megard, 1972), and 1890 in sediments of Lake Superior (Maher, 1977).

Although the Ambrosia rise in pollen profiles has not been dated in absolute terms in southern Manitoba, in view of the rapid population increase and land settlement of the area between 1872 and 1880, this horizon can probably be defined to represent about 100 years B.P. in many lakes of the region (e.g., Ritchie and Lichti-Federovich, 1968; Rtichie, 1976).

2.4 STATISTICAL METHODS

Statistical analyses of the data taken from observations made during this study ranged from simple descriptive statistics to univariate and multivariate inferential analyses. Statistical parameters developed from and summarizing grain size analyses were computed using both graphic data (read from the grain size cumulative curves) according to Folk (1966) and conventional statistical moment measure (as outlined in Friedman and Sanders, 1978, p. 78-81). Initial linear regression and correlation coefficient calculations were made on paired data sets using an Olivetti-Underwood Programa 101 desk-top calculator. More complete statistical analyses of larger data sets were done using the Manitoba Statistical Package (University of Manitoba Computer Centre). These will be further discussed in the appropriate sections. Lake morphometric parameters and statistics were computed according to formulae given in Wetzel (1975), Hutchinson (1975),and Cole (1975).

SECTION 3

LAKE MANITOBA AND ITS BASIN

3.1 INTRODUCTION

The purpose of this chapter is to present and discuss some of the important physical, chemical, hydrological, and morphometric aspects of present-day Lake Manitoba. Much of this material is review in nature, derived mainly from the various published articles and unpublished documents pertaining to the lake. The intent of this discussion is to provide background information which will be useful and necessary in evaluating and interpreting data presented in later sections on the post-glacial sediment characteristics of the South Basin and the historical development of Lake Manitoba.

3.2 PHYSIOGRAPHY AND CLIMATE

Lake Manitoba is located in the Manitoba Lowland physiographic subdivision of the Interior Plains (Fig. 3-1). The Manitoba Escarpment, about 60 km west of Lake Manitoba, rises to an elevation of about 650 m and forms a sharp physiographic break between the Westlake/Interlake Plain surrounding the lake and the Western Upland Plain. The Westlake and Interlake areas are characterized by gently undulating topography and low relief. The area south of the lake grades from a hummocky, sandy plain immediately below the Manitoba Escarpment (Upper and Lower Assiniboine Delta) to a flat, clay plain (Red River Lowland Lacustrine and Alluvial Plain) east of Portage la Prairie.

The climate of the Lake Manitoba region is classified as Dfb (microthermal, subhumid, snow-forest climate; coldest month below $0^{\circ}C$, warmest month above $10^{\circ}C$ but below $24^{\circ}C$). Mean annual temperature in

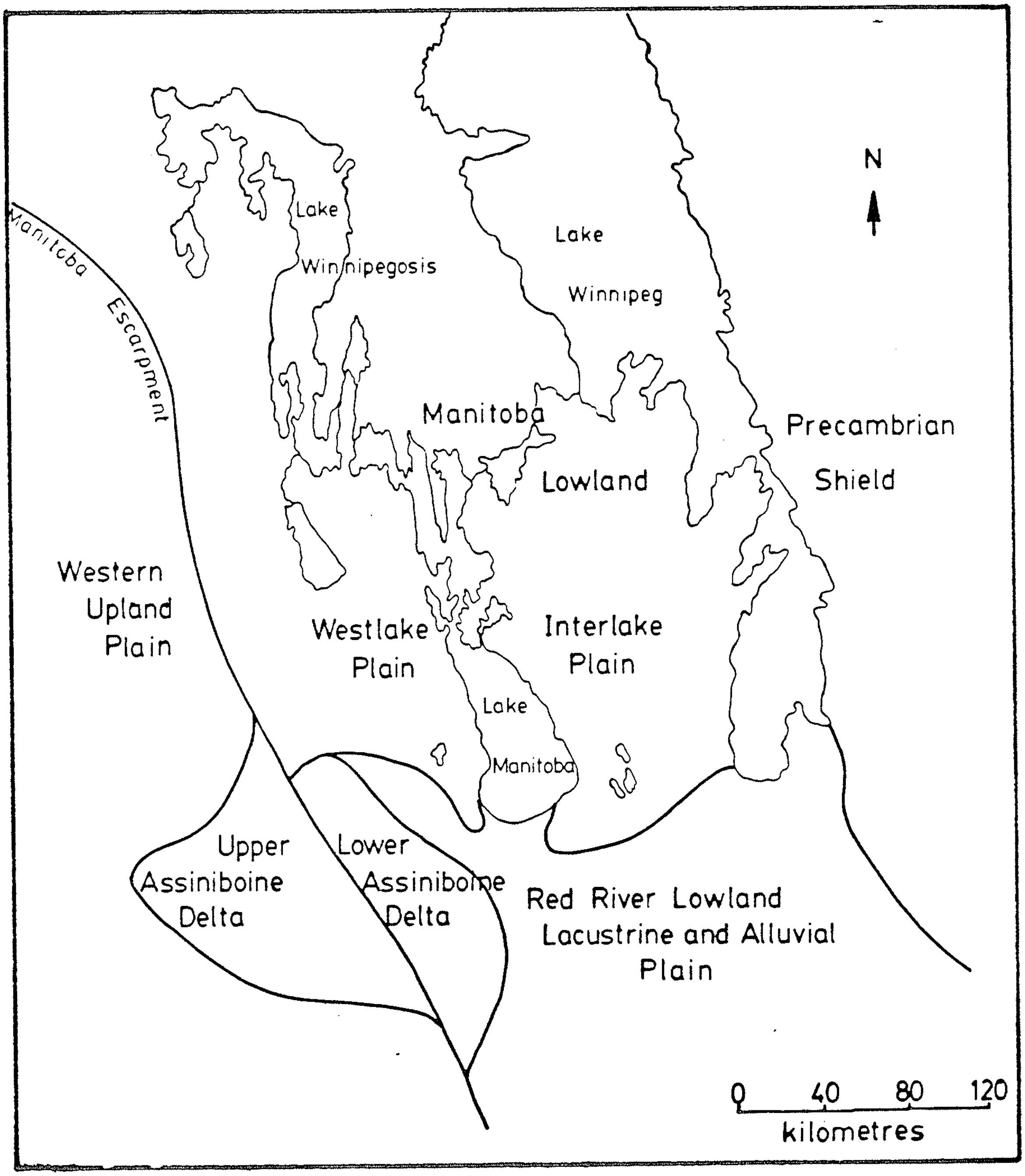

Figure 3-1. Physiographic areas of south-central Manitoba.

the Interlake area is approximately 1°C with a mean maximum daily temperature during July of 23°C and a mean minimum temperature during January of -24°C (Mills et al, 1971; Pratt et al, 1961). The region receives about 50 cm of precipitation per year, 75% of which falls as rain during April to October (Pratt et al, 1961).

3.3 BEDROCK GEOLOGY

3.3.1 Regional Geology

The regional bedrock geology of Manitoba is shown in Figure 3.2. Eastern and much of northern Manitoba is dominated by granitic, volcanic, and metasedimentary rocks of the Precambrian Shield. Overlying this uniform southwesterly-dipping Precambrian erosional surface in the southern portion of the province is a sequence of Paleozoic-, Mesozoic-, and Cenozoic-aged sediments (Table 3-1). The Paleozoic rocks consist mainly of dolomites and limestones with volumetrically small amounts of sand, shale, and evaporites. The Mesozoic and Cenozoic sediments are dominantly shales and sandstones with small amounts of coal, carbonates, and evaporites.

3.3.2 Outcrop and Subcrop Geology of the Lake Basin

Rocks of Silurian, Devonian, Jurassic, and Cretaceous age outcrop or subcrop in the Lake Manitoba region (Fig. 3-2). The Silurian Interlake Group, outcropping east of Lake Manitoba, consists of fossiliferous dolomite, with scattered limestone and anhydrite beds (Baillie, 1951). Limestone, gypsum, and anhydrite are quarried locally.

Formations of the Devonian Elk Point Group outcrop in the Narrows area of Lake Manitoba and along much of the shoreline of the

TABLE 3-1

GEOLOGICAL FORMATIONS IN MANITOBA (from McCabe, 1971)

ERA	PERIOD	FORMATION	BASIC LITHOLOGY AND THICKNESS	
CENOZOIC	Tertiary	Turtle Mountain	shale, sandstone, lignite;	150 m
MESOZOIC	Cretaceous	Boissevain	sandstone, kaolinitic shale;	30-45 m
		Riding Mountain	siliceous and bentonitic shales;	250-400 m
		Vermilion River	calcareous, carbonaceous, and bentonitic shales;	45-180 m
		Favel	calcareous shale;	20-40 m
		Ashville	shale, sandstone;	40-100 m
		Swan River	sandstone, shale, lignite;	0-120 m
	Jurassic	Waskada	shale;	0-45 m
		Melita	shale, limestone;	100-150 m
		Reston	limestone, shale;	0-50 m
		Amaranth	anhydrite, gypsum, shale, dolomite;	0-100 m
PALEOZOIC	Mississippian	Charles	dolomite, anhydrite;	35 m
		Mission Canyon	dolomite, limestone, anhydrite;	80-100 m
		Lodgepole	limestone, shale;	150-175 m
		Balken	shale;	3-15 m
	Devonian	Lyleton	shale;	10-60 m
		Nisku	dolomite, limestone;	15-50 m
		Duperow	limestone, dolomite, anhydrite;	120-200 m
		Souris River	limestone, shale;	60-95 m
		Dawson Bay	limestone, anhydrite, shale;	40-70 m
		Prairie Evaporite	halite, anhydrite, dolomite;	0-120 m
		Winnipegosis	dolomite;	10-100 m
		Elm Point	limestone;	0-15 m
		Ashern	dolomite, shale;	1-20 m
	Silurian	Interlake Group	dolomite;	50-100 m
	Ordovician	Stonewall	dolomite;	10-20 m
		Stony Mountain	dolomite, shale;	30-45 m
		Red River	dolomite, limestone;	50-150 m
		Winnipeg	sandstone, shale;	0-70 m
	Cambrian	Deadwood	sandstone, undetermined thickness	

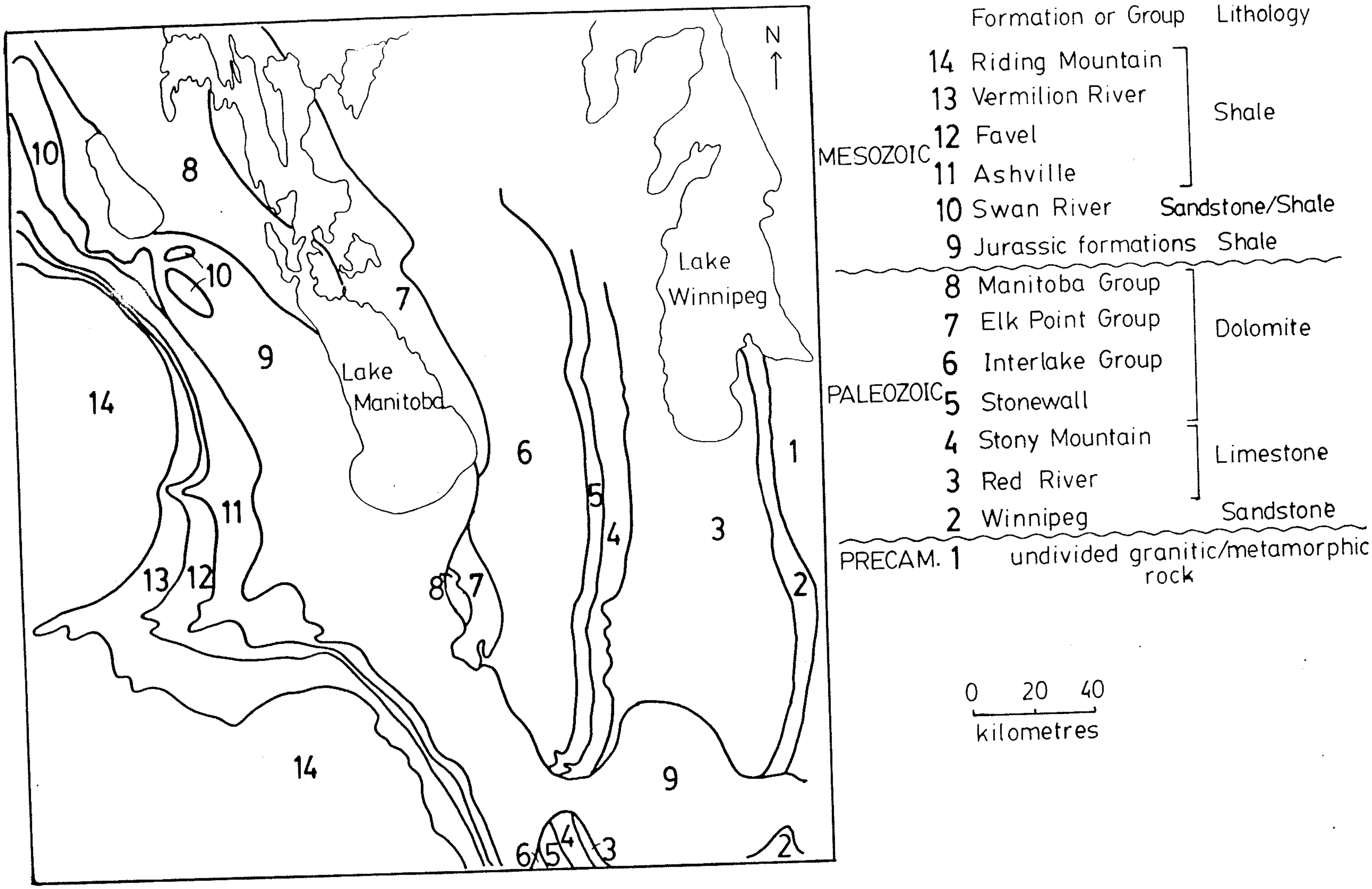

Figure 3-2. Bedrock geologic map of south-central Manitoba (generalized from Teller and Bannatyne, 1976).

North Basin. The lithology of these formations is spatially variable (Baillie, 1951) but is mainly shale and argillaceous dolomite (Ashern Formation), limestone and dolomitic limestone (Elm Point Formation), and fossiliferous and anhydritic dolomite (Winnipegosis Formation). In the Lake Manitoba area these formations are quarried as a source of limestone and aggregate (Bannatyne, 1971, 1975).

Overlying the Winnipegosis carbonate in the subsurface west of Lake Manitoba is the Prairie Formation which consists dominantly of halite and anhydrite with minor beds of potassium salts (McCabe, 1971; Bannatyne, 1959). Overlying these sediments and outcropping just west of the North Basin of the lake are the Dawson Bay and Souris River Formations (Manitoba Group) both consisting dominantly of a shale-carbonate sequence with minor evaporitic beds present. All of the younger Paleozoic formations are present only in the subsurface and are shown in Table 3-1.

The oldest Mesozoic bedrock in the area, the Jurassic Amaranth, Reston, and Melita Formations are not exposed at the surface but probably directly underlie much of the South Basin of the lake and the Westlake Plain area (Bannatyne, 1977, and personal communication, 1979; Teller and Bannatyne, 1976; Manitoba Water Resources Branch, 1972). The lithology of these formations is quite variable ranging from gypsum, anhydrite, and shale of the Amaranth Formation to sand, shale, and minor carbonates of the Reston and Melita Formations (McCabe, 1971; Stott, 1955). The Melita Formation also contains minor amounts of carbonaceous shale and coal (Manitoba Water Resources Branch, 1972). Gypsum and anhydrite from the Amaranth Formation have been, and are currently being mined and quarried at several localities surrounding Lake Manitoba (Bannatyne, 1977). The evaporite deposits of the Gypsumville area (approximately 20 km northeast of the Fairford River outlet of Lake Manitoba) have been quarried for over 75 years. During the early stages of exploitation (1901 to 1910), the quarried and crushed gypsum was shipped by barge from Portage Bay to the south end of the lake and up the Whitemud River to the railhead at Westbourne (Phillips, 1978).

Overlying these Jurassic sediments is a relatively thick sequence of siliceous, bentonitic, and carbonaceous shales of Cretaceous age. Many of the formations are well exposed in outcrop along the Manitoba Escarpment, approximately 70 km west of Lake Manitoba (see McCabe and Bannatyne, 1970, for outcrop locations). In addition to the shales, the lowermost Cretaceous units (Swan River Group and Ashville Formation) contain lignite and thin sand beds. The Favel and Ashville Formation also contain organic-rich shales which have been investigated as a potential source of commercial oil shale (Bannatyne, 1970). The shales of the Vermilion River and Riding Mountain Formations are high in bentonite and have been mined in the Pembina Mountain area of southern Manitoba (Davies et al, 1962).

Bedrock of probable Paleoceneage is exposed in the Turtle Mountain area of the province, 160 km southwest of Lake Manitoba. The Boissevain and Turtle Mountain Formations consist of interbedded sandstones, shales and lignites (Bamburak, 1973, 1978). The low-grade coal seams of these formations have been mined sporadically since the late 19th century.

3.3.3 Importance of Bedrock Geology to the Lake

The importance of the bedrock geology to Lake Manitoba can be summarized by the following points:

1. The morphologic characteristics of Lake Manitoba north of the Narrows are largely controlled by the presence of bedrock at or very near the surface. The distinctive relief on the exposed Winnipegosis Formation, which is due to the relative resistance of the massive, dolomitic reef facies versus the more easily eroded bedded dolomite of the inter-reef areas, creates a lake basin with a very irregular shoreline and numerous islands. This is in contrast to the South Basin which has very little exposed bedrock along the shore and is, therefore, much smoother in outline with few islands (see Fig. 3-4).

2. The presence of carbonates in significant amounts in the bedrock of the watershed suggests that the waters of Lake Manitoba will be hard and the lacustrine sediments high in calcareous material.

3. The presence of easily eroded shale bedrock helps dictate the high sediment yield of the streams entering the lake and, in part, the high natural turbidity levels in the lake water.

4. The presence of highly soluble Paleozoic bedrock, such as the Prairie Formation, has generated groundwater aquifers containing high salinity water (van Everdingen, 1971). The presence of brine springs in the watershed and their association with the Winnipegosis Formation indicates that Lake Manitoba has a concentrated source of dissolved ions.

5. The mineralogy (clay mineralogy in particular) of Lake Manitoba sediments, including ancestral Lake Agassiz deposits, is probably, in part, a reflection of the extensive contribution of sediment by the Cretaceous shales of the watershed.

6. The presence of organic-rich shales and lignites in the watershed suggests that there is a potential source of "old" organic matter

to the lake sediments which could act as a contaminant when attempting to date organic matter by the radiocarbon method.

3.4 SURFICIAL GEOLOGY AND SOILS

3.4.1 Late Quaternary Deposits

The nature and thickness of the surficial deposits varies considerably in the Lake Manitoba region. However, in contrast to the large body of knowledge existing for the bedrock, the details of the younger unconsolidated sediments are comparatively poorly known.

Water-laid sands and silts are present at the surface west and southwest of the lake (Fig. 3-3). These deposits are associated with nearshore and shoreline fluvial-deltaic sedimentation in glacial Lake Agassiz. Eastward these coarse clastics grade into finer, offshore sediments of the main depositional basin of Lake Agassiz. Where rivers and streams have developed subsequent to final draining of Lake Agassiz, silty and sandy alluvium is present. To the north, in the Interlake area, the surficial deposits consist mainly of highly calcareous till interspersed with local areas of silty clay, silt, and peat.

The unconsolidated material immediately south of Lake Manitoba ranges from 10 to 150 m in thickness (Teller, 1976b) and consists of a variable sequence of tills, fluvial and deltaic sediment, and offshore and shoreline Lake Agassiz material (Gilliland, 1965; Fenton and Anderson, 1971). The tills of this area show relatively little textural variation ranging from 30 to 40% sand, from 35 to 40% silt, and from 20 to 35% clay-sized material (Fenton, 1970, p. 15). Likewise, mineralogically, this ice-laid material appears to be rather homogenous, consisting dominantly of carbonate grains with smaller amounts of quartz, feldspars,and clay

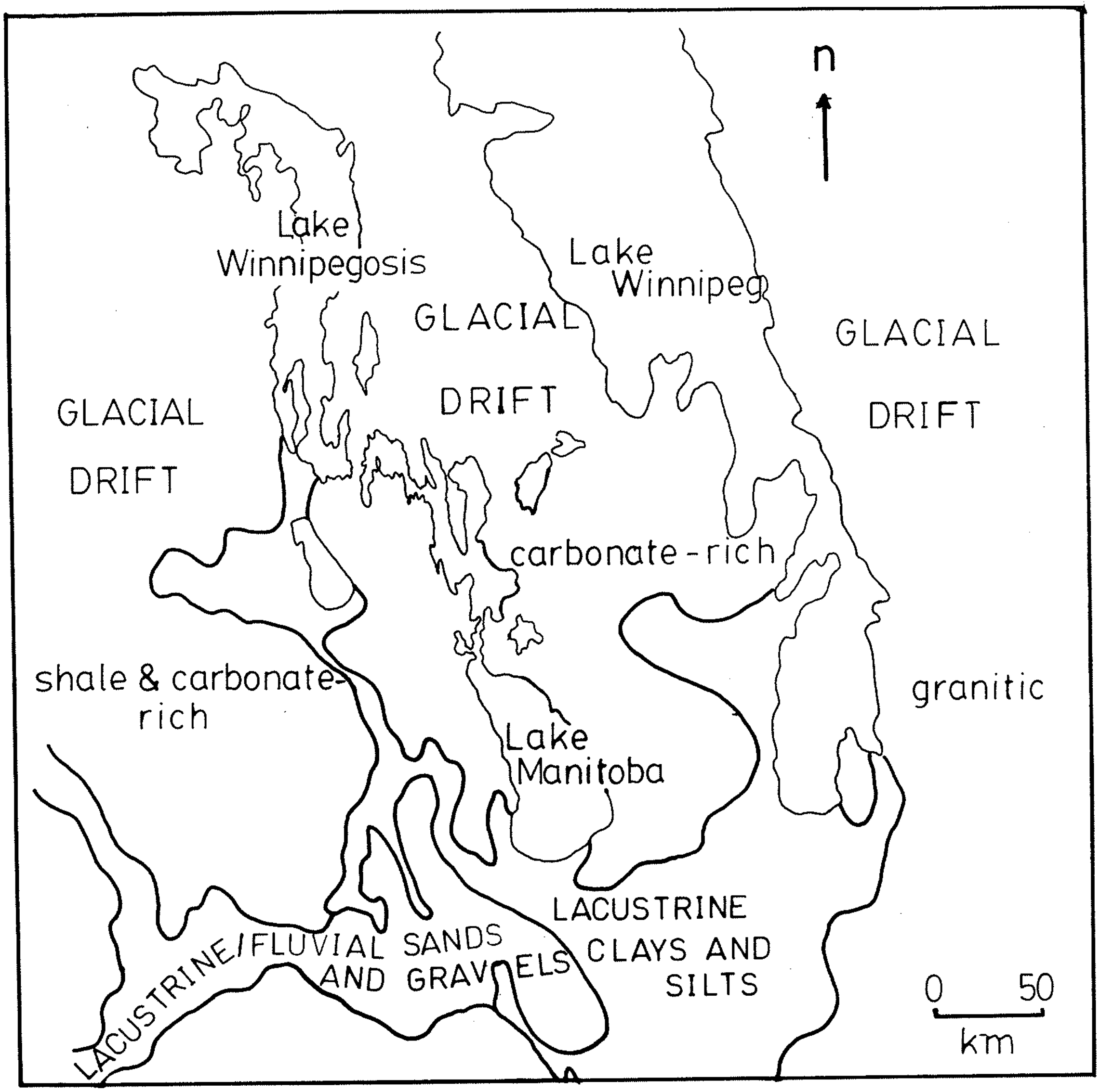

Figure 3-3. Surficial sediments of southern Manitoba (generalized from Barto and Vogel, 1978).

minerals. In the finer-than-sand-sized fraction of these tills, dolomite is the dominant carbonate mineral (Fenton, 1970, p. 14).

Interbedded with and overlying this ice-laid material south of Lake Manitoba are several offshore lacustrine units composed mainly of clayey silts and silty clays (Fenton, 1970, Figures 6 and 7; Gilliland, 1965, Figure 14). Ice-rafted stones and clasts are common components of this lacustrine sediment. The carbonate content is generally low, averaging 15% in the finer-than-sand-sized fraction (Fenton, 1970, p. 17) with dolomite again being dominant over calcite. The clay minerals consist of subequal proportions of illite, expandable clays, and kaolinite plus chlorite, with the illite content, in general, dominating over the expandable clays (Last, 1974, p. 135-137).

Overlying and cut into these fine-grained offshore lacustrine sediments of the area immediately south of Lake Manitoba are various nearshore (beach) and fluvial units composed mainly of quartz sand and silts (Gilliland, 1965; Fenton, 1970).

Outside of the Delta area, the nature and stratigraphic relationships of the unconsolidated deposits adjacent to Lake Manitoba are only poorly known. North and east of the South Basin the drift cover thins dramatically and bedrock is at or very near the surface in most places. West of the South Basin the stratigraphic relationships of the unconsolidated sediment appear rather complex, but, in general, consist of a relatively thin section of lacustrine and fluvial sands, silts and clays overlying a much thicker sequence of interbedded tills and fine to coarse-grained (lacustrine?) sediment (Manitoba Water Resources Branch, 1972, Figures 6 to 8).

3.4.2 Soils

The soils developed on the bedrock and unconsolidated sediments vary depending on the characteristics of the parent material and topography. The soils of the region are dominantly Black and Dark Grey Chernozem with scattered areas of Gleysolic, Organic, and Regosolic soils in areas of poor drainage or poor pedogenic development (Eilers et al, 1977). Grey Luvisolic and Brunisolic soils have developed in much of the highland regions of the Riding Mountain-Duck Mountain areas and in the areas north of Lake Manitoba.

3.5 MORPHOMETRIC CHARACTERISTICS OF LAKE MANITOBA

3.5.1 Size and Shape

Lake Manitoba, with an area of approximately 4700 km^2, is the thirteenth largest lake in North America.[1] It is the third largest lake in Manitoba and the second largest in western Canada located entirely off of the Precambrian Shield. One of the most conspicuous features of the lake's outline is the Narrows which effectively divides the lake into two connected but distinctly different basins (Fig. 3-4). The North Basin, containing approximately 30% of the lake's total surface area, has a very irregular shoreline with numerous, dominantly bedrock controlled islands, peninsula and straits. The average depth of the North Basin has

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[1] Estimates of the area of Lake Manitoba have varied as follows: 4792 km^2 (Cober, 1968), 4766 km^2 (Lakes Winnipeg and Manitoba Board, 1958; McKay, 1965), 4706 km^2 (Butler, 1949, Rawson, 1955; Burrows, 1970), 4680 km^2 (Crowe, 1972b), 4662 km^2 (International Joint Commission, 1977), 4660 km^2 (International Garrison Diversion Study Board, 1976), 4630 km^2 (Canadian National Committee for the International Hydrological Decade, 1978), 4624.5 km^2 (Inland Waters Directorate, 1973), 4597 km^2 (Bajkov, 1930), and 4431 km^2 (Denis and Challis, 1916). In this study, the mean of three area determinations of Lake Manitoba using a polar planimeter and 1:250,000 scale topographic maps was 4690 km^2.

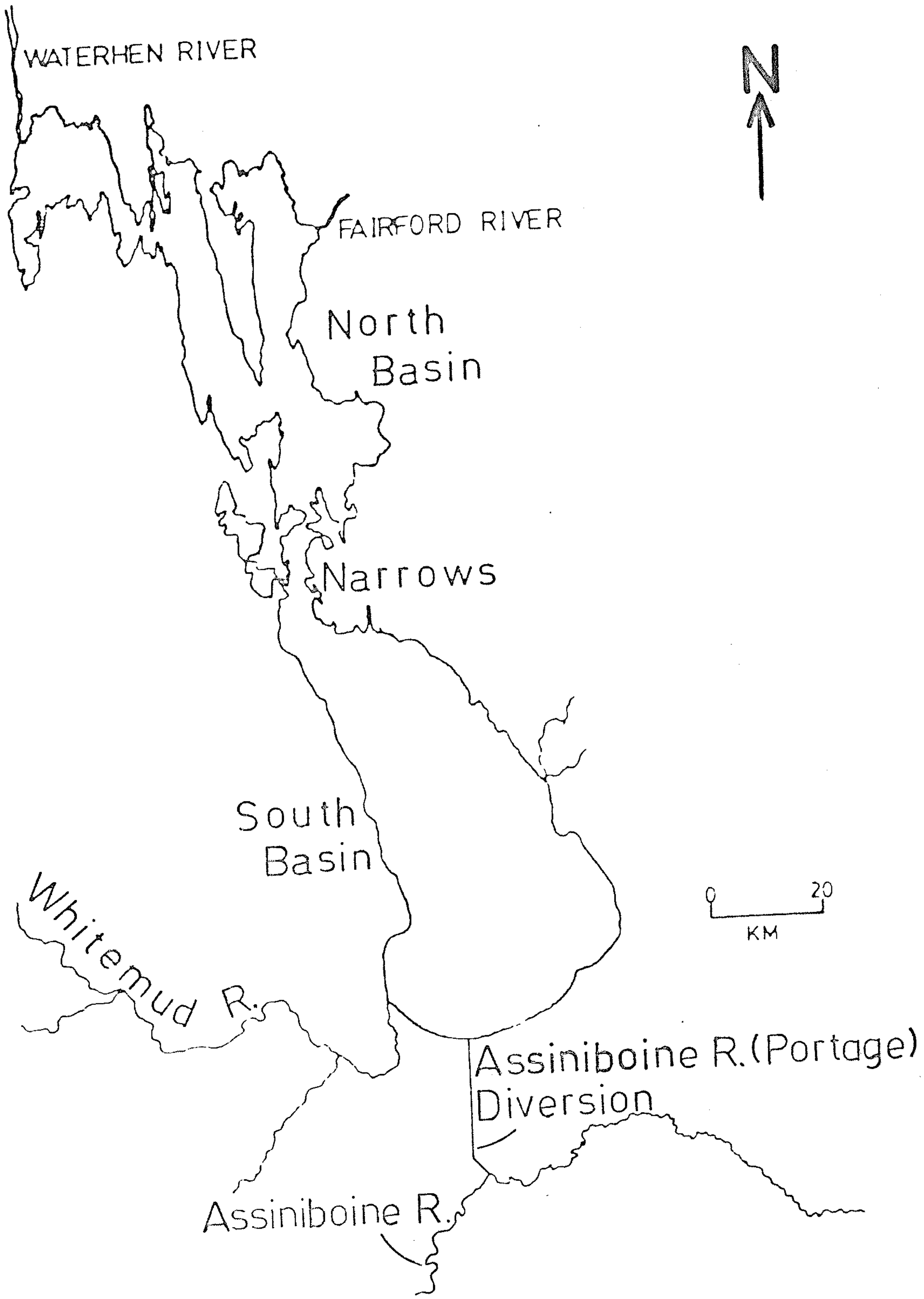

Figure 3-4. Lake Manitoba North Basin, Narrows, and South Basin.

been listed as 4.5 m by Burrows (1970) and 3.1 m by the International Garrison Diversion Study Board (1976). The South Basin, conversely, is characterized by a relatively smooth shoreline, few islands and a much larger area.

3.5.2 Bathymetry of South Basin

Despite its size (3107 km^2), the South Basin is extremely shallow. Figure 3-5 shows the bathymetry of the southern two thirds of the basin. This map was prepared and contoured from (a) soundings data obtained by the Manitoba Department of Mines, Resources and Environmental Management (Fisheries Branch) during 1969 (K. Campbell, personal communication, 1978), (b) data presented by Tudorancea and Green (1975; collected in 1973), (c) data collected by Manitoba Hydro in 1977 (J. Ellis, personal communication, 1978), and (d) soundings made during the present study. All data have been corrected relative to the long-term mean level of the lake (247.5 m above sea level). Tables 3-2 and 3-3 summarize the morphometric data, physical characteristics and calculations for the entire lake and for the South Basin.

The South Basin has a simple morphology with a flat bottom and relatively steeply sloping sides. The floor of the lake has a low mean gradient (0.03^{o}) and relatively low topographic roughness (i.e., the quotient between the real three-dimensional area and the two-dimensional map area) and relief (0.089) factors (compare with data in Hakanson, 1974). The maximum depth indicated in any of the South Basin sounding surveys is 6.3 m (corrected relative to long-term mean).[1]

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[1] This depth (6.3 m) will be regarded as z_{max} for the South Basin despite reference to 7.0 to 7.3 m by Bajkov (1930) and the Lakes Winnipeg and Manitoba Board (1958).

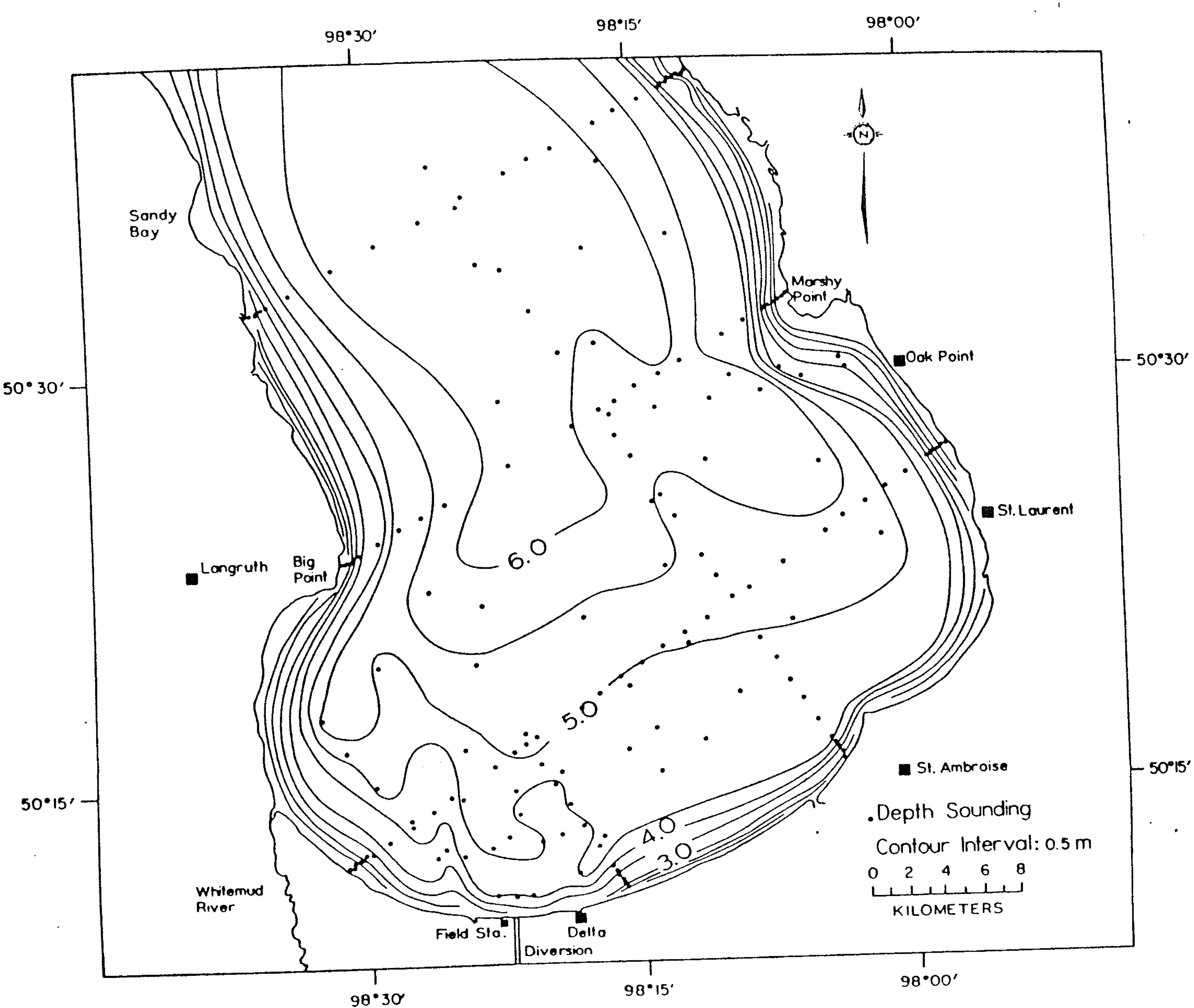

Figure 3-5. Bathymetry of the southern portion of Lake Manitoba. See text for explanation of sources of data.

Table 3-2. General physical and morphometric characteristics of Lake Manitoba

	South Basin only	Entire lake
Maximum length	105 km	197 km
Maximum width	47 km	47 km
Maximum depth	6.30 m	-
Mean depth	4.50 m	-
Surface area	3,107 km^2	4,624 km^2
Volume	14.1 km^3	-
Drainage area	17,343 km^2	80,299 km^2
Percent of area agricultural	71	59
Drainage area: lake area ratio	5:1	17:1
Number of Islands	10	22
Length of shoreline	392 km	-
River inflow per year	0.89 km^3	3.36 km^3
River outflow per year	-	2.49 km^3
Mean annual precipitation	1.55 km^3	2.31 km^3
Mean annual evaporation (est.)	2.08 km^3	3.00 km^3
Theoretical water renewal time (from the International Garrison Diversion Study Board, 1976)	28 years	-

Table 3-3. Detailed morphometric calculations for South Basin of Lake Manitoba.

DEPTH (m)	AREA (km^2)			STRATUM (m)	VOLUME (km^3)		
		cum.	%			cum.	%
0	93.2	3107.9	100	0.0-0.5	1.53	14.12	100
0.5	62.1	3014.6	97	0.5-1.0	1.49	12.64	89
1.0	62.1	2952.5	95	1.0-1.5	1.45	11.15	78
1.5	62.2	2890.4	93	1.5-2.0	1.42	9.70	68
2.0	62.2	2828.2	91	2.0-2.5	1.39	8.28	58
2.5	93.2	2766.0	89	2.5-3.0	1.35	6.89	48
3.0	128.9	2672.8	86	3.0-3.5	1.30	5.54	39
3.5	218.0	2543.9	82	3.5-4.0	1.21	4.24	29
4.0	298.2	2324.9	74	4.0-4.5	1.08	3.03	21
4.5	477.2	2027.7	65	4.5-5.0	0.88	1.95	13
5.0	540.4	1550.5	50	5.0-5.5	0.63	1.07	7
5.5	526.3	1010.1	33	5.5-6.0	0.36	0.44	3
6.0	483.8	483.8	16	6.0-6.5	0.08	0.08	0.5
6.5	-	-	-	-			

Shoreline Development $D_1 = \frac{L}{2\ (\pi\ A)^{\frac{1}{2}}} = 1.63$

Volume Development $D_v = \frac{3(\bar{z})}{z_{max}} = 2.14$ $z:z_{max} = 0.71$

Mean Basin Slope = 0.037°

Mean Slope between 0 and 4 meters depth = 0.08°

Relief Factor $R_r = \frac{z_{med}}{A^{\frac{1}{2}}} = 0.089$

Roughness Factor $R = \frac{0.165\ (e + 2)\Sigma\ S_{zi}}{z_{med}\ (A)} = 2.92$

L = length of shoreline

A = area of lake

e = contour interval

$\bar{z}$ = mean depth

$\bar{z}_{max}$ = maximum depth

$\bar{z}_{min}$ = minimum depth

z_{med} = median depth

The mean depth (volume/area) of the South Basin is 4.5 m. Median depth obtained from hypsographic curves (Fig. 3-6) is 5.0 m. Maximum length of the South Basin is 105 km, with a breadth of 47 km. Shoreline length is 392 km.

Shoreline development, a quantitative measure of the lake's outline, is 1.81. A lake whose outline is perfectly round would have a shoreline development index of 1.0 with values greater than 1 indicating departure of the shoreline from the outline of a circle. Volume development, or the ratio of mean to maximum depth, is rather large (0.71)indicative of the flat, shallow nature of the basin.

3.5.3 Summary of Important Morphometric Characteristics

In addition to their purely descriptive significance, the morphometric features and physical dimensions of Lake Manitoba are of obvious importance in helping control sedimentary characteristics mainly by governing the water flow of the lake and the energy regime on the lake's floor. A knowledge of the modern morphometric characteristics is also necessary in (a) attempting to find and evaluate potentially analogous lacustrine settings, and (b) in interpreting the ancient sediment record in terms of the lake's paleo-depositional environment. Some of the most important morphometric features of modern Lake Manitoba are:

1. The lake is composed of two separate and distinctive basins: a small, irregular, dominantly bedrock controlled basin (or series of basins) north of the Narrows, and a large, single basin characterized by a relatively smooth, regular shoreline with few islands south of the Narrows (Fig. 3-4).

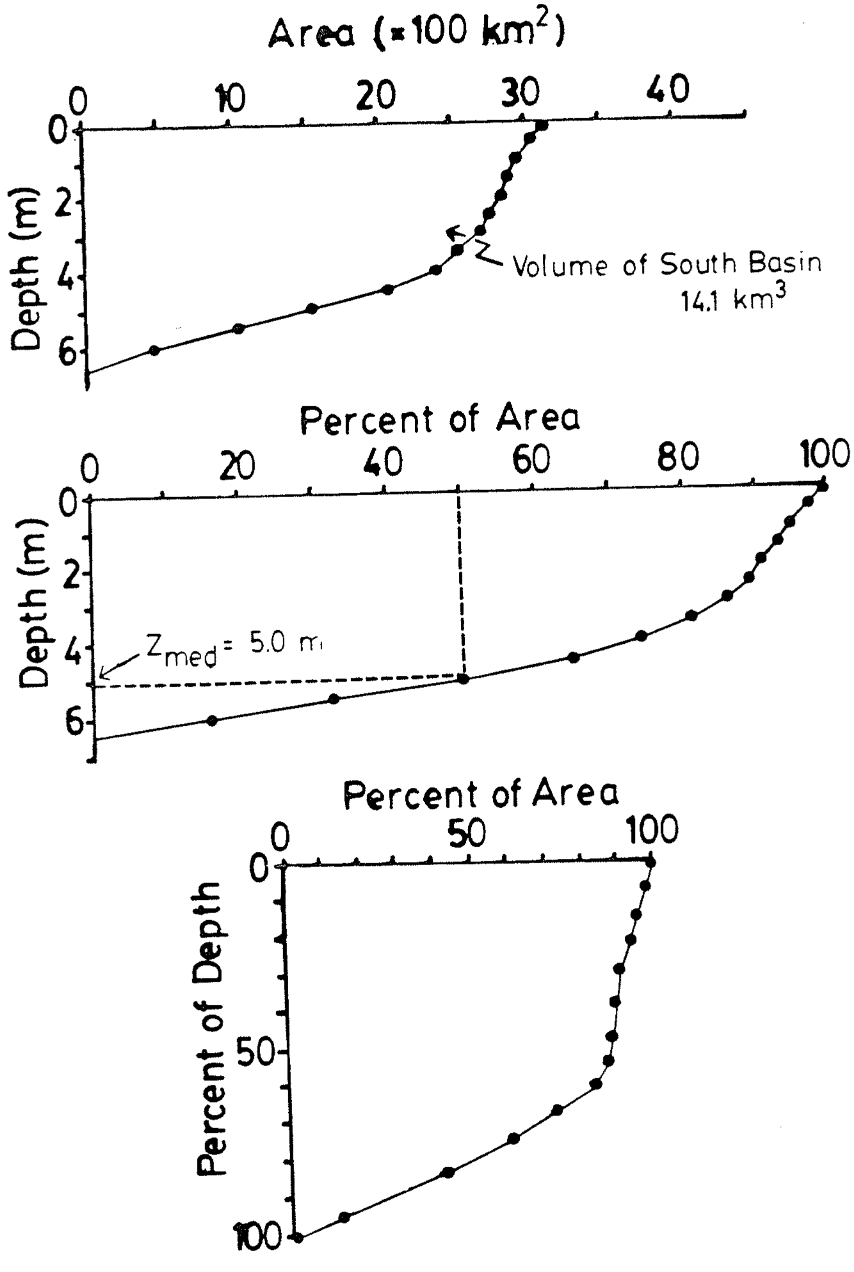

Figure 3-6. Hypsographic curves for the South Basin of Lake Manitoba.

2. The South Basin, despite its large geographic area, is extremely shallow, having a mean depth of 4.5 m and a maximum depth of 6.3 m (Fig. 3-5).

3. The South Basin is somewhat trough-shaped with steeply sloping sides and a flat, featureless bottom.

3.6 HYDROLOGIC CHARACTERISTICS OF LAKE MANITOBA AND ITS BASIN

3.6.1 Surface Water Hydrology

Lake Manitoba is situated at an intermediate elevation between Manitoba's two other large lakes: Lake Winnipegosis and Lake Winnipeg (Figs. 3-7 and 3-8). Lake Winnipegosis, at an elevation of 252.9 m, drains into the West Waterhen and Little Waterhen Rivers to Waterhen Lake and then via the Waterhen River to Lake Manitoba. Lake Manitoba, whose elevation has been regulated since 1963 at a level of about 247.5 m, drains northeastward into Lake Winnipeg (217.3 m) via the Fairford River, Lake St. Martin and Dauphin River. The drainage basin area of Lake Manitoba is approximately 26,000 km^2 and, with the 54,000 km^2 drained by Lake Winnipegosis, receives the runoff from an 80,000 km^2 watershed.

Water flowage characteristics in and through the Lakes Winnipegosis-Manitoba system are known from 130 gauging and sampling stations of the Water Survey of Canada that lie within the watershed. Table 3-4 summarizes the availability and length of records of published surface water data (Water Survey of Canada) for the river and lake systems supplying water to Lake Manitoba, and Figure 3-9 shows the location of these stations within the drainage basin.

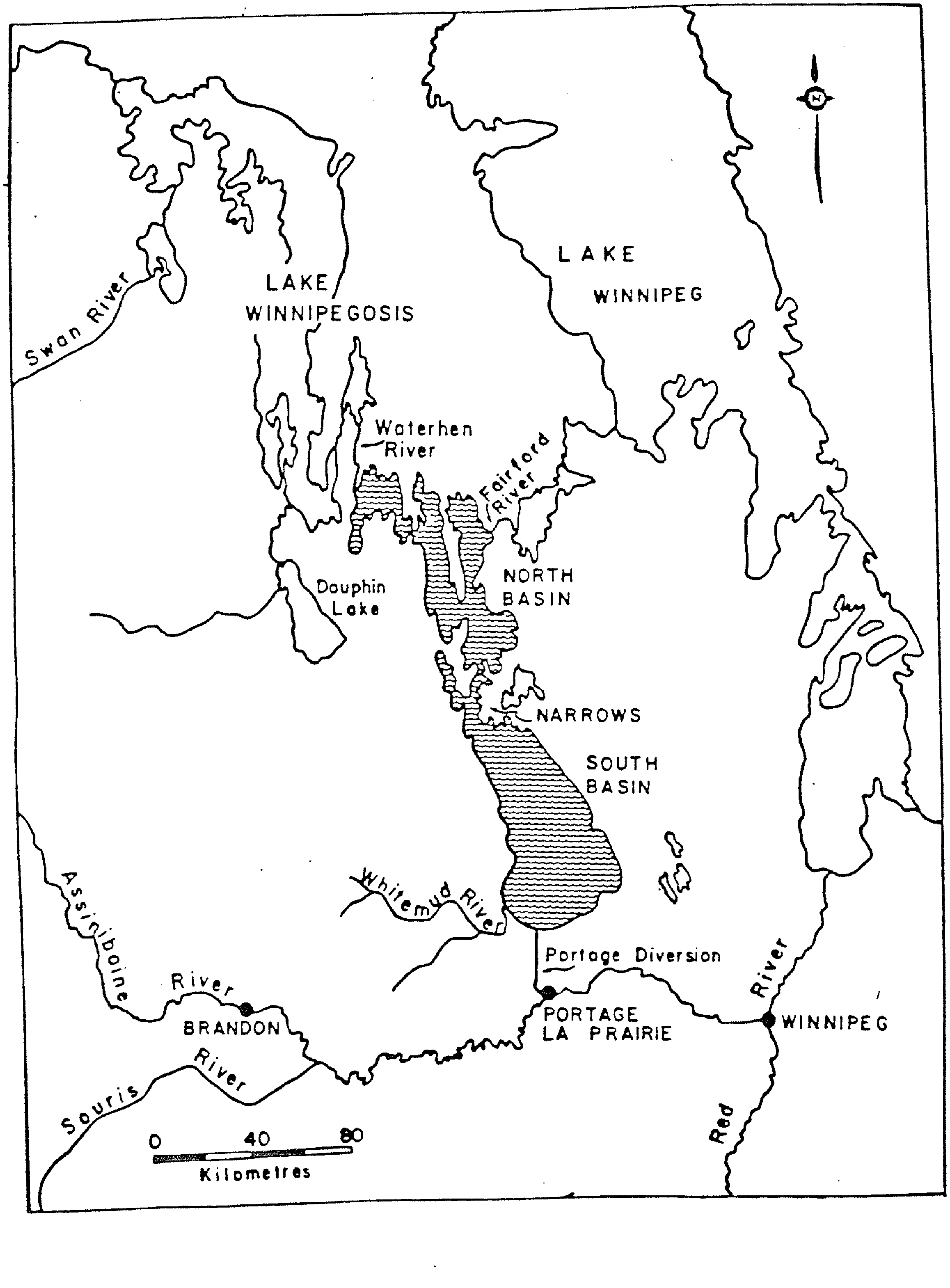

Figure 3-7. Manitoba's three largest lakes: Lakes Winnipegosis, Manitoba (shaded), and Winnipeg.

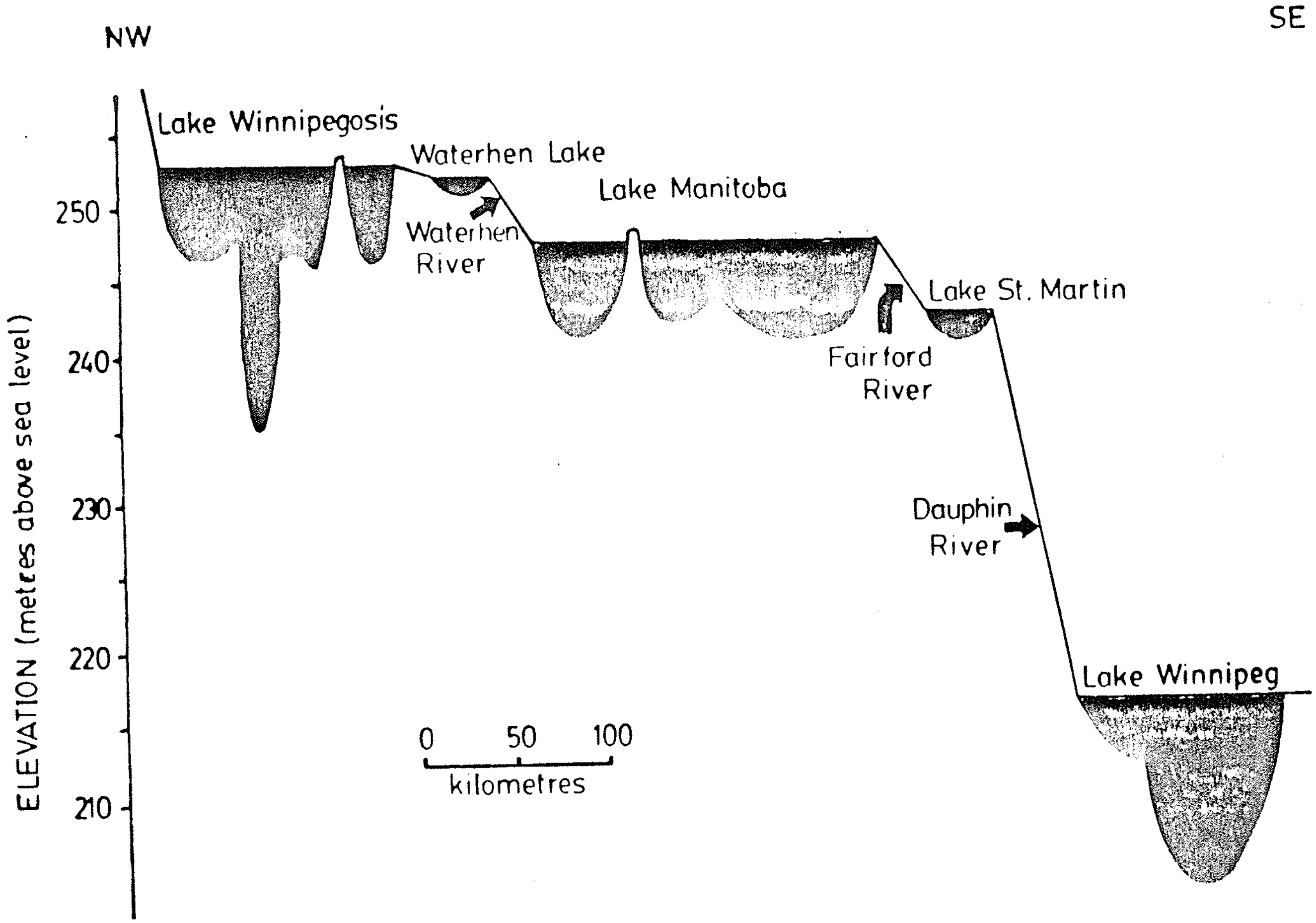

Figure 3-8. Elevation relationships between Lakes Winnipegosis, Manitoba, and Winnipeg.

Table 3-4. Water Survey of Canada Gauging Stations in the Lake Manitoba watershed. Refer to Figure 3-9 for locations.

	discharge data or lake level record	water quality data	sediment data
Lake Winnipegosis			
at Meadow Portage	1950, 1952 - present	-	-
at Winnipegosis	1913 - present	-	-
at Dawson Bay	1963 - present	-	-
Waterhen Lake at Skownan	1950 - present	-	-
Waterhen River			
at Waterhen	1923-24; 1950 - present	1966 - present	-
at McCreery's Farm	1928 - 1931	-	-
at Bernardin's Farm	1913; 1923 - 28	-	-
Lake Manitoba - North Basin			
at Steep Rock	1923 - present	-	-
at Toutes Aides	1968 - present	-	-
at Meadow Portage	1913; 1952; 1954 - 68	-	-
Lake Manitoba - Narrows	1958 - present	-	-
Lake Manitoba - South Basin			
at Oak Point	1913 - 14	-	-
at Delta	1914 - 69	-	-
at Westbourne	1964 - present	-	-
Whitemud River			
at Neepawa Reservoir	1961 - present	-	-
at Neepawa	1959 - present	-	-
at Keyes	1959 - present	-	1972 - present
at Gladstone	1914; 1922-29; 1943-57	-	-
at Woodside	1958 - 72	1967 - 74	-
at Westbourne	1912; 1914; 1922; 1972 - present	-	1972 - present
Burnt Lake Drain No. 1 (near Deerhorn)	1960 - present	-	-
Burnt Lake Drain No. 2 (near Lundar)	1960 - present	-	-
Neepawa Reservoir	1960 - present	-	-
Neepawa Creek	1959 - present	-	-
Dead Lake Drain (near Gladstone)	1974 - present	-	-
Gopher Creek	1974 - present	-	-
Big Grass Drain (near Langruth)	1974 - present	-	-
Big Grass River	1965 - present	-	-
Birnie Creek	1969 - present	-	-
Pelican Creek	1974 - present	-	-
Glenella Drain (near Glenella)	1974 - present	-	-
Jordon Creek	1960 - present	-	-
Pine Creek			
at Melbourne	1965 - present	-	-
at Pine Creek Station	1922-28; 1959-76	-	-
Squirrel Creek	1913-14; 1922-29	-	-
West Squirrel Creek	1962 - present	-	-
Beaver Creek			
at Beaver	1974 - 75	-	-
east of Beaver	1976 - present	-	-
Willowbend Creek	1974 - present	-	-
Assiniboine River Diversion			
at Portage	1970 - present	-	1970 - present
at Oakland	1970 - present	-	1970 - present
North Shoal Lake	1976 - present	-	-
Fairford River	1912-20; 1955 - present	1967 - 74	-

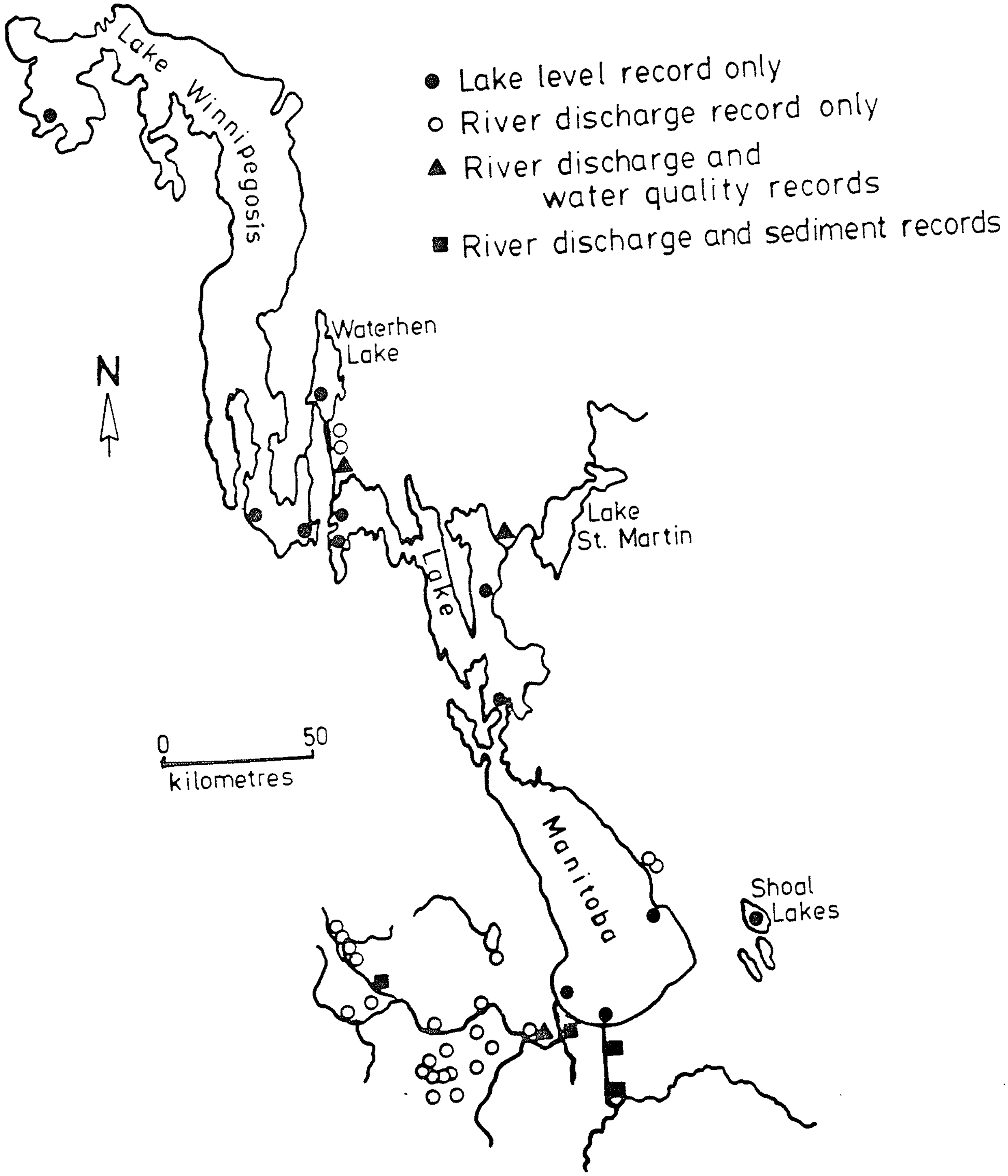

Figure 3-9. Location and type of Water Survey of Canada gauging stations in the Lake Manitoba vicinity (see Table 3-4).

The Waterhen River is the major stream entering Lake Manitoba, and it contributes approximately 70% of the total measured surface inflow to the lake (Fig. 3-10 and Table 3-5). The next largest natural river flowing into the lake is the Whitemud River, entering the southeastern corner of the South Basin. However, its average annual flow (about 12 m^3s^{-1}) is surpassed by the Assiniboine River Diversion (Portage Diversion), which also enters the South Basin fifteen kilometres east of the Whitemud River(see Fig. 3-4) For the eight years that the Diversion has operated, its flow, on an average annual basis,[1] is approximately 20 m^3s^{-1}.

The Fairford River, representing the only surface stream outflow from Lake Manitoba, has an average annual discharge of 80 m^3s^{-1}. A control structure - initially a small check dam built in 1942 and subsequently improved in 1963 - regulates the Fairford River discharge in order to maintain the level of the lake between about 247.3 m and 247.9 m. Comments regarding a second infrequently used outlet of the lake are found in Section 3.6.2.

Approximately 8000 km^2 (about 30%) of the drainage basin of Lake Manitoba is ungauged. Although there are no major rivers discharging into the lake from these areas, there are numerous ungauged artificial land-drainage ditches and waterways, six of which feed directly into the South Basin of Lake Manitoba (see maps in Elliot, 1978; Jenkins, 1974; Framingham et al, 1970; and comments in Hochbaum, 1965).

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[1] This "average annual" discharge rate is somewhat misleading because the Diversion operates for only a maximum of three months of the year. The average discharge on a monthly basis during this peak flow period is approximately 85 m^3s^{-1}. Also, the Diversion has not operated every year since 1970.

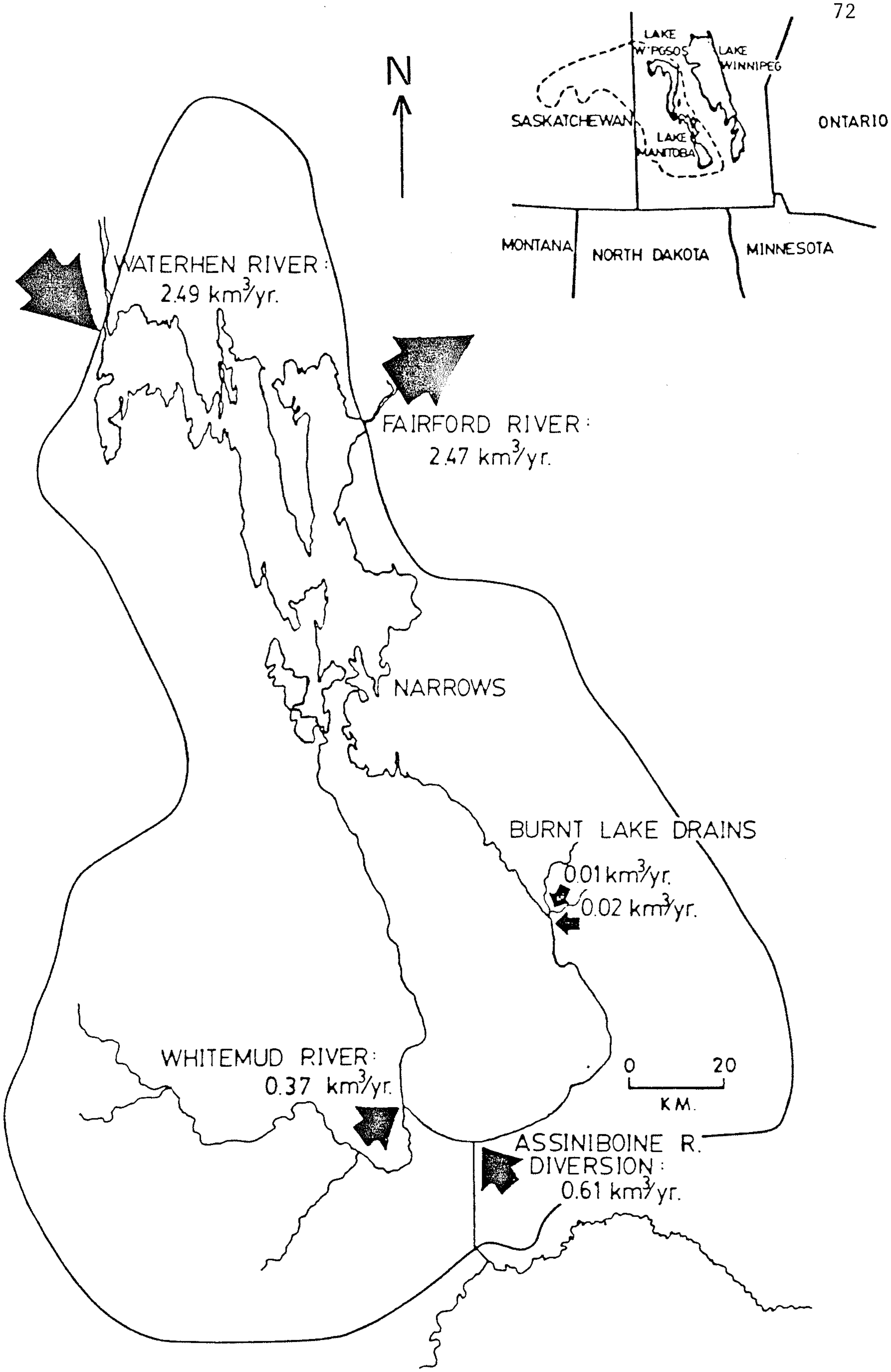

Figure 3-10. Lake Manitoba average surface stream inflow and outflow. Heavy solid line indicates the lake's immediate drainage basin. Heavy dashed line on the inset map in the upper right corner shows the Lake Manitoba watershed area in Saskatchewan and Manitoba.

Table 3-5. Lake Manitoba Mean Annual Surface Stream Inflow and Outflow

INFLOW			
Surface Streams (mean annual discharge)			
Natural			
Waterhen River	81.3 m^3s^{-1}	(2870 cfs)	71%
Whitemud River	11.9 m^3s^{-1}	(423 cfs)	10%
Constructed			
Assiniboine River Diversion	19.8 m^3s^{-1}	(698 cfs)	18%
Burnt Lake Drain No. 2	0.7 m^3s^{-1}	(25 cfs)	0.6%
Burnt Lake Drain No. 1	0.2 m^3s^{-1}	(8 cfs)	0.1%
OUTFLOW			
Fairford River	80.4 m^3s^{-1}	(2840 cfs)	

It is also important to note that both the present-day outlet and the main influent stream are located in the North Basin of the lake. This would suggest that there might be relatively little exchange of water between the two basins, with the North Basin acting more like a direct flow-through system and the large South Basin approaching a "closed" evaporating situation. This is confirmed by calculations of the theoretical water renewal times[1] for the two basins by the International Garrison Diversion Study Board (1976, p. 162; see also Table 3-2). This study estimates an average of 28 years residence time for the South Basin in contrast to about two years for the North Basin. Unfortunately, other than that of the International Garrison Diversion Study Board (1976), little quantitative work has been done on residence times, water exchange between the basins, or the effectiveness of the Narrows constriction in limiting circulation.

Burrows (1970) discusses flow characteristics through the Narrows and suggests empirical relationships between wind velocity, wind setup, and water interchange from one basin into the other. Discharges of up to 1800 m^3s^{-1} were measured by Burrows at the Narrows during the summer of 1966. Unfortunately, probably due to a rather limited data base (five observations for a north wind situation and five observations for south wind conditions, with a range in wind velocities of only 15 km per hour), the accuracy, predictive ability, and statistical significance of the derived relationships between outflow and wind velocity are questionable.

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[1] Theoretical water renewal times (or residence times) are computed by dividing the volume of the basin by the annual outflow from the basin, excluding evaporation (Brunskill and Schindler, 1971).

In particular, the discharge through the Narrows from the North Basin into the South Basin due to a north wind appears to have no direct relationship with wind speed on the basis of the available data (Fig. 3-11).

Burrows (1970, p. 32-33) also refers to high water current velocities developed during the winter under a complete ice cover. He suggests that these winter currents, which are capable of significant erosion of the ice cover at the Narrows, are possibly due to an atmospheric pressure differential between the two basins.

Several authors have recognized and attempted to investigate three distinct types of water-level fluctuations in Lake Manitoba (Tyrrell, 1892; Lakes Winnipeg and Manitoba Board, 1958; Galay, 1964; McKay, 1965; Burrows, 1970). Of the three types of fluctuations, two, namely, long-term variations and seasonal changes, have been substantially dampened by artificial control of the lake's outlet at Fairford. The third type of fluctuation is wind setup and associated surface seiche development.

Figure 3-12 shows that over the past sixty years the level of Lake Manitoba has varied between a high of approximately 248.5 m in the mid-1950's to a low of 247.0 during the early 1930's and the 1940's. McKay (1965) attributes these long-term, irregular fluctuations to alternating periods of high and low precipitation and runoff in the watershed. Figure 3-12 shows that there is a general correspondence between high lake levels and periods of high precipitation at the nearest long-term meteorological recording station in the watershed at Dauphin, Manitoba (70 km west of Lake Manitoba). Likewise, years of low precipitation seem to be reflected by generally lower lake levels.

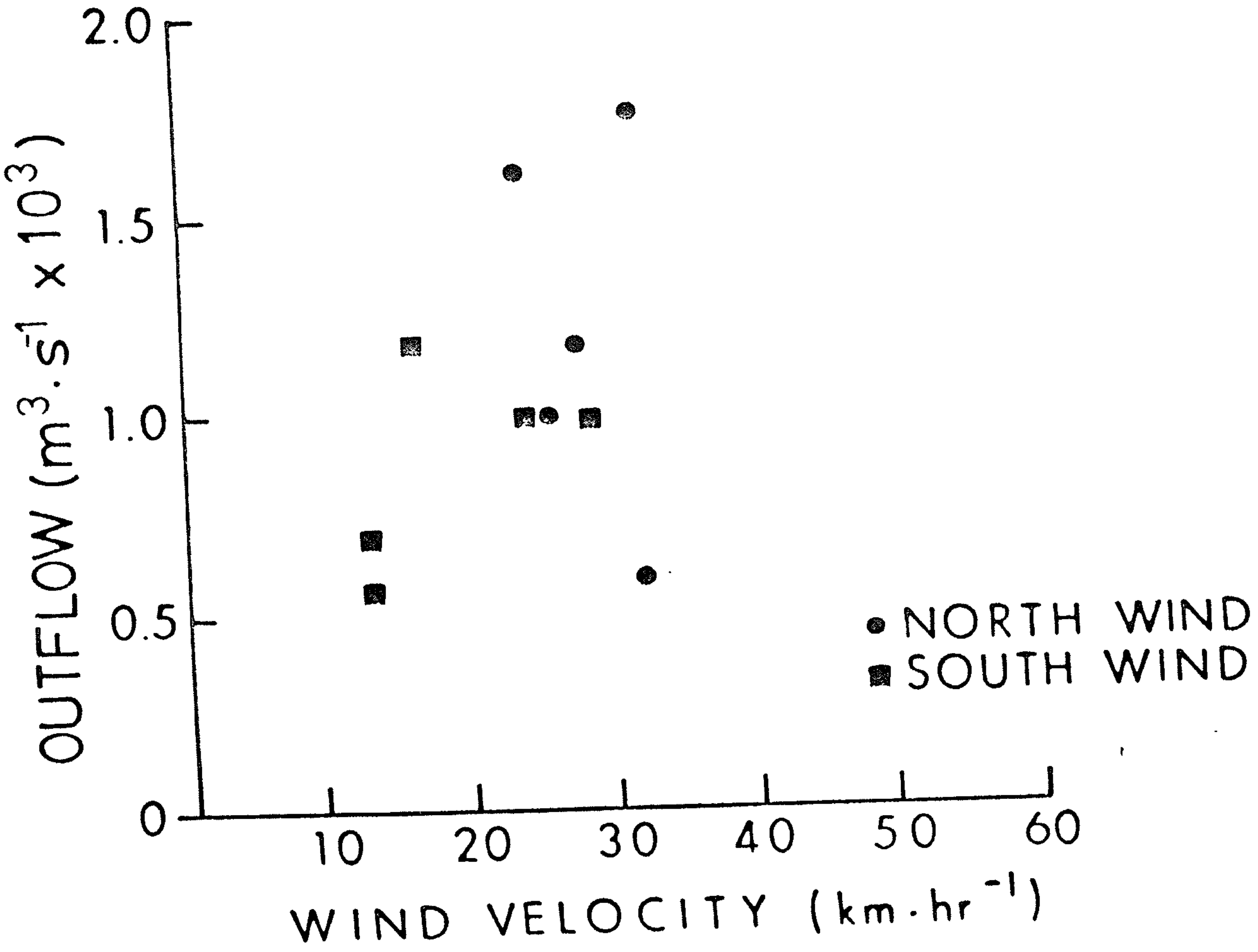


Figure 3-11. Relationship between wind velocity and "outflow" through the Lake Manitoba Narrows (from Burrows, 1970).

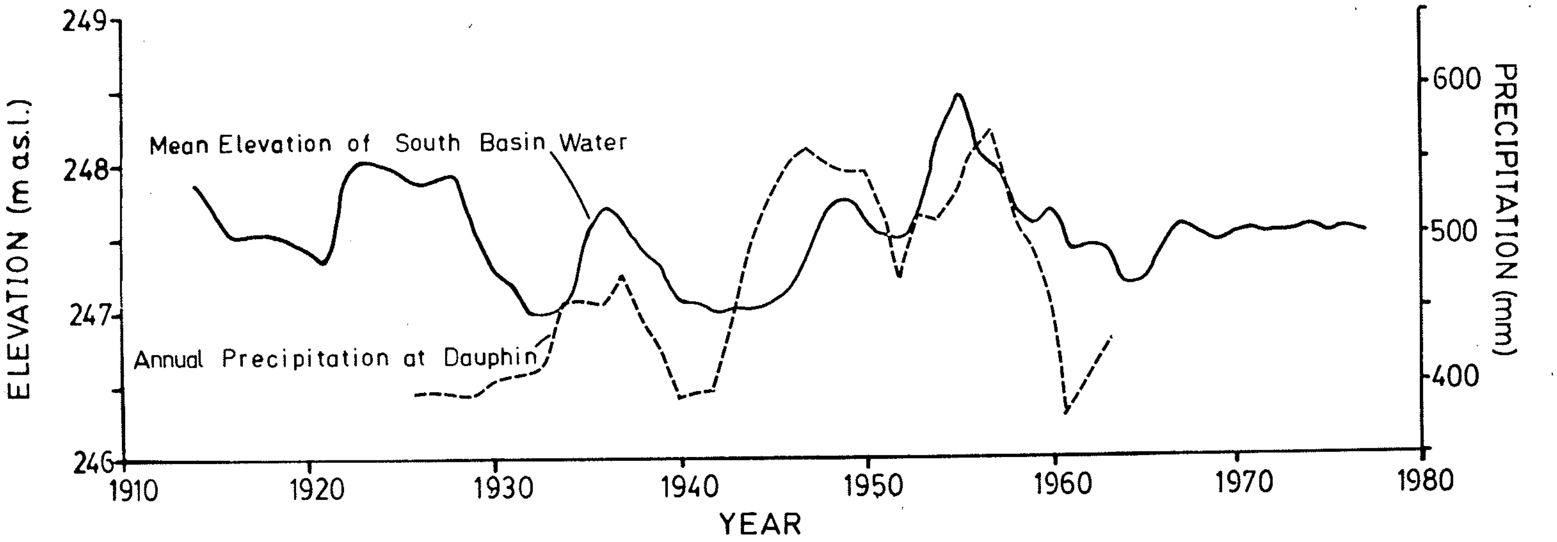


Figure 3-12. Mean annual level of Lake Manitoba (metres above sea level) and annual precipitation at Dauphin, Manitoba. Elevation data for Lake Manitoba taken from Water Survey of Canada publications; precipitation data taken from annual meteorological summary publications.

In addition to surface stream outflow, water is also lost from Lake Manitoba by evaporation. The long-term mean annual lake evaporation in the vicinity of the South Basin has been estimated at 600 to 700 mm (Canadian National Committee for the International Hydrological Decade, 1978; Morton, 1979; Gray et al, 1973) compared with approximately 500 mm annual precipitation. By examining the lake's monthly water level and outflow records for the period between 1914 and 1964, McKay (1965) confirms that significant evaporation does occur from the lake's surface. With its large geographic area and low shoreline development, the South Basin of Lake Manitoba is particularly susceptible to large water losses by evaporation. As pointed out earlier, the long-term mean annual discharge through the Fairford outlet is approximately 80 $m^3 s^{-1}$ compared to overland inflow from measured streams of over 100 $m^3 s^{-1}$. Although these statistics are subject to severe limitations which restrict interpretation (see McKay and Stichling, 1961), the magnitude of evaporation in the Lake Manitoba area can be seen.

Seasonal fluctuations in Lake Manitoba water levels have a magnitude of approximately 0.15 to 0.20 m, although reference has been made to much larger ranges by local inhabitants (Lakes Winnipeg and Manitoba Board, 1958). High spring lake levels are particularly significant when associated with the longer term high water levels.

Wind and atmospheric pressure-induced changes in lake level on large lakes have received a considerable amount of both theoretical and practical study (e.g., Hutchinson, 1975; Hamblin, 1976; Platzman, 1963). Again, the South Basin of Lake Manitoba is particularly susceptible to setup and storm surges because of the long maximum and effective fetch distances (170 and 95 km respectively), and the coincidence of the geographic orientation of the basin (north-northwest) with the predominant wind direction during the ice-free season (north-northwest). The maximum wind setup recorded at the south end of the basin is approximately 1.0 m (in 1944 at Delta; Galay, 1964; Burrows, 1970). Calculations by the Lakes Winnipeg and Manitoba Board (1958) indicate that a maximum setup of 1.1 m can be expected at the south end of the basin.

3.6.2 Lake Outlets

As mentioned in the previous section, the present-day outlet of Lake Manitoba is the Fairford River which drains into Lake St. Martin and ultimately into Lake Winnipeg. Although the flow of the Fairford River (and, hence, the lake level) has been closely regulated for over fifteen years, it is interesting to examine the pre-regulation situation of the lake. Figure 3-13 shows that prior to regulation and channel improvement, the flow of the lake through the Fairford outlet was controlled by a sill at an elevation of about 246.9 m. This means that prior to emplacement of the control structure, a drop in elevation of less than 1 m from the present-day "long-term" mean level of 247.5 m would have produced a closed basin.

Conversely, there is evidence that Lake Manitoba has used another outlet, in addition to the Fairford River, during periods of high water levels. Treherne (1881) was the first to describe a southern outlet to Lake Manitoba. He investigated and reported the elevations between the southern end of the lake and the area near Reaburn, Manitoba, and concluded that an "ancient" outlet of Lake Manitoba was south, via Portage Creek to Long Lake Creek, then eastward to Long Lake and finally into the Assiniboine River (Fig. 3-14). Upham (1890, p. 24E) reports

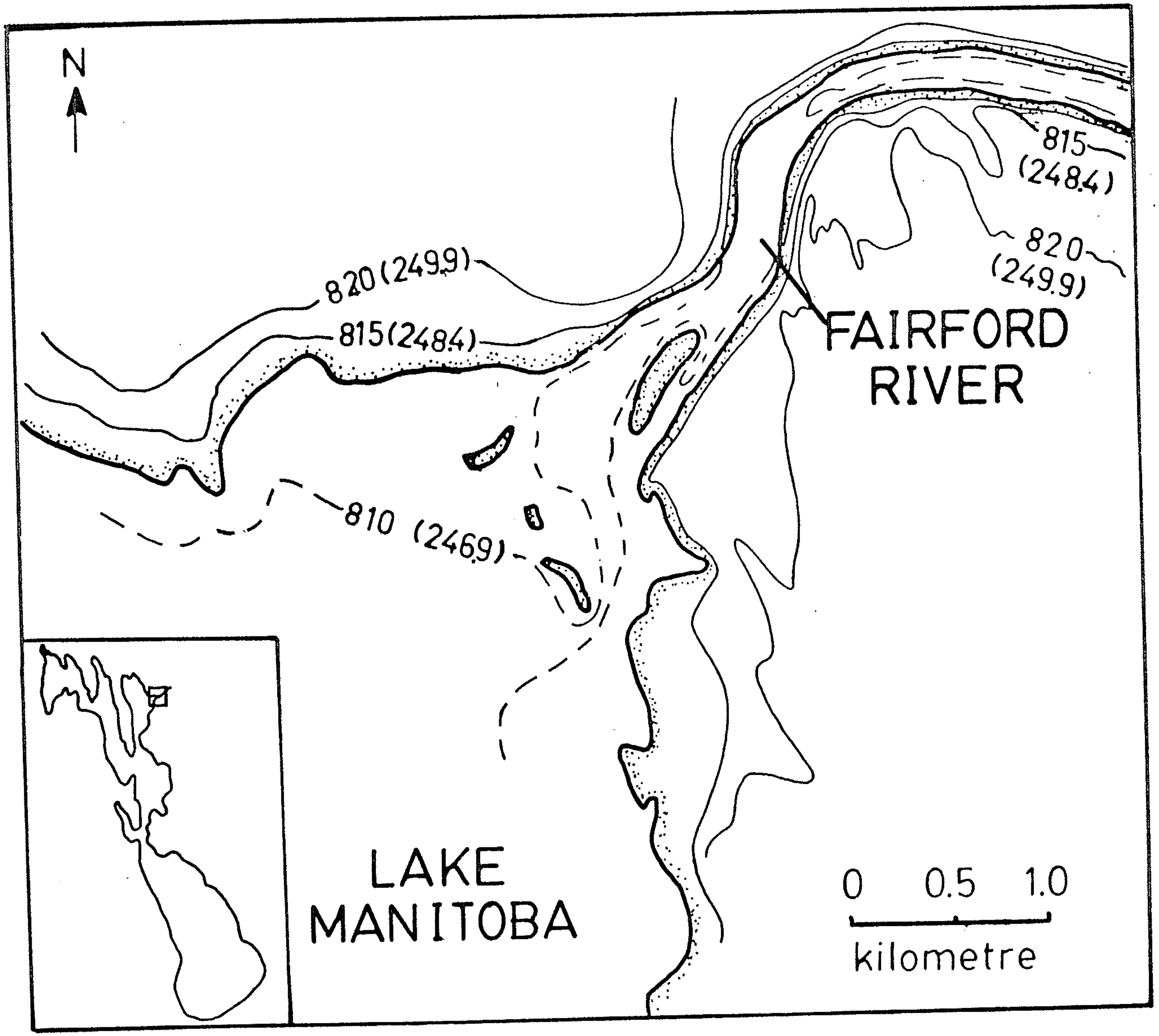


Figure 3-13. Topography of the Fairford River outlet of Lake Manitoba, pre-control structure (modified from Lakes Winnipeg and Manitoba Board, 1958). Elevation of land surface and lake bottom given in feet and metres (parentheses) above sea level. Subaqueous contour lines are shown as dashed lines. Contour interval is 5 feet. Small square within the inset map shows the location of the detailed area.

that in 1882, a year after Treherne's observations, Lake Manitoba did, in fact, spill over the southern end and flow southward (probably via Portage Creek) to the southern portion of Township 13, Range 3, West of the Principal Meridian, and then eastward to Long Lake and into the Assiniboine River. Figure 3-14 shows that the lake could overflow through this southern outlet if an elevation of approximately 249 m (or 1.5 m above mean level) is attained.

3.6.3 Groundwater Hydrology

The groundwater hydrology and hydrogeology of the area surrounding Lake Manitoba have been evaluated both in regional studies and in local district or basin evaluations. However, despite the probable importance of groundwater as a major source of ions to Lake Manitoba, only van Everdingen (1971) and the International Garrison Diversion Study Board (1976) have attempted quantitative appraisal of the contribution of the subsurface flow to the lake system in terms of volume of discharge and ionic input.

On a regional basis, the eastern Interior Plains is a main discharge area for the major groundwater flow system of western Canada (Meyboom, 1967). Elevations differences between the probable recharge areas in the western Plains and the Manitoba Lowland discharge area is approximately 600 m, suggesting a regional hydraulic gradient of 0.001 (van Everdingen, 1971). This regional component of the groundwater flow system is believed to dominate the Paleozoic and Mesozoic carbonate and sandstone aquifers of the area (Hitchon, 1969) and, because of the long travel distance and the chemistry of the rocks involved, the water of this system is usually considerably more saline than the local groundwater component.

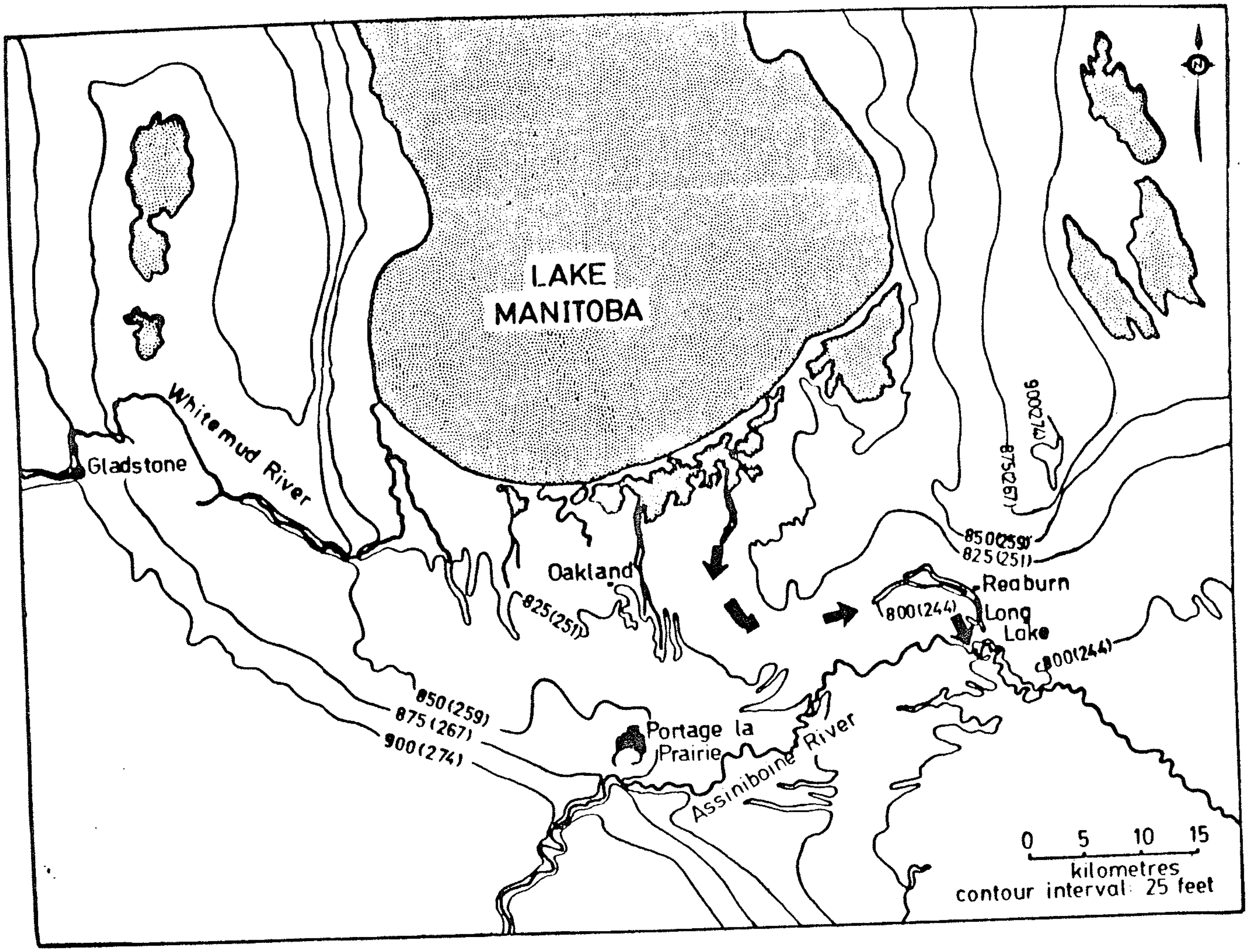


Figure 3-14. Route of southern overflow outlet (arrows) of Lake Manitoba. Land surface elevation contours given in feet and metres (parentheses). Elevation above 900 feet (274 m) not contoured.

In addition to this regional flow element, the local groundwater flow systems in several areas of the basin have been identified and studied. These local flow regimes, usually originating in or controlled, in part, by the elevated Escarpment area west of Lake Manitoba, are quite complex and variable throughout the basin depending mainly on the mineralogical and stratigraphic relationships of the Pleistocene and Holocene deposits.

In the area immediately south of Lake Manitoba, Cherry et al (1971) identified a dominant northward flow toward the lake from a recharge area to the southwest. Local upward gradients within these shallow (overburden) aquifers discharge saline water to the surface. The source of this salinity, according to the authors, is the dissolution of trace amounts of halite, gypsum, and other soluble minerals believed to be present in the Pleistocene deposits. It should be noted, however, that, with the exception of gypsum, the presence of these salts has not been documented in any of the Pleistocene or Holocene deposits of the area. The recent fluvial, aeolian, and beach deposits immediately adjacent to the lake are believed to be areas of local groundwater recharge with flows diverging northward under Lake Manitoba and southward into the marsh.

Groundwater flow and hydrochemical characteristics in an area of several small, shallow, closed lake basins within the Lake Manitoba watershed were examined by Goff (1971) and Cherry (1972). The Shoal Lakes are interesting from a hydrometeorological aspect because their water budget is dominated by groundwater discharge. Goff (1971) found that during the ice-free season of 1969 there was a net loss by evaporation of over 30 cm of water from each of the Shoal Lakes. Because the lake levels remained constant during this period and surface runoff was negligible, he concluded that diffuse groundwater discharge to the lakes was the source of most of the deficit. The chemistry of both the surface water of the Shoal Lakes and the sediment interstitial water, in part, reflect this groundwater input. The groundwater hydrochemistry, in turn, is again believed to reflect the dissolution of the carbonate bedrock and, particularly, any highly soluble chloride and sulfate minerals in the Pleistocene sediments. The dominant flow of the groundwater within the bedrock aquifer is from northeast to southwest (Goff, 1971).

Jenkins (1974) and Manitoba Water Resources Branch (1972), likewise, have identified two main groundwater flow systems in much of the area west of Lake Manitoba. The regional flow systems are generally confined to fracture and solution porosity in the Devonian and Jurassic carbonate and shale bedrock of the area. This regional system is highly saline, whereas the local component, derived mainly from the Escarpment recharge area and confined to a complex series of fluvial, deltaic, and lacustrine gravels, sands and silts, is mainly fresh water. The combination of lateral and upward movement of the regional flow system and the mixing of the two systems has resulted in moderately saline groundwater discharge over much of the sub-escarpment and lowland plain east of the Riding Mountain area (Jenkins, 1974; Rutulis, 1977).

The magnitude and influence of groundwater discharge and chemistry on the surface water characteristics of Lake Manitoba has not been completely resolved. Rough water budget calculations for the lake (Table 3-6) would seem to indicate that the groundwater contribution, in terms of volume, is not significant. Similarly, the International Garrison Diversion Study Board (1976, p. 159) estimates groundwater inflow to the South Basin

Table 3-6.

Water Budget of Lake Manitoba

Precipitation + Stream inflow + Groundwater influx + Overland inflow =
Evaporation + Stream outflow + Groundwater outflow

$2.31\ \text{km}^3 + 3.36\ \text{km}^3 + \text{unknown} + \text{negligible} =$
$3.00\ \text{km}^3 + 2.49\ \text{km}^3 + \text{unknown}$

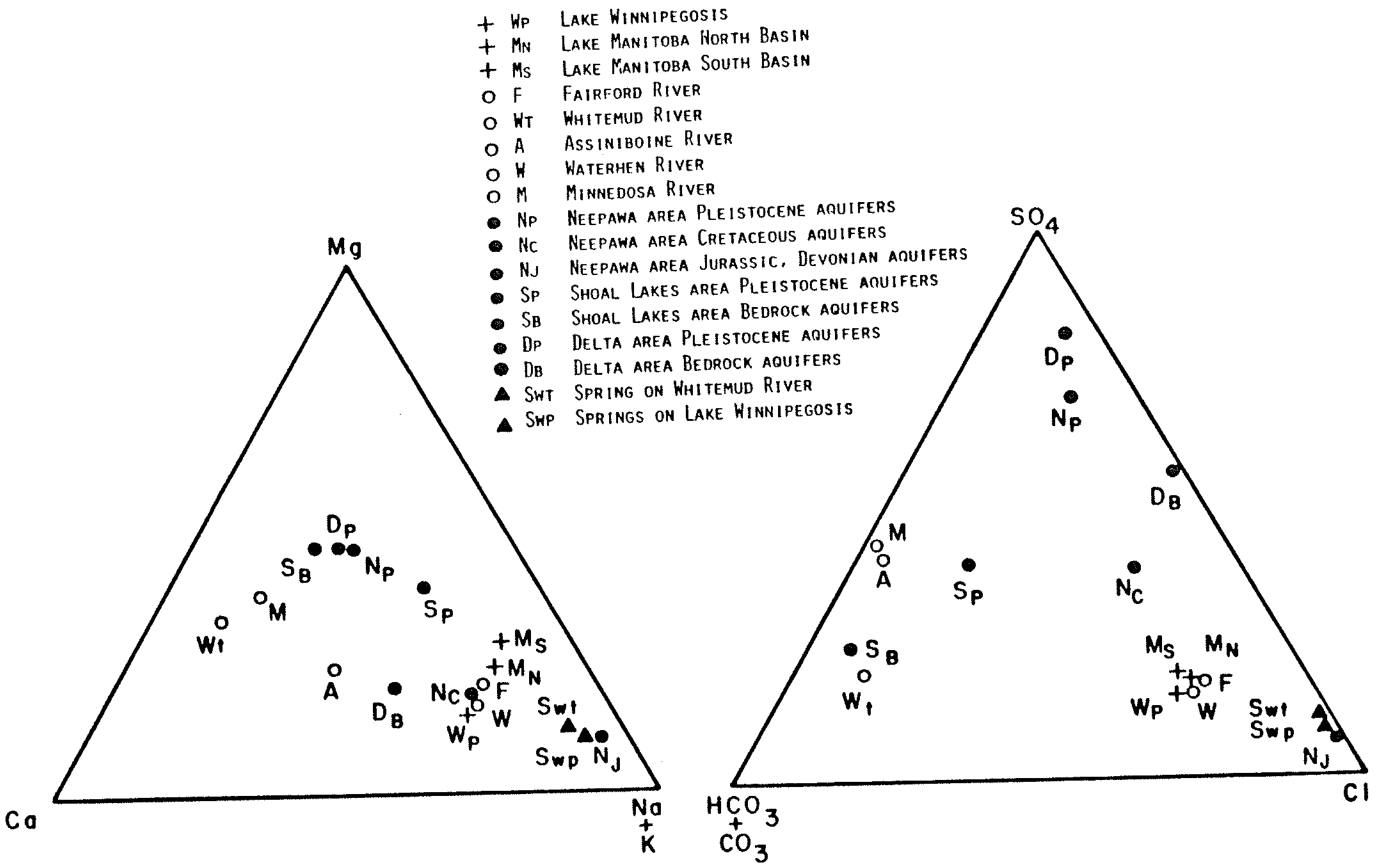
$5.67\ \text{km}^3 + \text{groundwater influx} = 5.49\ \text{km}^3 + \text{groundwater outflow}$

at about 5 to 10% of the total inflow to the Basin. However, in terms of ionic input, the water chemistry characteristics of the Lakes Manitoba-Winnipegosis system suggest an important contribution from the groundwater. Brine springs discharging directly into streams tributary to Lakes Winnipegosis and Manitoba have been described and analyzed by Tyrrell (1892) and Cole (1915, 1930; summarized in van Everdingen, 1971). The ionic content of these brine springs varies between about 10,000 and 63,000 mg l^{-1} and is predominantly sodium and chloride. By comparing the main ion composition of these springs with the "normal" surface stream runoff and with the lakes' water, van Everdingen (1971) concluded that the high Na^+ and Cl^- content of Lakes Winnipegosis and Manitoba reflect a substantial addition from these sodium chloride brines. It is evident from Figure 3-15 that the ionic "fingerprint" of the lake water (that is, of Lakes Winnipegosis and Manitoba) is not being derived from the surface streams because these are dominated by Ca^{+2}, Mg^{+2}, HCO_3^- and $SO_4^=$. The groundwater contained in shallow aquifers west, south, and east of Lake Manitoba is, likewise, generally low in Na^+ and Cl^- ions, whereas the groundwater from deeper (bedrock) aquifers appears to have the proper ratio of ions to account for the ionic compositions of the lake water.

3.6.4 Summary of Important Hydrologic Characteristics

An understanding of the hydrology of Lake Manitoba and its watershed is important in attempting to decipher the processes controlling sedimentation in the modern lake and, in particular, in interpreting the post-glacial sedimentary record of the lake. While the general hydrologic features of the lake are relatively well documented, many aspects are only poorly known and understood. Some of the important hydrologic considerations are:

Figure 3-15. Trilinear plots of ionic composition (in percent equivalents) of Lakes Winnipegosis and Manitoba surface water, and drainage basin surface streams and groundwater. Sources of chemical data are: Lake Winnipegosis: van Everdingen (1971); Lake Manitoba North Basin: Manitoba Water Quality Survey (A. Beck, personal communication, 1979) and van Everdingen (1971); Lake Manitoba South Basin: Crowe (1972b), Manitoba Water Quality Survey,and van Everdingen (1971); Fairford, Whitemud, Assiniboine, Waterhen, and Minnedosa Rivers: Inland Waters Directorate (1978a); groundwater aquifers of the Neepawa area: Manitoba Water Resources Branch (1972); groundwater aquifers of the Shoal Lakes and Delta areas: Cherry (1972); and springs on the Whitemud River and Lake Winnipegosis: van Everdingen (1971).


+ Wp Lake Winnipegosis
+ Mn Lake Manitoba North Basin
+ Ms Lake Manitoba South Basin
○ F Fairford River
○ Wt Whitemud River
○ A Assiniboine River
○ W Waterhen River
○ M Minnedosa River
● Np Neepawa area Pleistocene aquifers
● Nc Neepawa area Cretaceous aquifers
● Nj Neepawa area Jurassic, Devonian aquifers
● Sp Shoal Lakes area Pleistocene aquifers
● Sb Shoal Lakes area Bedrock aquifers
● Dp Delta area Pleistocene aquifers
● Db Delta area Bedrock aquifers
▲ Swt Spring on Whitemud River
▲ Swp Springs on Lake Winnipegosis
Mg
Ca
Na + K
Dp
Sb
Np
Sp
M
Wt
A
Db
Nc
F
W
Wp
Ms
Mn
Swt
Swp
Nj
SO4
HCO3 + CO3
Cl
Dp
Np
Db
M
A
Sp
Nc
Sb
Wt
Ms
Mn
F
Wp
W
Swt
Swp
Nj

1. The lake presently receives surface runoff from one dominant stream, the Waterhen River, which drains an area of approximately 54,000 km^2. On a long term annual basis, this river contributes over 70% of the gauged surface inflow to the lake. Several smaller streams entering the lake bring the total surface stream inflow to an annual average of about 3.6 km^3.

2. The lake presently has one outlet, the Fairford River, with an annual average discharge of roughly 2.5 km^3.

3. Evaporation from the lake surface is an important water loss mechanism. Mean annual evaporation from the South Basin exceeds mean annual precipitation by over 25%.

4. Lake level fluctuations during historic times have been of three main types: relatively long-term fluctuation associated with prolonged periods of high or low precipitation; seasonal changes associated with high spring runoff; and wind and storm-induced changes. Control of the lake's discharge stream since 1963 has greatly reduced the magnitude of the first two types of fluctuations.

5. Both the major input stream and the lake's outlet are located in the North Basin. The influence of the Narrows constriction on water movement between the North and South Basin, and on residence times in the two basins is not well understood.

6. The largest natural stream entering the South Basin is the Whitemud River which drains an area of approximately 4500 km^2 and has a mean annual discharge of 0.37 km^3. This discharge, however, is surpassed by the annual discharge of the Assiniboine River Diversion

which, during most of the years since 1970, has routed excess flood water from the Assiniboine River into the South Basin for several months each spring.

7. The influence of groundwater input to Lake Manitoba may be small in terms of water volume, but the chemical effect cannot be considered negligible. Although the hydrologic characteristics of the groundwater flow systems surrounding Lake Manitoba are only poorly known, the ionic composition of the lake water is believed to reflect significant contributions from saline springs or diffuse subaqueous groundwater discharge.

3.7 PHYSICAL LIMNOLOGY

Besides the basic hydrologic characteristics discussed in the previous section, relatively little information exists regarding the physical limnology of Lake Manitoba. The lake is believed to be essentially isothermal during the ice-free season, although data confirming this supposition in the offshore portion of most of the lake is lacking. Direct thermal stratification can probably develop temporarily in the South Basin after successive warm, calm days, although the extreme shallow depths and long fetch distances of the basin easily lead to complete mixing by wind generated waves and currents. Inverse stratification, with dense $4^{\circ}C$ water below colder but less dense water, does occur in the South Basin under the winter ice cover (see Fig. 3-16).

Water transparency in the South Basin during the ice-free season is generally very low, ranging from 17 to 85 cm (Secchi disk transparency; Tudorancea and Green, 1975). Data recently acquired in a study of wind-generated mixing in the South Basin by staff of the Freshwater Institute shows that open season turbidity is closely associated with wind and current speeds (B. Kenny, personal communication, 1979; National Water Resources Institute, 1978). This suggests that the dominant factor in the reduction of light transmission is re-suspension of bottom sediments rather than increased turbidity caused by dense algal populations.

As previously noted, specific information regarding water movements and currents in Lake Manitoba is rare. Burrows' (1970) conclusions regarding wind-generated water movements between the two basins are probably justified (see Section 3.6.1), although his data suggests that the relationship between wind speed and flux through the Narrows' channel is complicated.

Cursory examination of Landsat imagery suggests a general counterclockwise circulation pattern in the South Basin. This is confirmed by comments from local residents of the south shore area regarding the eastward drift of the Assiniboine River Diversion effluent during spring runoff (D. Garnham, P. Ward,personal communications, 1978; F. D. Caswell, cited in Derksen, 1978). In addition, the general pattern of movement of walleyes leaving the Whitemud River suggests a counterclockwise current pattern in the South Basin (Derksen, 1978).

The surface wave characteristics over the South Basin have been discussed by Galay (1964). Using wind velocities of 25 and 85 km per hour and a fetch distance of 80 km, he calculates wave heights of 0.7 m and 1.5 m at Delta for normal and maximum storm conditions respectively. Despite the recognition of surface seiches by several authors (e.g., Tyrrell, 1892; Galay, 1964; Burrows, 1970), no one has calculated their period or attempted to hydrodynamically model the basin's response to given wind situations.

3.8 CHEMICAL CHARACTERISTICS OF LAKE WATERS

Lake Manitoba water is saturated with oxygen at all depths in the South Basin during the entire ice-free season (Turdorancea and Green, 1975; Crowe, 1972b). Water quality data on file with the Environmental Management Division of the provincial government (A. Beck, personal communication, 1979) shows that saturation values can remain high during the winter (see Appendix H). There has been reference, however, to winter fish kills probably resulting from oxygen depletion under the ice cover (Hinks, 1938; Anonymous, 1961).

A considerably body of chemical data on the lake has accumulated over the past 10 to 15 years mainly through an extensive water quality monitoring program carried out by the provincial government during the late 1960's and early 1970's. During this time, up to sixteen stations in the lake were sampled regularly and standard chemical parameters analyzed. The sampling program was reduced to three stations in the South Basin and three in the North Basin in 1973, and finally eliminated completely in 1977. Although much of this information is unpublished, Crowe (1974, 1972a and b; Cober, 1968, 1967) has informally summarized the earlier results. In addition, summaries of chemical analyses of the major influent streams (Waterhen and Whitemud Rivers) and the outlet stream (Fairford River) have been published by Inland Waters Directorate (1978c).

The South Basin of the lake falls within Northcote and Larkin's (1966) Saline Zone of Western Canada lakes. Overall, Lake Manitoba water is alkaline and has a high (up to 3000 mg l^{-1}) total dissolved solid content. As pointed out in the groundwater discussion, the ion content of the lake water is dominated by the sodium and chloride components with a secondary abundance of bicarbonate/carbonate and sulfate anions (see Fig. 3-15). The abundances of the major ions (in meq %) are $Na > Mg > Ca > K$ and $Cl > HCO_3 > SO_4 > CO_3$. Chemically, the waters belong to the sodium-chloride hydrochemical facies of Back (1966) or to Filatov's (1948, as cited in Barcia, 1975) Class IV Intermediate chloride-bicarbonate sodium-magnesium type.

Seasonal changes in concentrations of the major ions are noticeable, with generally higher values found under an ice cover and markedly lower concentrations during spring and early summer (Cober, 1968). During late summer and early fall, values rise slightly. These differences are supposedly due to a "freezing-out" effect and lake volume reduction during winter, and to snow and ice melting with increased runoff causing a dilution during May and June. The addition of significant volumes of relatively low salinity water through the Assiniboine River Diversion probably also affects this spring-time dilution.

Water samples from depths of 6.1 m, 3.0 m and 0.5 m at core site D-1 (see location map, Fig. 2-1) were analyzed to determine the vertical profiles of the major ions under a winter ice cover. All components show an increase with depth in the water column (Fig. 3-16).

Crowe (1972b) has observed significant spatial variations in abundance of the major ions in the lake with the South Basin being considerably higher than the North Basin in all components except calcium (Table 3-7). She attributes this difference essentially to differences in watershed characteristics. She points out that the watershed of the South Basin is more intensively agricultural than that of the North and, therefore, runoff from this southern area would be expected to be relatively

Table 3-7. South Basin water chemistry and relationship to North Basin values, 1966-1969 (data from Crowe, 1972b).

PARAMETER	SOUTH BASIN AVERAGE	NORTH BASIN AVERAGE	PERCENT HIGHER THAN NORTH BASIN AVERAGE
pH	8.30	8.07	1.9
Hardness	480 *	393	22.1
Alkalinity	253 *	199	27.1
Calcium	50.9	53.3	-4.5
Magnesium	86.2	63.3	36.1
Sodium	360	315	14.2
Iron	0.08	0.06	33.3
Boron	0.28	0.07	300
Bicarbonate	280	227	23.3
Carbonate	13.8	7.7	79.2
Chloride	530	484	9.6
Sulfate	208	163	27.6
Phosphate	0.07	0.04	75.0
Total Dissolved Solids	1515	1309	37.0

* parameter expressed in mg $CaCO_3$/1;

all other ionic concentrations in mg/1

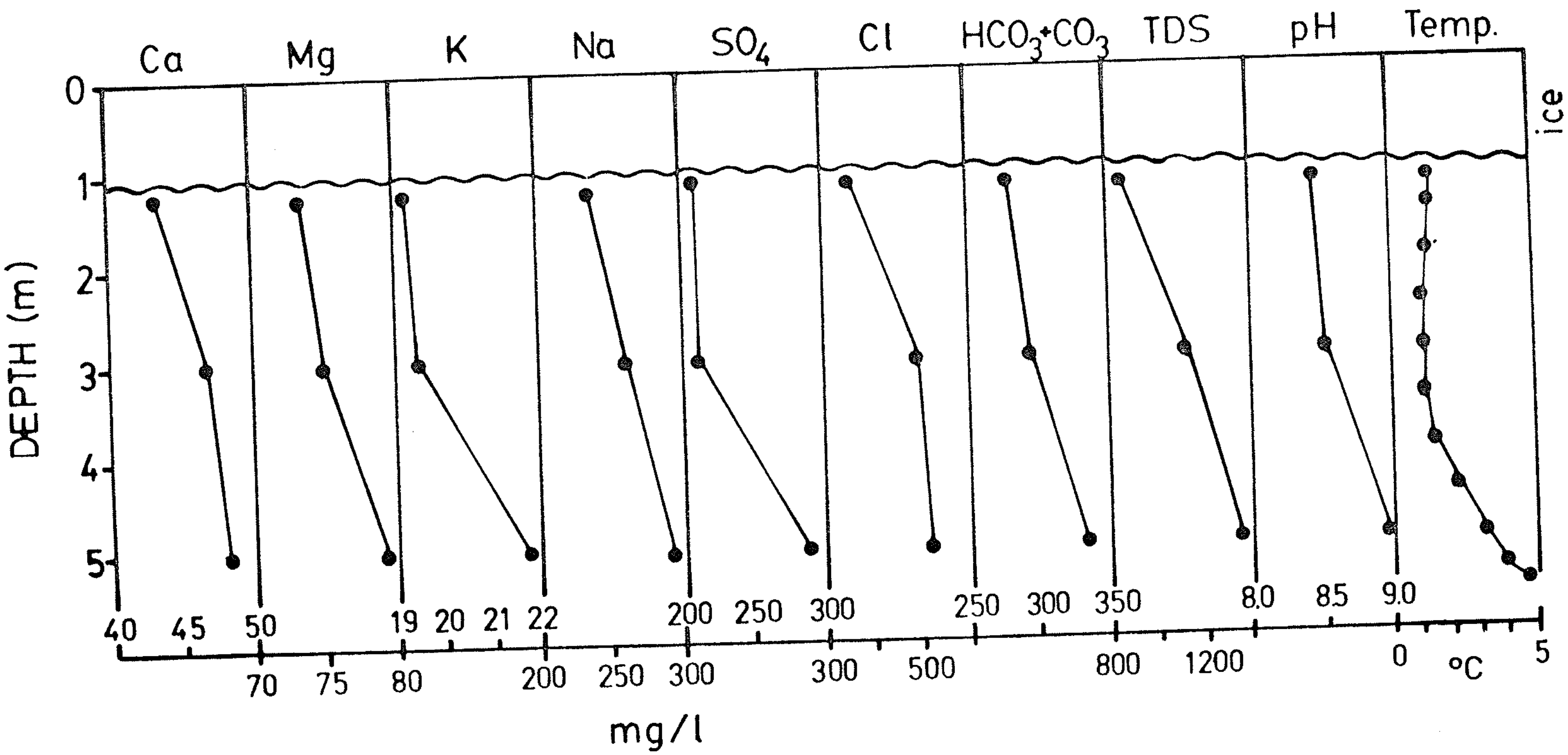


Figure 3-16. Vertical variation in major ions, total dissolved solids (TDS), pH, and temperature of lake water at locality D-2, February, 1978.

higher in dissolved substances. Crowe also feels that high levels of salinity should be expected in the South Basin due to the presence of "salt deposits" in the Whitemud River watershed.

While it is possible that some of the water chemistry variations may be due to differences in watershed characteristics and in land use between the two basins, another, and more likely explanation, is that water in the South Basin, which has a longer residence time (International Garrison Diversion Study Board, 1976) and incurs higher evaporation losses, is enriched in the major ions relative to that of the North Basin. Calcium, conversely, is lower in the South Basin because in situ calcite precipitation may be depleting the Ca^{+2} content of the water.

Several lines of evidence support this latter hypothesis concerning the spatial differences between the two basins. First, although the concentrations of major ions are higher in the South Basin, relative proportions of ions in both basins are nearly identical (see Fig. 3-15). This fact would be rather unlikely if the observed salinity variations were mainly reflecting the differences in the two watersheds. Second, hydrochemical characteristics of the major streams supplying water directly to the South Basin are incompatible with both the concentration and the ion content of the South Basin water. Figure 3-15 shows that both the Whitemud River and the Assiniboine River (from which the Portage Diversion derives its flow) are characteristically high in Ca^{+2} and HCO_3^- but very low in Na^+ and Cl^-. Conversely, South Basin water is high in Na^+ and Cl^- but relatively low in HCO_3^-, $SO_4^=$, Mg^{+2} and Ca^{+2} compared to the Whitemud and Assiniboine Rivers. Although several artificial waterways draining agricultural land are not routinely sampled for water analysis and, thus, may be a source of added nitrogen and phosphorous, it is extremely unlikely that the high levels of Na^+ anc

Cl^- ions could be derived from soils that are not characteristically high in these components (see, for example, soil analyses in Mills and Smith, 1971; Pratt et al, 1961; Ehrlich et al, 1957, 1958; Ellis and Shafer, 1943).

Returning to Figure 3-15, the plots show that the ionic content (in terms of ionic ratios) of both the North and South Basins of Lake Manitoba, as well as Lake Winnipegosis, is the result of mixing high salinity groundwater with more dilute surface runoff. The higher TDS content of the South Basin is probably a reflection of the greater concentrating influence of increased evaporation over the South Basin relative to that of the North. However, a second possible explanation is that the South Basin is receiving considerably higher inputs of saline groundwater through subaqueous springs or diffuse groundwater seepage. Quantitative appraisal of this possible subaqueous discharge contribution is unfortunately impossible without more detailed records of precipitation, evaporation, all surface inflow and outflow, as well as a somewhat better idea of the mass transfer between the two basins.

3.9 HISTORICAL CHANGES IN WATER CHEMISTRY

In addition to the spatial variation in water chemistry discussed above, Crowe (1974a, 1972; Cober, 1968, 1967) has recognized significant temporal changes in the water chemistry of the South Basin. By comparing her 1966 to 1973 results with the analyses of Bajkov (1930), Crowe concludes that the South Basin has undergone significant enrichment in many of the major ions over the past 45 years. A more complete compilation of the available water chemistry data for the South Basin appears in Table 3-8

Table 3-8. Water chemistry data for the South Basin, 1928-1978 (see text for sources of data). Dates indicate year of study. Ion concentrations are in mg/l except as noted. Where author does not report "basin averages", the values listed are the means of his data.

	Bajkov[s]	Thomas[+]	Gilliland[w1]	Crowe				van Everdingen[x]	Janusz[s]	Tudorancea & Green	Manitoba Water Quality Survey[y]					This study[w]
	(1928)	(1953)	(1963)	(1966)	(1967)	(1968)	(1969)	(1969)	(1971)	(1973)	(1973)	(1974)	(1975)	(1976)	(1977)	(1978)
pH	8.45	8.4	8.1	8.33	8.27	8.10	8.35	--	8.59	8.6	8.7	8.3	8.5	8.6	8.4	8.4
Total Hardness[a]	258	393	433	523	513	459	509	437	434	400	385	380	374	355	392	448
Total Alkalinity[a]	--	--	260	267	266	221	280	--	230	273	208	202	239	217	236	376
Specific Cond.[b]	--	2082	--	2351	2540	2380	2730	--	2166	--	1910	1955	2072	1681	1833	--
Total Dissolved Solids	712	1293	1325	1566	1549	1525	1594	--	--	1550	1265	1185	1047	974	1085	1138
Calcium	26	37	24	56	52	45	53	68	--	--	--	48	43	45	48	49
Magnesium	47	73	91	94	91	73	93	65	--	--	69	72	68	59	69	79
Sodium	--	305	339	360	364	351	391	342	--	330	280	272	262	227	245	296
Potassium	--	20	--	--	--	--	--	20	--	--	--	16	22	20	20	20
Iron	.07	.04	.20	--	--	--	.08	--	--	--	.06	.03	.35	.21	.06	--
Chloride	177	417	510	563	546	520	584	553	--	520	465	392	415	326	393	496
Sulfate	105	184	184	212	211	205	228	110	--	--	179	185	182	162	174	267
Carbonate	105*	6	24	26	20	9	10	331	--	--	9	4	15	9	8	22
Bicarbonate	--	291	293	279	278	270	307		--	--	217	239	260	244	272	329
Phosphate	--	--	--	--	.04	.09	.06	--	61	--	.02	.03	.06	.06	.08	--
Nitrate	--	1.15	.25	--	--	--	--	--	--	--	.21	.03	.22	.14	.08	--
Fluoride	--	0.23	--	--	--	--	--	--	--	--	.44	--	--	--	--	--
Boron	--	0.21	—	--	--	--	0.31	--	--	--	--	--	--	--	--	--

[a] in mg $CaCO_3/\ell$.

[b] micromhos/cm.

[s] Summer sampling only.

[w] Winter sampling only.

[1] Analysis from only one station in South Basin.

[x] Although these results are reported by van Everdingen (1971), the water samples were collected and analyzed by L.D. Delorme, Inland Waters Branch, Calgary.

[y] Manitoba Water Quality data also includes temperature, total residue, OH alkalinity, As, Cd, Cu, Pb, Ni, Zn, Mn, O_2, BOD, total organic and inorganic carbon, turbidity, total organic nitrogen, ammonia, orthophosphate, and O_2 saturation.

*Bajkov reports this value as $CO_3^=$; it is rather, possibly, $HCO_3^=$.

[+] In addition to the chemical parameters listed, Thomas also reports water temperature, O_2, colour, turbidity, suspended matter, L.O.I., silica, noncarbonate hardness, percent sodium, and saturation and stability indices.

-- indicates analysis not done.

and Figures 3-17 and 3-18. Several comments regarding these figures and the table are required before attempting to interpret or identify any trends in the data.

1. The years appearing under the author or source refer to the year of collection and analysis of the water samples, not to the year that the results were reported. The data was extracted from publications by Bajkov (1930), Thomas (1959), Gilliland (1965), Crowe (1972b), van Everdingen (1971), Janusz (1972), and Tudorancea and Green (1975). Mr. A. Beck supplied unpublished data from files of the Manitoba Water Quality Survey, Environmental Management Branch. To the author's knowledge, these published and unpublished reports represent a complete listing of all water chemistry data completed on the South Basin.

2. The locality of the sampling stations within the South Basin is, unfortunately, variable (Fig. 3-19). With the exceptions of Crowe, Tudorancea and Green, and the present study, most sampling stations were confined to within several kilometres of shore. This places significant restraints on the confidence with which the data can be extrapolated to "average" basin values. Furthermore, the "precise" location of several of the stations is also questionable as several authors simply locate a particular site as, for example, "off Oak Point." Notable is Bajkov's reference to a station "between Elm Point and Long Point." Unfortunately, modern maps do not include an Elm Point in the South Basin.

3. Neither the season of the year in which the sample was acquired nor the number of samples per station has remained constant. Bajkov (1930) and Janusz (1972) sampled during the ice-free season only, while Gilliland (1965) and this study analyzed water collected only under an

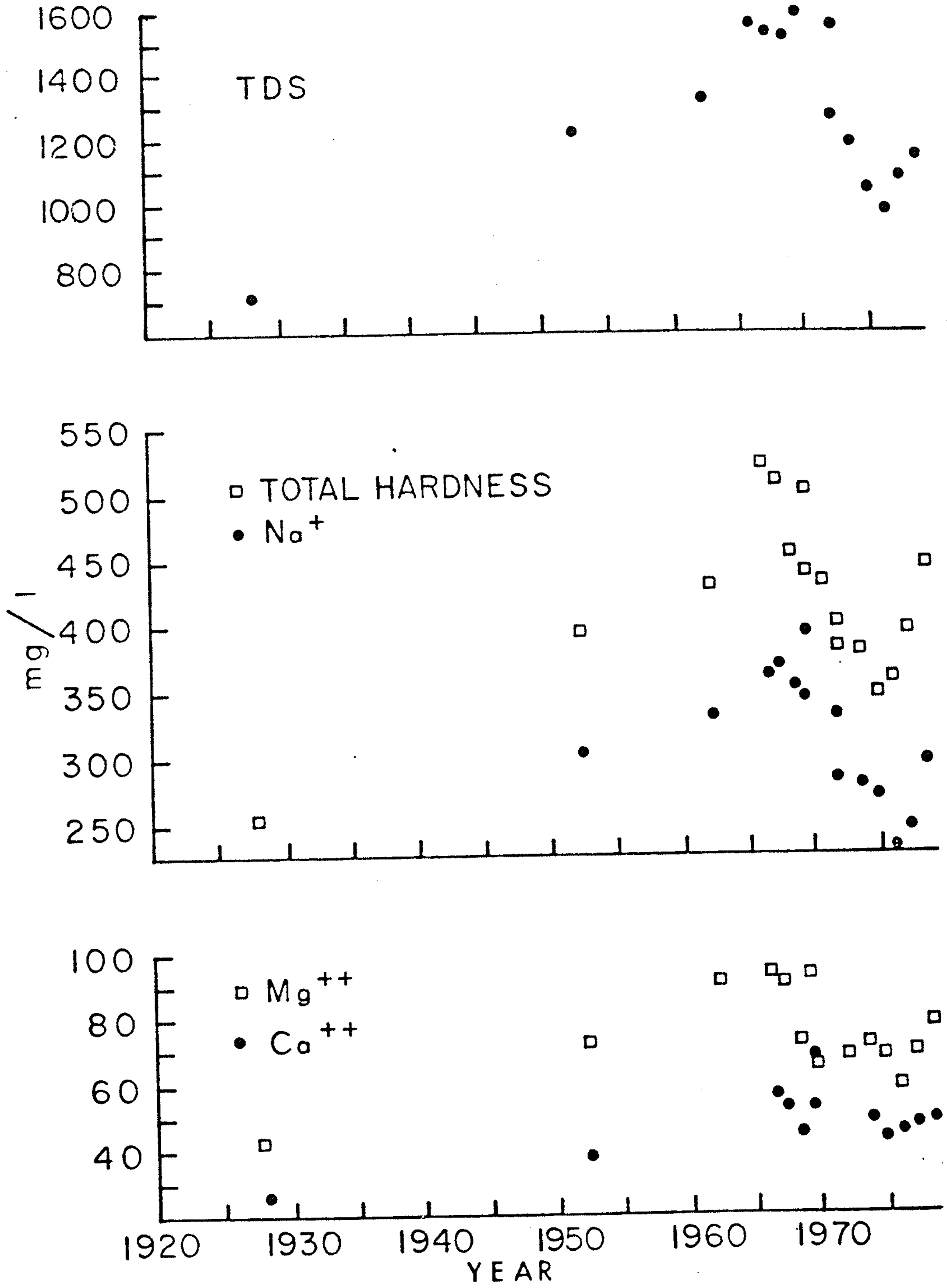


Figure 3-17. Historical trends of total dissolved solids, total hardness, sodium, magnesium and calcium ion content in the South Basin.

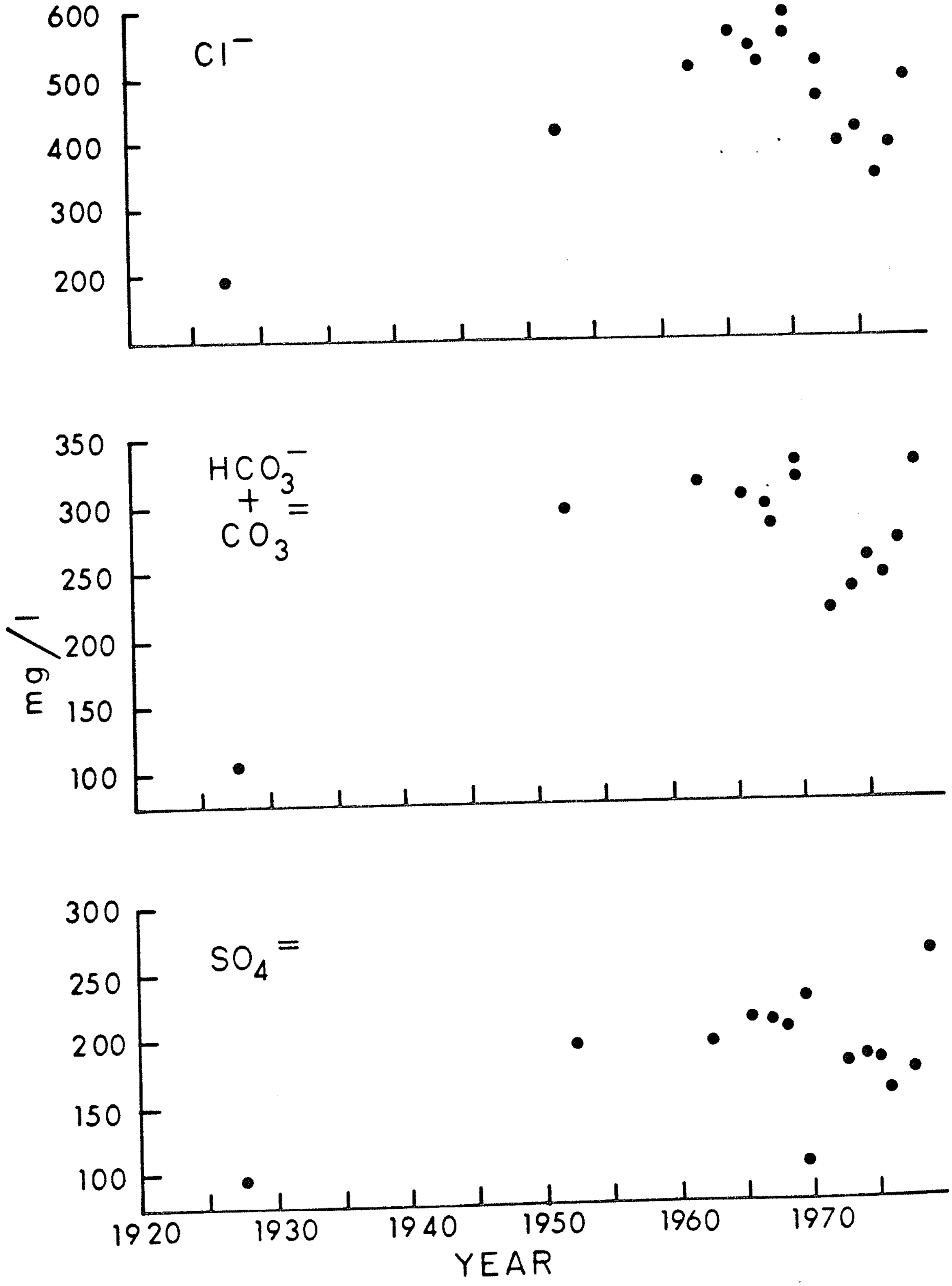


Figure 3-18. Historical trends of chloride, bicarbonate plus carbonate, and sulfate ion content in the South Basin.

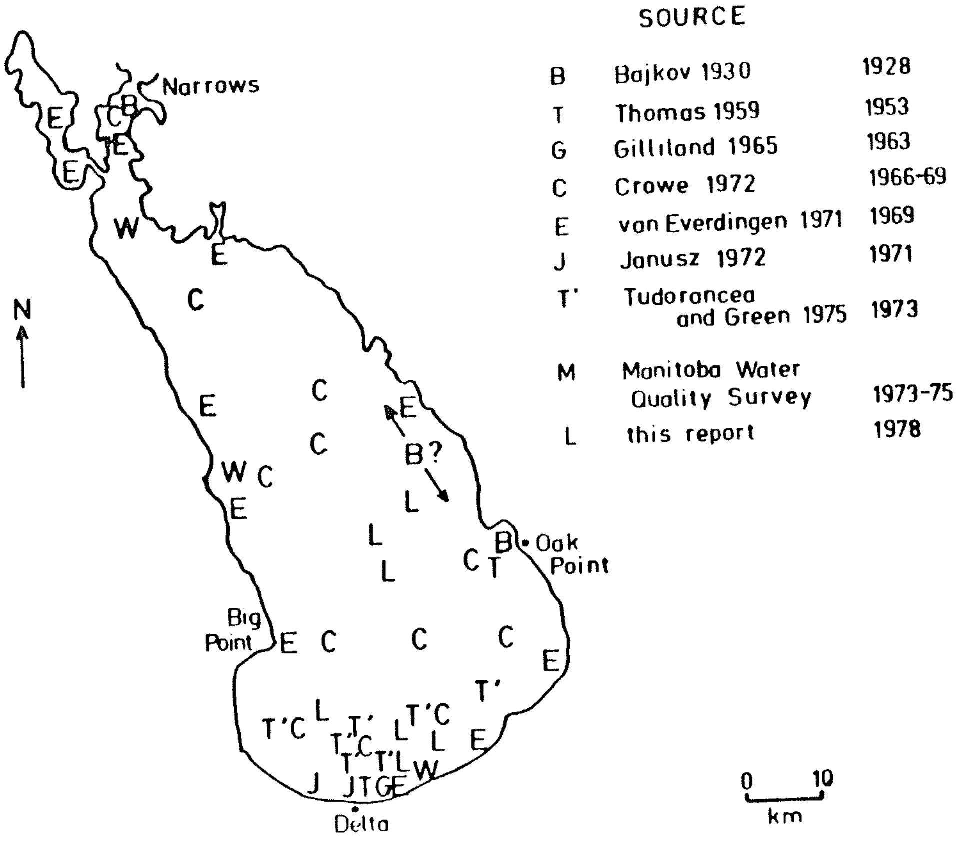


Figure 3-19. South Basin water chemistry sampling stations, 1928-1978.

ice cover. Thomas (1959) reports the results of analysis of fourteen samples from his Delta station but only one from his Oak Point locality. Consequently, the values listed in Table 3-8 and shown in Figures 3-17 and 3-18 may represent an average of many locations sampled periodically throughout the year or simply an isolated locality sampled only once. The reader is referred to the particular reference for further details on sampling frequency.

4. Basin averages of the various chemical parameters are rarely available. Because of her rather extensive network of sampling stations, Crowe (1972b) has summarized her data in terms of South Basin averages. Tudorancea and Green (1975) also note that, because of the homogeneous nature of the water mass of the South Basin, their data is similar at all stations. Likewise, very little spatial variation in the hydrochemistry was observed in samples analyzed as part of this study. For this temporal comparison discussion, the simple arithmetic mean of all values listed by the author was taken to be representative of the particular chemical parameter on a basin-wide scale.

5. Analytical techniques have varied. This is a common problem when attempting to use the chemical data from a variety of laboratories over a large number of years (see comments in Beeton, 1965). Analytical precision varies as the newer techniques gradually evolve and replace somewhat less accurate or more time consuming methods.

In spite of these restrictions, the trends in water chemistry of the South Basin with time that were identified by Crowe (1972b), namely that of increasing concentrations of chloride, sulfate, calcium, and magnesium, are probably real. Data between Crowe's 1966 to 1969 survey and Bajkov's analyses of 1928 (i.e., the results of Thomas from 1953 and Gilliland from 1963) generally confirm the increased concentration of Ca^{+2}, Mg^{+2}, $SO_4^=$, and Cl^-, as well as of Na^+, TDS and HCO_3^- (Table 3-8, Figs. 3-17 and 3-18). However, the prediction of continued increases in concentrations based on the observed trends between 1928 and 1969 (Crowe, 1974a) are not confirmed by more recent analyses. Where the total dissolved solids had increased by more than 800 mg 1^{-1} (more than a 100% increase) from 1928 to 1969, this parameter has apparently decreased by about 500 mg 1^{-1} during the last four to five years. Similar post-1970/71 downward trends are also evident in the concentrations of Ca^{+2}, Mg^{+2}, Na^+ and Cl^-.

Several possible hypothesis can be constructed in an effort to explain these observed temporal variations. These include (1) variation due to possible analytical errors; (2) variation arising from specific hydrometeorological conditions (such as lake level) existing at the time of water sampling; (3) changes in runoff characteristics and watershed use; and (4) variations in groundwater contribution to the lake. Although each of these hypotheses will be evaluated and discussed separately, the temporal variations in the ions discussed above are likely the net result of more than one causal mechanism.

1. One possible hypothesis suggested by the preceding comments regarding variable station locations, methodology, and averaging problems is that the variations in the data do not actually represent any real trends in the water quality of the South Basin.

The bulk of the most reliable basin-wide average data is concentrated during the late 1960's and early 1970's. This, plus the fact that there are only two data sets prior to 1963, suggests that any trends identified may not be statistically reliable or significant. In addition, Table 3-8 and Figures 3-17 and 3-18 show that variations of almost 20% can occur within one year's average values derived from differenct sources (i.e., 1969's Crowe versus van Everdingen; 1973's Tudorancea and Green versus Manitoba Water Quality Survey).

Despite these and the other obvious problems of incompatible sampling and analytical techniques and differing station locations mentioned above, the variations in the chemical parameters probably do represent real trends in the water chemistry. There does not seem to be a valid reason to suspect or eliminate either Bajkov's or Thomas' results on the grounds of analytical uncertainty.

2. A second possible explanation is that the data variation is an artifact of some hydrometeorological condition existing at the times of sampling. For example, the trends might be adequately explained if the early sampling periods were done at times when the lake levels were abnormally high and, therefore, the water probably more dilute. The peak concentration period of the late 1960's would then correspond to relatively lower lake levels and, thus, higher concentrations. This, however, does not seem to be consistently true for each ion. There is only a very poor correlation between lake levels at the time of sampling and TDS (Fig. 3-20; the linear correlation coefficient, $r = -.44$; r values greater than $|.62|$ and $|.74|$ are significant at the 0.01 and 0.001 alpha levels, respectively). However, Figure 3-20 does show that there are several ions whose abundance do exhibit moderately high inverse correlations with water levels. Both Cl^- and $HCO_3^- + CO_3^=$ correlate significantly with water levels at the $0.01\,\alpha$ level, suggesting that there is a direct relationship between lower volumes of water and increased concentrations of these components.

3. One of the most obvious hypotheses is that the trends

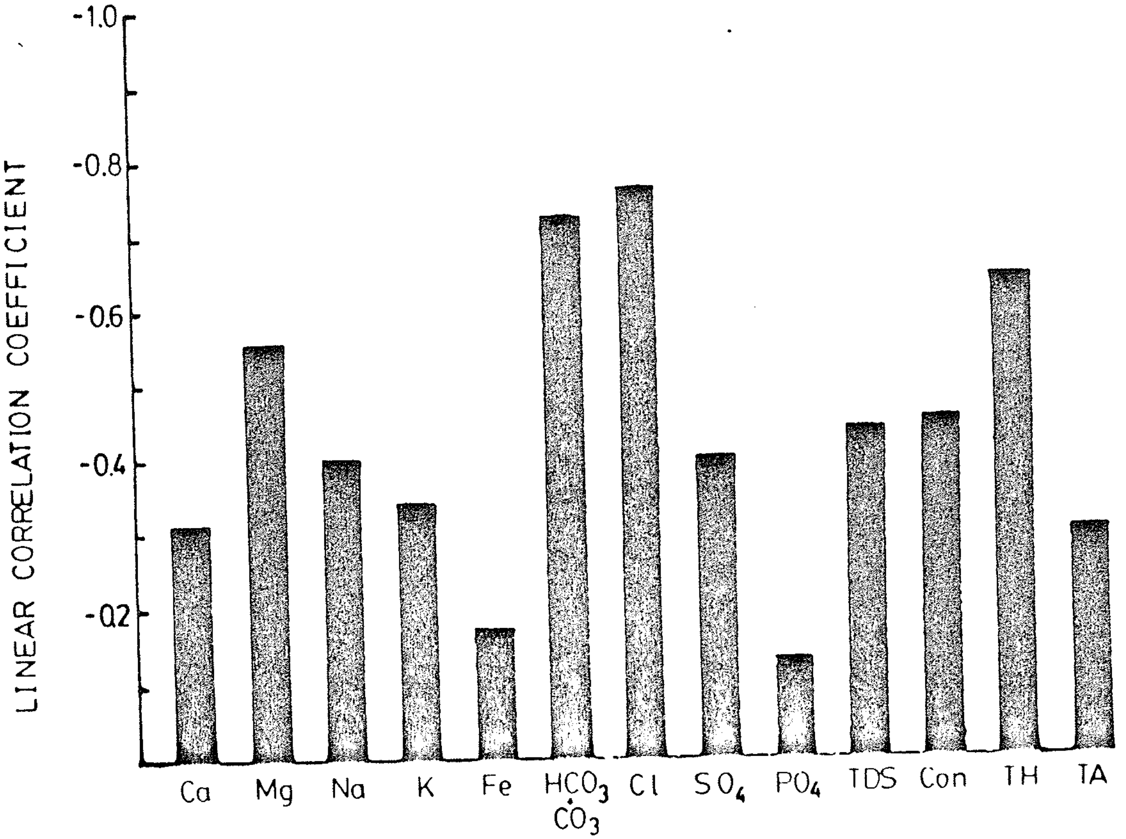


Figure 3-20. Linear correlation coefficients between the various water chemistry variables and the South Basin water level at the time of sampling. TDS, Con, TH, and TA refer to total dissolved solids, specific conductivity, total hardness, and total alkalinity, respectively.

reflect changes in runoff characteristics and watershed use, and are, thus, probably the result of human influence in the drainage basin. This suggestion is attractive, particularly in light of similar historical changes in water chemistry of many other North American lakes (e.g., Beeton, 1965, 1969; Sly, 1976). However, man's influence in the Lake Manitoba basin during the 1928 to late 1960's period is considerably more subdued than the often quoted Great Lakes examples. Within the lake's immediate watershed, the area of land used for agricultural purposes had increased only slightly during this time (Fig. 3-21). Jenkins (1974, p. 24) further points out that the agricultural limits of settlement in the Whitemud River watershed were reached by 1921, suggesting that the period of most rapid expansion of farmland at the expense of natural vegetation cover was prior to the surveyed period. Most of the artificial waterways and drainage ditches of this watershed, which Hochbaum (1965) suggests as contributing to increased salinity in the basin, were installed between 1901 and 1934 (Elliott, 1978; Jenkins, 1974). Furthermore, as discussed in Section 3.8, the South Basin's inflowing streams are presently probably not the main source of most of the dissolved material to the lake. Figure 3-22 shows that the ionic composition of the Whitemud River for the period between 1953 and 1978 has not changed significantly and further emphasizes that this fluvial contribution is consideraly different in terms of ionic ratios.

The above observations strongly suggest that the historical changes observed in these particular ions in the South Basin are probably not dominantly the result of intensification of the agricultural efforts in the watershed.

4. One of the most likely explanations regarding the temporal chemical variations in the South Basin is that the water chemistry has reflected variations in the relative contribution of the groundwater component of the hydrologic cycle. Because the present-day amount and

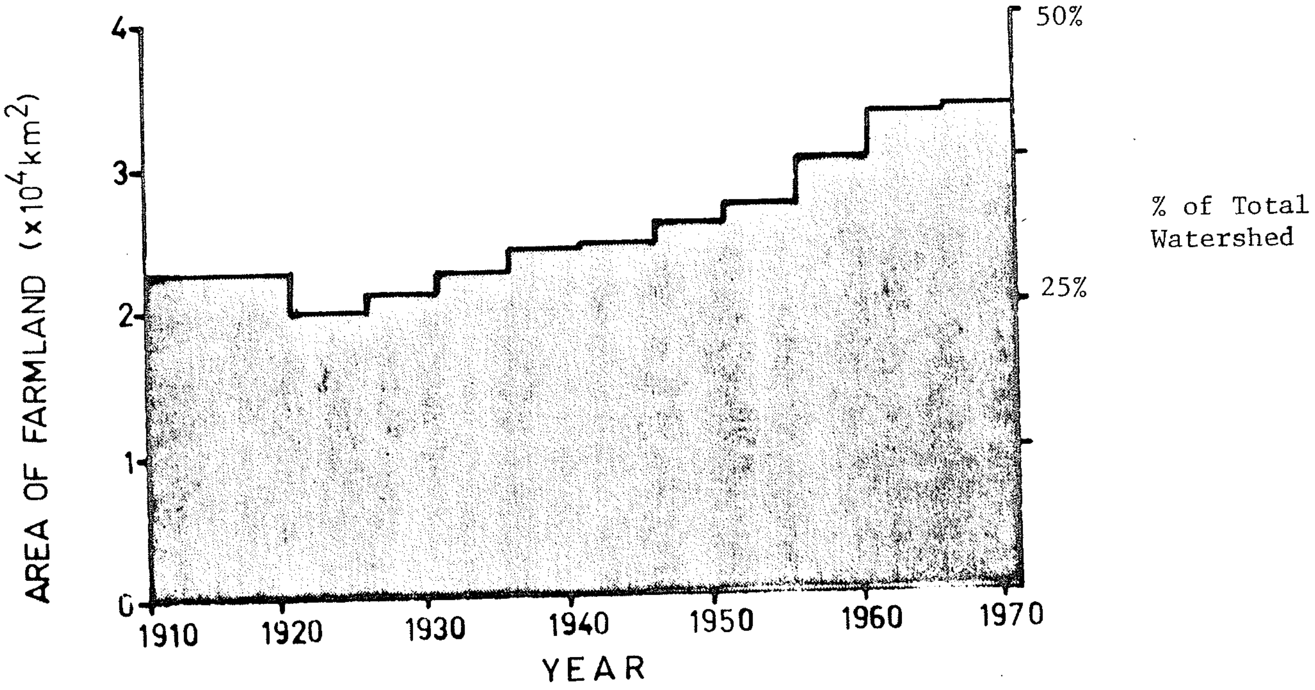


Figure 3-21. Historical trend of farmland acearage in the approximate Lake Manitoba drainage basin. (Data from Statistics Canada publications; because census division boundaries have changed between 1910 and 1970, these values should only be considered approximate.)

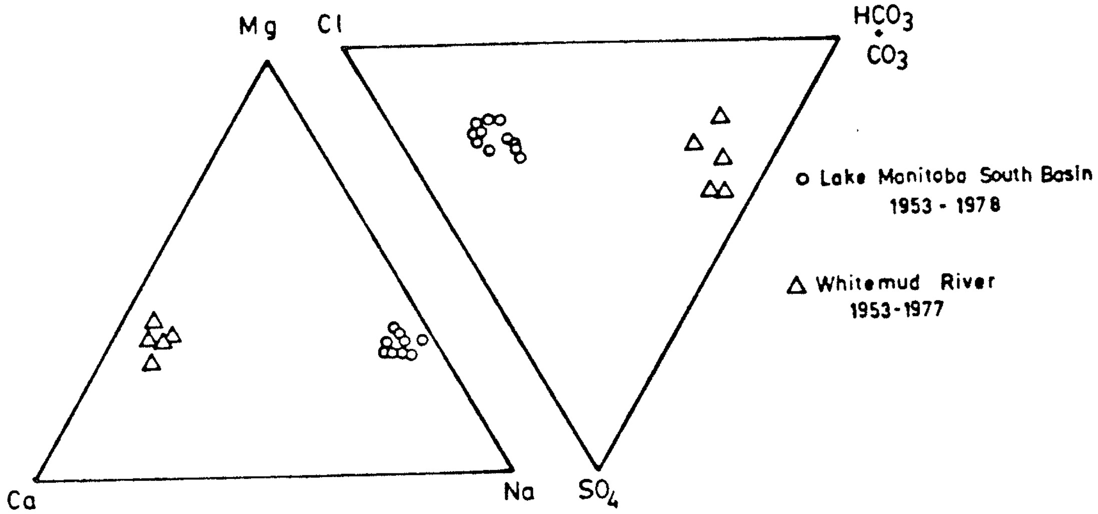


Figure 3-22. Trilinear plots of ionic composition (in percent equivalents) of South Basin water and Whitemud River water, 1953 to 1978. (Refer to Fig.3-15 for sources of data.)

types of ions in the South Basin are probably the result of (a) subaqueous groundwater discharge to the basin, and/or (b) evaporative concentration of North Basin-type water which, in turn, also reflects brine spring additions, it follows that any changes in the concentration of the ions will be due primarily to fluctuations in the discharge of this groundwater flow system.

The cause of this changing discharge with time is not known. Climate can be shown to have an obvious significant influence on the nature of the flow system (e.g., Delorme, 1972; Brown, 1967) by controlling the rate of recharge to the aquifers. On a more local scale, variations in the moisture surplus (annual precipitation minus net evapotranspiration) can result in variation in relative contribution of the various flow components in a multi-system regime. For example, the area west of Lake Manitoba is characterized by (a) a shallow, mainly freshwater, largely local flow system and (b) a deep, saline, regional groundwater component. If the area's hydrological and meteorological conditions were such that, during the early lake water sampling efforts by Bajkov, the local freshwater flow system tended to dominant the groundwater influx to the lake, the higher concentration during the 1950's and 1960's might be explained by a decreasing local moisture surplus which would largely eliminate the local groundwater component and greatly increase the relative contribution of the regional flow (saline) discharge.

In summary, several possible explanations can be suggested to account for the observed temporal variations in ion concentrations of the water of the South Basin since the 1920's. Although each of these hypotheses probably influences these ion concentrations trends to some degree, it is concluded that fluctuation in groundwater contribution to the lake system and changes in lake level are the two most significant influencing factors.

3.10 BIOTA OF THE PRESENT-DAY LAKE

Much of the scientific work conducted by others on Lake Manitoba has been biological in nature. Most of the reports dealing with the biota have been concerned with the characteristics and management of the lake's fishery (see Boyd, 1972). Lake Manitoba is generally considered to be highly productive although published detailed information regarding primary and secondary productivity in the lake is totally lacking.

Lowe (1924), in a listing and description of algae in lakes of Manitoba, identifies several species of phytoplankton belonging to the Myxophyceae (blue-green algae), Dinophyceae (dinoflagellates), Bacillariophyceae (diatoms), and Chlorophycae (green algae) groups as common in Lake Manitoba waters. Scenedesmus quadricauda and Pediastrum duplex are particularly abundant. The pioneer work by Bajkov (1930) on the three largest lakes in Manitoba still stands as the most comprehensive discussion of the general and specific characteristics of the planktonic community in Lake Manitoba published to date. He points out that green and blue-green algae are predominant in the lake over diatoms, copepods, and phyllods. Appendix C summarizes Bajkov's findings for Lake Manitoba. Daphnia longispina var. hyalina, Triarthra sp., Polyarthra platyptera, Notholca longispina, Scenedesmus quadricauda and Rivularia pisum are listed as particularly abundant in Lake Manitoba.

Crowe (1974a) states that the lake is the most productive in Manitoba with respect to the benthos. Tudorancea and Green (1975) stress that the benthic population in the South Basin is marked by a very poor diversity which they, in part, attribute to a reflection of the environment's physical and chemical homogeneity. Bottom sampling by Janusz

(1972) in the South Basin approximately 0.1 to 0.6 km offshore from Delta Marsh shows oligochaetes and Tendipedidae to dominate the benthic fauna. Tudorancea (1975) and Tudorancea et al (1979) list the numerically dominant benthic groups in the South Basin as Nematoda, Ostracoda, Chironomidae, and Mollusca, with Trichoptera, Hydracarina and Ceratopongonidae as minor constituents. Sieminiuk (1970) lists Cryptochironomus species and ostracods as being most abundant in the shallow water, nearshore areas (0.5 to 1.7 m depth, 75 to 150 m from shore) off Delta, and remarks that the low number of individuals found at all sites is a reflection of the "rugged" (high energy?) environment.

Lake Manitoba supports an active winter commercial fishery yielding a several million pound catch annually (Park, 1971; Anonymous, 1973; Campbell, 1976). An average of 75% of this production is from the South Basin. Walleye, northern pike, mullet, sauger, carp, whitefish, and perch are the most important commercial species (Crowe, 1974a). Marked fluctuations have occurred in catches of these major commercial species over the 100-year history of the fishery. Derksen (1978) shows that prior to 1951 there was a good correlation between spring water levels of the lake and the following season's walleye catch. It is believed that lower water levels will generate slightly higher turbidity in the lake which would favour the reproduction and growth of saugers over walleye (Kennedy, 1948). Since the mid to late 1950's, the lake has experienced a general decline in commercial fish production. Loss of spawning habitat in the South Basin due to accelerated sedimentation rates has been cited as a major factor contributing to this decline (Derksen, 1978; Crowe, 1974a). Also, in recent years there has been a marked decrease in the walleye and sauger catch and a corresponding increase in rough fish landings. Approximately 25% of the 1977-78 catch was taken in the spring sucker and carp season (Manitoba Department of Mines, Natural Resources and Environment, 1979).

The biological community in Lake Manitoba can significantly influence the nature and pattern of sedimentation in the basin by (a) contributing both organic and inorganic components to the record, (b) altering the water chemistry through, for example, high levels of CO_2 uptake associated with periods of high phytoplankton productivity, (c) destroying primary sedimentary structure and extensively mixing the sediment through burrowing and grazing activities, and (d) altering the rates of chemical exchange between the sediment and water.

SECTION 4

DESCRIPTION OF LAKE MANITOBA SEDIMENTS

4.1 INTRODUCTION

The purpose of this chapter is to describe the post-glacial sediments of the South Basin of Lake Manitoba in terms of selected physical, chemical, and mineralogical parameters. For ease of discussion this data presentation has been divided into two sections: (a) description of the present-day (modern) sediments on the floor of the lake, and (b) description of the pre-modern sediments. The modern sediment discussion emphasizes the characteristics and spatial variations of the uppermost 2 cm of sediment within the South Basin based on up to 60 control points. The description of pre-modern sediment concentrates on the temporal variations and trends identified mainly in the three longest cores within the basin.

4.2 DESCRIPTION OF MODERN SEDIMENTS OF THE SOUTH BASIN

4.2.1 Introduction

The data presented here are derived primarily from analyses of the upper 2 cm of cores collected as part of this study, but also include some unpublished results from J. Crowe and A. Beck (personal communications, 1978) and published sedimentological data from Tudorancea and Green (1975). This discussion is confined to the southern two-thirds of the South Basin.

For this report, the terms "modern bottom sediments" or "surficial sediments" refer to the deposits of the uppermost 2 cm of core or to the sediment collected by bottom "grab" sampling using an Ekman-style dredge. It is recognized that this 2 cm sediment zone represents several years deposition or may represent sediment that is actively being eroded.

If bioturbation and wave-generated disturbances are major factors at the sediment-water interface, this 2 cm interval will represent the integration of sediment deposited over a much longer time span.

The terms "offshore" and "nearshore" are frequently found in limnological and sedimentological literature and often imply a variety of energy and/or biological conditions dependent on the particular author. Considering the very shallow overall depth of Lake Manitoba, the long effective wind fetch distances, the high turbidity, and the lack of a definitely defined zone of rooted aquatics (Tudorancea and Green, 1974), the offshore/nearshore transition in Lake Manitoba is very difficult to delineate. For this report, the offshore region of Lake Manitoba is arbitrarily defined as having water depths greater than 3 m.

The results of analyses of physical, chemical, and mineralogical parameters of the surficial sediment in the South Basin are summarized in Tables 4-1 to 4-3, and shown on maps in Appendix D (Figs. D-1 to D-34). The results at each sampling site are presented in tabular form in Appendix E. The results of statistical analyses (variable interrelationships and factor analyses) of the surficial sediments are discussed in Appendix G.

As can be seen in Figures D-1 to D-34, there are two areas in the South Basin within which most of the surficial sediment parameters are considerably different than those of the immediately adjacent area. These anomalous areas are locations of <u>relict</u> (pre-modern) <u>sediments</u> that are exposed today at the bottom of the lake. These two relict sand areas occur northwest of the University Field Station (near Delta, Manitoba) and just off Marshy Point (near Oakland, Manitoba). They are roughly defined by the 20% sand contour on Figure D-5. Because these anomalous areas contain pre-modern sediment, the modern-sediment parameter summaries in Tables 4-1 to 4-3 do not include data collected within these relict areas of the basin.

4.2.2 Physical Properties (see Table 4-1)

4.2.2.1 Moisture content and general consistency

The moisture content of the surficial sediments in the South Basin ranges from 50% to 81% with a mean value of approximately 71% (excluding relict areas). Highest values are generally found at the sites most distant from shore and at depths of water greater than 4 m (Fig. D-1).

In general, the surface sediment is soft to gelatinous and even soupy except in areas of dominantly coarse-grained material where the deposits are firm and compact.

4.2.2.2 Organic content

The surface sediments of the South Basin contain moderate to low amounts of organic matter. Organic content (L.O.I.) ranges from less than 1% in the relict sand areas to a maximum of 30% in offshore, fine-grained sediment. The amount of organic matter shows a general increase in the offshore direction (Fig. D-2).

Both whole and fragmented mollusk shells are scattered throughout the matrix usually in moderate to high amounts. In general, the

Table 4-1. Summary of physical parameters of surface sediment (0-2 cm) from South Basin of Lake Manitoba (relict sand areas excluded)

										Calculated	
Parameter	Sand %	Silt %	Clay %	Mean φ	Sorting φ	Skewness	Kurtosis	Moisture content %	Organic matter %	Bulk density g km^3	Porosity %
Mean	3.0	70.3	26.7	6.9	2.6	+0.7	2.4	71.4	14.1	1.18	88.2
Standard deviation	3.4	12.8	14.4	0.9	0.9	0.4	0.6	7.3	1.6	0.09	4.6
Number of measurements	39	39	39	39	39	39	39	39	39	25	25
Range	0 - 14.0	35.7 - 90.3	0 - 64.3	5.1 - 8.4	0.9 - 3.1	0.7 - +1.6	0.3 - 4.0	50.0 - 81.0	6.7 - 30.4	1.08 - 1.44	77.3 - 94.7

bottom sediment of the eastern portion of the basin contains more shells than that of the western or northern sectors of the lake, although very high concentrations of mollusks similar to that observed at greater depths in the sediment, were not present at any sampling locality. In addition to whole and fragmented mollusk shells, abundant rootlets and plant fibers were present in the surface sediment at localities 21 and 35.

4.2.2.3 Color

The color of fresh (moist) bottom sediment in the South Basin is dominantly grey to dark grey (5Y 4.5/1 to 5Y 4/1). Sediment in the southwestern portion of the basin shows more variability in colors ranging from grey to very dark grey, black, and dark greenish grey (5Y 5/1, 2.5Y 3/0, 5Y 2.5/2 and 5GY 4/1).

4.2.2.4 Derived physical properties

The calculated bulk density of the surface sediment ranges from 1.08 to 2.15 g/cm^3 (excluding relict areas). Calculated porosity values range from 30 to 94%. As each of these parameters is, in part, a function of the moisture and organic contents of the samples, their variation in the basin should closely follow the trends of these two other properties. The higher density values and lower porosities are found in the areas of coarse-grained relict sediment of the southwestern and offshore Marshy Point regions (Figs. D-3 and D-4). In the remaining portion of the basin, both parameters show relatively little variation.

4.2.2.5 Grain size and textural properties

The offshore bottom sediments of the South Basin are mainly silt, clayey silt, and silty clay (Fig. 4-1). The average grain-size distribution excluding sediment collected from within the relict areas is 3% sand, 70% silt, and 27% clay.

The spatial distribution of the relative percentages of these three components are shown in Figures D-5 to D-7. The abundance of sand is highest in the two relict areas. Outside of these two areas, the amount of sand-sized material in the modern offshore bottom sediments does not exceed 12%. The distribution of clay also shows the influence of these anomalously coarse-grained relict areas, as well as a general increase in abundance in the offshore direction. Silt abundance shows a complicated spatial distribution which is difficult to interpret due to the closed nature of the sand-silt-clay values (i.e., % sand + % silt + % clay equals 100%). In general, the highest silt values are found in the eastern portion of the basin.

The mean grain size of the bottom sediment ranges from 1.9 phi (within the relict areas) to 9.3 phi. Spatially, the sediment shows a general decrease in mean grain size in the offshore direction (Fig. D-8).

The offshore bottom sediments are dominantly poorly to very poorly sorted with grain size standard deviations of 0.9 to 3.1 phi (Fig. D-9). The relict sand unit area in the southwestern portion of the basin, however, is well-sorted with standard deviations ranging from 0.2 to 0.6 phi.

The grain-size frequency distributions are, in general, positively skewed and platykurtic. Again, the sediment of the anomalously coarse-grained unit in the southwestern area shows slightly different

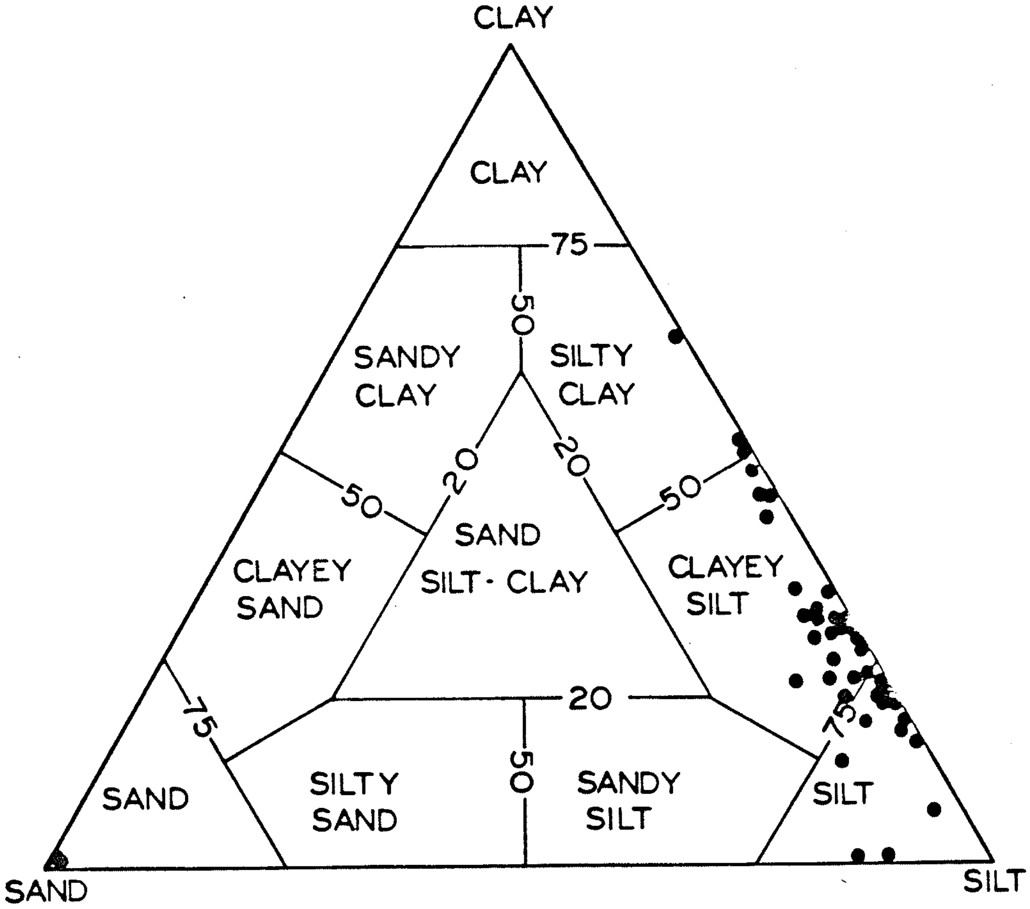


Figure 4-1. Trilinear plot of sand, silt, and clay in the surface sediment from the South Basin of Lake Manitoba. Nomenclature after Shepard (1954). Data from relict sand areas are included and all plot near the 100% sand point.

distribution characteristics and is negatively skewed and leptokurtic. Overall, these third and fourth moment statistics show no consistent spatial trends over the South Basin (Figs. D-10 and D-11).

4.2.3 Sediment Mineralogy (see Table 4-2)

4.2.3.1 Bulk mineralogy

The surface sediments of the South Basin of Lake Manitoba are composed of quartz, feldspars, carbonate minerals, and clay minerals. The relative proportions of quartz + feldspar, calcite + dolomite, and clay minerals are shown in Figure 4-2. The quartz content (excluding data from the relict sand areas) ranges from 11.9% to 45.9% ($\bar{x}$ = 22.5%) but is considerably higher within the relict sand areas (Fig. D-12). Feldspar abundance ranges from 1.9% to 16.2% ($\bar{x}$ = 5.3%) and also shows the effects of these anomalous areas (Fig. D-13). Plagioclase is generally more abundant than potassic feldspars. Overall, both quartz and feldspars show a general decrease in abundance in the offshore direction.

Calcite is generally the dominant carbonate mineral in the surface sediments of the South Basin, ranging in abundance from 2.2% to 48.2% ($\bar{x}$=27.0%). Spatially, calcite shows an increase in abundance in the offshore direction (Fig. D-14). Approximately 80 to 100% of this calcite is a disordered species, probably high magnesian calcite, with up to 11 mole percent $MgCO_3$ concentration (Fig. D-15). There does not appear to be any systematic variation in the amount of Mg incorporation in the calcite throughout the basin (Fig. D-16).

Dolomite makes up an average of 18% of the bottom sediment mineralogy (excluding relict areas) and, unlike calcite, shows a decrease in abundance in the offshore direction (Fig. D-17).

Table 4-2. Summary of mineralogical parameters of surface sediment (0-2 cm) from the South Basin of Lake Manitoba (relict sand areas excluded).

			Calcite							
Parameter	Quartz %	Feldspar %	total %	low Mg %	high Mg %	Dolomite %	total Clay mins. %	Expandable lattice clays[c] %	Illite[c] %	Kaolinite + chlorite[c] %
Mean[a]	22.5	5.3	27.0	1.2[b]	22.0[b]	18.0	27.2	25.3	40.3	34.5
Standard deviation	7.3	2.3	8.0	0.2	9.4	5.2	6.7	16.6	14.2	9.9
Number of measurements	39	39	39	27	27	39	39	34	34	34
Range	11.9-45.9	1.9-16.2	2.2-48.2	0-4.4	5.5-30.9	9.6-39.4	7.2-41.0	0-65.0	20.0-66.0	17.5-47.0

[a] The average percentages of quartz, feldspar, calcite, dolomite and total clay minerals have been normalized to equal 100%. Similarly, the average relative percentages of clay minerals have been normalized to equal 100%.

[b] The average percentage low Mg calcite plus high Mg calcite does not seem to equal the average percent total calcite because a smaller number of samples were analyzed for detailed carbonate mineralogy.

[c] Clay mineral content expressed as relative percent.

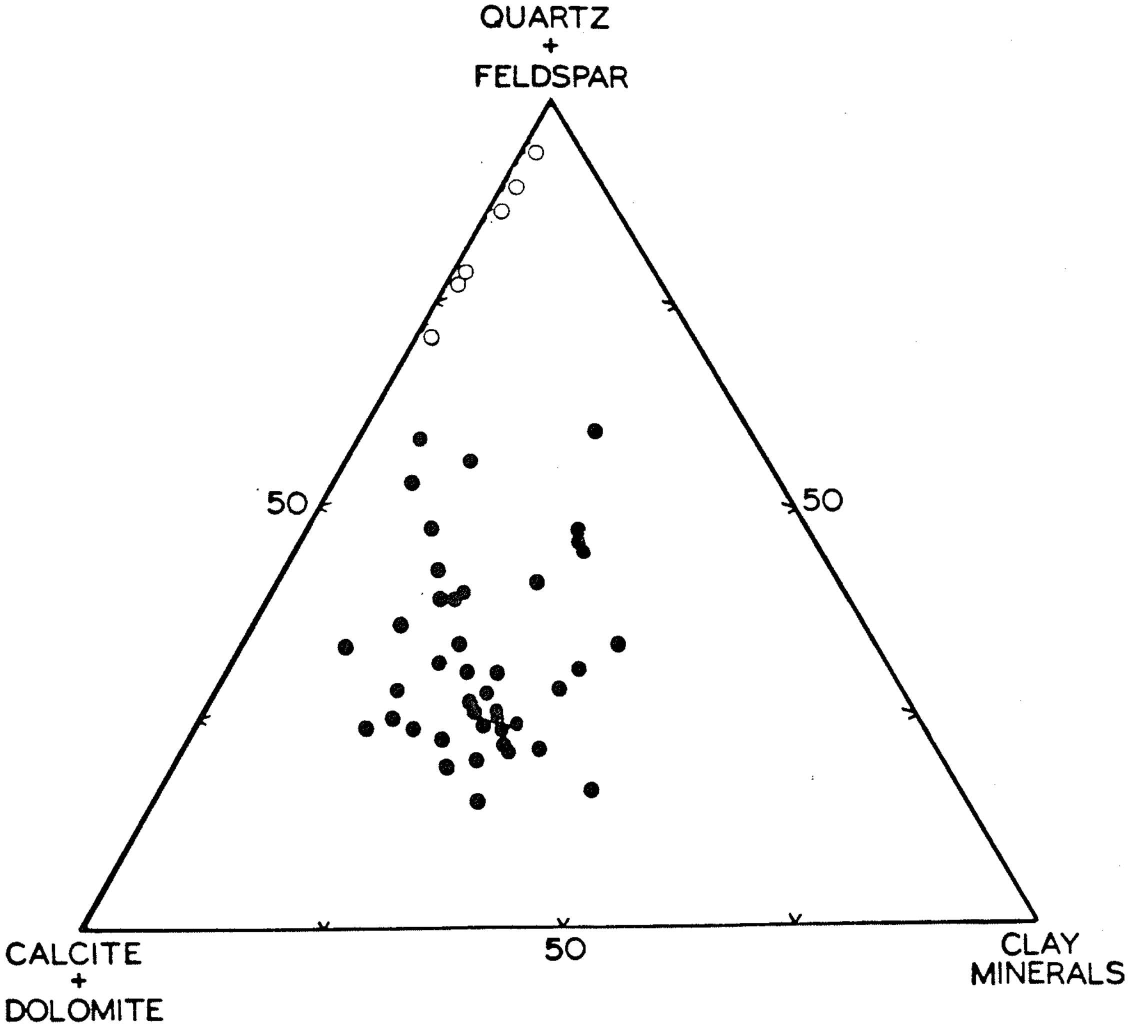


Figure 4-2. Trilinear plot of quartz + feldspar, calcite + dolomite, and clay minerals in the surface sediment from the South Basin of Lake Manitoba. Data from the relict sand areas are plotted as open circles.

Aragonite, the only other carbonate mineral identified in Lake Manitoba bottom sediments, was present only in trace amounts at several locations in the basin (e.g., sites 17 and 27).

4.2.3.2 Clay mineralogy

Clay minerals make up an average of about 27% of the mineral suite (excluding relict areas) and spatially show an increase in abundance in the offshore direction (Fig. D-18). The average relative abundances of the main clay mineral groups are illite: 40.3%; kaolinite plus chlorite: 34.5%; and expandable lattice clay minerals: 25.3%. The spatial distribution of these three groups in the South Basin is shown in Figures D-19 to D-21. Expandable clays are highest in the western and southern sectors of the basin, while the illite and kaolinite plus chlorite groups are dominant in sediments of the eastern portion of the lake.

4.2.4 Chemical Characteristics (see Table 4-3)

4.2.4.1 Hydrogen ion concentration

The pH of the surface sediment showed a rather narrow range from 7.1 to 8.1 with a basin mean of 7.8. Lowest values occurred in the relict sandy area of the southwest (Fig. D-22).

4.2.4.2 Redox potential

The South Basin sediments showed considerable variation in Eh values ranging from +110 mv to -240 mv. The lowest values were found in the central and southeastern portions of the sampling area, while the highest readings were in the western and northeastern sectors (Fig. D-23).

Table 4-3. Summary of chemical parameters of surface sediment (0-2 cm) from the South Basin of Lake Manitoba (relict sand areas excluded).

Parameter	pH	Eh mv.	K %	Na %	Ca %	Mg %	Fe %	Mn %	P %	Cu ppm	Zn ppm	Pb ppm	Cd ppm	Hg ppb
Mean	7.8	-86	1.02	0.49	12.68	2.81	1.82	0.050	0.090	23	55	<20	<1	60
Standard deviation	0.1	15	0.12	0.07	1.57	0.55	0.25	0.005	0.026	5	13	-	-	35
Number of measurements	35	35	29	29	29	29	29	29	29	29	29	5	4	6
Range	7.1-8.1	-240-+110	0.78-1.44	0.32-0.62	8.66-15.20	2.14-3.68	1.24-2.04	0.040-0.059	0.044-0.170	13-36	33-63	-	-	10-170

4.2.4.3 Elemental composition

Of the twelve elements analyzed as part of this study (K, Na, Ca, Mg, Fe, Mn, P, Cu, Z, Pb, Hg, and Cd), relatively few show significant variations in abundance in the surface sediment of the basin. Calcium concentration ranges from 8.66 to 15.20%, and shows a general increase in the offshore direction (Fig. D-26). Iron and phosphorous also exhibit similar trends, while sodium and magnesium show decreasing abundances in the more offshore localities (Figs. D-24, D-27, D-28, and D-30). Outside of the relict sand areas, copper, zinc, manganese, and potassium show very little consistent variation in abundance (Figs. D-25, D-29, D-30 and D-32). The limited number of analyses of lead, cadmium, and mercury in the surface sediments (Figs. D-33 and D-34) do not permit delineation of any spatial trends.

4.3 DESCRIPTION OF PRE-MODERN SEDIMENTS IN THE SOUTH BASIN

4.3.1 Introduction

This section will describe the sediment characteristics and parameter changes observed in the three deepest cores in the basin. The location of these cores, D-1, D-2, and D-3, as well as the other shorter cores, is shown in Figure 2-1. Where pertinent data from the forty-nine intermediate and short cores will be presented. The lithostratigraphy presented later in this thesis, however, is based mainly on the sediment sequence observed in the three long cores. The variations with depth of each sediment parameter in these longest cores are shown graphically in Appendix J. Appendix I provides a description of each core, and Appendix E lists, in tabular form, the analytical results of all the cores. Figure

4-3 (in back pocket) shows the temporal lithologic changes within the upper 3.5 m of sediment at each core site. To help better describe and understand the variable trends and interrelationships, a simple correlation coefficient matrix was generated from selected parameter data in the three deep cores (Table 4-4).

4.3.2 Summary of Features and Trends

4.3.2.1 Physical properties

The post-glacial sediment of the South Basin consists dominantly of silty clay and clayey silt except in the extreme southern end where less clayey and more sandy units are present (Figs. J-1, J-6, and J-11). In general, sediment near the base of the long cores contains the highest percent of clay but also contains an abundance of pebbles and granules "floating" in the clay. Above this, the clasts disappear and the mean grain size increases. Moisture content decreases with depth from 70 to 80% in the youngest sediment to 20 to 30% near the base of the cores (Figs. J-1, J-6, and J-11). Organic matter likewise decreases with depth in the cores from values of 15 to 30% near the sediment/water interface to consistently less than 7% below depths of about 3 to 4 m (Figs. J-1, J-6, and J-11). The trends of organic matter and moisture contents show a high positive correlation (r = 0.84; Table 4-4). Bulk density increases with depth closely following the inverse trend of the moisture content.

Sediment colors (Munsell, moist) are generally dark grey (5Y 4/1) to dark greenish grey (5GY 4/1) and do not follow any specific trend. Core

Table 4-4. Correlation coefficient matrix of 24 physical, chemical, and mineralogical sediment variables from cores D-1, D-2, and D-3.

	Moisture content	Organic matter	Total carbonate	pH	Eh	Potassium	Sodium	Calcium	Magnesium	Iron	Manganese	Phosphorous
Moisture content	1.000											
Organic matter	.839	1.000										
Total Carbonates	.253	.355	1.000									
pH	.346	.334	.258	1.000								
Eh	.150	.341	.056	.288	1.000							
Potassium	-.745	-.748	-.664	-.358	-.272	1.000						
Sodium	-.741	-.680	-.510	-.306	-.150	.850	1.000					
Calcium	.531	.592	.866	.254	.149	-.718	-.684	1.000				
Magnesium	-.489	-.389	.300	-.087	-.056	.270	.547	.044	1.000			
Iron	-.662	-.738	-.739	-.302	-.243	.940	.736	-.742	.114	1.000		
Manganese	.342	.101	.163	.162	.068	-.156	-.476	.461	-.313	.024	1.000	
Phosphorous	.488	.565	.310	-.126	.278	-.466	-.321	.511	-.069	-.445	.111	1.000
Quartz	-.464	-.605	-.307	-.373	-.479	.558	.572	-.503	.223	.571	-.130	-.304
Total clay minerals	-.029	-.219	-.367	.094	.158	.294	.060	-.186	-.057	.377	.298	-.254
Feldspar	-.177	-.169	-.531	-.089	-.170	.548	.637	-.535	-.147	.373	-.348	-.285
Calcite	.764	.740	.645	.349	.161	-.831	-.912	.823	-.428	-.756	.546	.416
Dolomite	-.395	-.241	.484	-.128	-.145	.016	.271	.147	.714	-.139	-.307	-.057

Table 4-4 (cont.)

	Moisture content	Organic matter	Total carbonate	pH	Eh	Potassium	Sodium	Calcium	Magnesium	Iron	Manganese	Phosphorous
Expandable clays	-.240	-.361	-.320	.100	.240	.222	.111	-.390	-.025	.328	.007	-.160
Illite	.355	.477	.517	-.006	-.173	.402	-.236	.581	.073	.510	-.040	.300
Kaolinite+ chlorite	.099	.198	.150	-.036	-.193	-.157	.080	.079	.121	-.214	-.192	.119
Zinc	-.020	-.152	-.100	-.247	-.241	.040	-.006	-.268	-.019	.024	-.224	-.318
Copper	-.361	-.369	-.540	-.256	-.124	.518	.603	-.581	.084	.502	-.194	-.222
Silt	.429	.487	.752	.109	-.054	-.655	-.491	.739	.176	-.720	.127	.417
Clay (size)	-.554	-.543	-.619	.000	.137	.601	.447	-.684	-.100	.673	-.100	-.585

Table 4-4 (cont.)

	Quartz	Total clay minerals	Feldspar	Calcite	Dolomite	Expandable clays	Illite	Kaolinite+ chlorite	Zinc	Copper	Silt	Clay (size)
Quartz	1.000											
Total clay minerals	-.166	1.000										
Feldspar	.333	-.246	1.000									
Calcite	-.468	-.158	-.445	1.000								
Dolomite	.365	-.508	-.424	-.144	1.000							
Expandable clays	.000	.358	-.002	-.301	-.302	1.000						
Illite	-.138	-.396	-.061	.422	.349	-.833	1.000					
Kaolinite+ chlorite	.045	-.432	.116	.024	.377	-.655	.427	1.000				
Zinc	.339	-.150	.275	-.153	.167	.007	.021	-.087	1.000			
Copper	.451	-.020	.267	-.548	-.013	.097	-.307	.097	-.074	1.000		
Silt	-.335	-.319	-.541	.611	.347	-.464	.586	.240	.038	-.403	1.000	
Clay (size)	.309	.412	.391	-.569	-.219	.477	-.647	-.277	.049	.360	-.982	1.000

D-3, however, exhibits relatively thicker sections of darker colors, greys and black (2.5Y 2/0 to N 3 to N 2.5) than do the other cores.

The sediment is generally poorly laminated. Core D-3, however, tends to be slightly better laminated with well-developed thin to medium (1 mm to 5 mm thickness) even, parallel laminae present in the lower 5 m.

4.3.2.2 Sediment mineralogy

Mineralogically, the pre-modern post-glacial sediments are similar to the modern surficial sediments. Quartz, carbonate minerals, and clay minerals usually make up over 90% of the mineral suite with feldspars (dominantly plagioclase) generally comprising less than 10% (Figs. J-2, J-7 and J-12). Calcite is the dominant carbonate mineral (15 to 45%) in the upper 3 to 4 m of sediment, but its abundance decreases below this depth to values of less than 10%. Similar to the surface sediment, most (70 to 100%) of the calcite in the upper 9 m of sediment is high-Mg calcite with $MgCO_3$ contents in the calcite ranging from 3 to 14 mole percent (Figs. 6-9 and 6-10). Importantly, it is actually the abundance of this high-Mg calcite that accounts for the variation with depth in the total calcite profile. The low-Mg calcite in the sediment of D-1 shows essentially no variation with depth.

Dolomite, in contrast to calcite, shows a general increase in abundance with depth ranging from 10 to 15% in the upper sections of sediment to over 40% in the lower units (Figs. J-2, J-7, and J-12). Overall, the total carbonate content of the sediment decreases with depth in the record.

Both quartz and feldspar show an increase in abundance with depth (Figs. J-2, J-7, and J-12). The total clay mineral content shows only a very slight increase with depth in cores D-1 and D-2 (Figs. J-2 and J-7) but a strong decrease in the lower part of core D-3 (Fig. J-12). The relative abundances of the major clay mineral groups - illite, expandable lattice clays, and kaolinite plus chlorite - show rather sporadic and inconsistent trends with depth (Figs. J-3, J-8, and J-13).

In addition to the expected significant correlations, such as between calcite and total carbonate (r = 0.65; Table 4-4), the calcite trend also shows good positive association with the moisture content (r = 0.76) and organic matter (r = 0.74) variations but significant negative correlation with the clay trend (r = -0.56). Quartz also tends to vary inversely with organic matter (r = -0.60).

4.3.2.3 Chemical Characteristics

Among the elements analyzed in this study, potassium, sodium, iron, manganese, and magnesium contents increase slightly with depth, while calcium and phosphorous decrease. The trends of all elements in cores D-1, D-2, and D-3 are shown in Figures J-4, J-5, J-9, J-10, J-14, and J-15. Copper shows little variation with depth in the cores, but zinc exhibits strong, erratic fluctuations above baseline values in cores D-1 and D-2. The cores become slightly less reducing (less negative Eh) with depth, whereas pH shows no consistent trends.

The trends of the elements Na, K. Fe, and Cu are all strongly positively correlated with each other and inversely correlated with Ca (Table 4-4). Similarly, calcium and phosphorous contents follow closely the trends of organic matter, moisture content, and silt, and are inversely related to clay. The K-Fe-Na group shows the opposite relationships with these physical parameters: i.e., positive association with clay and negative correlation with moisture content, organic matter, and silt. Calcium content shows the expected significant positive relationship with the carbonate mineralogy variables (total carbonate and calcite) and inverse correlation with quartz and feldspar trends.

4.3.3 Marker Zones

4.3.3.1 Introduction

Some of the most distinctive and important deviations from the parameter trends described above occur in "zones" scattered throughout the deep cores. Some parameters, such as moisture content, vary considerably, while other parameters do not. The degree of variance from one "zone" to another also differs. The term marker horizon is used for these zones which are easily recognized both visually and by distinctive parameter characteristics, and can be traced and correlated over long distances in the South Basin.

4.3.3.2 Characteristics

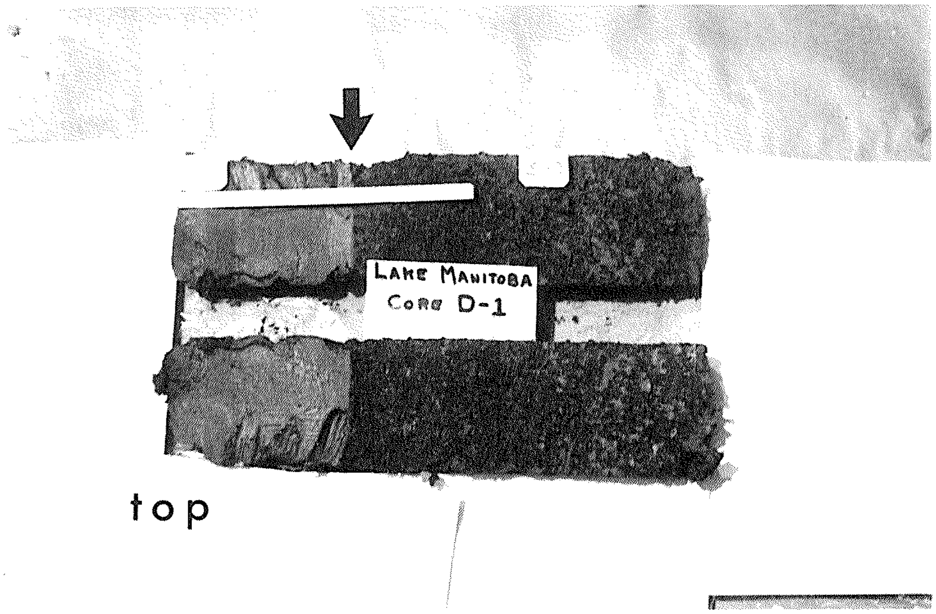
The marker horizons are characterized by several distinctive features or changes in parameters. Although several of the following characteristics, such as color, moisture content and structure, are common to all of the marker horizons, all are not. The upper (youngest) marker zone is generally the best developed and has been cored more often than the lower zones; therefore, many of the examples and illustrations showing the various features will be derived from it. Appendix L lists the cores and depths in which marker zone characteristics are identified and summarizes the main characteristics present in each zone.

1. Color. The zones commonly exhibit a gleyed dark greenish grey (5GY 4/1) color. This is often in sharp contrast to the dominantly dark grey (5Y 4/1 to 5YR 4/1) colors of the rest of the sediment column.

2. Moisture content. One of the most distinctive characteristics of the marker horizons is a significant decrease in moisture content relative to the overlying and underlying sediment. At the upper marker horizon this decrease in moisture content is abrupt and the change can be as much as 60% from that of the overlying sediment over a vertical distance of less than 5 cm. For example, Figure J-6 shows an abrupt decrease in moisture content at the upper marker horizon (295 cm depth) and several lower marker zones at 605 cm, 757 cm, and 895 cm in core D-2. The lower part of the horizon commonly grades into the underlying higher moisture sediment over a greater vertical distance.

3. Structure. The marker horizons commonly exhibit a very distinctive angular, blocky structure (Fig. 4-4). This structural development, or arrangement of aggregates of particles, is in sharp contrast to the essentially smooth and structureless overlying and underlying sediment. Although fine to coarse angular, blocky structure similar to that shown in Figure 4-4a is the most common form developed in the marker horizons, it is not the only kind. The upper marker zone in core 23 (Fig. 4-4b) shows a nodular to pelletal structure. The aggregates of this sediment are well-rounded and nearly spherical with sizes between a maximum of 9 mm and a minimum of 1 mm. These pellets are firm and packed moderately tightly in a softer clay matrix. Hand lens and microscopic examination of individual pellets does not reveal any type of accretion lamination or any visible nuclei. Cores 42 and 45 also have similar-appearing, closely-packed, rounded pellets. Likewise,

Figure 4-4a. Examples of angular blocky structured marker zones in core D-1. The core has been split into two halves. The numbers on the core refer to the depth (in centimetres). The top of the core is to the left in each case. The bar scale is 15 cm long. The contact between the blocky marker zone and the overlying structureless sediment is indicated by an arrow.



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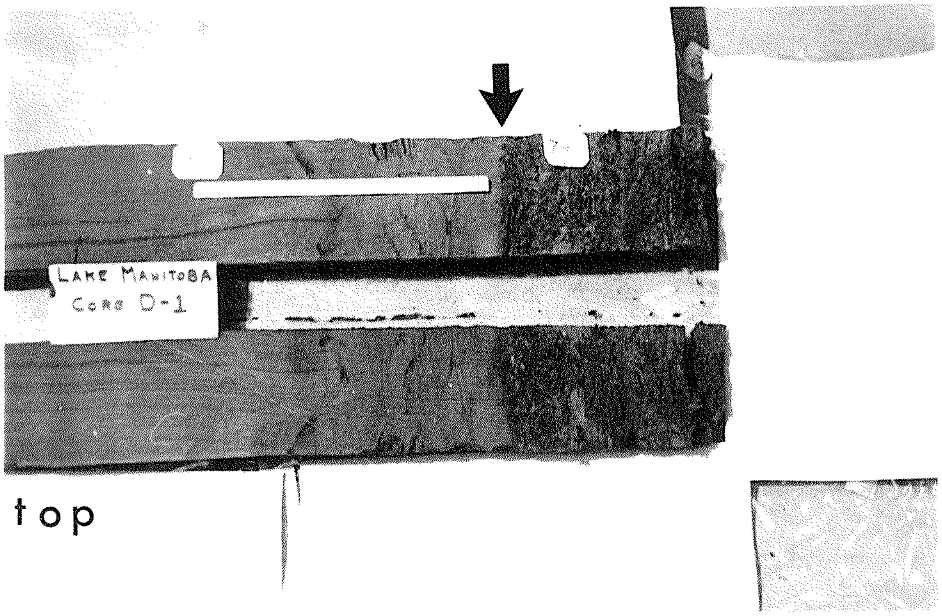

top

Figure 4-4b. Example of pelletal structured marker zone in core 23. In the upper illustration the top of the core is to the right. The length of the key is about 5 cm. The lower illustration shows a closer view of this same pelleted marker zone. The bar scale is 1 cm long.


CORE 23
245-265 cm
→

sections of core D-1 (441 to 473 cm and 746 to 752 cm) are described as "lumpy" pelleted clay with the rounded grains floating in a softer clay matrix (see core description in Appendix I).

A third type of structure exhibited by the marker horizons is a crumbly to granular structure. This is similar to the normal angular, blocky development except that the aggregates are smaller and not as compact. This crumbly, almost friable, structure seems to be associated with the lowest water content in this zone.

Finally, the marker horizons occasionally exhibit a prismatic or columnar structure. The variation from the more "normal" angular, blocky structure to this prismatic structure may occur within a single zone in a core.

4. Root fibers. The upper marker horizon in cores 3, 21, 26, 39, 40, and 47 contain scattered to abundant rootlets and organic vegetal fibers. These cores are relatively near the present shoreline.

5. Contacts. The contact between the marker zone and the overlying sediment is, almost without exception, sharp and well defined. There is usually no recognizable or measurable transition zone from one type of sediment to the other. The lower boundary of the zones is not as well defined, with its characteristics transitional over as much as 10 to 30 cm. A problem arose in trying to delineate the lower boundary of the marker zones because the nature of the sediment in these zones (i.e., blocky, crumbly, friable, dry, etc.) often prevented full sediment core recovery.

6. Texture. In all cores analyzed, the upper marker horizon is associated with a significant change in grain size. Generally in the

more offshore locations (such as cores D-1, D-2, 23, and 28) the sediment in this upper marker zone is considerably more clay-rich relative to the overlying material. In core D-1, for example, the mud overlying the upper marker horizon is approximately 75% silt and 25% clay, whereas the blocky, dry sediment within the upper marker zone is about 75% clay and 25% silt (Fig. J-1). The lower marker zones generally do not show a significant textural change.

7. Other characteristics. In addition to the above features, the marker zones are also recognized as being non-laminated, generally non-fossiliferous, sticky, and compact relative to the overlying material. Table 4-5 identifies those quantitative variables whose means show a statistically significant difference above the uppermost marker zone versus within the zone in cores D-1, D-2, D-3, and 23. Notable is the fact that there are relatively few significant and consistent changes in either mineralogy or chemistry across the horizon. Of the elements and minerals evaluated, only Mg, and the mole % of Mg in calcite, show a significant consistent variation at the marker horizons in each core analyzed.

4.3.3.3 Distribution of marker zones in cores and their correlation and lateral extent in the basin

Within a single sediment core there may be a number of marker zones having some or all of the above characteristics. Figure 4-5 shows the vertical distribution of these zones in seven cores in a south to north basin profile. On the basis of stratigraphic position, underlying and overlying sediment characteristics (specifically mineralogy and texture), and ^{14}C chronology, two and possible three of these zones can be correlated across the basin.

TABLE 4-5.

NATURE AND STATISTICAL SIGNIFICANCE OF PARAMETER CHANGES AT THE UPPERMOST MARKER HORIZON IN THE SOUTH BASIN

Parameter	Cores D-1	 D-2	 D-3	 23
Moisture Content	**u	**u	**u	**u
Organic Matter	**u	f**u	**u	f**u
Sand				
Silt	**u	*u	f*u	f**u
Clay	**L	*L	f*L	f**L
pH			**L	
Eh	*L			
K	*L			N.D.
Na			**L	N.D.
Ca		*u	**u	N.D.
Mg	*u	*u	**u	N.D.
Fe	*L			N.D.
Mn	**L	**L		N.D.
P			f*u	N.D.
Cu				N.D.
Zn	f**u	f**L	*u	N.D.
Quartz		*u	**L	f
Feldspar		f	f	
Calcite	*L	**L	*u	f*L
Dolomite	**u			
Total Clay Minerals		f		
Expandable Clays	**L		f	N.D.
Illite	f*u	f**u	f*u	N.D.
Kaolinite plus Chlorite		f		N.D.
Calcite plus Dolomite			*u	
Total Carbonate		f	**u	*u
Mg in Calcite	**u	**u	**u	**u

A blank indicates that there is no statistically significant difference between the parameter mean in the sediment immediately overlying the marker zone versus the parameter mean within the sediment of the marker zone.

* means are significantly different at $\alpha = 0.01$

** means are significantly different at $\alpha = 0.001$

u = mean above the marker zone is higher

L = mean within the marker zone is higher

f = the two means failed an F-test (i.e., the variance of the two sample groups is not equal)

N.D. = parameters not determined

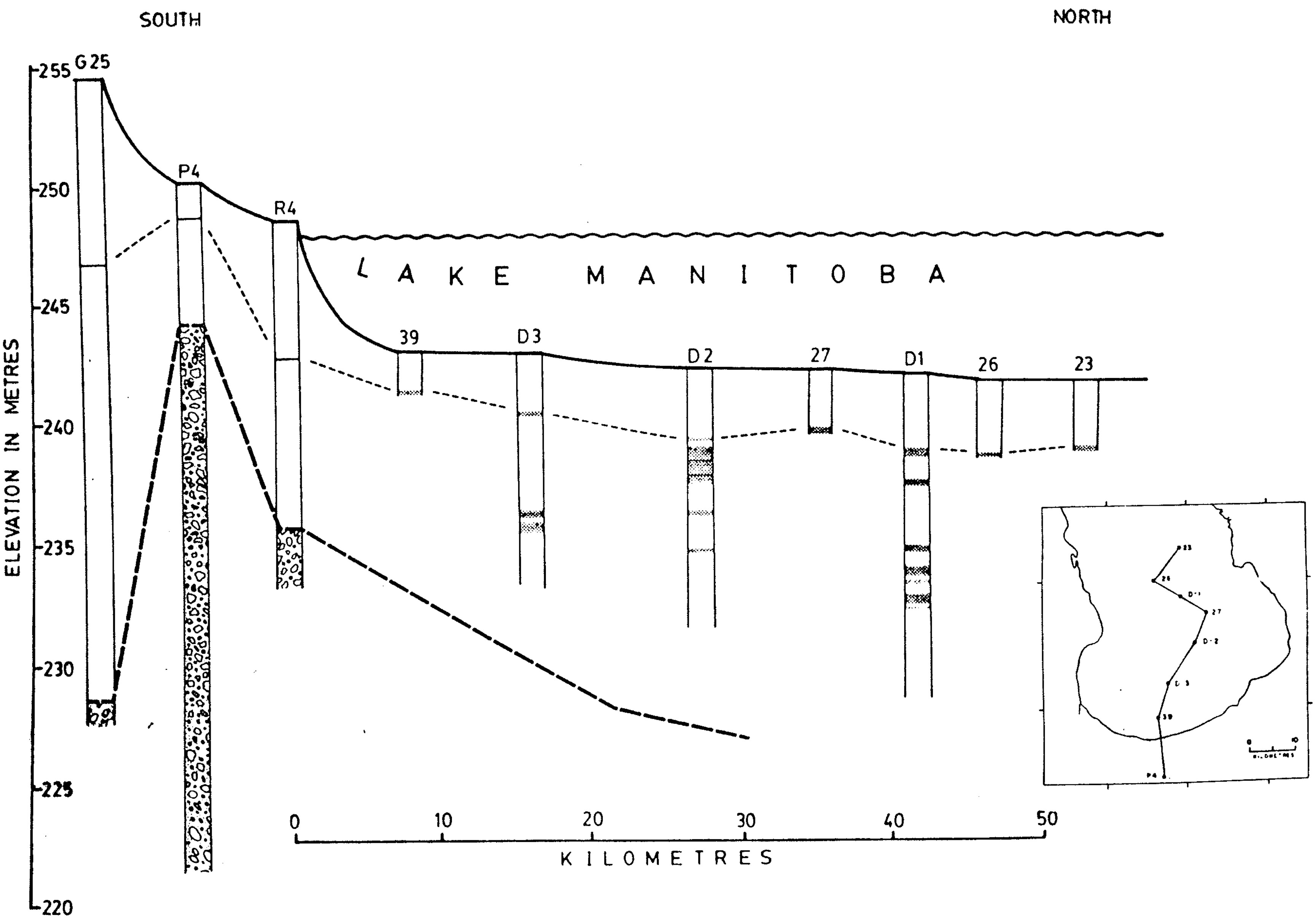

Figure 4-5. Distribution of marker horizons in seven cores in the South Basin of Lake Manitoba. Also shown is the correlation of the uppermost zone within the basin and with the stratigraphy south of the lake. The inset map indicates the locations of the cores used in the cross-section.

The uppermost marker horizon can be correlated with the most confidence. Wherever the upper 4 m of sediment was sampled, this marker horizon was encountered. It is present in cores 23, 26, 27, 28, 37, 38, 39, 40, D-1, D-2, and D-3; and may be represented in cores 3, 21, 25, and 32 (see location map, Fig. 2-1). Furthermore, its presence is confirmed by hand augering and soil tube samples below the terminal depth of the cores at locations 41, 42, 45, 46, and 47. An elevation contour map (Fig. 4-6) of the top of the uppermost marker horizon shows that there is relatively little topographic relief over much of the horizon in the main part of the basin.

Proceeding downward from the uppermost marker horizon in core D-2, a series of zones (or possibly one continuous zone) are encountered between core depths of about 350 and 500 cm. Although core recovery was poor, the zones are distinctively dry and show various degrees of angular, blocky to pelletal structure and a dominant 5GY 4/1 color. A similar and probably, in part, correlative interval is present in core D-1 between about 440 and 480 cm, although poor core quality and recovery in this section makes precise delineation and correlation of these zones in the two cores difficult. Core D-3 does not show an equivalent zone.

Below this, the next correlable marker horizon which is identified in all three deep cores occurs at about 750 cm depth in both D-1 and D-2, and at 675 cm in D-3. Again the zone in all three cores is characterized as firm, sticky, and dry with a blocky structure and gleyed color.

Approximately 1 m below this horizon in cores D-1 and D-3 another marker zone can be identified with similar characteristics. Although a

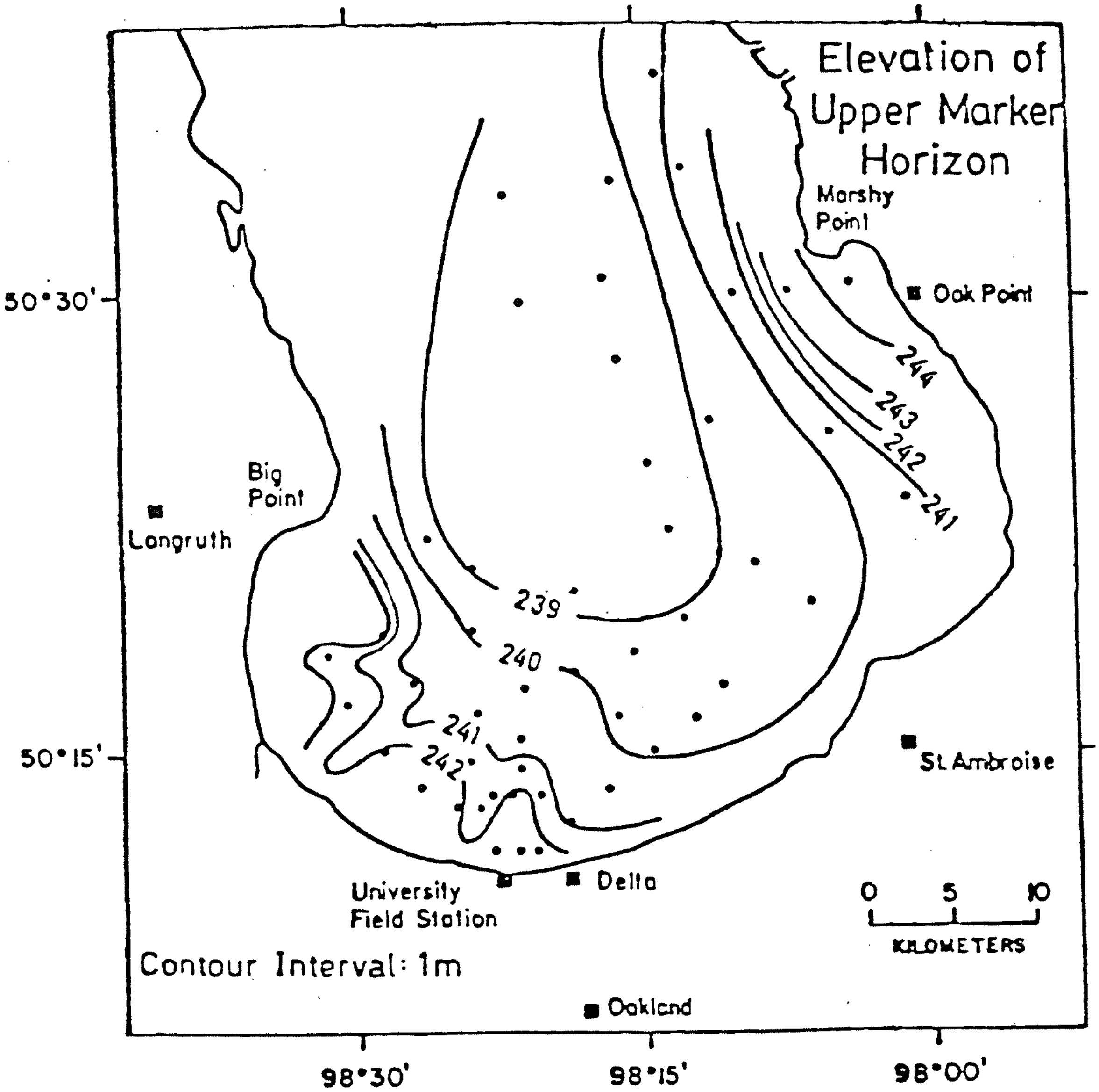

Figure 4-6. Elevation contour map on the top of the uppermost marker horizon in the South Basin. Elevation is in metres above sea level.

corresponding dry and distinctly blocky zone is missing from D-2, the corresponding interval has the dominantly gleyed, dark greenish grey color characteristic of the other marker horizons.

Finally, at approximately 1.5 m below the 810-cm horizon in core D-1, still another dry, blocky zone is present. This lower-most zone in D-1 cannot be precisely correlated to either D-2 or D-3 because of poor core recovery.

4.3.4 Description of Relict Sand Areas

4.3.4.1 Southwestern area anomaly

The larger of the two relict sand areas exposed today at the bottom of the South Basin is located about 10 km northwest of Delta, Manitoba. Four cores within this area have recovered up to 75 cm of coarse-grained sediment. In addition, stratigraphic "probing" with a soil auger beyond the terminal depth of these cores indicates that the thickness of this coarse-grained material is in excess of 150 cm.

The surface sediment at core location 1 (refer to Fig. 2-1 and Table 4-6) has the finest mean grain size (2.3 phi) and location 43 the coarsest (1.9 phi). Table 4-6 also shows that there is little variation in sorting, skewness, or kurtosis. The surface sediments in this area exhibit little change in moisture content (14.2 to 15.1%), organic matter (0.4 to 0.7%), total carbonate (3.4 to 6.8%), quartz (71 to 79%), feldspar (14 to 18%), calcite (4 to 5%), dolomite (2 to 7%), or any chemical variable within this area (see Appendix D).

The boundaries of the unit on the lake floor are quite sharp as evidenced by the abrupt change in grain size between locations 48

Table 4-6

Summary of grain size distribution characteristics and variation in cores located within the anamolous area of the southwestern portion of the basin.

Location	Depth in sediment (cm)	Sand	Silt	Clay	Mean Size (Ø)	Sorting	Skewness	Kurtosis
1	0-2	100	0	0	2.3	0.46	+0.10	3.85
	2-4	99	1	0	2.0	0.90	-0.09	4.20
	10-12	98	2	0	1.9	0.74	-0.12	6.90
	20-23	100	0	0	2.1	0.51	-0.01	4.12
	30-33	99	1	0	2.2	0.64	-0.12	4.95
	40-43	100	0	0	2.3	0.68	-0.09	3.60
	50-52	99	1	0	2.3	0.92	-0.62	2.87
2	0-2	99	1	0	2.2	0.57	-1.4	3.23
	4-6	98	2	0	2.5	-	-	-
	10-12	99	1	0	2.0	-	-	-
	18-20	99	1	0	2.4	-	-	-
41	0-2	100	0	0	2.0	0.58	-0.12	6.21
	20-23	98	2	0	2.6	-	-	-
43	0-2	98	2	0	1.9	0.63	-0.14	3.81
	10-12	99	1	0	2.2	0.54	-0.10	5.78
	20-23	99	1	0	2.1	0.47	-	-
	30-33	99	1	0	2.2	0.50	-	-
	40-43	99	1	0	2.3	0.47	-	-
	50-53	99	1	0	2.4	0.50	-0.75	4.21
	60-63	99	1	0	1.9	0.95	-	-
	70-73	98	2	0	2.3	1.06	-0.24	3.89

(sand), 8 (silty clay), 30 (sand), and 31 (clayey silt) which are only 2 to 3 km from each other (see Fig. 2-1).

4.3.4.2 Marshy Point anomaly

A second, smaller area of relict sediment identified in the South Basin is located offshore from Marshy Point. The surface sediments in this 30 km^2 area are sandy gravels and gravelly sands. Igneous and carbonate grains up to 30 mm diameter were recovered in coring operations. Two cores (20 and 21) penetrated the sediment to a depth of 25 cm. Although core recovery was very poor, the sediment underlying the coarse-grained surface material is described as gravelly, sandy clay.

SECTION 5

STRATIGRAPHIC SUBDIVISION OF THE POST-GLACIAL SEDIMENTS OF LAKE MANITOBA

5.1 BASIS OF UNIT DEFINITION

Six lithologic units have been identified in the post-glacial sediment record of Lake Manitoba. While many of the various sediment parameters analyzed in this study are of some use in defining, delineating and correlating these units in the subsurface, the most useful characteristics and features of the record are: (a) grain size; (b) bulk mineralogy; (c) carbonate mineralogy; (d) stratigraphic position and unit thickness; (e) sedimentary structures including bedding characteristics and the presence or absence of floating clasts and granules; and (f) moisture content. In addition, the boundaries of most of the units are, in part, defined and correlated by the presence of the basinwide markers described in Section 4.3.3 and discussed in Section 6.2.

These six units, defined A, B, C, D, E and F (from bottom to top), are shown on the parameter profiles of Appendix J. Core descriptions can be found in Appendix I. The main distinguishing characteristics of the six units are summarized in Table 5-1. The average values of the various physical, chemical and mineralogical parameters for each unit identified are tabulated in Tables 5-2 to 5-8 and shown graphically in Figures 5-1 to 5-3. A south to north basin cross-section (Fig. 5-4) shows the stratigraphic relationships of these units.

Table 5-1. Summary of main identifying characteristics of the six stratigraphic units in the South Basin of Lake Manitoba.

UNIT F - Very silty although less so than in Unit E; Calcite very high (basin maximum) rising toward top but with a lower mole percent $MgCO_3$ than in Unit E; Dolomite low; High moisture content; Total organic content maximum with upward increase.

UNIT E - Very silty (basin maximum); Calcite high to very high, rising toward top with maximum mole percent $MgCO_3$ in the calcite; Dolomite intermediate in value; High moisture content; Total organic content higher than all underlying units but lower than in Unit F.

UNIT D - Clayey; Calcite high with increasing values toward top; Sharp increase in mole percent $MgCO_3$ in calcite at base; Dolomite low to moderate with decreasing values toward top; Intermediate overall moisture content with numerous dry zones; Upper boundary is the youngest dry zone in basin.

UNIT C - Intermediate in silt and dolomite content between the very high values of Unit B and the low values of Unit D; Calcite content rises above low values of underlying units and feldspar falls below values of underlying units; Low moisture content with dry zones within unit.

UNIT B - Very silty with some sand at base; Maximum dolomite content and low calcite content; Oldest occurrence of Mg-calcite; Well-laminated with scattered dry zones within unit and in top; Low moisture content; Feldspar less than in Unit A but greater than in Unit C.

UNIT A - Clayey with abundant granule- and pebble-sized clasts; Low calcite and low to moderate dolomite content; High feldspar content (basin maximum).

Table 5-2

Summary of average parameter values of the six stratigraphic units recognized in the post-glacial sediment record of Lake Manitoba. Based on analyses of cores D-1, D-2, D-3, and 23.

Unit	% Moisture	% Organic	% Sand	% Silt	% Clay	% Quartz	% Feldspar	% Total Calcite	% Mg-Calcite	Mole % $MgCO_3$ in calcite	% Dolomite	% Total clay minerals	% Expandable clays	% Illite	% Kaolinite + Chlorite	pH	Eh (mv.)	% K	% Na	% Ca	% Mg	% Fe	% Mn	% P	ppm Cu	ppm Zn
F	74.2	14.2	0.9	57.2	42.3	22.9	6.0	26.8	26.3	7.8	13.8	30.5	23.6	48.2	30.9	8.0	-190	1.34	0.54	13.21	2.61	2.19	0.067	0.089	29	70
E	65.6	8.7	1.5	62.4	34.5	23.6	6.2	20.9	18.1	10.4	17.8	31.5	24.7	40.3	31.7	8.0	-210	1.31	0.53	10.15	2.70	2.39	0.065	0.071	28	295
D	43.5	5.7	1.2	40.6	57.2	29.3	6.1	14.7	11.7	4.9	16.1	33.8	39.0	28.2	30.6	7.9	-200	1.53	0.55	7.33	2.44	2.97	0.078	0.065	29	223
C	29.5	5.7	6.0	47.3	45.6	29.8	6.7	7.4	5.8	4.0	25.0	31.1	34.3	39.1	35.9	7.9	-170	1.79	0.72	7.87	3.49	3.12	0.058	0.072	29	505
B	23.8	3.9	2.6	58.6	39.3	28.6	8.5	3.0	1.3	1.3	37.1	22.8	35.0	34.3	31.3	8.1	-110	1.52	0.72	8.39	4.85	2.56	0.053	0.063	29	536
A	32.2	5.1	2.5	25.9	71.5	30.8	8.8	2.2	0	0	18.7	39.5	48.9	22.4	28.7	8.0	-150	1.83	0.84	5.55	3.46	3.31	0.048	0.065	35	84

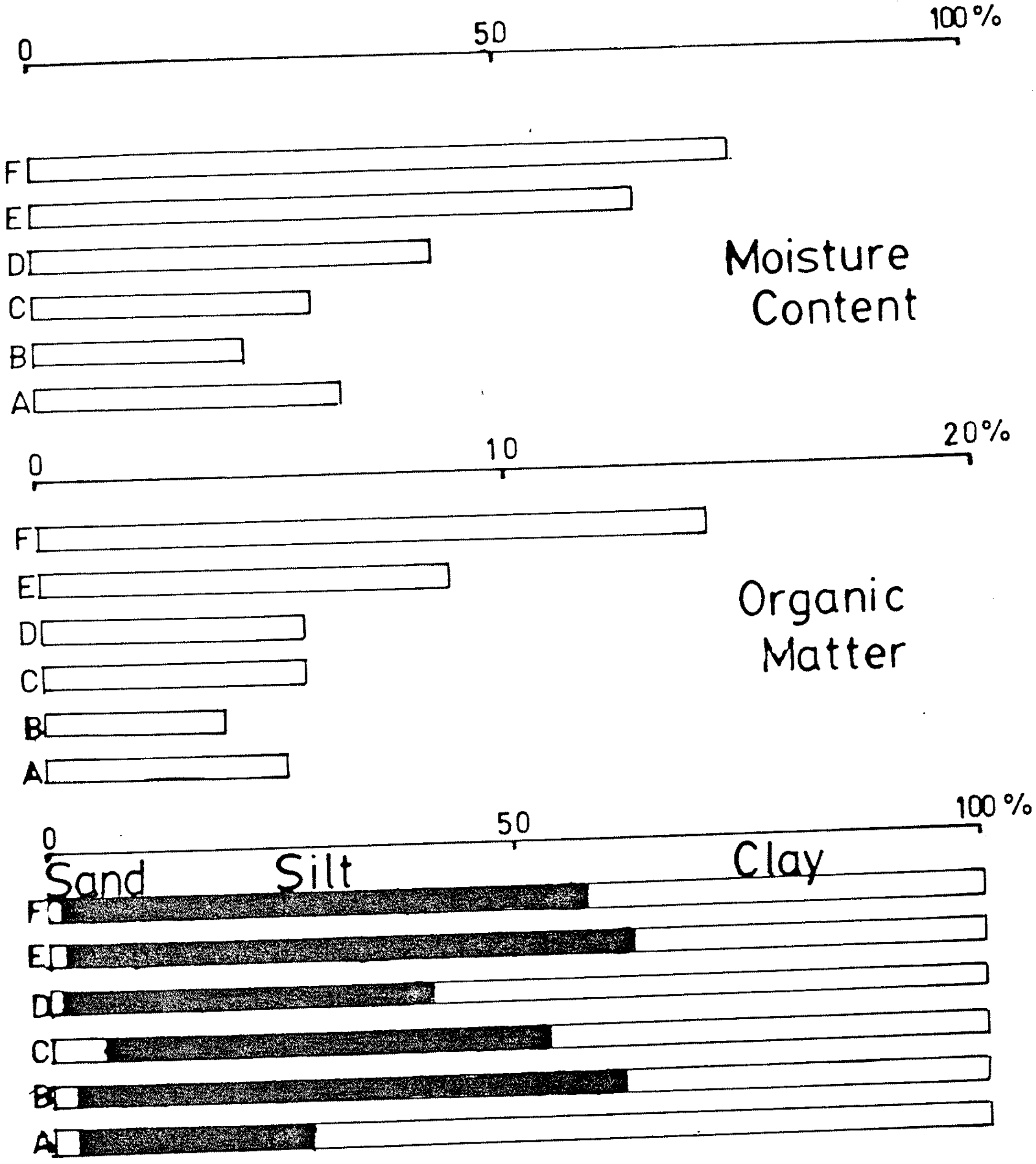

Figure 5-1. Variation in the physical parameter average values of Units A-F.

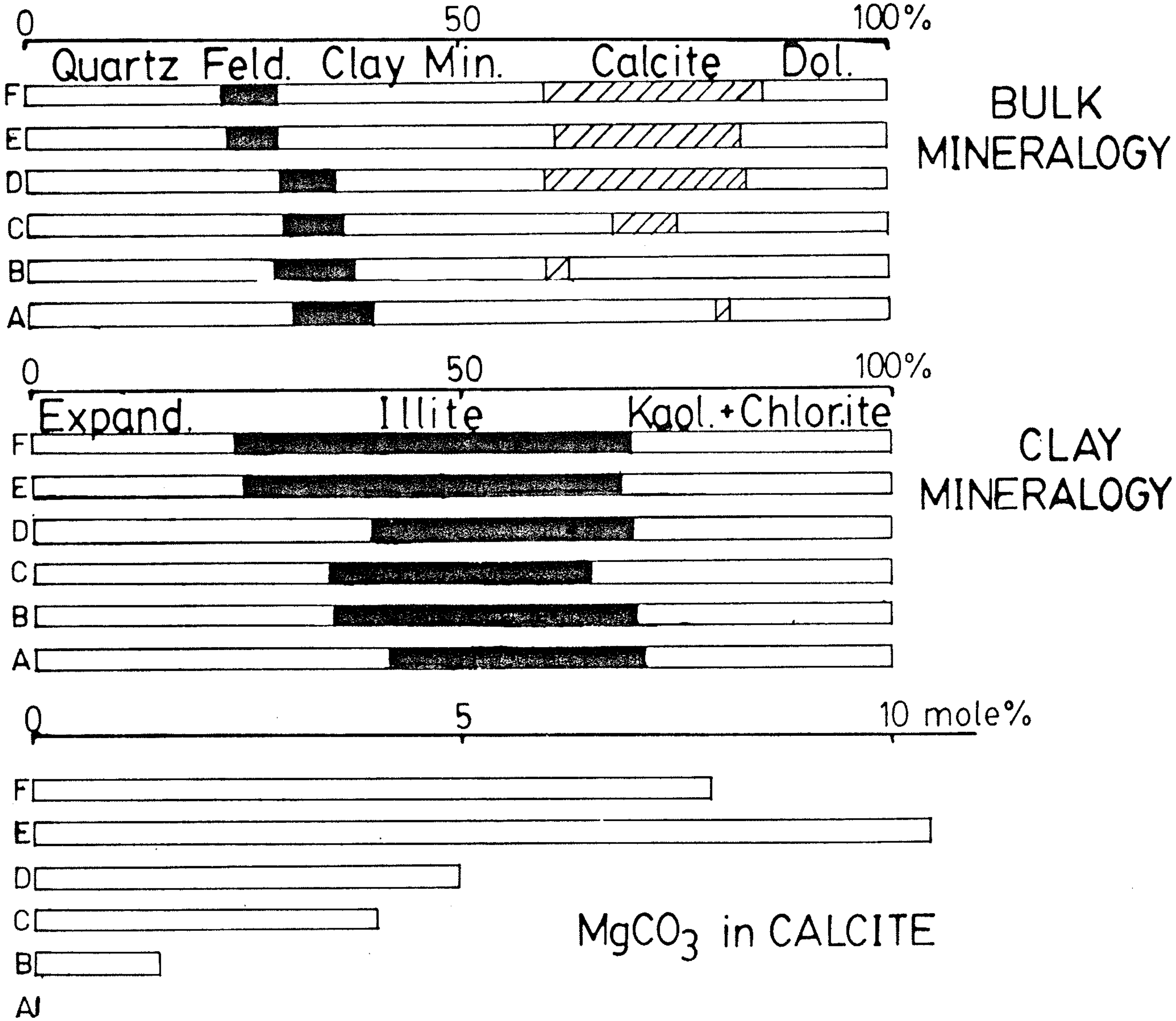

Figure 5-2. Variation in the mineralogical parameter average values of Units A-F.

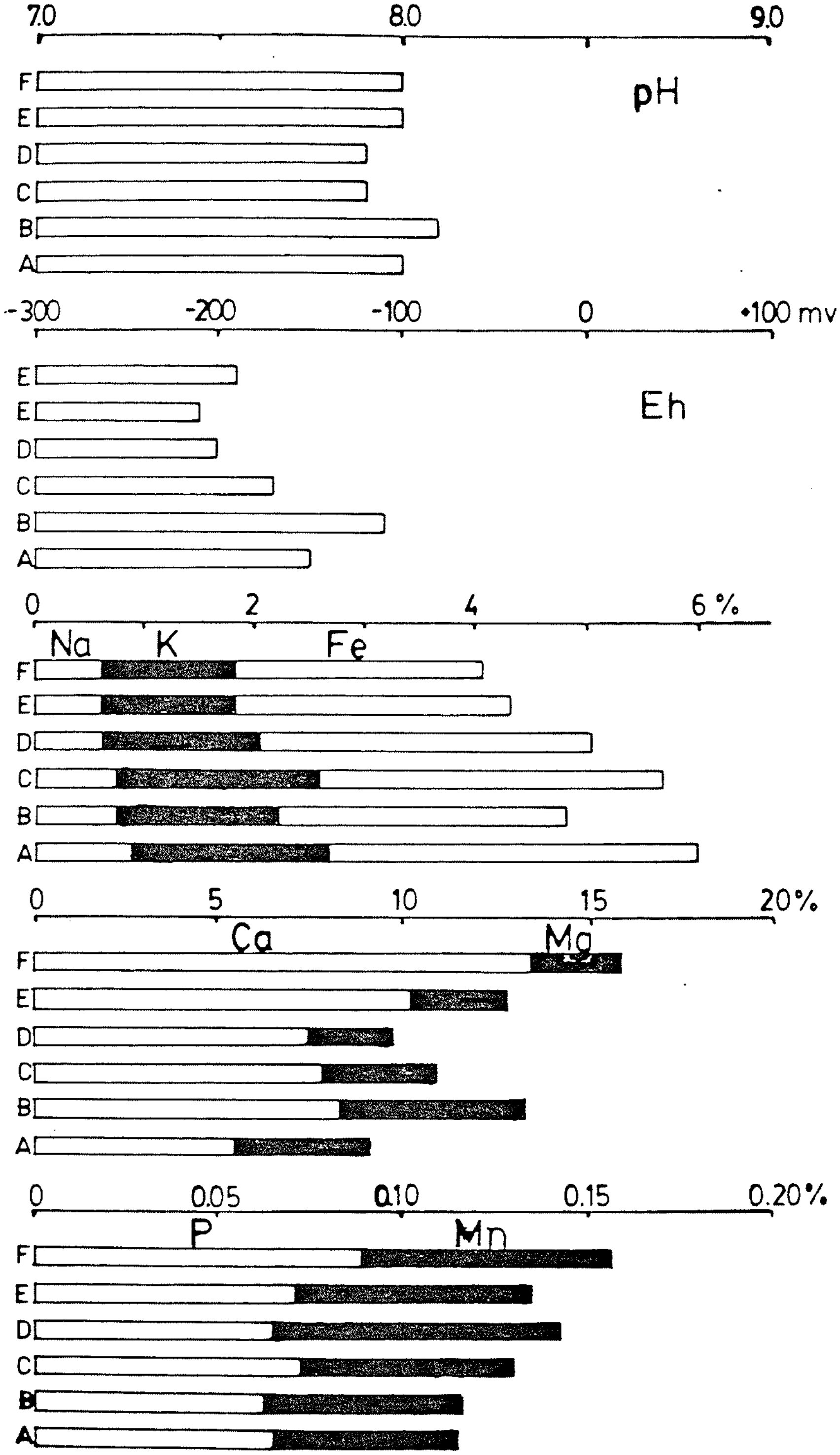

Figure 5-3. Variation in the chemical parameter average values of Units A-F.

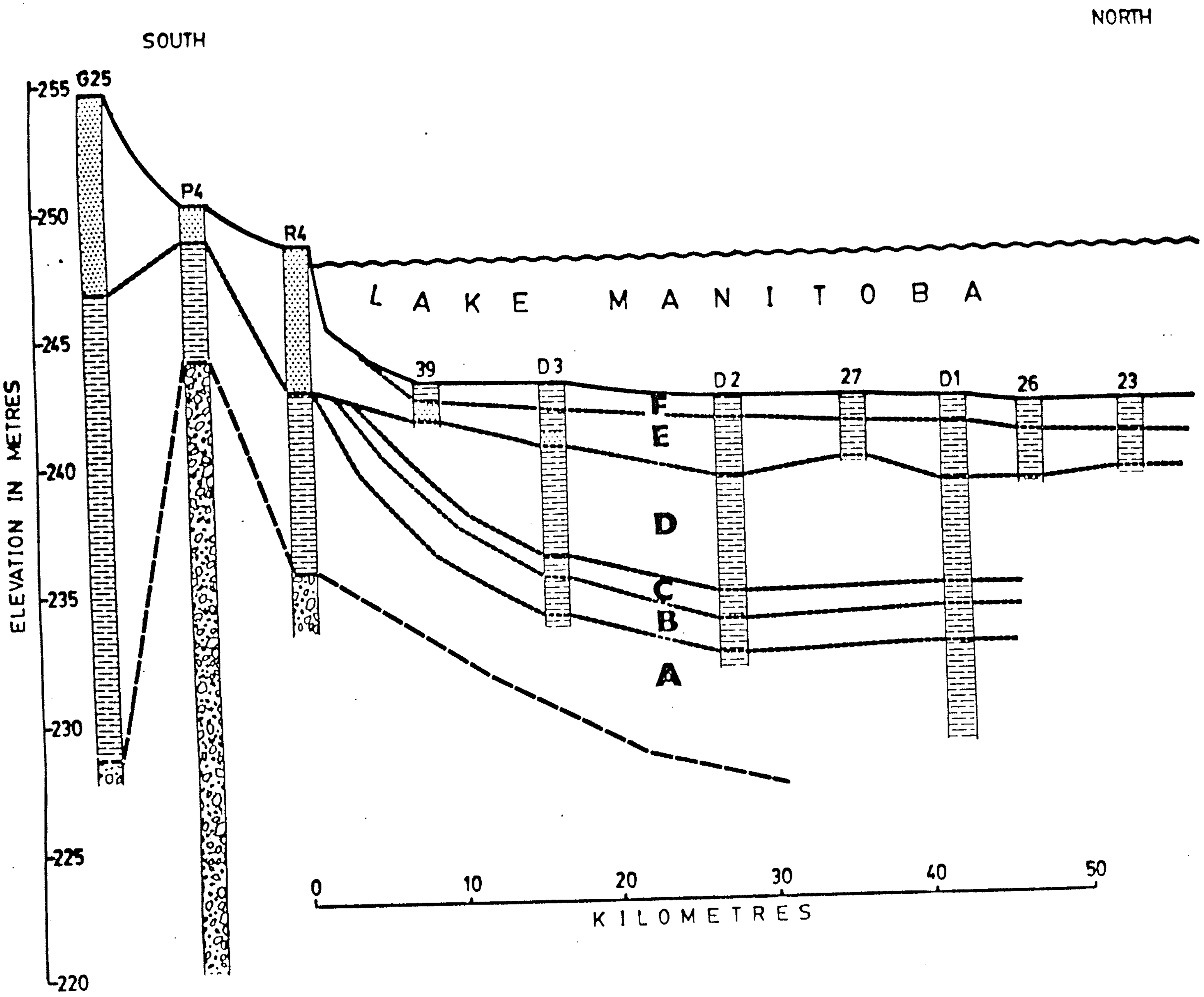

Figure 5-4. Cross-section showing the correlation of Units A to F across the southern part of the Lake Manitoba basin. Refer to Figures 2-1 and 4-5 for location of the cores in the section.

5.2 UNIT A (see Table 5-3)

Unit A is defined at the base of all three deep cores in the basin as well as in core D-4 located on shore near Oakland (see Fig. 2-1). It is present from approximately 1080 cm to the base of the core in D-1; from about 1000 cm to the base of core D-2 (poor core recovery between 915 and 1015 cm depth in D-2 prohibits exact delineation of upper boundary of Unit A in this core); from 883 cm to the base of the core in D-3; and from 142 cm to 690 cm in core D-4.[1] In holes W-1 and W-2 in the southwestern corner of the lake about 1 to 2 km offshore from the Whitemud River (drilled, described, and analyzed by Manitoba Hydro in 1977), the lower 3 to 5 m of brown and grey, mottled, plastic, silty clay with "gravel" and "silt pockets" is interpreted as Unit A (see Appendix I).

The unit is, in general, a slightly to moderately silty clay, with up to 95% of the material finer than 8 phi. The clay content averages about 71% and is the highest of all the units. Furthermore, if the relatively coarse clastic material of the silt and till clasts is eliminated from the grain size analysis, the average clay content of the sediment is close to 85%. Both moisture and organic contents are relatively low although not the lowest in the section. Color is dominantly dark to very dark grey (5Y 4/1 to 5Y 3/1) and dark olive grey (5Y 3/2). Weak olive brown (5Y 4/4) staining is present on some of the clasts and pebbles within the unit in core D-3.

The carbonate content of Unit A is relatively low with very low calcite and moderate to low amounts of dolomite. There is no high-Mg

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[1] Underlying Unit A in core D-4 is a gravelly, silty, sandy clay interpreted as till (see description in Appendix I).

Table 5-3. Unit A Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	2.5	$\left(\begin{smallmatrix}+3.4\\-2.5\end{smallmatrix}\right.$	13	0-11.3
Silt (%)	25.9	13.1	13	4.6-54.1
Clay (%)	71.5	14.7	13	41.1-94.5
Moisture (%)	32.2	9.0	26	19.4-50.2
Organic Matter (%)	5.1	1.4	26	1.45-7.68
Quartz (%)	30.8	6.4	18	23.1-49.0
Feldspar (%)	8.8	3.9	18	3.5-15.5
Total Calcite (%)	2.2	2.1	18	0-5.6
% $MgCO_3$ in calcite	0	0	4	-
High-Mg Calcite (%)	0	0	4	-
Dolomite (%)	18.7	10.3	18	4.5-42.1
Total Clay Minerals (%)	39.5	10.3	18	11.2-67.9
Expandable Lattice Clays (%)	48.9	14.4	9	15.0-60.3
Illite (%)	22.4	9.0	9	15.0-46.0
Kaolinite + Chlorite (%)	28.7	6.9	9	16.5-41.7
pH	8.0	0.2	11	7.9-8.1
Eh (mv)	-150	87	11	+10 to -250
K (%)	1.83	0.33	8	1.14-2.37
Na (%)	0.84	0.14	8	0.62-1.11
Ca (%)	5.55	2.55	8	2.94-11.29
Mg (%)	3.46	1.25	8	1.85-6.33
Fe (%)	3.31	0.76	8	4.19-1.63
Mn (%)	0.048	0.001	8	0.039-0.064
P (%)	0.065	0.001	8	0.046-0.070
Cu (ppm)	35.3	7.4	8	20-44
Zn (ppm)	84.6	21.3	8	66-105

calcite present. The total clay mineral content is high with the expandable lattice group dominant over the illite and kaolinite plus chlorite groups. Feldspar and quartz contents are also high.

Chemically, Unit A is characterized by comparatively low values of calcium but high amounts of sodium and potassium.

The unit is also easily recognized by its massive and non-laminated to very poorly bedded appearance, a distinctly plastic to sticky feel, and the presence of scattered to abundant clasts and "blebs" of silt, clasts of till, and pebbles floating in the fine-grained clayey matrix. In core D-1, the relative abundance of these clasts of unconsolidated sediment and pebbles increases below about 1234 cm depth. Similar zones of high clast and pebble content are evident in the unit within cores D-2, D-3, and D-4.

The maximum thickness of Unit A in the South Basin of Lake Manitoba is unknown but is in excess of 4 m. The contact of Unit A with the overlying Unit B is identified in core D-1, in part, by a weakly developed marker horizon in the top of Unit A. This marker zone is not identified in D-2 because of poor core recovery, and is absent from D-3 probably because of significant erosion and sediment removal associated with the period of low water and/or subaereal exposure after deposition of the unit.

5.3 UNIT B (see Tables 5-4a and b)

Unit B overlies Unit A in each of the long cores in the Lake Manitoba basin. It is present between depths of 807 cm and 975 cm in core D-1, 887 cm to about 1000 cm in D-2, and 750 cm to 883 cm in D-3. Although Unit B cannot be precisely delineated from the stratigraphic description and information available on drill holes W-1 and W-2, the

Table 5-4a. Unit B Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	2.6	1.5	15	0-4.8
Silt (%)	58.6	20.2	15	30.5-96.8
Clay (%)	39.3	20.3	15	3.0-68.4
Moisture (%)	23.8	4.0	20	17.4-31.2
Organic Matter (%)	3.9	1.3	20	1.45-6.34
Quartz (%)	28.6	6.8	16	18.6-41.5
Feldspar (%)	8.5	4.1	16	3.4-18.0
Total Calcite (%)	3.0	2.9	16	0-13.2
% $MgCO_3$ in calcite	1.3	1.5	3	0-4.4
High-Mg Calcite (%)	1.3	1.4	3	0-3.1
Dolomite (%)	37.1	9.5	16	21.6-49.4
Total Clay Minerals (%)	22.8	15.4	16	5.5-50.4
Expandable Lattice Clays (%)	35.0	8.1	10	16.6-46.1
Illite (%)	34.3	3.4	10	23.7-40.5
Kaolinite + Chlorite (%)	31.3	4.9	10	23.7-42.9
pH	8.1	0.1	17	7.9-8.4
Eh (mv)	-110	96	17	+100 to -200
K (%)	1.52	0.36	8	0.80-1.82
Na (%)	0.72	0.07	8	0.60-0.82
Ca (%)	8.39	1.80	8	4.58-11.41
Mg (%)	4.85	0.63	8	4.16-5.70
Fe (%)	2.56	0.74	8	0.95-3.22
Mn (%)	0.053	0.000	8	0.034-0.067
P (%)	0.063	0.000	8	0.044-0.079
Cu (ppm)	29.3	8.3	8	12-39
Zn (ppm)	536	2399	8	26-2348

Table 5-4b. Detailed grain size analysis of samples from Unit B.

Location	Depth in Sediment (cm)	Sand (%)	Silt (%)	Clay (%)	Mean Size (phi)	Sorting (phi)	Skewness	Kurtosis
D-3	800 - 803	1.5	83.9	14.6	6.8	1.31	-0.02	3.72
D-3	756 - 760	3.7	90.7	5.6	6.2	1.10	-0.17	4.02

lower 2 to 3 m of silt and sand-rich sediment overlying the clayey, silt clast-rich material is probably equivalent to Unit B (see Appendix I).

Unit B is recognized from the underlying and overlying units primarily by its distinctive textural and mineralogical parameters, the presence of well-developed laminae, and the presence of marker horizons.

Unit B is, on the average, a clayey silt but can consist of up to 96% silt-sized material (Table 5-4a). This is in sharp contrast to both Unit A and Unit C which are considerably more clay-rich. Detailed grain-size distribution analyses of several samples from this unit show that the sediment is moderately sorted with a mean grain-size in the medium silt range (Table 5-4b). The grain-size relationships exhibited by the unit in D-3 suggests a gradual coarsening upward from about 70% silt plus sand/30% clay at the contact with Unit A to about 95% silt plus sand/5% clay near the top of the unit. Sediment colors are somewhat more variable than those of the underlying unit but are dominantly grey to very dark grey and dark olive grey (N.5 to 5Y 4/1, 5Y 3/1 and 5Y 3/2) and olive (5Y 5/3 and 5Y 5/4). Both organic and moisture contents remain very low.

Unit B is also identified by its very high dolomite content which is the maximum recorded in the lacustrine sediments of the basin. Calcite content remains low but is slightly higher than that of the underlying Unit A. The calcite in the upper 80 cm of the unit in core D-1 contains up to 4 mole percent $MgCO_3$. Feldspar and quartz contents remain relatively high. However, the percentage of clay minerals is the lowest average of any of the units.

Chemically, Unit B is marked by high average values of Mg and Ca and a considerably higher (less reducing) redox potential relative to the underlying and immediately overlying units.

Unit B is also easily distinguished by its well-developed bedding characteristics. Thin to medium (1 to 3 mm), even, parallel laminae are very common. This laminated bedding is usually enhanced and sharpened by both a color change (light to dark variations) and a corresponding distinct textural change (sandy and silty to clayey and silty). "Floating" clasts and pebbles, which are common in Unit A, are rare in Unit B. The unit contains several scattered marker zones and overlies the marker horizon developed in the top of Unit A. The upper contact of Unit B also is identified by a firm, blocky, dry zone at 807 to 839 cm in core D-1. Although a typical dry, blocky horizon was not recognized at the top of Unit B in the other deep cores, the corresponding interval in D-2 does have a gleyed, dark greenish grey (5GY 4/1) color.

The maximum thickness of Unit B in the Lake Manitoba basin is 1.6 m in core D-1.

5.4 UNIT C (see Table 5-5)

Unit C overlies Unit B in each of the three long cores of the basin. It is present between depths of 735 cm and 807 cm in core D-1; 757 cm and 887 cm in core D-2; and 675 cm and 750 cm in core D-3. Unit C cannot be differentiated from the overlying and underlying lacustrine sediment in the deep rotary holes W-1 or W-2 on the basis of the limited information available from these two holes, and it is not present in core D-4 (see Appendix I).

Unit C is distinguished from the underlying Unit B and the overlying Unit D chiefly on the basis of its carbonate content and mineralogy, texture, and presence of well-developed marker horizons.

Table 5-5. Unit C Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	6.0	(+8.3 (-6.0	11	0.2-26.3
Silt (%)	47.3	8.4	11	39.2-68.1
Clay (%)	45.6	15.5	11	5.0-60.8
Moisture (%)	29.5	6.2	12	22.2-44.5
Organic Matter (%)	5.7	0.8	12	3.9-6.9
Quartz (%)	29.8	5.2	11	20.7-35.0
Feldspar (%)	6.7	1.5	11	4.6-9.6
Total Calcite (%)	7.4	2.1	11	4.0-11.0
% $MgCO_3$ in calcite	4.0	-	1	-
High-Mg Calcite (%)	5.8	-	1	-
Dolomite (%)	25.0	2.6	11	19.7-29.2
Total Clay Minerals (%)	31.1	6.7	11	20.3-42.7
Expandable Lattice Clays (%)	34.3	21.6	10	0-56.1
Illite (%)	39.1	17.5	10	19.2-66.6
Kaolinite + Chlorite (%)	35.9	16.2	10	20.9-67.3
pH	7.9	0.1	10	7.5-8.1
Eh (mv)	-170	80	10	+20 to -250
K (%)	1.79	0.041	7	1.44-2.03
Na (%)	0.72	0.06	7	0.61-0.82
Ca (%)	7.87	0.67	7	6.55-8.50
Mg (%)	3.49	0.51	7	2.32-3.98
Fe (%)	3.12	0.44	7	2.24-3.69
Mn (%)	0.058	0.010	7	0.050-0.085
P (%)	0.072	0.014	7	0.040-0.085
Cu (ppm)	29.3	5.3	7	21-35
Zn (ppm)	505	1025	7	56-3016

The unit is, on the average, a silty clay and slightly finer-grained (more clay-rich) than the underlying Unit B but coarser-grained than Unit D. In core D-3, the sediment is marked by a relatively high sand content and is, in the lowermost portion, a sandy, clayey silt. Sediment color is dominantly gleyed, dark greenish grey (5GY 4/1) throughout the recovered section. Similar to the underlying units, both organic matter and moisture content are very low.

One of the main criteria in distinguishing Unit C from the underlying Unit B is its relatively lower dolomite content (average of 25% versus 37%). Conversely, the average calcite content is more than double that of Unit B. Most of this calcium carbonate is 3 to 4 mole percent Mg-calcite. The clay mineral content is considerably higher than that of the underlying unit reflecting its finer-grained nature, with the illite and kaolinite plus chlorite groups dominant over the expandable lattice clays. The feldspar content is lower relative to Unit B.

Chemically, both the Ca and Mg contents of Unit C are lower than those of Unit B, undoubtedly in response to the dramatic decrease in dolomite values. Fe is intermediate between the high values of Unit A and the lower values of Units D to F.

Although present, the laminations of Unit C are not as distinct or common as in Unit B. The unit is also separated from the underlying and overlying sediment by the presence of marker horizons. The blocky, dry zone developed in the top of Unit C is present in all three long cores. The correlation of this marker zone is further confirmed by the significant rise in $MgCO_3$ incorporation into the calcite immediately above the horizon (i.e., in Unit D) in each long core. As previously mentioned, the lower marker zone separating Unit C from Unit B is definitely present only in core D-1. In addition, there is some suggestion that the entire interval of Unit C is characterized by marker horizon features. However, the dry, blocky nature of the unit prevented good sediment recovery over the interval in each of the cores. Finally, Unit C is comparatively thin, averaging about 90 cm.

5.5 UNIT D (see Table 5-6)

Unit D overlies Unit C in each of the three long cores in the basin. It is present between depths of 330 cm and 735 cm in core D-1; 295 cm and 765 cm in D-2; and 245 cm and 675 cm in D-3. In addition, the upper part of Unit D is present in the lowermost few centimetres of numerous short and intermediate length cores in the basin. Although the precise delineation of the unit could not be made in cores W-1 and W-2, it is probably present below about 1.3 m depth in W-1 and 2.6 m depth in W-2. Unit D is not present in D-4.

Unit D is distinguished from the underlying Unit C and the overlying Unit E mainly on the basis of its grain size, carbonate content and mineralogy, moisture content, and organic matter. Unit D underlies the uppermost marker horizon in the basin.

Texturally, Unit D shows little variation from a silty clay which is in contrast to the slightly coarser sandy to clayey silt of the underlying Unit C and of the overlying Unit E. Similar to the other units, the grain size of Unit D in core D-3 is slightly coarser grained compared to the other two long cores because of its closer position to the south shore of the lake. Sediment colors in D-1 and D-2 are a constant dark grey (5Y 4/1) except at the marker zones which

Table 5-6. Unit D Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	1.2	(+5.7 -1.2	48	0-39.9
Silt (%)	40.6	9.5	48	27.4-66.5
Clay (%)	57.2	9.8	48	31.0-75.2
Moisture (%)	43.5	6.2	57	32.5-52.6
Organic Matter (%)	5.7	1.1	57	4.2-10.5
Quartz (%)	29.3	8.4	54	18.2-51.0
Feldspar (%)	6.1	4.8	54	2.2-17.5
Total Calcite (%)	14.7	6.7	54	3.0-30.9
% $MgCO_3$ in calcite	4.9	1.0	18	0-8.0
High-Mg Calcite (%)	11.7	5.0	18	0-21.6
Dolomite (%)	16.1	5.3	54	7.3-28.6
Total Clay Minerals (%)	33.8	7.1	54	18.2-47.8
Expandable Lattice Clays (%)	39.0	14.0	43	2.0-67.4
Illite (%)	28.2	9.0	43	15.0-46.0
Kaolinite + Chlorite (%)	30.6	8.1	43	17.5-51.7
pH	7.9	0.1	56	7.8-8.1
Eh (mv)	-200	50	56	-130 to -300
K (%)	1.53	0.18	26	0.94-1.75
Na (%)	0.55	0.09	26	0.33-0.78
Ca (%)	7.33	1.42	26	5.56-10.28
Mg (%)	2.44	0.40	26	2.18-3.12
Fe (%)	2.97	0.40	26	2.28-3.67
Mn (%)	0.078	0.010	26	0.054-0.110
P (%)	0.065	0.010	26	0.046-0.085
Cu (ppm)	29.3	6.4	26	20-47
Zn (ppm)	223	346	26	49-1304

are the characteristic gleyed, dark greenish grey (5GY 4/1). The colors in D-3 are generally darker, tending toward black and very dark greys (N 3 to N 2.5, 2.5Y 2.5/0 to 2.5 Y 3/1). Moisture content is considerably higher than the underlying unit but in general lower than that of Unit E. Organic content is low and macroscopic shell remains are rare to common. Dr. I. Lubinsky (personal communication, 1979) reports that the sediment of the lower part of Unit D is essentially barren of benthic invertebrate remains (see Appendix C). A preliminary examination of the diatoms in the sediment of Unit D by Dr. R. Carter (personal communication, 1979), however, reveals numerous species of both planktonic and benthic diatoms with Fragilaria construens, Stephanodiscus niagarae, Microsiphona ? sp. and Cyclotella sp. as the most common (see Appendix C).

Unit D is also distinguished from the underlying unit by a significant increase in calcite abundance and in the mole percent $MgCO_3$ content of the calcite. In D-1 and D-2, the expandable lattice clays are the dominant clay mineral group of the unit in contrast to generally lower values in the underlying and overlying units. Dolomite and feldspar contents are lower in Unit D relative to Unit C. Chemically, the unit exhibits low to intermediate values of Na, K, Ca, Mg and Fe.

The sediment is generally very poorly laminated to non-laminated wit the interval in core D-3 exhibiting a slightly better laminated nature. The upper and lower contacts of the unit are marked by very well-developed marker zones. The upper boundary with Unit E is the youngest and best developed marker horizon in the South Basin sediment. In addition, several distinct dry, blocky-structured marker zones are present within the unit in cores D-2 and D-1. Maximum thickness of Unit D is 4.5 m in core D-2.

5.6 UNIT E (see Table 5-7)

Unit E overlies Unit D in each of the three long cores as well as in most of the intermediate-length cores in the basin. The unit is differentiated from the underlying and overlying units mainly on the basis of its grain size, calcite content, Mg content of the calcite, organic matter, moisture content, and stratigraphic position overlying the uppermost basinwide marker horizon.

Unit E, in general, is considerably coarser grained than Unit D, averaging about 2% sand, 64% silt, and 34% clay. In the southernmost portion of the basin, the lower 10 to 150 cm of the unit is sandy and silty ranging from sandy silt and sandy, clayey silt to sand (1.9 phi mean grain size). This coarse facies of the unit grades basinward and stratigraphically upward to clayey silt. Sediment colors are consistently dark grey (5Y 4/1) except in the coarser facies where they are more variable grey to olive grey and black (5Y 5/1 to 5Y 4/2 and 5Y 2.5/2). Moisture content averages about 65% and is considerably higher than Unit D. Organic matter content is also higher than that of Unit D but lower than the overlying Unit F. Mollusk shells and fragments are common to abundant. Lubinsky (personal communication, 1979, see Appendix C) reports _Pisidium_ sp. _Amnicola_ sp. and _Valvata_ sp. as the most common mollusks in a sample from core D-1, 200 to 208 cm. Carter (personal communication, 1979, see Appendix C) lists _Cyclotella_ sp., _Diploneis_ sp. and _Surirella_ _peisonis_ as the most common diatoms from the unit at 290 cm in core D-1.

Table 5-7. Unit E Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	1.5	1.4	32	0-21.2
Silt (%)	62.4	17.9	32	32.3-83.6
Clay (%)	39.5	16.7	32	14.5-44.2
Moisture (%)	65.6	2.0	105	40.0-73.5
Organic Matter (%)	8.7	4.4	103	3.51-19.8
Quartz (%)	23.6	8.6	48	18.0-42.5
Feldspar (%)	6.2	2.8	48	4.6-11.9
Total Calcite (%)	20.9	9.4	48	5.6-32.4
% $MgCO_3$ in calcite	10.4	1.6	14	8.4-14.5
High-Mg Calcite (%)	18.1	7.2	14	8.3-31.2
Dolomite (%)	17.8	5.2	48	9.5-25.1
Total Clay Minerals (%)	31.5	8.3	48	16.2-46.9
Expandable Lattice Clays (%)	24.7	19.7	16	0-66.6
Illite (%)	40.3	24.0	16	16.6-62.5
Kaolinite + Chlorite (%)	31.7	16.8	16	15.2-58.3
pH	8.0	0.1	111	7.9-8.5
Eh (mv)	-210	47	111	-50 to -250
K (%)	1.31	0.16	17	0.95-1.54
Na (%)	0.53	0.07	17	0.34-0.71
Ca (%)	10.15	2.01	17	5.42-12.71
Mg (%)	2.70	0.30	17	2.24-3.21
Fe (%)	2.39	0.34	17	1.66-2.81
Mn (%)	0.065	0.000	17	0.043-0.078
P (%)	0.071	0.001	17	0.037-0.110
Cu (ppm)	28.4	4.4	17	22-34
Zn (ppm)	29.5	42.6	17	45-1304

The abundance of calcite is slightly higher in Unit E than in Unit D but is less than that of Unit F. The unit is easily recognized, however, by the very high Mg content of the calcite which averages more than twice that of Unit D and about 30% higher than the values shown in Unit F. Of the clay minerals, the illite group shows a significant increase in abundance corresponding to a decrease in the expandables relative to the underlying unit. Chemically, Unit E shows a substantially higher content of Ca and lower (more reducing) Eh values relative to Unit D.

In general, the unit is non-bedded and soft but shows a slight increase in firmness with depth. Occasional, very indistinct color banding and laminae are visible, particularly in the sandy silt facies of the unit in core D-3. No observable bedding or laminations were present, however, in cores penetrating the coarsest sand facies of the unit (i.e., cores 1, 2, 3, 41 and 43). The lower contact of the unit is readily recognized on a basin-wide scale as the uppermost marker horizon in the sediment column. The upper contact with Unit F, however, is not as striking and has been identified only on the basis of the detailed carbonate mineralogy and a subtle textural change.

5.7 UNIT F (see Table 5-8)

The uppermost unit recognized in the post-glacial sediment record of Lake Manitoba is distinguished from the underlying units mainly on the basis of its calcite mineralogy and grain size. Although Unit F is probably present in the upper 0.75 to 1.5 m of sediment in most of the short

Table 5-8. Unit F Parameter Statistics

Parameter	Mean	Standard Deviation	n	Range
Sand (%)	0.9	(+1.9 −0.9	35	0-9.2
Silt (%)	57.2	18.7	35	39.4-82.4
Clay (%)	42.3	18.7	35	7.5-60.5
Moisture (%)	74.2	1.9	106	62.1-80.5
Organic Matter (%)	14.2	7.4	106	8.7-19.6
Quartz (%)	22.9	7.1	37	10.2-28.4
Feldspar (%)	6.0	5.2	37	1.3-28.0
Total Calcite (%)	26.8	7.4	37	12.8-42.4
% $MgCO_3$ in calcite	7.8	2.0	12	6.5-9.8
High-Mg Calcite (%)	26.3	7.2	12	24.1-42.4
Dolomite (%)	13.8	4.1	37	7.6-24.2
Total Clay Minerals (%)	30.5	9.7	37	17.5-38.4
Expandable Lattice Clays (%)	23.6	20.4	12	0-50.0
Illite (%)	48.2	29.0	12	32.6-100
Kaolinite + Chlorite (%)	30.9	12.9	12	0-50.0
pH	8.0	0.2	110	7.9-8.5
Eh (mv)	-190	105	110	-75 to -250
K(%)	1.34	0.18	33	0.86-1.25
Na (%)	0.54	0.09	33	0.39-0.67
Ca (%)	13.21	2.65	33	7.61-16.13
Mg (%)	2.61	0.55	23	2.24-3.66
Fe (%)	2.19	0.40	33	1.68-2.34
Mn (%)	0.067	0.001	33	0.040-0.077
P (%)	0.089	0.010	33	0.061-0.170
Cu (ppm)	29.2	7.3	33	16-54
Zn (ppm)	70.3	10.4	33	35-91

and intermediate length cores in the basin, it was positively identified only in cores D-1, D-2, D-3, and 23. It is present above 90 cm depth in core D-1, above about 125 cm in D-2, above 100 cm in D-3, and above 125 cm in 23.

Unit F, similar to the underlying Unit E, is a clayey silt. However, it is distinguished from Unit E by being slightly less silty and more clay-rich. Sediment color is nearly everywhere dark grey (5Y 4/1). Both organic matter and moisture contents are the highest in the sediment record, averaging about 14 and 74 percent respectitvely. Both parameters show an increase upward in the sediment. Macroscopic shell remains, both whole and fragmented, are common to abundant in the unit. Lubinsky (personal communication, 1979, see Appendix C) lists specimens of *Valvata* sp., *Lymnaea* sp., *Marstonia* sp. and *Pisidium* sp. as the numerically most abundant mollusks in two samples from the unit from cores 13 and 29.

In addition to the textural change, the unit is also defined on the basis of a significant decrease in Mg content of the calcite in the sediment. The average mole percent $MgCO_3$ in the calcite of the unit is relatively close to that of today's value of about 7. This is in contrast to the 9 to 14 mole percent values of the underlying Unit E. In addition, the total amount of calcite is very high (27%) while the average dolomite content (14%) is the lowest of all six units.

Chemically, Unit F is characterized mainly by the expected very high Ca content. Phosphorous also shows relatively high values.

The unit is soft to very soft and gelatinous with, in general, no observable bedding. However, in cores located in the eastern section of the basin, the unit does contain discrete beds or zones of shell concentrations. These shell zones range in thickness from 0.2 cm up to 3.0 cm and can be composed of over 50% (by volume) mollusk remains (volume estimate by Lubinsky, personal communication, 1979). Individual laminae cannot, however, be correlated from one core to another. In addition, rarely very thin (0.1 to 0.3 cm), black (5Y 2.5/1 to N 2.5) carbonaceous laminae or partings can be observed in the unit. The lower contact of Unit F with Unit E is rather sharp but is not visually distinctive. Maximum thickness of the unit is 1.5 m in core D-2.

SECTION 6

INTERPRETATION OF SPECIFIC SEDIMENTARY COMPONENTS AND TRENDS

6.1 ORIGIN OF RELICT SAND AREAS ON FLOOR OF THE LAKE

6.1.1 Introduction

Perusal of Figures D-1 to D-34 shows that there are two areas in the mapped South Basin within which the present-day bottom sediments do not fit the general or expected basin-wide trends: (a) a large area (about 70 km^2) in the southwestern portion of the lake, offshore northwest of Delta, and (b) a smaller area (about 30 km^2) offshore south of Marshy Point and west of Oak Point. These anomalies are, in general, considerably coarser grained, with associated higher percentages of sand, quartz, feldspar, and Na, and lower values of moisture, porosity, silt, clay, clay minerals, calcite, dolomite, Fe, Mn, P, Ca, Mg, Cu, and Zn relative to the "normal" modern offshore lacustrine muds.

6.1.2 Southwestern Area Anomaly

6.1.2.1 Possible Portage Diversion source

The proximity of the southwestern area anomaly to the point at which the Assiniboine River Diversion (Portage Diversion) enters the South Basin of Lake Manitoba suggests that possibly the coarse-grained material in this area is the result of sediment contributed by this artificial drainage canal (see Fig. 3-4), This section will attempt to show that such an explanation is not likely.

The Portage Diversion, constructed in 1970 to alleviate flooding along the lower Assiniboine River, is designed to carry excess water (up to 700 m^3s^{-1}; W. Newton, Manitoba Water Resources Branch, personal communication, 1979) from the Assiniboine River immediately upstream from Portage la Prairie, to Lake Manitoba. Although the Diversion operates on an average of only slightly over two months per year, it contributes nearly 20% of the total surface stream inflow to the lake (based on eight-year mean flows including 1973 and 1977 during which the Diversion did not operate).

In 1976 the Diversion carried approximately 1.5 X 10^6 tonnes of suspended sediment past Oakland, Manitoba (8 km south of Lake Manitoba).[1] The eight-year mean annual suspended load is 0.4 X 10^6 tonnes (including the years the Diversion did not operate). An average of over 97% of this suspended load is silt and clay-sized material; 36% is clay (based on 1970, 1971, 1972, 1974, 1975, and 1976 data). The bedload material in the Diversion averages about 30% sand-sized sediment.

There is almost no change in sediment load characteristics (either suspended or bedload) between the two monitoring stations at Portage and Oakland (21 km distance), and Crowe (1974b) similarly concludes that there is little change in the suspended load between Oakland and Lake Manitoba (8 km distance). Although a "settling basin" has been constructed within the channel along the Diversion route, Crowe (1974b) indicates that it is largely ineffective in preventing any of the suspended load from entering the lake.

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[1] The sediment data for the Portage Diversion used in this section was calculated from Inland Waters Directorate reports (1979, 1978a, b, 1977, 1976a, b, c, 1975a, b, and 1973).

Given these flow and sediment characteristics and the channel morphometry, it is possible to calculate a rough approximation of the amount of sand-sized bedload material transported by the Diversion during an average flow year (for an outline of this calculation procedure see, for example, Simons and Senturk, 1976, chapter 8 or Einstein, 1964). This can then be added to the amount of sand-sized material being transported as suspended load, and the total compared with the estimated volume or mass of sand-in-place in the anomalous area. Table 6-1 summarizes the results of these calculations.

Although these estimates may not be precise (particularly the calculations of bedload; see Colby and Hembree, 1955), it is evident from Table 6-1 that there has been an insufficient amount of coarse-grained sediment introduced over the past eight years of Diversion operation to account for the sandy, offshore sediment in the southwestern portion of the basin. Also arguing against a Diversion contribution to this area is the fact that locations 34, 36, and 40, each located about 1.5 km offshore between the mouth of the Diversion and the sandy area (see Fig. 2-1), contain relatively little sandy material.

6.1.2.2 Stratigraphic relationships and facies changes

To better understand the origin of this sand-rich area, it is necessary to look at the stratigraphic relationships between the unit and the more "normal" offshore lacustrine muds. Examination of sediment cores outside of the mapped limits of the sand body on the floor of the lake indicates that there is coarse-grained sediment underlying relatively fine surface silts and clays in many locations in the vicinity (see Fig. 4-3 in back pocket). For example, core 34 shows approximately

TABLE 6-1.

Comparison of estimates of sand-in-place in the southwestern anomalous area with the sediment contribution of the Portage Diversion from 1970 to 1977.

VOLUME OF OFFSHORE SAND-SIZED SEDIMENT:*		41.3×10^6 m^3
DRY WEIGHT OF OFFSHORE SAND-SIZE SEDIMENT:*		12.7×10^6 tonnes
ASSINIBOINE RIVER DIVERSION INPUT 1970-1977:		
Suspended load:	total (all grain sizes):	3.0×10^6 tonnes
	sand-sized only:	0.09×10^6 tonnes
Bedload:	total (by Modified Einstein Method):	1.9×10^6 tonnes
	sand-sized only:	0.45×10^6 tonnes
Total sand-sized sediment input by the Assiniboine River Diversion, 1970-1977: (maximized estimate)		0.55×10^6 tonnes

* based on the 70 km^2 area outlined by the 20% sand contour line of Figure D-5, and an average thickness of the unit of 75 cm. In fact this surface area represents a minimum estimate as can be seen in Figs. 4-3 and 6-2.

75 cm of fine-grained sand underlying 25 cm of clayey silt; core 32 has at least 30 cm of sand below 45 cm of clayey silt; core 3 shows 40 cm of sand underlying 12 cm of silt.

The unit is not everywhere a medium to fine-grained sand. A facies change is evident, for example, at location D-3 where the unit is a sandy silt which grades upward into a clayey silt. Likewise, farther basinward (core 37) the unit appears to grade into a sandy clayey silt and finally becomes texturally unrecognizable. These stratigraphic relationships are diagramed in a south to north (shore to basin) cross section (Fig. 6-1).

Figure 6-2 shows the isopach of this coarse-grained unit in the South Basin. Maximum thickness in excess of 150 cm are interpreted to occur in a northwest-southeast trend which roughly parallels the present-day south shore of the lake, approximately 9 km offshore. Southwest of this maximum thickness trend (i.e., toward the Whitemud River and Westbourne), there is ample core control indicating that the sand body does not exist at the surface or at depth shoreward in this direction (i.e., cores 33, 44, 45, W-1, W-2). Basinward the contour lines indicate a more gradual loss in thickness until the unit is not recognized in cores 42, 4, 5, 6, 12, 13, and 38. However, five of these sites (4, 5, 6, 12, 13) have retrieved only 1 m cores, and it is possible that the 25 and 0 cm contour lines on Figure 6-2 can be extended considerably basinward at least up to, but not including, cores D-2 and 38.

Core control along the 2 km-wide south shoreline of the lake does not exist, but it seems likely that the sand body connects with the "Blind Channel" (also termed Fort La Reine Channel) approximately 4 km

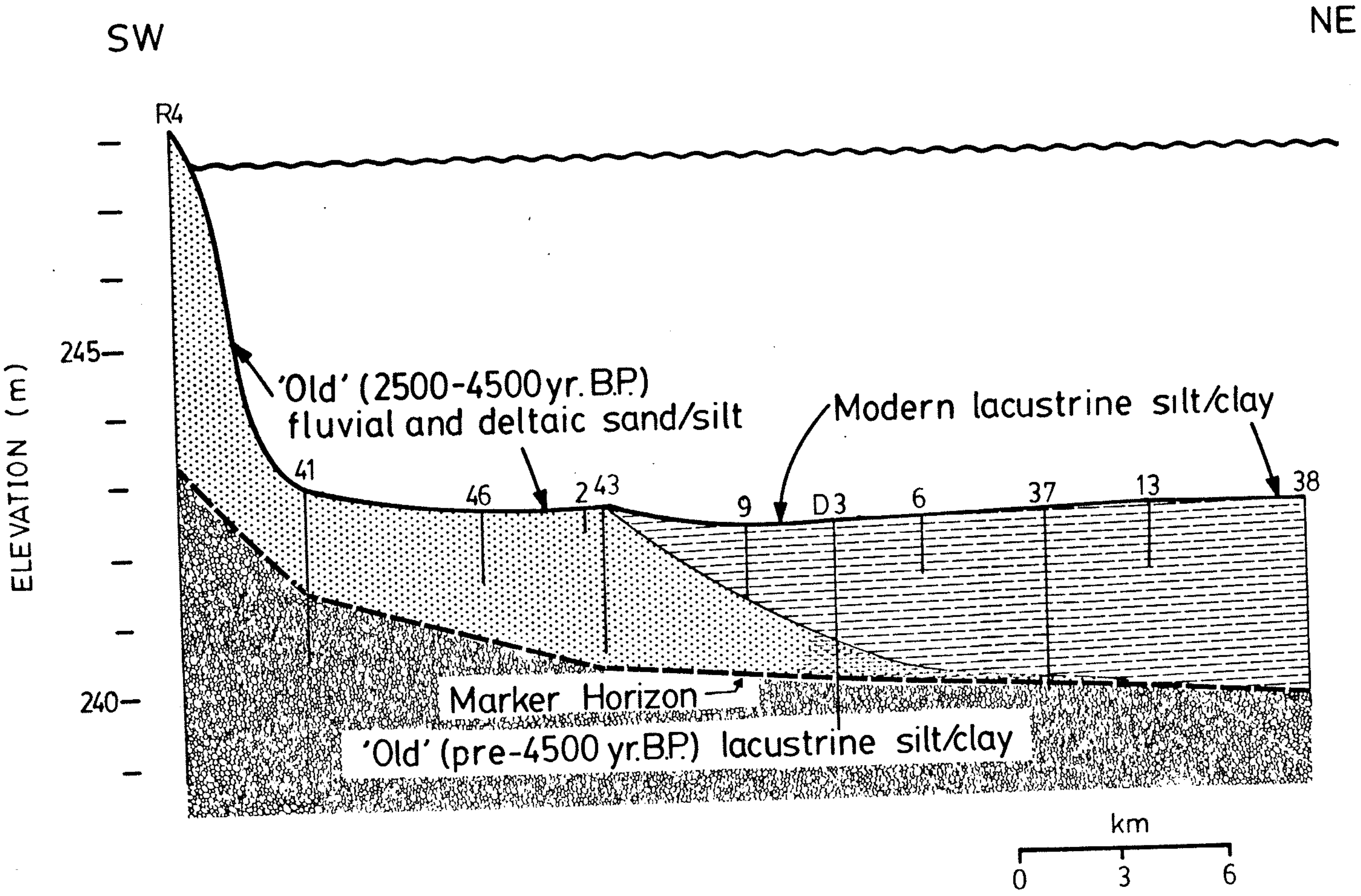

Figure 6-1. Stratigraphic cross-section showing the relationship of anomalous (relict) coarse-grained unit with the modern offshore lacustrine sediment. See Figure 6-2 or 2-1 for location of cores included on section.

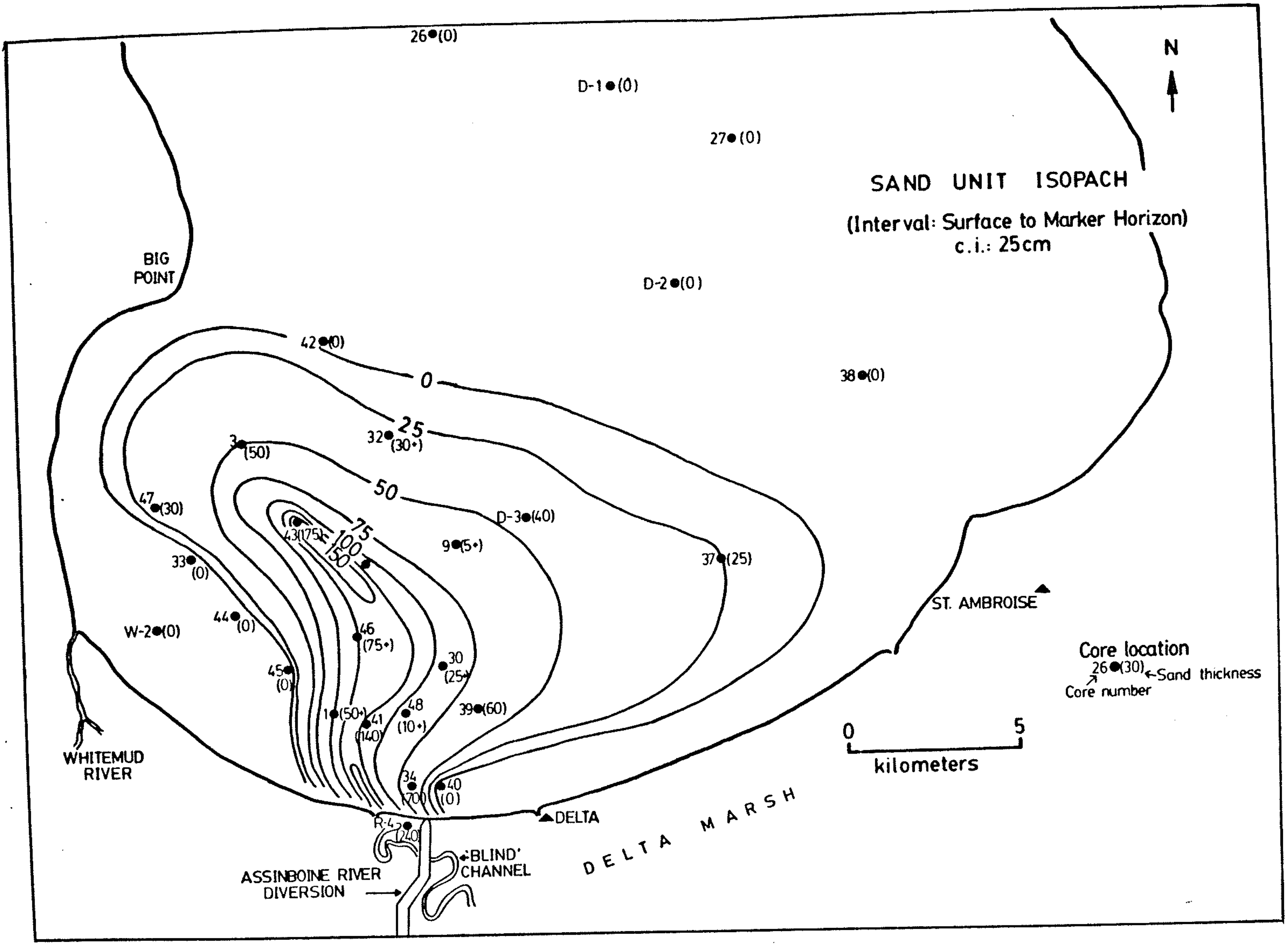

Figure 6-2. Isopach of coarse-grained sediment (sand, sandy silt, and silt) in the southern portion of the South Basin of Lake Manitoba.

west of Delta. Gilliland (1965, Figure 14) reports approximately 3 m of "alluvial sand" underlying the modern beach sands near the "mouth" of the Blind Channel (SE¼ of 18-14-7 WPM). These alluvial sands are separated stratigraphically from the beach sands by 3 m of "alluvial" silty clay (Gilliland, 1965). The sand unit in the lake thus can be traced onshore to this elongate, meandering, coarse-clastic body that trends southeasterly and follows closely the present topographic feature referred to as the "Blind Channel."

6.1.2.3 Interpretation and origin

The sand unit is interpreted as representing a relict fluvial-shoreline complex deposited when Lake Manitoba stood at a lower level than today. This lower stage of the lake represents reflooding of the basin following a lengthy period of extremely low (or no) water conditions in the basin approximately 5500 to 4500 years ago. The deposit in question records the influx of sediment from the Assiniboine River which was diverted into the basin from the south and helped to reflood the lake (see Section 9 for a more complete discussion). Subsequent rising water levels in the basin due to both the increased contribution by this "old" Assiniboine River and a moderating climate (less arid), resulted in a transgression of the shoreline southward and a concomitant southward onlap of the more modern offshore lacustrine muds onto the older, relatively coarse-grained sands and silts of the previous nearshore complex.

The sand body in the offshore region represents either a beach ridge/barrier island type of transitional environment or a delta. The overall delta-like geographic form of the coarse facies and the fact that the unit can be traced shoreward and onshore to a meandering fluvial deposit ("Blind Channel") which trends approximately perpendicular to the present-day shoreline would argue for a delta model.

Whatever type of depositional environment is pictured for this relict sedimentary unit, a seeming inconsistency is the fact that younger lacustrine mud has been, and probably is being, deposited adjacent to the unit in areas which are, today, bathymetrically shallower than the areas of the basin in which the relict sands are found. For example, the upper 35 cm of core 40, which consists of soft, dark grey, clayey silt and silty clay, has been "dated" at being deposited within roughly the last 100 years by picking the ragweed pollen rise (E. M. V. Nambudiri, personal communication, 1979). This essentially modern fine-grained sediment has been deposited in water about 3.8 m deep. However, the water depth at core 41, approximately 4 km away from location 40 and one of the sites at which the relict sand is exposed at the bottom of the lake, is about 0.75 m deeper. If modern fine-grained sedimentation could occur at site 40, which, it is expected, would be in a slightly higher energy regime by virtue of its shallower depth, similar fine-grained sedimentation should also occur over the relict sand unit. While it is expected that in lakes of more complex basin bathymetry or ones dominated by river processes such a situation can be readily explained; however, considering the rather simple morphology of the South Basin and the lack of major stream inflow on a year round basis, the solution is not as evident.

Neglecting the possibility of depth mismeasurement, there are several conceivable explanations that can be put forth to account for this apparent contradiction. It is possible that localized current and/or wave-induced energy is affecting the bottom sediments in this area of the basin, thereby either (a) keeping fine-grained sediments from settling over the 70 km^2 area of exposed sand, or (b) if the fines have settled, periodically scouring the area to remove them.

In addition, the differences in critical shear stress (or critical velocity) of clays versus fine sands may be of some importance. Because fine to very fine sand will be eroded and transported at a lower shear stress (velocity) than fine-grained silts and clays, a very thin laminae of clay or silt deposited over the sand during quiet water periods (i.e., winter) could be hydrodynamically unstable as the critical velocity of the sand is reached during the following ice-free season. Once eroded and suspended because of the inherent instability of its sand base, the clay-sized material will stay in suspension and be transported basinward, whereas the sand will be quickly redeposited with the first slight decrease in current strength. Conversely, the "winter laminae" of clay deposited on an equally fine-grained substrate will be more stable and will not be eroded until sufficiently high velocities or shear stresses are achieved. There is, unfortunately, very little data on the currents in Lake Manitoba to either confirm or reject this hypothesis. It does seem rather unlikely that a current would be localized in such a mann some 10 to 15 km offshore. The Whitemud River probably does not have a sufficient flow during the summer to affect such a large area.

Another possibility is that the 70 km^2 area of sand is being kept free of fine-grained sedimentation because it is an area of concentrated groundwater discharge. It has been previously noted that the Lake Manitoba Lowland is a groundwater discharge area for much of the western Canada bedrock groundwater flow system. However, the lake itself is also a discharge area for the shallow Pleistocene groundwater system to the south. Gilliland (1965) and Cherry et al (1971) indicate a northward direction of flow in the shallow aquifers from a local recharge area in the south near the Assiniboine River to the edge of Lake Manitoba. Flow in the relatively coarse-grained permeable alluvial sediment of the Fort La Reine Channel complex, for example, is comparatively large and rapid and, in places, has a strong upward component(Cherry et al, 1971). Although n piezometer control exists north of the beach at Delta, it is conceivable the f could continue northward in the confined paleo-channel system under Lake Manitoba and finally be forced upward as a subaqueous discharge. Similarly, because the flow rate and position of this subaqueous discharge would be controlled by permeability contrasts, areas lateral to the more permeable sands (such as core site 40) would not be discharge areas because of their lower permeability (i.e., finer grain size). Therefore, fine-grained sedimentation could occur peripheral to the discharge area.

However, whether any hydraulic gradient in these shallow aquifers is sufficient to generate an upward flow component strong enough to prevent the cohesive bond of the fine-grained sediment from forming a "resistant" cover on the relict area is unknown.

6.1.3 Marshy Point Anomaly

The origin of the second anomalous area located offshore from Marshy Point is more straightforward. Figure 3-5 indicates that there is an abrupt break in slope basinward of location 20 and that the contour lines closely follow the general outline of Marshy Point. The obvious interpretation is that this shallow water area, covered by poorly sorted sand and gravel, is an extension of Marshy Point. The soils map of this area (Pratt et al, 1961) indicates that the land portion of Marshy Point is covered by mucky, silty, clayey, marsh soil overlying calcareous till. Thus, wave and/or focused current action reworking the subaqueous portion of this ridge could remove the overlying fine-grained sediment and rework the till to produce a gravel lag at the surface. The southward extension of the unit as a surface feature on the lake bottom is unknown, but the presence of 1 m of fine-grained "normal offshore" lacustrine mud at core sites 18 and 17 limit it to less than 7 km. Had other cores been taken close to the shoreline, especially near headlands extending into the lake, similar reworked lag deposits probably would have been found.

6.2 DISCUSSION AND INTERPRETATION OF MARKER HORIZONS

6.2.1 Introduction

Many of the most distinctive variations in the sediment parameter trends with depth illustrated in Figures J-1 to J-15 occur associated with several marker zones within the section. The most characteristic features of these marker zones include a relatively low moisture content, a gleyed, dark greenish grey color, an angular blocky to pelletal to crumbly structure and a sharp upper contact but a gradational lower boundary. In addition, the sediment within the zones is often sticky, dense and compact, non-laminated, and occasionally contains root and vegetal fibers. Also, the moisture content profile within a particular marker zone often shows the lowest values near the top of the zone and a slight increase in moisture deeper in the zone.

Several possible hypotheses can be constructed regarding the origin and development of these marker zones. These include (1) variation in sedimentation rate; (2) variation in clay mineralogy; (3) variation in lake water chemistry; and (4) cryogenic and/or pedogenic desiccation. Although each of these hypotheses will be evaluated and discussed separately, no one single hypothesis is entirely acceptable in accounting for all of the various characteristics of the marker zones. It must also be realized that the hypotheses discussed are not necessarily independent of one another. For example, the changes in lake level that would be associated with the desiccat hypothesis would probably significantly affect the chemical characteristics of the lake water. The main features that any hypothesis under consideration must attempt to explain are: (a) the blocky to pelletal structure; (b) the changes in moisture content and color; and (c) the overall lack of significan change in sediment chemistry, mineralogy, and organic content.

6.2.2 Sedimentation Rate Hypothesis

Meade (1966) showed that in recent clayey sediments of the Mississip River delta area, material deposited during times of high rates of sedimentat is associated with greater water contents for equal depths of burial. He accounts for this phenomena by suggesting that, given the poor permeability of the clay, it is basically a function of time: for an equal thickness of sediment, the rapidly deposited material will have had less time to compact and dewater.

Thus, the Lake Manitoba situation might be explained by invoking ve low sedimentation rates during the time that the compact, dry marker zones we being formed and then drastically changing the rate of sedimentation to accou for the sediment with a higher water content above the horizon. For the uppe marker horizon this would also be in keeping with the grain size trends: duri periods of low sedimentation the deposit would likely be relatively finer-grained (more clay-rich) than during the periods of extremely rapid sedimenta Similarly, if the sources of sediment remain relatively constant and the only factor that varied was the rate at which the sediment was supplied to the basin, this might also account for the lack of a significant change in many of the chemical and mineralogical parameters.

However, this variable sedimentation rate hypothesis does not account for the angular blocky structure of the sediment, nor the distinctive gleyed color of the marker horizon intervals.

6.2.3 Clay Mineralogy Hypothesis

Numerous studies have shown that, in general, montmorillonitic clays retain more water than clays composed dominantly of illite or kaolinite (e.g., Chilingar and Knight, 1960; Powers, 1967; Meade, 1964, 1966). This is mainly in response to the smaller crystal size of the montmorillonite clay minerals which in turn translates to (a) higher porosity, therefore, higher water content; (b) smaller pore openings, therefore, greater pressure differential required to remove the water; and (c) greater surface area, therefore, more sites available for water molecule sorption. Also aiding this greater water retaining capacity are the weaker crystal lattice bonds of the montmorillonitic clays which allow variable amounts of water to be "stacked" between silicate layers. However, in the Lake Manitoba situation the higher expandable lattice clay contents are generally associated with the sediment within the low-moisture content marker horizons rather than the overlying high moisture content deposits. Thus, this aspect of the clay mineralogy does not seem to be a likely explanation.

6.2.4 Variation in Water Chemistry

Closely allied with the above clay mineralogy hypothesis is the role of changing water chemistry. Originally discussed by van Engelhardt and Gaida (1953) and somewhat expanded by Meade's (1964) discussion of clay fabric, this hypothesis makes use of the well known effect of increased salinity on clay particle flocculation and, hence, clay mineral orientation and, ultimately, the moisture content of the sedimentary deposit. In relatively salt-free water, clays will tend to settle out of suspension with little or no flucculation or aggregation occurring. Consequently, the resulting deposit will contain a large number of clay particles having a preferred parallel orientation (see, for example, Hyne et al, 1979) and, therefore, a relatively lower porosity (Rosenquist, 1962). In a concentrated electrolyte solution, however, the clays, particularly the illite and kaolinite minerals, will readily form loose aggregates which have two important characteristics: (a) they will settle and be deposited faster because the aggregate or floccule is often many times larger than the original clay parti making up the structure; and (b) the aggregate, because of the random orientation of the individual clay mineral particles, contains a large amount of voi space or porosity. Hence, the resulting sedimentary deposit, assuming a constant mineral composition, will contain more water because of higher porosity relative to the same depositional period in the fresher water situation.

Thus, in the Lake Manitoba situation, the sediment within the marke horizons might record a period of deposition during which the lake water was relatively fresh. Because little or no flocculation was occurring at this time, the clays could attain good parallel orientation, and a relatively firm deposit with a low moisture content (i.e., low porosity) would result. A change in water chemistry, which could be as small as 1 or 2 ppt (Whitehouse, 1960; Gibbs, 1977), might then result in a major change in sedimentation characteristics with relatively more porous sediment (i.e., high moisture content and a less-firm aspect) being deposited. In the classic study on sedimentation of flocculated fine-grained sediments, Sherman (1953), working in Lake Mead, Colorado, confirms the presence of these high-porosity floccules and further points out that because of the relatively small size of the pores within the floccules, water in these pores is often trapped and becomes an integral part of the deposit.

It is also possible to speculate that this change in water chemistry can account for the decrease in moisture content by a process analagous to osmosis (E. M. V. Nambudiri, personal communication, 1979). If the overlying lake water has a significantly higher salinity than the interstitial water of the underlying sediment, this comparatively fresh pore water will diffuse upward into the higher salinity solution (lake water) in an attempt to equalize the concentrations. The resulting deposit is one having a moisture content that is relatively lower than the sediment beneath it from which the water has not migrated. This deposit will also be more compact due to the loss of water, and possibly will exhibit the blocky structure characteristic of the marker horizon.

6.2.5 Cryogenic or Pedogenic Desiccation

The most likely hypothesis (or group of hypotheses) concerning the origin of the marker horizons in the South Basin sediment is that they represent periods of extreme low water levels during which dehydration of the bottom sediment occurred. There are two ways in which this desiccation can occur. Both require that the lake be considerably lower (shallower) than today's 6+ metres. The hypothesis favored in this report is very simply that the lake completely dried, thus subaerially exposing the bottom sediments, causing a loss of moisture, development of the distinctive pedogenic-like structure, and induction of the gleyed color.

The second hypothesis is that the lake was low enough and/or the winter season severe enough to cause complete or nearly complete winter freezing of the lake volume. Loss of moisture and development of structure could then occur in two ways: (a) As the downward advancing base of the lake ice approaches the sediment-water interface, moisture will migrate out of the sediment and be transported toward the "freezing front" resulting in a net loss of moisture, a more compact sediment, and possibly the development of desiccation and/or ice crystal-induced cracks and structures. The principles of moisture migration out of water-saturated soils have been well documented in association with permafrost studies (see, for example, Tsytovich, 1975, chapter II, for a comprehensive review of the theories and mechanisms of this phenomena). (b) Alternatively, the ice front could penetrate the lake bottom sediments and result in a net loss of moisture by either "squeezing out" (laterally or downward) unfrozen water (Tsytovich, 1975, p. 59) and/or segregating the water (ice) phase from the sediment phase thereby, upon spring and summer thawing, allowing the moisture which was originally trapped in the sediment pore to become part of the overlying lake water.

Both of these desiccation hypotheses have several positive and negative aspects which will be discussed briefly. The chief dispute with the complete drying and desiccation suggestion is that the sediment records very little change in mineralogy, chemistry, or organic matter across the horizons. If the lake today, for example, were to dry completely, it is expected that (a) a wide variety of sulfate and possibly chloride salts would be precipitated in the final stages of brine concentration, and (b) vegetation would quickly colonize the newly exposed mud flats. The lack of exotic salts in the record might easily be explained considering their rapid dissolution upon reflooding of the lake such as suggested by Richardson (1969) and shown by Flint and Gale (1958) to have occurred in the

Searles Lake record. Similarly, as pointed out by Jones and Bowser (1978), substantial changes in the sediment pore water chemistry which, indeed, may be present at these intervals, may not necessarily be recorded in the bulk, solid phase chemical analyses done in this study.

However, the absence of abundant vegetal remains in the marker horizon sediments cannot be accounted for so easily and remains a problem. Although roots and root fibers are present in a few places, cores recovering organic fiber material from the marker horizons are almost always limited to the uppermost marker horizon. It is, however, conceivable that the sedimentsof the marker zones are only the lower parts of a young soil profile, with the more highly organic and leached horizons having been stripped away by the event that reflooded the lake basin. In considering the initial phases of reflooding of the basin, it is, in fact, likely that wave disruption of the bottom sediment did occur. The pelletal and well-rounded nodular structure of the upper marker horizon in several cores is evidence that reworking did take place.

Finally, there is some support for the lake drying-sediment desiccation hypothesis because similar horizons elsewhere have likewise been interpreted as representing old drying surfaces. In fine-grained Lake Agassiz sediment of Minnesota and North Dakota, Rominger and Rutledge (1952) have identified, on the basis of a decrease in moisture content and liquid limit values and on increases in preconsolidation stress,[1]

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[1] Preconsolidation stress is essentially a measure of compaction. It evaluate the greatest effective pressure above that of overburden or normal load pres required to account for the given void space/solid ratio of the sample. A soil that has high preconsolidation stress values (i.e., is "overconsolidate has either been subjected to a large overburden load which subsequently has been removed, or has had its physical properties (i.e., moisture content, porosity, void ratio, etc.) altered by desiccation. Although compaction data was not collected for the Lake Manitoba sediment, it is probable that the marker horizon deposits would record high preconsolidation stress values

a basin-wide (15,000 km^2) horizon which they interpreted as indicating a period of lake bottom exposure and surface drying of the lacustrine muds. Although Arndt (1975, 1977) has since re-evaluated Rominger and Rutledge's interpretation mainly on the basis of more extensive drilling, and suggested that the sediment of this interval actually represents fluvial-overbank deposits, nonetheless, both interpretations are in keeping with a low water phase of the lake.

Callender (1968) and Owen et al (1973) similarly interpreted a stiff, grey clay with anomalously low moisture content at a depth of approximately 7 m in cores from Devil's Lake, North Dakota, as representing an old desiccation surface. However, Callender (1968) also identified abundant plant remains (but not higher organic matter contents) and some evidence for carbonate leaching associated with the zone.

Hecky and Degens (1973) and Stoffers and Hecky (1978) use the presence of dry, crumbly-textured sediment "similar to soil," which has low organic and water contents, to help confirm a lower lake level and subaereal exposure at several coring sites in Lake Kivu, Africa.

Komornik et al (1970) contend that, on the basis of preconsolidati profiles in cores of marine Holocene clays of the eastern Mediterranean area they can differentiate the causes of overconsolidation (namely, erosion of overburden, desiccation, temporary lowering of groundwater, or diagenesis and cementation) and conclude that the compact clays of their study area were subjected to severe desiccation under subareal conditions.

The main point to be taken from all of these studies, and one that needs emphasis in the Lake Manitoba situation if this hypothesis is to be accepted, is that complete drying (or draining) of the overlying body of water must occur at least periodically for these characteristic features to develop. Simply lowering the lake level substantially or even relegating the lake to a marsh or swamp status will not result in the loss of sediment moisture or the development of the distinguishing pedogenic-like structures. Thus, in accepting this hypothesis, Lake Manitoba, on the basis of the multiple marker zones, is interpreted to have dried or completely drained at least three and possibly four times during its post-glacial history.

The cryogenic hypothesis of desiccation attempts to soften the blow of having to call on numerous complete lake drying events by creating a situation in which structural development and loss of moisture can still occur under a water column. While more than 3 m of ice is not likely to have formed on the lake since late glacial time (even high arctic lakes today rarely have more than 2 m of ice), a reduced lake depth would allow the freezing zone to come into contact with the sediment, thus permitting moisture migration out of the sediment, possibly inducing the blocky, fractured cryogenic structure each winter, and development of the marker horizons. In addition to this mechanical dehydration of the sediment, the result of freezing of much of the lake's volume would be to increase the salinity of the remaining water, thereby enhancing the possiblity of chemically-induced desiccation as outlined under 6.2.4.

Although soil moisture migration is well known, the net result (i.e., whether a higher or lower soil moisture content develops) seems to be, at least in part, controlled by whether the "freezing system" is closed or open (Tsytovitch, 1975). An open system, which would allow the free drainage of unfrozen water and, hence, a reduced moisture content, might be suggested for the lake sediments because freezing is occurring from essentially one direction - above. However, the lateral or vertical transmission of water in sediment composed of up to 70% clay-sized material must be questioned. Despite this, the compaction and mechanical rearrangemer of both saturated and unsaturated soils upon thawing is a well known phenomena (Tsytovitch, 1975, p. 216) and would seem to favor the cryogenic mechanism whether or not the freezing system is open.

6.2.6 Summary of Marker Horizons

The following points summarize the observations, interpretations and conclusions regarding the marker zones and their origin.

1. Several of the marker zones can be confidently correlated on a basin-wide scale. The uppermost horizon has the densest core control and, in general, has better developed (more recognizable) characteristic features. The lower zones, while sometimes not as well developed and not as easy to correlate, are similar in appearance and probably were formed in a similar way to the uppermost zone.

2. The zones are characterized by a significantly lower moisture content relative to the overlying and underlying sediment, a gleyed, dark greenish grey color, a distinctive pedogenic-like blocky structure, and a sharp upper contact but a gradational lower boundary.

3. Although no one hypothesis regarding their origin is totally satisfactory, the most likely explanation is that the horizons represent episodes of extreme low water levels of Lake Manitoba at which time either complete drying of the lake and desiccation of the bottom muds occurred or winter freezing of the reduced lake volume caused bottom sediment dehydration.

Detailed microscopy (particularly scanning electron microscopy) and pore-water chemical analyses of the sediment of the marker zones should help to resolve the contribution of other possible hypotheses such as water chemistry variation and variation in sedimentation rates.

6.3 DISCUSSION AND INTERPRETATION OF CARBONATE SEDIMENTS

6.3.1 Introduction

As pointed out by Jones and Bowser (1978), carbonate minerals are somewhat unique because they can be derived not only by the erosion of carbonate bedrock but also by direct chemical and biological precipitation within the lake's water column and by diagenetic alteration of pre-existing carbonate sediment in the mud. Distinguishing between the various genetic types of carbonates is an important but often very difficult task (see Kelts and Hsü, 1978). Rarely can one genetic species of carbonates be eliminated a priori from consideration. In fact, frequently the sediment record can be shown to reflect several or all of the different genetic types with each contributing to the record in varying amounts.

In Lake Manitoba sediments, three basic carbonate minerals have been identified by X-ray diffraction: calcite, dolomite, and aragonite. Aragonite has been identified in trace amounts only and is present at two sample sites only. Although aragonite has been shown to originate as an inorganic precipitate in numerous lakes (e.g., Müller, 1971; Müller et al, 1972; Callender, 1968, 1969), the elevated Mg^{++}/Ca^{++} atomic ratios generally thought to be required before this in situ precipitation can occur (greater than 12; Müller et al, 1972) are not observed in Lake Manitoba. The rare occurences of this dimorph of $CaCO_3$ in the surface sediment of the South Basin are believed to originate from biogenically-precipitated carbonate shell material. X-ray analyses of both gastropod and pelecopod skeletal material found in Lake Manitoba sediment shows that aragonite is the dominant shell-forming mineral (Fig. 6-3). This

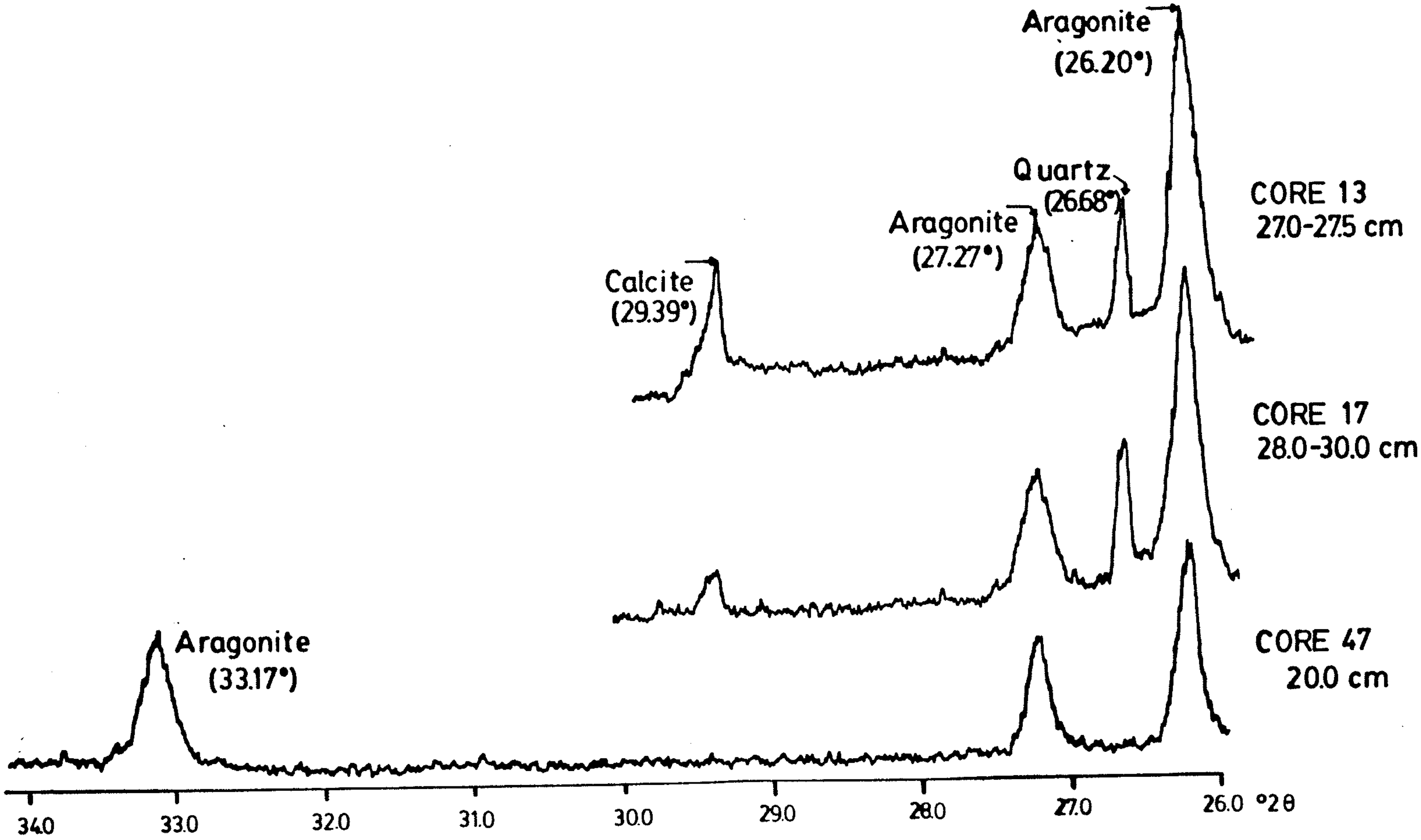

Figure 6-3. X-ray diffraction patterns of several samples of shell material from Lake Manitoba sediment. The sample from core 47 is a fragment of a large pelecypod shell. Those from cores 13 and 17 are zones of mollusk shell concentrations in a mud matrix.

is also the case reported by Brunskill and Graham (1979) for shell material found in Lake Winnipeg and by Lippman (1973) for marine mollusks.

The other two carbonate minerals, calcite and dolomite, are much more abundant in Lake Manitoba sediment and can constitute up to 60% of the total mineral components. In the modern bottom sediments of the lake, calcite shows an increase in abundance in the offshore direction, whereas dolomite tends to decrease in the offshore direction (see Figs. D-14 and D-17). Stratigraphically, the abundance of these two minerals also exhibits significant and important variations (see Figs. J-2, J-7, and J-12). Calcite shows a strong decrease with depth in the cores, while dolomite tends to increase downward. Furthermore, the significant positive correlation coefficients between the Ca - calcite variables ($r = 0.82$) and the Mg - dolomite variables ($r = 0.61$) in the three long cores in the basin confirms that the variation in concentrations of these two elements (Ca and Mg) is mainly a reflection of variation in the carbonate fraction of the sediment.

In addition to this variation in the total abundance of calcite in the sediment, the composition of the calcite itself varies in two ways. First, the abundance of the high-Mg calcite phase (that is, calcite with more than 2 mole percent $MgCO_3$) shows a general increase upward in the section from no Mg-calcite in the basal Unit A to calcite with 80 to 100% high-Mg species in the uppermost Unit F (see Fig. 6-9). Importantly, the abundance of the "normal" (low-Mg) calcite shows little change stratigraphically.

Second, the mole percent $MgCO_3$ in the high-Mg calcite shows significant variations associated with specific marker horizons in the

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[1] Although the calcite in the upper unit is dominantly (80-100%) high-Mg calcite, the total amount of calcite (relative to all other minerals in the sample) is, as pointed out above and shown in Fig. 6-9, less than 60%.

section (see Figs. 6-9 and 6-10). All of the calcite in the sediment of Unit A and the lower part of Unit B contains no $MgCO_3$. Then, beginning in the upper part of Unit B, a portion of the calcite has about 4 mole percent $MgCO_3$ incorporated in the crystal lattice. The Mg content of this disordered calcite species remains relatively constant between 3 and 4 mole percent upward in the section until the marker horizon at the top of Unit C is reached. The calcite in the sediment immediately above this marker zone shows a significant increase in $MgCO_3$ content, then gradually returns to a 3 to 5 mole percent species higher in Unit D. There is yet another striking increase in the $MgCO_3$ content of the calcite (to a maximum of 14 mole percent) immediately above the uppermost marker horizon in the basin. The Mg content in the calcite remains relatively constant at about 10 mole percent in Unit E above this marker zone. Finally, in Unit F the $MgCO_3$ values decline to about 5 to 8 mole percent.

The modern bottom sediments in the basin show little consistent spatial variation in either the amount of high-Mg calcite or the amount of $MgCO_3$ incorporation into the crystal lattice (see Figs. D-15 and D-16).

6.3.2 Modern Calcite Sedimentology

6.3.2.1 Introduction

As discussed in Appendix G, the spatial variations in calcite and dolomite in the modern sediments of Lake Manitoba can be quite adequately explained simply in terms of terminal grain size and mineral density differences. Dreimanis and Wagners (1971) have shown that the comminution of glacier-eroded, multi-lithologic bedrock will result in the production of several different particle size modes depending primarily on the mineralogy of the grains. The dominant grain size mode, or terminal grade, for dolomite in their study was 4 to 6 phi; that of calcite was 4 to 8 phi. This, plus the fact that the density of dolomite is about 8% more than that of calcite, could explain the spatial trends and relationships of the two minerals on the floor of the South Basin. The abundance of dolomite shows a general decrease in the offshore direction as opposed to calcite's increase simply because the hydrodynamic characteristics of the heavier, larger dolomite grains prevent it from being sorted and moved basinward with the smaller, less dense calcite grains. Implied in this scenario, although not necessarily a requirement, is that both minerals are detrital, originating from stream and wave erosion of the carbonate-rich surficial sediments of the region.

However, there are several lines of evidence which suggest that this is not the only, or even the most likely, explanation for the origin and distribution of calcite in the South Basin.

6.3.2.2 Grain size - mineralogy relationships

If the dominant process controlling the mineral distribution in the basin is physical breakage by glacier transport and ensuing hydrodynamic sorting as suggested above, it would be expected that the abundance of the minerals would show a strong association for their respective terminal grades. Indeed, the correlation coefficient matrix discussed in Appendix G confirms that dolomite and quartz show a strong negative correlation with clay; quartz and feldspar have high positive correlation coefficients with sand; and clay minerals and calcite tend to show trends similar to that of the clay.

Figure 6-4 examines this mineralogy-size association for the modern surficial sediments in more detail. Plotted are the correlation coefficients calculated between the weight percentage of individual 1 phi size intervals and the total amount of the particular mineral in the sample. A high positive correlation would indicate that the abundance of the mineral is increasing or decreasing proportionately to the variation in the particular phi interval. This would, thus, suggest that the particular mineral is concentrated or segregated in that size fraction.

As can be seen in Figure 6-4, the abundance of quartz shows significant positive correlations with the coarser-than-5-phi sizes and negative correlations with the finer-than-11-phi sizes suggesting that the quartz is concentrated in the sand fraction of the sediments. Similarly, the clay minerals show high negative correlation with the medium and coarse silt sizes and strong positive association with the fine silt and clay sizes. For dolomite, high positive correlations occur in the 4 to 6 phi size fractions which confirm the terminal grade hypothesis for this mineral. Calcite, however, although showing some suggestion of size segregation in the finer fractions of the sediment, exhibits only rather weak correlation coefficients (all less than 0.46) and does not substantiate the terminal grade mechanism for Lake Manitoba sediment.

6.3.2.3 Paucity of fine-grained calcite

Throughout this discussion, it has been rather tacitly assumed that because of the abundance of carbonate bedrock in the area (see Section 3.3), there could be no question of a possible source of detrital calcite and dolomite. Furthermore, the tills surrounding Lake Manitoba

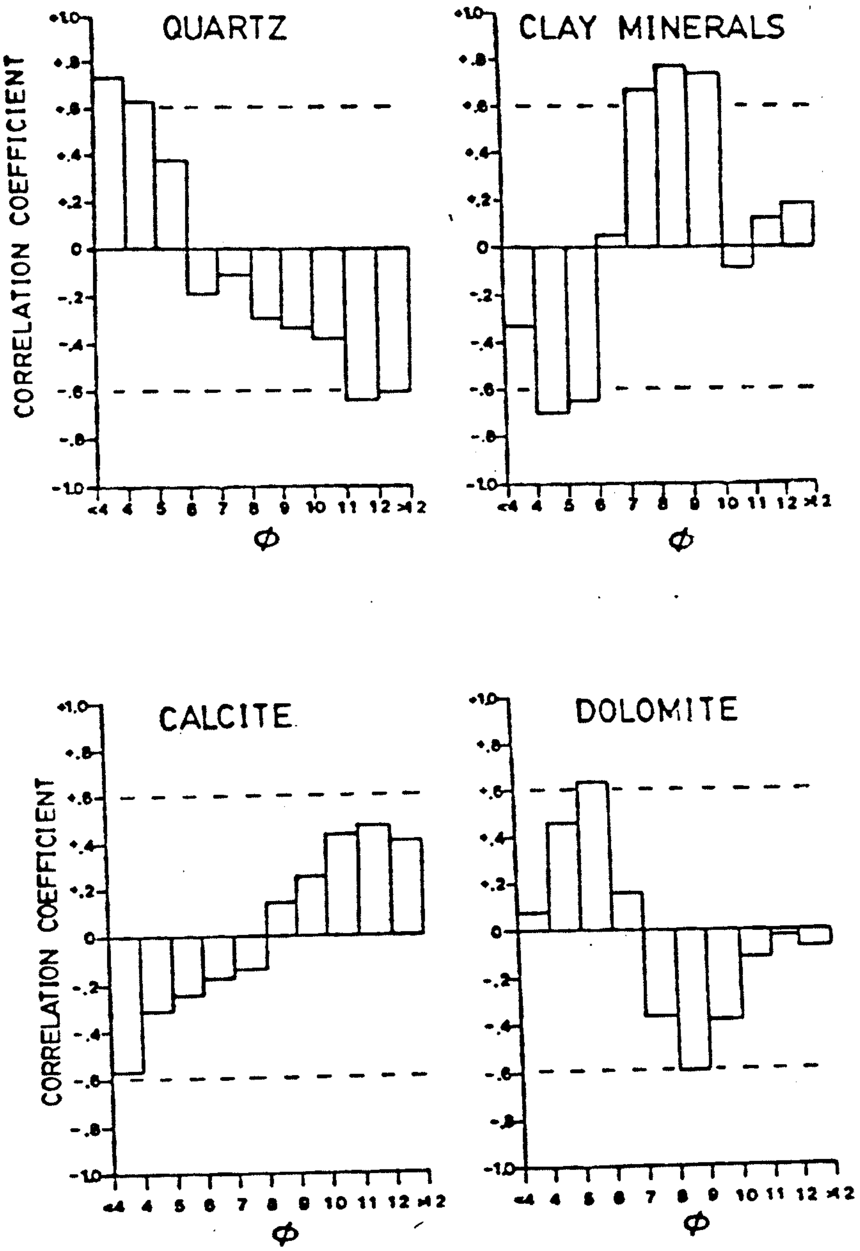

Figure 6-4. Correlations between relative abundance of sediment in each phi interval and total mineral content of sample. The horizontal dashed line indicates statistical significance at the .001 confidence level.

and soils developed on them are noted for their high carbonate content (e.g., Pratt et al, 1961; Mills and Smith, 1971; Ehrlich and Rice, 1955). However, Fenton (1970, p. 17) reports that the average calcite content of the Holocene alluvial and Lake Agassiz lacustrine units immediately south of Lake Manitoba is only 6%. The tills in his study area average only about 20% calcite in the finer-than-sand sized fraction. Conversely, dolomite contents are high, averaging approximately 35%. The Lake Manitoba surface sediments, excluding the relict sands, average close to 30% calcite but less than 20% dolomite. On the basis of this limited comparison, there seems to be a discrepancy between the relative percentages of calcite and dolomite being deposited in the lake versus the amounts contained in the probable sources assuming a detrital origin.

6.3.2.4 South Basin water chemistry

The chemical characteristics of the South Basin water were reviewed in Section 3.8. The following points summarize some of the salient features of this discussion:

(a) the South Basin is presently brackish with up to 3.0 $g \cdot l^{-1}$ salinity;

(b) evaporation and/or subaqueous groundwater discharge probably play a major role in determining the water chemistry characteristics; and

(c) the North Basin of the lake, the lake's dominant inflowing stream, and the lake's outlet stream are more dilute in all components (except calcite) relative to the South Basin, suggesting that water exchange between the two basins through the Narrows is poor.

The results of R-mode analysis of the modern bottom sediment data shows that much of the sample variance in the basin can be accounted for by a factor interpreted to reflect calcium carbonate precipitation in the lake (see Appendix G). To confirm or reject the interpretation of this factor, the degree of saturation of the South Basin water with respect to calcite was calculated. Unpublished water quality data covering a period of four years was supplied by A. Beck (Manitoba Water Quality Division, 1979) from two sampling sites in the South Basin (summarized in Appendix H). Although these sites do not exactly coincide with any sediment sampling station of this study, the Delta site is within about 1 km of cores 36 and 40.

To determine the saturation state of the lake water with respect to calcite, the calculated ion activity product (IAP) of the solution is compared to the product of the calcium and carbonate ionic activities for the reaction $CaCO_3 \rightleftharpoons Ca_{aq}^{++} + CO_{3aq}^{=}$ at equilibrium (K_c). Values of IAP/K_c greater than one indicate supersaturation, less than one is undersaturation, and one indicates saturated conditions. Values of K_c are, at a given pressure, dependent only on temperature and have been experimentally derived. Those listed in Schwartz (1974) were used in these calculations. The IAP is the product of the ionic activities of the calcium ($a_{Ca^{++}}$) and carbonate ion ($a_{CO_3^{=}}$) in the water. However, in natural water the $CO_3^{=}$ is also controlled by the reaction:

$$HCO_3^- \rightleftharpoons CO_3^= + H^+$$

and must be calculated on the basis of the equilibrium reaction with bicarbonate such that $a_{CO_3^=} = \dfrac{K_{HCO_3^-} \cdot a_{HCO_3^-}}{a_{H^+}}$.

The activity of the ion is essentially a measure of the effective reactive concentration of that ion in the solution and is calculated as the product of the ion's total concentration and an activity coefficient. The activity coefficient (γ) in dilute solutions can be approximated by the Debye-Huckel relation:

$$-\log \gamma = \frac{A\ Z^2\ (I)^{\frac{1}{2}}}{1 + \mathring{a}\ B\ (I)^{\frac{1}{2}}}$$

where I is the ionic strength defined as "half the sum of the term obtained by multiplying the molality of each ion in the solution by the square of its valence" (Domenico, 1972, p. 197); A and B are temperature dependent characteristics of the water; $\mathring{a}$ is the effective diameter of the ion; and Z is the valance of the ion. In these calculations, A, B, and $\mathring{a}$ were taken from Berner (1971, p. 217-218).

However, complex ions formed by ion pairing of the major cations and anions in the solution become more important at higher ionic concentration In Lake Manitoba waters, whose ionic strength reaches 0.033, the formation of the ion pairs $CaCO_3^0$, $CaHCO_3^{-1}$, $CaSO_4^0$, $MgHCO_3^{-1}$, $MgCO_3^0$, $MgSO_4^0$, $NaHCO_3^{-1}$, $NaCO_3^{=}$, $NaSO_4^0$, and KSO_4^0 were taken into account following the iterative procedure outlined by Berner (1971, p. 42). The ion pair dissociation constants used in these calculations were taken from Berner (1971, p. 43). Thus, the calcite saturation indices shown in Figure 6-5 are based on the activities of the uncomplexed ions.

Figure 6-5 plots the calcite saturation index (IAP/K_c) at two locations in the South Basin over a period of four years. Also shown in this figure are the variations in pH, temperature, and specific conductance. The lake water at both sites was supersaturated with respect to calcite at all times of the year during the sampling period.[1] Values fell almost

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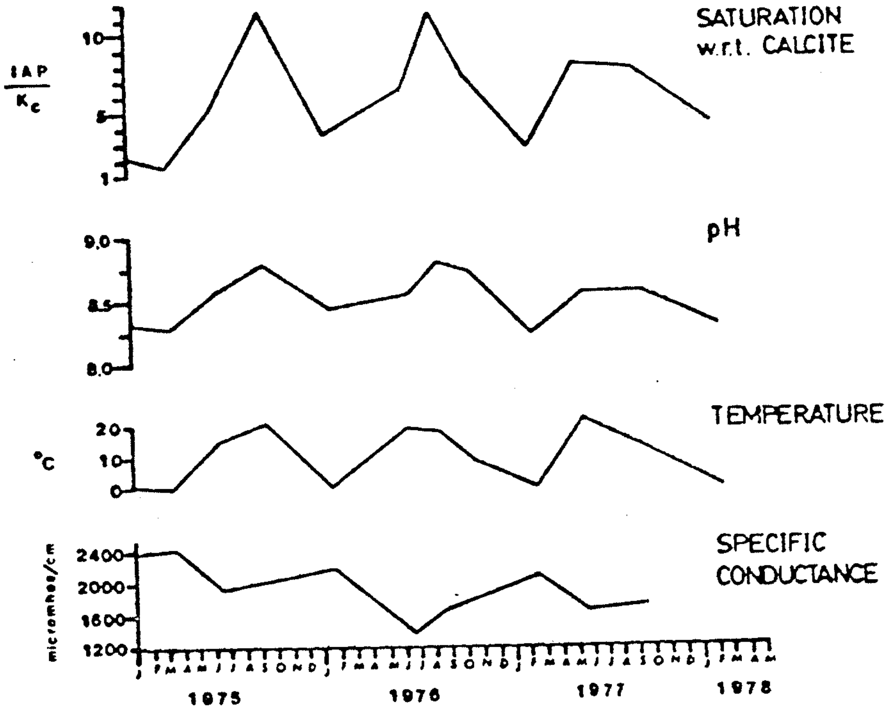
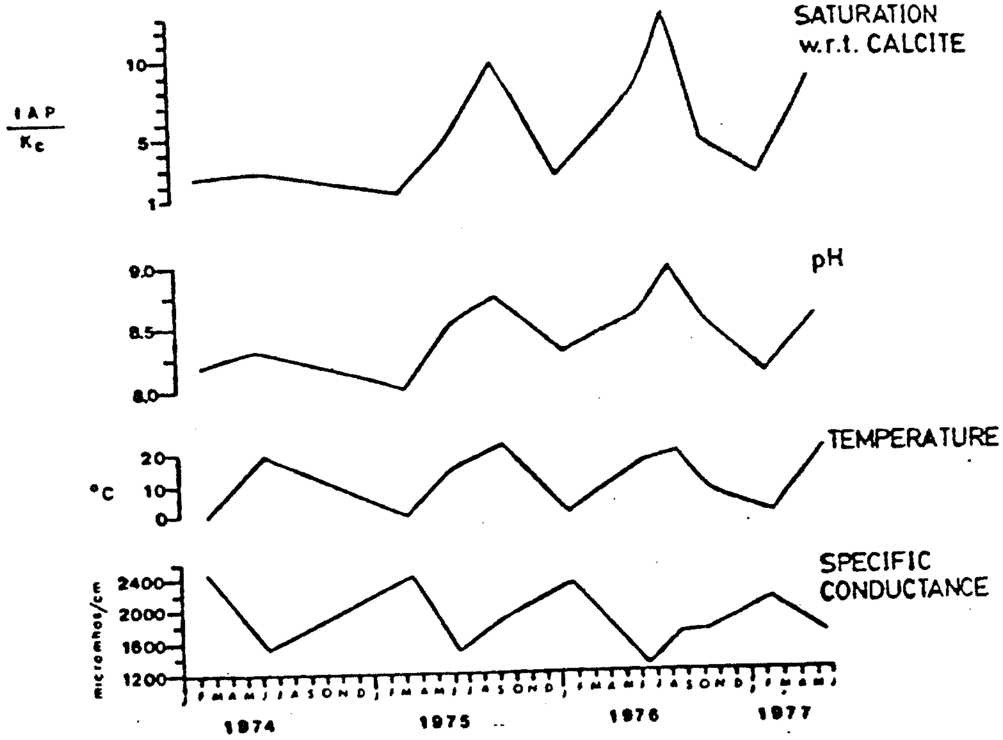
[1] The International Garrison Diversion Study Board (1976, p. 166) also conclud based on " a computerized analysis by Mr. F. Render of the Manitoba Departmen of Mines, Resources and Environmental Management," that $CaCO_3$ is actively being precipitated (that is, saturated or supersaturated conditions exist) in Lake Manitoba.

Figure 6-5. Comparison of calculated calcite saturation index (IAP/K_c), pH, temperature, and specific conductance of water at two sites in the South Basin of Lake Manitoba, 1973 to 1978. Chemical data collected by Manitoba Water Quality Survey (see Appendix H). See text for details of saturation index calculations.



SANDY BAY SITE



DELTA SITE

to the saturation level during the winter months under an ice cover, while during the ice-free season of each year, supersaturation reached almost thirteen times equilibrium values. A striking rise in pH and temperature can be observed during the spring and summer.

Unfortunately, no biological productivity data exists for Lake Manitoba with which to compare this carbonate and chemical information. However, it can be suggested that with the loss of ice and subsequent warming water temperatures, biological activity, and specifically phytoplankton productivity, increases significantly. Uptake of CO_2 by plant respiration lowers the amount of CO_2 present in the water and consequently raises the pH. This, combined with the higher temperature, and, thus, lower calcite solubility, produces a 10 to 12 fold increase in supersaturation of the water with respect to calcite and eventual calcite precipitation.

No attempt was made in this study to harvest the calcite grains which are being precipitated in response to the high levels of supersaturation There has been no report of whitings in the lake, nor of carbonate crustations onkoids, or discrete carbonate laminae; all features which are commonly associated with authigenic inorganic precipitation of calcium carbonate in lacustrine environments. However, the absence of these complimentary features by no means suggests that calcite is not being precipitated. Their absence can be explained by the physical nature of the South Basin. For example, because of its natural high levels of turbidity due to both re-suspension of bottom sediment and dense phytoplankton growth, the visual effects of whitings would probably be lost. Similarly, annual or otherwise periodic re-suspension of bottom muds and high levels of bioturbation would discourage the preservation of discrete carbonate laminae.

It is fully recognized that calculated supersaturated conditions of a solution need not necessarily mean that precipitation will occur. Indeed, the fact that supersaturation exists suggests that there is some physical or chemical barrier to nucleation. The absence of seed crystals, shown by de Boer (1977) to cause elevated levels of supersaturation, does not seem applicable in the Lake Manitoba situation. Folk (1974) has suggested that the presence of relatively high amounts of Mg^{++} in the precipitating water ($Mg/Ca = 2$ to 10) can act as a "surface poison" selectively inhibiting the formation of crystalline calcite. Similarly, experimental work by Bischoff (1968), Lippman (1960, quoted in Lippman, 1973, p. 109) and Murry (1954) showed that magnesium ions in excess of calcium ions in a solution tends to discourage the crystalization of calcite. More recently experimental work on seeded precipitation from sea water by Berner (1975) confirms this inhibiting action of Mg^{++}, but also shows that the calcite that does eventually precipitate from these supersaturated solutions (i.e., supersaturated and having high Mg^{++} contents) contains 7 to 10 mole percent $MgCO_3$ in solid solution.

6.3.2.5 Magnesian calcite

X-ray diffraction analyses reveal the presence of a disordered calcite in the sediment of Lake Manitoba. Although this material has not been segregated and chemically or microscopically analyzed, it is assumed that magnesium ion substitution in the calcite lattice is responsible for the shift in the mineral's reflections toward higher diffraction angles. Furthermore, the low concentrations of iron and manganese in the lake water suggest that these two ions, which would be the next most likely (after magnesium) to substitute for calcium in the crystal lattice (Lippman, 1973), are not a major factor.

Most authorities consider these high-Mg calcites to be metastable (Pettijohn, 1975, p. 323; Lippman, 1973, p. 193; Berner, 1971, p. 146), and as such could probably not be derived from the surrounding Paleozoic carbonate bedrock of the watershed. This is confirmed by X-ray diffraction analyses of ice-rafted carbonate pebbles and granules from several parts of cores 20 and D-3 (Fig. 6-6). In addition, carbonate grains (larger than sand-sized) were extracted from core D-4 at 573 cm, 609 cm, and 640 cm (from a unit interpreted as till), and from core 21 at 0 to 8 cm depth. None of these dolostone or limestone grains showed variation from the "normal" 3.03 Å calcite or 2.88 Å dolomite reflections. Likewise, samples of both limestone and dolostone bedrock from the Paleozoic Red River, Stoney Mountain, Elm Point, and Winnipegosis Formations showed no Mg^{++} incorporation in the calcite.

Figure 6-6 also shows two representative modern lacustrine sediments from the basin. Both show a dominant high-Mg calcite peak in addition to a much smaller "normal" calcite peak.

It is suggested that the high-Mg calcite is derived from authigenic precipitation in the lake water in response to supersaturated conditions possibly brought about by high levels of phytoplankton productivit and the concomitant rise in temperature and pH during the ice-free season. However, until firm biological data is acquired for Lake Manitoba, the relative importance of a biologically-initiated precipitating mechanism versus precipitation brought about simply by the change in water temperature and CO_2 content during the summer cannot be determined.

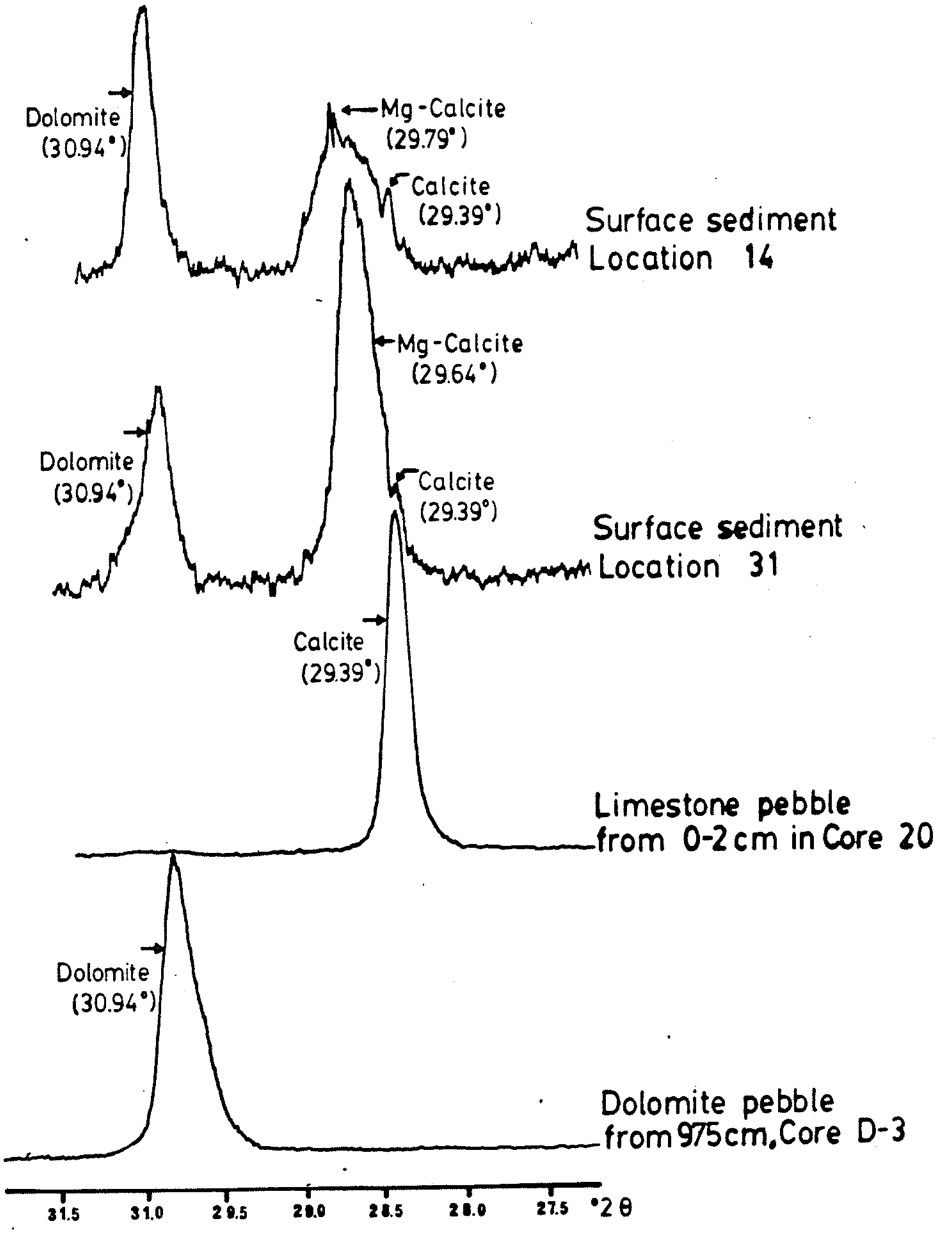


Figure 6-6. Representative X-ray diffraction patterns showing detailed carbonate mineralogy of detrital carbonate grains and surficial sediment from the South Basin of Lake Manitoba.

For example, the influence of groundwater in establishing the supersaturated conditions may be important. Cherry (1972) and Cherry et al (1971) note that the northward flowing, shallow aquifer groundwater system, which is considerably more concentrated in Ca^{++}, Mg^{++} and $HCO_3^{=}$ ions relative to Lake Manitoba's surface water, is at a temperature of between 4° and 6°C and a pH of 7.0 to 7.8. If the hypothesis regarding the continued flow of this system northward under Lake Manitoba and finally discharging in the lake via the coarse-grained relict sand unit is true, as suggested in Section 6.1.2, the mixing of these two significantly different waters could lead to supersaturation and carbonate precipitation as Müller et al (1972) and Kelts and Hsü (1978) have shown to occur elsewhere.

The magnesium content of Lake Manitoba water is also a possible factor in creating supersaturated conditions in the lake. As mentioned in Section 6.3.2.4, Mg^{++} is believed to act as an inhibitor of calcite precipitation. Folk (1974) suggests that the magnesium ion makes it difficult for calcite to form because it selectively poisons sideward growth of the crystal. Thus, $CaCO_3$ in a precipitating situation will prefer to take the form of either aragonite or small, very narrow, "fibrous" rhombs of magnesian-calcite. Apparently the ratio of magnesium to calcium in the solution controls many of the crystal forming mechanisms. Mg/Ca ratios of less than about 2 will have little effect, and "normal" calcite (i.e., without any Mg^{++}) is precipitated from solution. Ratios of greater than 2 favor precipitation of calcite with varying concentrations of Mg^{++} ion substitution. The amount of Mg incorporation in the calcite lattice is directly related to the Mg/Ca ratio of the solution (Müller and Wagner, 1978; Fuchtbauer and Hardie, 1976).

The Mg/Ca ratio of the water in the South Basin of Lake Manitoba averages about 2.9 (Fig. 6-7). Thus, the $MgCO_3$ content of the calcite in the modern bottom sediments as determined by X-ray diffraction analyses agrees very well with the mole percent $MgCO_3$ predicted from experimental precipitation data for the particular Mg/Ca ratio of the water (Fig. 6-8; see also Fuchtbauer and Hardie, 1976; Müller and Wagner, 1978; and Winland, 1969).

This high Mg/Ca ratio of the South Basin water offers yet additional support for the precipitation of calcite in the lake. Table 6-2 shows that all the measured surface streams flowing into the lake as well as the major groundwater systems surrounding the basin have low Mg/Ca ratios. Thus it is evident that the South Basin water is being "enriched" in Mg^{++} relative to Ca^{++}.

One of the easiest ways to cause this enrichment is simply to extract the Ca^{++} as a precipitate such as $CaCO_3$. Thus, with continual calcite precipitation, a given pool of ions in the lake will become preferentially depleted in calcium. If the rate of replenishment of the Ca^{++} via, for example, the undersaturated inflowing streams, is insufficient to make up for the loss, the resulting high Mg/Ca ratio will persist.

This type of mechanism was put forth by Müller (1970) to account for the overall high Mg/Ca ratio of Lake Balaton water (about 1.0 to 2.5) relative to the inflowing rivers (less than 0.5), as well as to explain the observed increase of this ratio along the 60 km length of the lake from where the main inflow stream enters the basin (Mg/Ca about 1.0 to 1.5) to the outlet of the lake (Mg/Ca about 1.8 to 2.6).

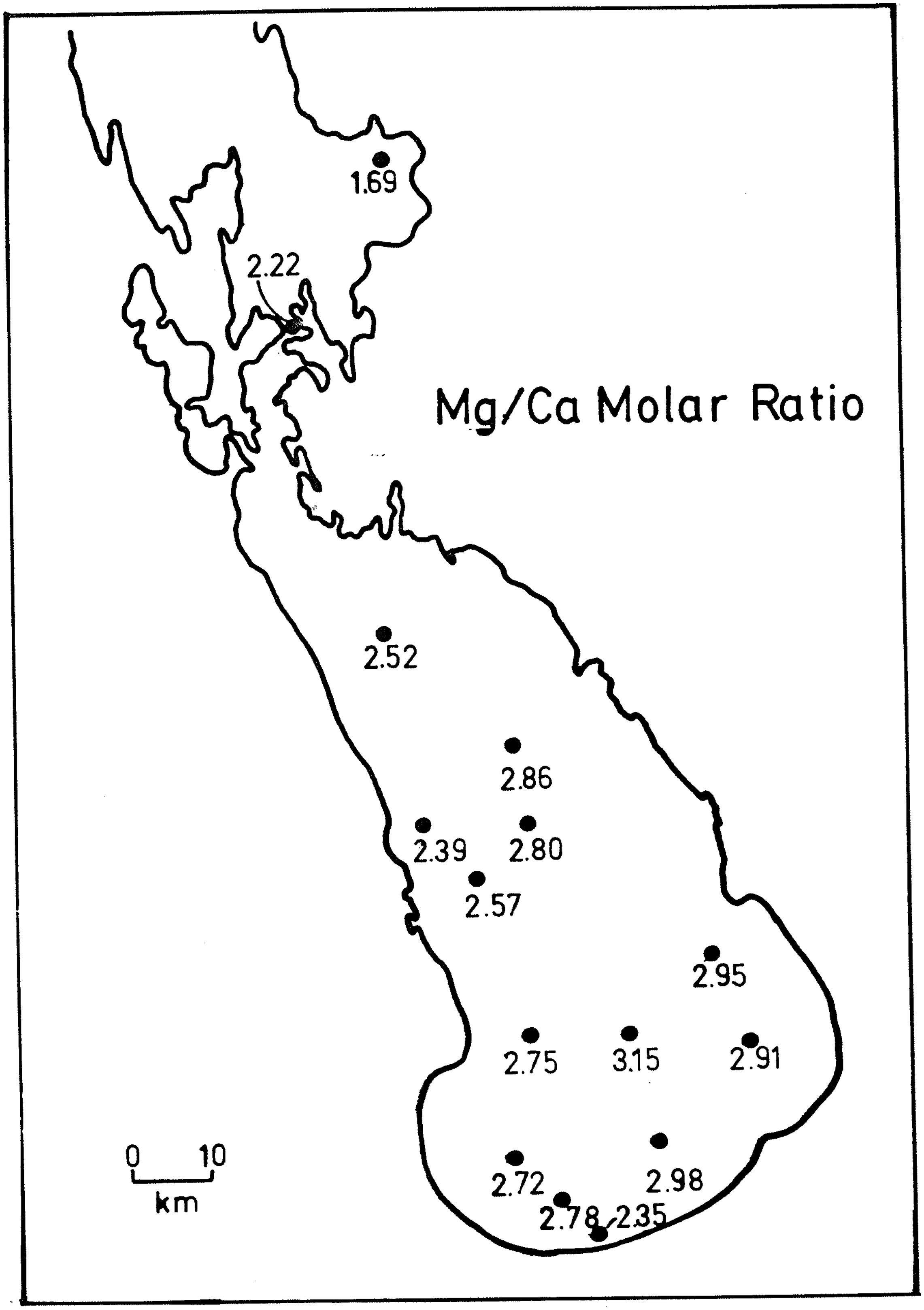


Figure 6-7. Mg/Ca molar ratio of Lake Manitoba water. Values calculated from data supplied in Cober (1968), Crowe (1972a), and by A. Beck (personal communication, 1979). Locations are approximate.

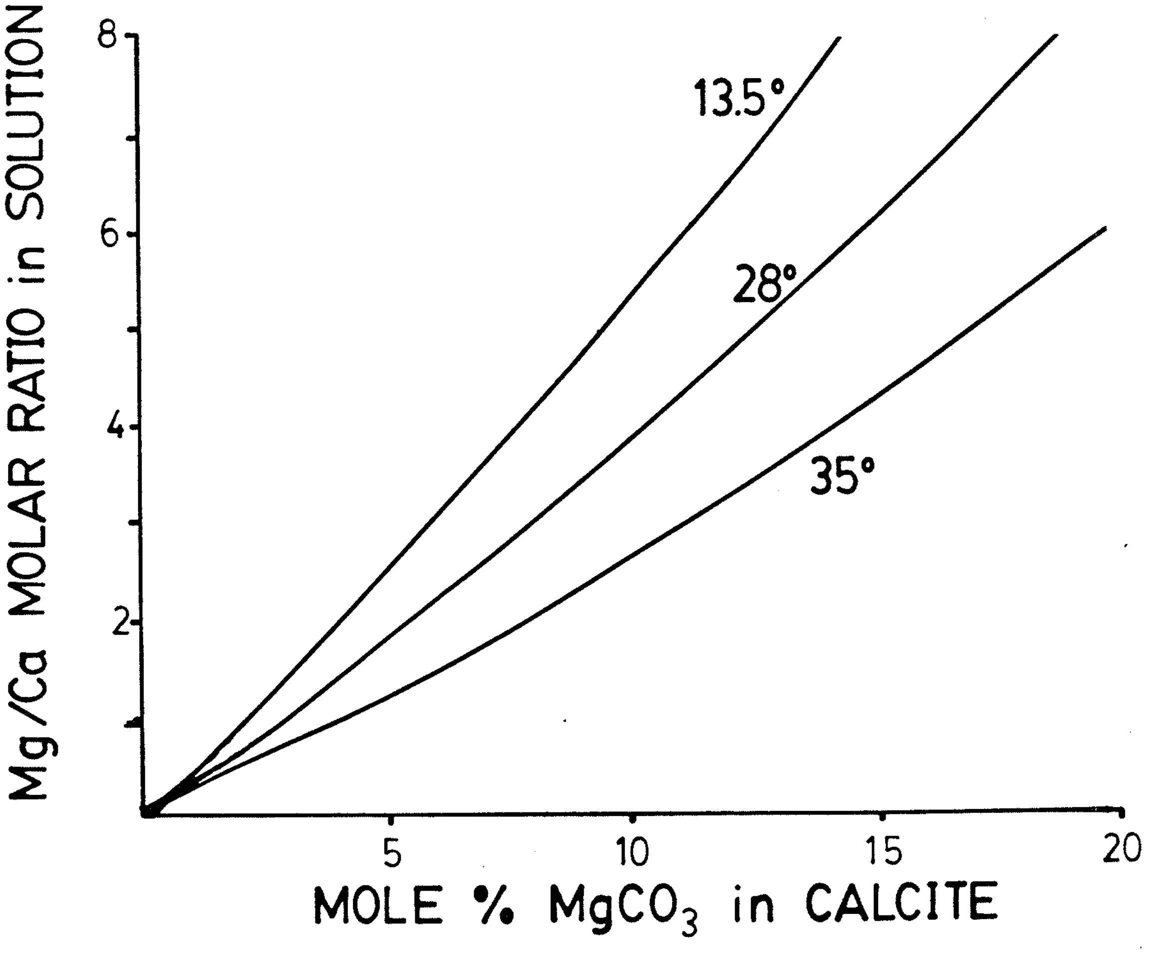


Figure 6-8. Relationship between Mg/Ca ratio of the solution and the mole percent $MgCO_3$ in the precipitated calcite at various temperatures of formation (after Müller and Wagner, 1978).

TABLE 6-2
Mg-Ca RATIOS IN SURFACE STREAMS, GROUNDWATER AND LAKE WATER IN THE LAKE MANITOBA WATERSHED

Surface Streams[+]			
	Waterhen River		0.67
	Whitemud River		0.50
	Assiniboine River		0.75
Groundwater			
	Delta area[1]	Shallow aquifers	0.87 - 1.50
		Bedrock aquifer	0.55
	Shoal Lakes area[2]	Shallow aquifer	1.55
		Bedrock aquifer	1.66
	Westlake area[3]	Shallow aquifers	1.45
		Bedrock aquifers	1.01
	Springs in the Lake Manitoba-Winnipegosis area[4]		0.40
Lake Water			
	Lake Manitoba South Basin[a]		2.90
	Lake Manitoba North Basin[b]		1.30
	Shoal Lakes[c]		13.49

[+] Ratios calculated from long-term means reported in Inland Waters Directorate (1978d).

[1] Ratios calculated from means reported by Cherry (1972) and Gilliland (1965).

[2] Ratios calculated from means reported by Cherry (1972).

[3] Ratios calculated from means derived from Table 1 in Manitoba Water Resources (1972).

[4] Ratios calculated from means derived from Table III in van Everdingen (1971).

[a] Ratios calculated from long-term means derived from data in Crowe (1972b), Cober (1968), and A. Beck (personal communication, 1979).

[b] Ratios calculated from long-term means derived from data in Crowe (1972b), Cober (1968), and van Everdingen (1971).

[c] Ratios calculated from mean derived from Appendix C in Goff (1971).

Lake Balaton's surface sediments have a high carbonate mineral content, most of which is authigenic calcite and contains between 6 and 8.5 mole percent $MgCO_3$ (Müller, 1970).

Similarly, in central Manitoba east of Lake Manitoba, Goff (1971) calls upon precipitation of calcite to deplete the Shoal Lake's waters of Ca^{++} and account for the very high Mg/Ca ratios present in the lakes (Mg/Ca ratios of up to 52; calculated from data in Goff's Appendix C, p. 110). Unfortunately, the mineralogy of the bottom sediments of these small, closed lakes, which are located within the watershed area of the South Basin of Lake Manitoba, was not presented.

6.3.2.6 Summary

To summarize the above comments regarding the modern calcite sedimentology of the South Basin, I concude that calcite is being authigenically precipitated in the water column on the basis of (a) high levels of lake water supersaturation; (b) the presence of high-Mg calcite in the bottom sediments; (c) the relatively low proportion (and, hence, low availability) of calcite in the sediments and soils of the watershed; and (d) the lack of good size segregation of the bottom sediment calcite. This calcite precipitation is largely inorganic, physicochemical precipitation, possibly controlled by primary organic production in the lake. The normal calcite, which makes up a relatively small amount of the total calcite percentage, as well as the dolomite in the bottom sediment are interpreted as detrital in origin, being derived from erosion of the unconsolidated ice-laid, lacustrine, and fluvial sediments of the watershed.

6.3.3 Dolomite in the Modern Sediments

It is possible that some (or all) of the dolomite in Lake Manitoba sediment is not detrital in origin. Although primary precipitation of dolomite has been demonstrated in only a few natural environments (many authorities would contend that in situ precipitation from a water body has not been convincingly demonstrated), diagenetic alteration of pre-existing carbonates to dolomite has been suggested and widely accepted in numerous recent settings (see Bathurst, 1975, for a review).

Sherman et al (1962) and Sherman and Thiel (1939) suggested a rather simple dolomitization process affecting detrital carbonates in soils developed on tills and on fine-grained Lake Agassiz sediments in Minnesota. They point toward partial dissolution of the clastic carbonates to form calcium bicarbonate which could then react with the Mg^{++} ion of the groundwater or precipitated magnesium salts (e.g., $MgSO_4$) to form the mixture $CaCO_3 \cdot MgCO_3$. However, the precise X-ray and crystal nature of this resulting diagenetic "dolomite" is not clearly discussed; nor is it evident if or how this diagenetic product could be distinguished from the clastic detrital dolomite of the soil horizon. St. Arnaud and Herbillon (1973) are similarly ambiguous regarding the question of dolomite formation in prairie soils of Western Canada. However, they do imply that due to the buffering effect of cation exchange processes in the soil, there is some upper limit of $MgCO_3$ content in the diagenetic product of this type of dissolution-translocation-reprecipitation process.

Müller and co-workers (Müller and Wagner, 1978; Müller and Fishbeck, 1973; Müller et al, 1972; Müller, 1970; Müller and Irion, 1969) have done much to qualitatively and semi-quantitatively advance our knowledge of secondary dolomite formation in lacustrine environments. Briefly summarizi this extensive work on European and African lakes, they conclude that the presence of high-Mg calcite and elevated Mg/Ca ratios in the water (greater than about 7) are both prerequisites for the secondary formation of dolomite. The resulting diagenetic product is a poorly ordered[1] carbonate mineral containing 35 to 50 mole percent $MgCO_3$ but having the characteristic of lower solubility relative to calcite and Mg-calcite. This stable, cation-disordered, calcium magnesium carbonate (termed protodolomite) is morphologica identical to high-magnesian calcite and is generally found concentrated in the finer grain sizes (Müller and Wagner, 1978).

Conversely, Folk and Land (1975) suggest that dolomite can readily form at Mg/Ca ratios as low as 1:1 providing crystallization rates are slow enough. Rapid crystallization, such as Folk and Land (1975) suggest is responsible for the protodolomite formation in Müller's studies, require higher Mg/Ca ratios. They further point out that high water salinities actually inhibit the formation of dolomite and that fresh water dilution of brines with moderately high Mg/Ca ratios may be the easiest way to form the mineral.

Finally, Callender (1968, 1969, 1974) has suggested that in Devil's Lake, North Dakota, high-Mg calcite is being converted to dolomite at or very near the sediment/water interface. Based on (a)a significant

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[1] Ordering here refers to the regular alternation of Ca and Mg in the mineral's crystallographic planes (Berner, 1971).

decrease in the amount of high-Mg calcite in sediment of the upper several centimetres of the lacustrine deposit versus the material at the water-sediment interface, and (b) a concomitant increase in dolomite in the sediment versus the water-sediment interface material, he postulates that the high magnesian calcite is undergoing dissolution and re-crystallization as low-Mg calcite and/or aragonite. Dolomite is then produced by the reaction of these carbonates with the high-Mg interstitial water. This is supported by interstitial water Mg/Ca ratios of over 11 which are some three times higher than the lake water. However, again, it is not clear from Callender's work how the dolomite formed in this way is different from the clastic dolomite he has identified as detrital (allogenic) in origin, being derived from the erosion of the carbonate-rich tills of the watershed. Similarly, he has apparently not recognized or identified any type of imperfectly ordered dolomite (protodolomite) in the samples. This is somewhat unusual since most authorities (e.g., Berner, 1971; Bathurst, 1975; Gaines, 1977; Goldsmith and Heard, 1961) recognize an intermediate, metastable protodolomite precursor to the fully ordered stable stoichiometric dolomite.

The dolomite in Lake Manitoba's surface sediments is presently being interpreted as entirely clastic, detrital dolomite derived from shoreline and stream erosion of exposed glacial sediments. This interpretation is based on the lack of data supporting a diagenetic hypothesis in Lake Manitoba. It is recognized, however, that further chemical, microscopic, and X-ray diffraction work may confirm the presence and mechanism of formation of penecontemporaneous dolomite in the sediment.

6.3.4 Interpretation of Stratigraphic Changes in Carbonate Parameters

6.3.4.1 Introduction

Given the modern carbonate sedimentology situation discussed above, several comments are in order regarding the profiles of calcite (Figs. J-2, J-7, and J-12), mole percent $MgCO_3$ in the disordered calcite (Figs. 6-9 and 6-10), and dolomite (Figs. J-2, J-7, and J-12). Much of the following discussion will concentrate on changes exhibited in core D-1 because this was the only core in which detailed carbonate X-ray diffraction studies were performed at relatively close sample intervals.

6.3.4.2 Calcite

Calcite precipitation in Lake Manitoba commenced during the deposition of Unit B. Prior to this the low amount of "normal" calcite in Unit A is interpreted as mainly detrital calcite derived from the shoreline and watershed erosion. The lack of variation in this normal calcite profile throughout the section indicates that the input of detrital calcite to the lake has been relatively constant throughout the lake's history. From a depth of about 9 m to the surface in core D-1, the Mg-calcite shows a steady increase in abundance from less than 5% to over 35% of the total bulk mineralogy (Fig. 6-9). Because organic productivity might be responsible for controlling calcite precipitation in the modern lake, it is tempting to view this Mg-calcite profile with the same logic - gradually increasing productivity levels in the lake.

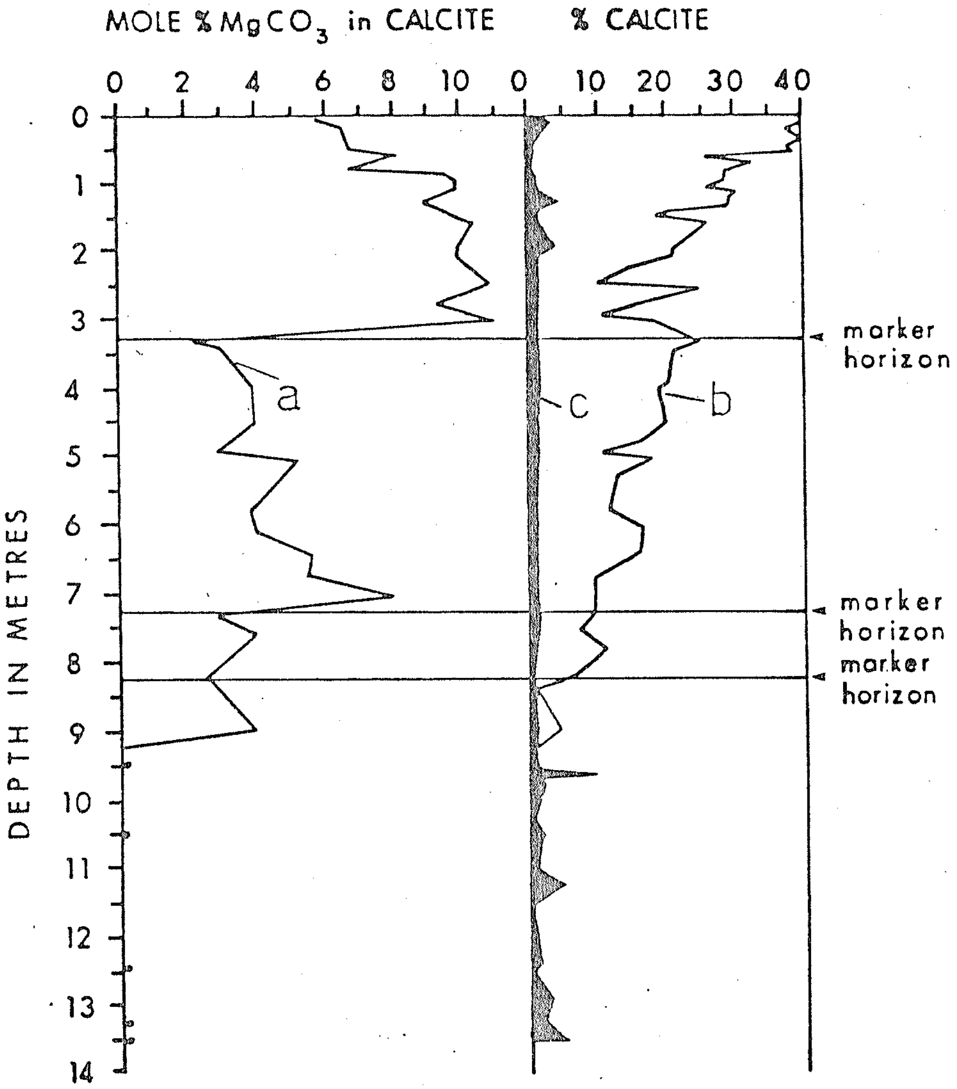

Figure 6-9. Variation with depth in mole percent $MgCO_3$ in disordered Mg-calcite (curve a), percent total calcite (curve b), percent detrital calcite (curve c), and percent Mg-calcite (difference between curves b and c) in core D-1. In core D-1, Unit A extends from the base of the core up to 9.8 m; Unit B from 9.8 m to 8.2m; Unit C from 8.2 m to 7.3 m; Unit D from 7.3 m to 3.3m; Unit E from 3.3 m to 1.0 m; and Unit F from 1.0 m up to the top of the core.

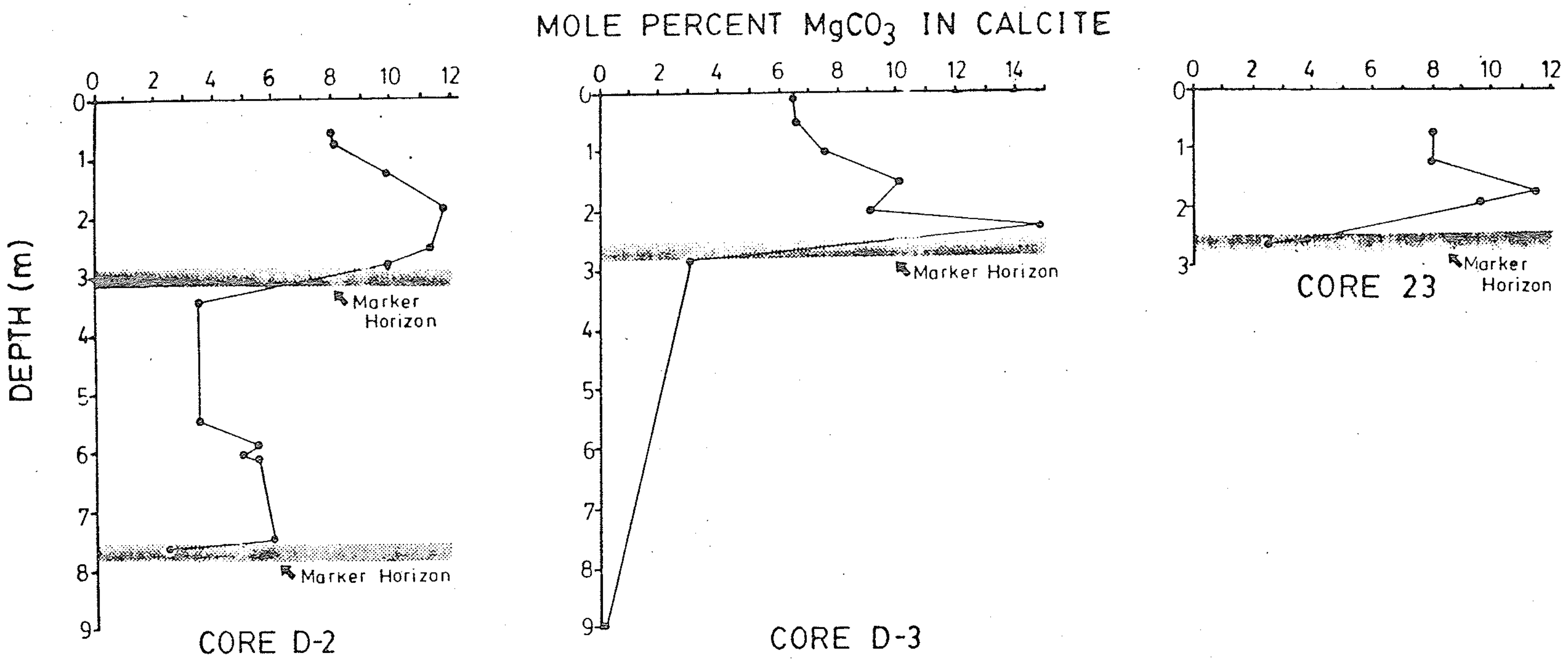

Figure 6-10. Variation in the mole percent $MgCO_3$ in disordered Mg-calcite in cores D-2, D-3 and 23. In core D-2, Unit B extends from about 10 m up to 8.9 m; Unit C from 8.9 m to 7.6m; Unit D from 7.6 m to 3.0m; Unit E from 3.0 m to 1.3 m; and Unit F from 1.3 m up to the top of the core. In core D-3, Unit A extends from the base of the core up to 8.8 m; Unit B from 8.8 m to 7.5 m; Unit C from 7.5 m to 6.7 m; Unit D from 6.7 m to 2.5 m; Unit E from 2.5 m to 1.0 m; and Unit F from 1.0 up to the top of the core. In core 23, Unit D extends from the base of the core up to 2.7 m; Unit E from 2.7 m to 1.4 m; and Unit E from 1.4 m up to the top of the core.

However, this conclusion should be viewed with caution because the organic productivity-calcite precipitation linkage in the present-day situation has not been established beyond any doubt. It is possible that purely physical and/or chemical factors may be responsible for the calcite precipitation and, hence, the stratigraphic variation in the abundance of calcite. It is also possible that the calcite profile could conceivably be the result of diagenetic changes. For example, dissolution of the calcite in the subsurface could be invoked to explain the decreasing trend with depth; with greater depth in the sediment, progressively more time has been available for the pore water to redissolve the calcite, resulting in a decrease in abundance of the calcite downward in the section. However, there is no data to support or refute either of these two latter suggestions.

6.3.4.3 $MgCO_3$ content of calcite

Several hypotheses can be constructed to explain the stratigraphic variation in the mole percent $MgCO_3$ parameter. These can be grouped into three main families of causal mechanisms: (a) in situ water chemistry and/or temperature change, (b) variation in inflowing stream chemistry or volume, and (c) variation in inflowing groundwater chemistry or volume. Although these various groups of possible hypotheses will be discussed separately, they are all closely interrelated, and variations in one probably will exert a considerable feedback effect on the lacustrine situation and cause changes in the other factors.

It is generally held that $MgCO_3$ incorporation into the calcite lattice is a response to high Mg/Ca ratios of the water in which the calcium carbonate is forming. Both field and laboratory investigations (e.g., Müller, 1970; Müller and Wagner, 1978; Winland, 1969; Katz, 1973; Fuchtbauer and Hardie, 1976) have convincingly shown that the degree of Mg^{++} uptake by the calcite lattice is clearly related to two main factors: (a) the Mg/Ca molar ratios of the precipitating solution and (b) temperature. In general, higher values for either (or both) of these factors favor higher amounts of Mg^{++} incorporation.

Although there seems to be definite physical and chemical constraints which limit the applicability of this relationship (e.g., calcite with more than about 18 to 20 mole percent $MgCO_3$ is so unstable that aragonite becomes the preferred crystal form for $CaCO_3$; Müller et al, 1972; Berner, 1966, 1978; Winland, 1969; Fold and Land, 1975; see also discussions in Thorstenson and Plummer, 1977; Lafon, 1978; Garrels and Wollast, 1978), within the range of $MgCO_3$ mole percentages and temperatures recorded in the Lake Manitoba sediment and water this simple higher Mg/Ca ratio (or higher temperature) - greater Mg incorporation generalization probably applies.

1. In situ temperature or chemical changes. One of the most straightforward mechanisms to account for stratigraphic variation in the $MgCO_3$ content of the calcite is simply to alter the temperature of the lake water in which the calcite was precipitating. Using the data shown in Figure 6-8, it can be seen that if the Mg/Ca ratio of today's lake water (about 3) is used, a water temperature of approximately 50°C is required to account for a 10 to 14 mole percent $MgCO_3$ calcite species such as occurs in the sediment immediately above the uppermost marker horizon. Under today's climatic regime such temperatures are probably well in excess of reasonable maximums. However, during the warmer and

drier Hypsithermal interval (approximately 9000 to 2500 years B.P.; Deevey and Flint, 1957), temperatures may have been considerably higher. Furthermore, the temperatures at the surface of the earth may be considerably higher than those of the atmosphere.

In addition to a differing temperature regime in the lake, the Mg/Ca ratio of the water also may have varied. According to Figure 6-8, an increase in the Mg/Ca ratio from today's value of 3 to about 4 will account for the 10 to 14 mole percent $MgCO_3$ in the calcite if the precipitate was forming in water temperatures of only about 28°C - values which are often exceeded in central Manitoba water bodies today.[1]

The cause of such a variation in the Mg/Ca ratio of the lake water is not known. It was suggested in Section 6.3.2 that the high Mg/Ca ratio of today's South Basin water (relative to the inflowing water) can be explained by the preferential extraction of Ca^{+2} ions from the lake through $CaCO_3$ precipitation. Continued depletion of the Ca^{+2} pool and, hence, enrichment of Mg^{+2} relative to Ca^{+2}, results in the high Mg/Ca ratios in the basin and, of course, in the precipitation of high-Mg calcite.

If this mechanism is operable in the lake today, it seems logical to attempt to apply it to the Holocene stratigraphic record in the basin. This was done by Müller and Wagner (1978) in the carbonate stratigraphy of cores from Lake Balaton, Hungary. They contend that the level of $MgCO_3$ incorporation into the calcite lattice is indicative of the water levels of the lake and, hence, is an expression of the relative "dryness" of the Balaton region during the past 8000-year period. Their reasoning is as follows:

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[1] Goff (1971) reports frequent daily maximum water temperatures in excess of 30°C in the Shoal Lakes, 20 km east of the South Basin.

During the low water periods, which are due to an increase in the evaporation/precipitation + inflow ratio, Lake Balaton becomes a closed basin. However, river inflow maintains a source of salinity, and continuous calcite precipitation in the basin raises the Mg/Ca ratio of the water. As outlined above, the result is an elevated level of $MgCO_3$ incorporation into the calcite lattice. Certainly implied in this scheme but never specifically mentioned by the authors is the requirement that the rate of calcite precipitation must actually increase during the low water period. That is, in order to adjust the Mg/Ca ratio of the lake water upward, which they and Müller et al (1972) contend is primarily responsible for the increased $MgCO_3$ incorporation in the calcite, relatively more Ca must be extracted from the water than was previously being taken out by the precipitation process (assuming the inflow characteristics do not change). The result should, of course, be a substantial increase in calcite abundance in the sediment during these low level stages.

However, in Lake Manitoba, the highest mole percentage of $MgCO_3$ in the calcite (immediately above the two uppermost basin-wide marker horizons Figs. 6-9 and 6-10) are associated with generally lower percentages of Mg-calcite in the sediment. While this phenomenon is readily explained (i.e., the higher Mg^{++} and other ion concentrations in the water are likely inhibiting calcite crystal formation), it is not in keeping with the hypothesis of preferential Mg^{++} enrichment due only to calcite extraction of Ca^{++}.

It is, of course, possible that the Ca^{++} ions could be selectively extracted from the water by other means. In situ precipitation of more evaporitic Ca-bearing minerals such as gypsum ($CaSO_4 \cdot 2H_2O$) or glauberite

($CaSO_4 \cdot Na_2SO_4$) or any one of numerous calcium phosphates (e.g., chlorapatite, $Ca_{10}Cl_2(PO_4)_6$; fluorapatite, $Ca_{10}F_2(PO_4)_6$; hydroxylapatite, $Ca_{10}(OH)_2(PO_4)_6$; voelckerite, $Ca_{10}(PO_4)_6$; carbonate-apatite, $Ca_{10}CO_3(PO_4)_6$; see also McConnell, 1950) could lead to higher Mg/Ca ratios in the water and, hence, higher $MgCO_3$ incorporation. However, the high solubilities of many of these mineral species relative to $CaCO_3$ would preclude the possiblity of being able to substantially enrich the solution in Mg <u>before</u> extensive calcite precipitation occurred.

Alternatively, the mechanism could conceivably work in reverse. During the low level episodes of the lake, a wide variety of evaporitic salts would be precipitated in the final stages of complete drying and desiccation. Initially, low-Mg calcite, high-Mg calcite, and possibly aragonite would form, followed in the latter stages of brine concentration by a variety of more soluble chlorides, sulfates, and carbonates depending upon the precise ionic balance of the water (see Eugster and Hardie, 1978; Hardie et al, 1978; Surdam and Sheppard, 1978, for reviews).

Then, with reflooding of the lake, several things happen. Substanti reworking of the previously deposited sediment would occur probably resulting in erosion and loss of the uppermost material of the marker zones. Also, the most soluble evaporitic minerals, which probably formed a thin crust on the lacustrine clays during the desiccation periods, would redissolve as more humid conditions returned (either by the actual reflooding of the lake or by higher rainfall). The dissolution of any highly soluble magnesium-bearing sulfates (e.g., epsomite, $MgSO_4 \cdot 7H_2O$; hexahydrite, $MgSO_4 \cdot 6H_2O$; kiesirite, $MgSO_4 \cdot H_2O$), chlorides (e.g., bischofite, $MgCl_2 \cdot 6H_2O$; carnallite, $MgCl_2 \cdot KCl \cdot 6H_2O$), or carbonates (magnesite,

$MgCO_3$; high-Mg calcite) could lead to elevated Mg/Ca ratios in the water because most of the calcium would still be associated with the relatively less soluble low-Mg calcite. Thus, when the physical and chemical conditions of the lake water were again such that $CaCO_3$ precipitation could occur (probably in response to seasonally high productivity levels), relatively high magnesian calcite (9 to 14 mole percent) would be precipitated

2. Groundwater input variation. In addition to these changes in the water chemistry of the lake caused by selective precipitation, dissolution, or temperature variation, the water entering the lake via groundwater discharge may have fluctuated generating changes in the $MgCO_3$ incorporation into the calcite. However, as is evident from Section 3.6.3, the present-day chemical nature and flow characteristics of most of the groundwater systems surrounding the lake, and their roles in controlling the lake's water chemistry and in dictating the Mg/Ca ratio of the lake are only poorly known. Thus, any discussion of the changing nature of these groundwater systems through time is largely speculative.

The variation necessary to account for the implied relatively higher Mg/Ca ratios might be due to the introduction, or at least increased relative contribution, of groundwater with a distinctly high Mg/Ca ratio. Gilliland (1965), for example, has identified a groundwater chemical type characterized by Mg/Ca ratios of about 2 (his type 5 and the only group of his 10 groundwater types with Mg/Ca ratios greater than 1.2) in shallow alluvial silts just north and west of Portage la Prairie. Although he is somewhat ambiguous about the origin of this water type[1] and does not

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[1] Gilliland (1965) suggests that this water type may represent a mixing of essentially two end members: water from the lacustrine clay and silt (with a strong bedrock aquifer imprint) and water from the alluvial sands. However, as both of these types have relatively lower Mg/Ca ratios, it is difficult to understand how simple mixing, without an additional selective precipitatic or dissolution mechanism, can explain the increase in Mg/Ca.

attempt to explain this high Mg/Ca ratio, it is possible that the increased influence of this chemical type of groundwater on the lake could help raise the Mg/Ca ratio of the water. Subsequently, a change in groundwater flow patterns resulting in a decreased volume contribution of this chemical type could then be invoked to account for the decrease in Mg/Ca ratios as recorded by the decreasing $MgCO_3$ incorporation in the calcite of the sediment.

Examination of the groundwater chemistry data supplied by Cherry et al (1971, p. 330) shows that portions of the shallow aquifer system between Delta Marsh and Portage la Prairie are characterized by high Mg/Ca ratios. This is attributed (p. 329-331; see also Cherry, 1972), in part, to (a) groundwater dissolution of magnesium-bearing evaporitic salts (specifically magnesium sulfates) which were emplaced in the Quaternary deposits as a result of an earlier period of strong upward flow of the more saline bedrock aquifer system, and, in part, to (b) cation exchange of Ca^{++} for Na^{+} and Mg^{++} on the montmorillonitic clay minerals of these deposits.

If these suggestions are valid, then both mechanisms (i.e., groundwater dissolution of soluble salts and cation exchange) become variables which could fluctuate through time to account for chemical differences in the water being supplied to Lake Manitoba. For example, regarding (a), it is probable that the regional, saline bedrock groundwater flow component assumed a relatively dominant role in the watershed during the times of greater aridity because the freshwater, shallow aquifer flow component, which depends on local recharge areas, would be greatly reduced. These concentrated brines might then have precipitated various Mg-bearing sulfate and chloride salts within the pore spaces of the late Pleistocene and Holocene sediments which subsequently would be readily dissolved by the later re-introduction of the local flow system. Drever and Smith (1978) and Jones, Eugster, and Rettig (1977) stress the importance of this type of precipitation-dissolution process in the chemical evolution of brines in closed basins.

Also, because the ionic ratios and activities of the water control, to a large degree, the cation exchanges between the solution and the montmorillonitic clays (see Garrels and Christ, 1965, Chapter 8) this variation in regional (saline) versus local (fresh) flow components might be used to derive the necessary Mg/Ca ratio of the groundwater and, hence, the lake water.

3. River input variations. In addition to the groundwater inflow variation, the other main source of dissolved ions to Lake Manitoba - the surface stream inflow - could have changed through time to account for the fluctuation in Mg content of the precipitated calcite. For example, if the Assiniboine River were a source of Mg (or high Mg/Ca ratio water), it is evident that the mole percent $MgCO_3$ in the calcite profile of the cores might readily be interpreted simply in terms of the Assiniboine River's variable contribution to the lake. However, as pointed out in Section 3.8, today's Assiniboine River water does not have a high Mg^{++} ion concentration or a high Mg/Ca ratio.

The Mg/Ca ratio of the river water could be increased by any of the precipitation, dissolution, or cation exchange mechanisms mentioned above. As shown by Green and Smeck (1979), for example, the carbonate equilibria for the Maumee River system in northwestern Ohio are quite dynamic, resulting in variable in situ (that is, within the stream) carbonate precipitation (their secondary calcite) and dissolution depending mainly on algal productivity in this lotic environment. As a generalization, however, highest relative amounts of "secondary" calcite occur during periods of low flow in the river basin (Wall and Wilding, 1976). This is probably due to increased ionic concentrations which are basically the result of decreased surface runoff dilution of the river system (Jones, Smeck, and Wilding, 1977).

It is reasonable to suggest that the Assiniboine River, likewise may have been characterized by lower flows and higher salinities (relative to today) during periods of greater aridity. Precipitation of calcite in the stream, possibly controlled by algal productivity altering the CO_2 budget of the river water, would result, as discussed above, in raising the Mg/Ca ratio of the fluvial media and, if the Assiniboine River inflow was a major factor in the South Basin's hydrologic budget, also in raising the Mg/Ca ratio of the lake water.

Finally, mineral precipitation need not necessarily be involved to account for the Mg/Ca ratio increase of the old Assiniboine River. As suggested by numerous researchers (e.g., Eugster and Jones, 1979; Drever and Smith, 1978; Miller and Drever, 1977; Smith and Drever, 1976) pronounced solute fractionation as well as increased solute load can occur as dilute surface water (runoff and stream water) selectively dissolves the most soluble constituents of efflorescent crusts formed in the drainage basin soils during a more arid episode.

6.3.4.4 Dolomite

The dolomite content of the surficial sediment of Lake Manitoba is interpreted to be entirely detrital in origin, having been derived from wave and stream erosion of the dolomite-rich glacial sediments of the watershed. This interpretation, as opposed to in situ dolomitization of pre-existing carbonates in the sediment, was based mainly on three lines of reasoning: (a) the abundance of dolomite in the glacial sediments and bedrock of the watershed, (b) the suggestion of size segregation of the dolomite in the silt fraction of the modern bottom sediments, and (c) the lack of X-ray evidence of cation-disordered protodolomite in the sediments.

The dolomite in the subsurface sediments of Lake Manitoba is similarly interpreted as detrital for two of the same reasons. The detailed carbonate X-ray analysis of over fifty samples from cores D-1, D-2, D-3, and 23 has failed to identify any type of dolomite other than "stoichiometric," 2.89 Å dolomite which is exactly like the dolomite in the tills and bedrock of the area. Likewise, the abundance of dolomite in the tills south of Lake Manitoba (see Fenton, 1970, p. 17) would suggest that there is an ample source of glacier-comminuted detrital dolomite in the watershed.

Accepting that the dolomite of Lake Manitoba sediments is entirely detrital in origin, the dolomite profile in the three deep cores in the basin can be viewed with two basic processes in mind: (a) loss of dolomite through chemical weathering, and (b) size segregation. The dolomite profiles in each of the three long cores shows a general decrease in abundance upward in the sediment column. I believe that this is due to a gradual loss of this carbonate mineral with time through dissolution while still in the watershed soils. In a study of the soils developed on the strongly calcareous tills of the Interlake Area approximately 40 km east of the South Basin, Ehrlich and Rice (1955) show a striking loss of carbonate material in the A and B horizons of the profile. Similar leaching of the dolomite (and calcite) in the upper soil horizon has been reported by Mills and Smith (1971) in the Grahamdale area north of the South Basin and by Ehrlich et al (1957) in the Carberry map sheet immediately south of Lake Manitoba. Thus, with time and increased chemical weathering at the dolomite source (i.e., mainly tills), smaller amounts of the carbonate mineral will be available for transport and deposition in the lake.

Superposed on this is the effect of size segregation of the detrital dolomite grains. It was shown that in the surface sediments of the South Basin, the dolomite content exhibits a strong positive correlation for the medium and coarse silt fractions and a strong negative association for the fine silt and coarse clay-sized material. This was used to confirm Driemanis and Vagner's (1971) terminal grade concept for glacier-comminuted dolomite. Similarly, it is evident in the stratigraphic profiles of D-1, D-2, and D-3 that, in general, dolomite values are highest in sediment with a higher silt content. For example, in core D-1 (see Figs. J-1 and J-2) below a depth of about 11.5 m, the dolomite content is low corresponding to the low silt-high clay content of the sediment. Between about 6 m and 9.75 m depth the sediment contains a higher amount of dolomite corresponding to a generally higher silt content. Similar trends are evident in the other two long cores. That dolomite does not show a statistically significant correlation with the textural parameters in cores D-1 and D-2[1] can be explained by the above mentioned gradual decrease in the abundance of this detrital carbonate mineral with time. That is, although the upper several metres of the cores are silt-rich, they do not show strikingly high dolomite contents because much of the dolomite has already been lost at the source by carbonate leaching and possibly dissolution while in transport to the deposition site.

6.3.4.5 Summary of interpretations

The interpretations of the fluctuations in the profiles of the various carbonate parameters in cores of the post-glacial sediment record of Lake Manitoba can be summarized as follows:

1. All of the dolomite and a portion of the total amount of calcite in the sediment record is detrital in nature, having been derived primarily from wave action along the shoreline of the lake and by watershed stream erosion of the calcareous (but dominantly dolomitic) surficial sediment of the area. The detrital calcite content is minor (amounting to less than about 4%) and shows essentially no systematic variation in the section. This is due to the low amount of detrital calcite relative to dolomite available in the watershed sediments. The dolomite profile is believed to reflect (a) the effect of size segregation of the mineral with generally higher dolomite contents associated with higher silt percentages, and (b) dissolution and loss of dolomite from the source (tills) by soil forming processes over the past 10,000 to 12,000 years.

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[1] Linear correlation coefficients for the dolomite-silt variable pair in D-1, D-2, and D-3 are 0.30, 0.34 and 0.49. These r values for both D-1 and D-2 are not significant at $\alpha = 0.02$; the D-3 correlation is significant at $\alpha = 0.001$.

2. Most of the calcite in the sediment above Unit A is authigenic in origin, having been physicochemically precipitated in the lake water possibly in response to increasing levels of organic productivity in the lake.

3. The variation in the amount of $MgCO_3$ incorporated into the precipitating calcite lattice can best be explained by the interaction of several plausible mechanisms:

(a) Increased water temperature associated with shallower water and warmer, drier conditions. This results in the incorporation of significantly higher amounts of $MgCO_3$ in the calcite lattice without necessarily substantially changing the Mg/Ca ratio of the lake water.

(b) Precipitation of evaporative salts and particularly very soluble Mg-bearing sulfates, chlorides, and carbonates associated with the latter phases of lake desiccation. Subsequent reflooding of the lake after drying results in selective re-solution of the most soluble salts, thus raising the Mg/Ca ratio of the lake water.

(c) Similar precipitation of soluble salts in interstitial pore spaces of the Pleistocene and Holocene sediments at the times of aridity due to an increased influence of the regional, saline groundwater flows relative to the less brackish, local flow components. Subsequent changes in the hydrologic balance caused by less arid conditions re-established the local, relatively fresh groundwater systems resulting in dissolution of the highly soluble minerals. This dissolution plus the probable exchange of Ca^{++} for Mg^{++} on the montmorillonitic clays of the deposits results in a net increase in the Mg/Ca ratio of the groundwater which probably made up a significant proportion of the lake's hydrologic budget at this time.

(d) Precipitation of calcite in the lacustrine environment and particularly in rivers supplying water and ions to the lake results in the selective loss of Ca^{++} and an increase in the Mg/Ca ratio.

Cation exchange studies on the clays of Lake Manitoba as well as more detailed mineralogical investigations in correlable units outside of the Lake Manitoba basin should help resolve the relative magnitudes of these various influencing factors.

6.4 INTERPRETATION OF CLAY MINERALOGY

Compared to its sister lake, Lake Winnipeg (see Kushnir, 1971; Brunskill and Graham, 1979), Lake Manitoba offshore sediments contain rather low amounts of clay-sized material. However, this clay-sized fraction and the associated clay minerals of the sediment are a significant source of variation in the modern sediments on the lake floor (see Appendix G). The eastern third of the basin contains mainly illite and kaolinite + chlorite, with little or no detectable expandable lattice clays (see Figs. D-19 to D-21). The remaining portion of the sampled basin (after disregarding the relict sand area of the southwest) generally contains subequal proportions of the three groups with the expandables being slightly more abundant than the other two groups. Although the constraints imposed by using a closed data set such as this (that is, all three clay mineral groups must sum to 100%) may play a role in overly emphasizing what are actually considerably more subtle mineral differences; it is, nonetheless, felt that these trends are real.

In Lake Winnipeg, Kushnir (1971, Table VIII, p. 61-62) shows that the "relict" glacial and glacio-fluvial deposits exposed in the south basin are relatively low in montmorillonite and high in illite and kaolinite + chlorite. Similarly, in Lake Manitoba, a sample of a gravelly silty clay sediment immediately underlying the "relict" gravelly sand at location 21 (see core description, Appendix I) showed a relatively low percentage of expandables (6%) and high illite and kaolinite + chlorite values. Thus, erosion of this sediment and redistribution in the eastern portion of the basin would account for the low expandable-high illite and kaolinite + chlorite imprint of the modern deposits of the area.

The sediment of the western and central portion of the basin, however, is considerably higher in expandable clays, probably because the clay mineral assemblage imprint is derived more from the fluvial influx to the basin. The Whitemud River and Portage Diversion (via the Assiniboine River) both drain areas in which the bedrock, surface sediments, and soils are relatively high in montmorillonite (Madden, 1974). Thus, the only two sizeable streams delivering sediment to the South Basin today should be enriched in montmorillonite relative to the proposed eastern glacial sediment sources.

Stratigraphically, the relative abundances of the three groups of clay minerals show often striking but very erratic fluctuations with depth (see Figs. J-3, J-8, and J-13). Furthermore, there is very little similarity in the variations of these profiles between the three long cores in the basin. This lack of consistency and "trend development" within the clay mineral profiles precludes any type of reasonable interpretation of these minerals in the post-glacial sediment record of Lake Manitoba.

In summary, any interpretation of the clay mineralogy of the post-glacial sediments in Lake Manitoba is hampered by (a) a dearth of information in terms of mineral assemblages of the likely sources and (b) a wide variety of separating, mounting, identification, and semi-quantitative calculation techniques. Comparison and identification of quantitative differences in clay mineral suites in the sediments of the Canadian Prairies is often more a study in methodology rather than any inherent mineralogical variation. Numerous investigations have documented the striking effects of variation in such factors as mounting techniques, amount and thickness of clay film irradiated, and "weighting" factors (Last, 1974; Stokke and Carson, 1973; Johns et al, 1954; Gibbs, 1965).

One of the primary uses of clay mineral data in higher latitude, temperate regions is as a provenance indicator. However, for such a study to be effective, significant differences in source materials must exist. Such differences do not exist in the western Canada Plains (see Kushnir, 1971, p. 48-52, for review). Consequently, the clay mineral assemblages of the surficial sediments of the region are qualitatively very similar. Most quantitative differences are very subtle and difficult to interpret in light of a realistic appraisal of the determinative accuracies involved.

6.5 INTERPRETATION OF QUARTZ AND FELDSPAR CHANGES

The feldspar content in each of the long cores in the basin shows a general decrease in abundance upward in the section (see Figs. J-2, J-7, and J-13). This is probably in response to the increased time available for chemical weathering of the feldspar at the source (mainly in the soils of glacial sediments of the watershed). The small change in the quartz content of the cores probably reflects the ubiquitous nature of this mineral in the glacial sediments of the watershed (Wicks, 1965; Fenton, 1970; Last, 1974).

The general decrease in abundance of both quartz and feldspar in the offshore direction within the modern bottom sediments of the basin (see Figs. D-12 and D-13) is a reflection of size segregation. As discussed in Appendix G, it is generally accepted that both of these detrital minerals tend to be enriched in the coarser fraction of the sediment (see also Fig. 6-4).

6.6 INTERPRETATION OF CHANGES IN CHEMISTRY

The lack of significant and consistent temporal variation in most of the chemical variables analyzed in the cores is surprising as well as somewhat disappointing. Overall, the chemical parameters analyzed gave little new insight into the paleolimnology and/or changes in watershed characteristics with time that could not have been gleaned from analysis of the mineralogical and physical variables alone. This is probably a reflection of the inability of chemical analysis of the solid sediment phase to adequately detect subtle changes which may be more readily reflected by pore water analysis (Jones and Bowser, 1978, p. 183). In the case of the more recent sediments, an absence of significant human introductions accounts for the absence of the type of changes observed in regions of greater population density and industrial development.

The chemical analyses do, in general, confirm the mineralogical trends. For example, the calcium profiles closely follow the calcite and total carbonate variations ($r = 0.82$ and 0.87 respectively; see Figs. J-2, J-4, J-7, J-9, J-12, and J-14) confirming the obvious supposition that in the sediment's multi-mineralic agglomeration, Ca tends to be combined primarily with calcite. Similarly, the Mg content varies in sympathy with the dolomite abundance, confirming the $CaMg(CO_3)_2$ linkage. The significant correlation shown by Fe and K for clay-sized material, and for illite in particular (see Table 4-4), supports the fixed cation content and formula calculations of Wicks (1965, p. 161-163) for illite (and mixed-layer illite-montmorillonite) in Lake Agassiz clays, in addition to confirming the strong adsorptive nature of clay-sized particles for these metals. The association of Na and K with the feldspar content of the samples ($r = 0.63$ and 0.55, respectively) is also indicative of the dominant cation content of the plagioclase and potassic feldspars in the sediment.

The slight increase in phosphorous content upward in the cores can be shown to relate significantly to calcium, calcite, and organic matter variations ($r = 0.51$, 0.42 and 0.56,respectively). This is probably due to phosphate adsorption onto the precipitating $CaCO_3$ crystal surfaces as shown to occur in Lawrence Lake, Michigan, by Otsuki and Wetzel (1970). This, in turn, could possibly be controlled by gradually increasing levels of organic productivity in the lake. The alternative suggestion, that the P is associated with a phosphate mineral, such as the ferrous phosphate, vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$) or numerous varieties of apatite, is rejected because these crystaline components were not identified in the sediment.

Of the trace metals analyzed only Zn and Hg show significant fluctuations above baseline values in the cores. Although extreme care was taken to prevent or eliminate possible contamination of the sediment samples, the highly erratic variation of the Zn profile in cores D-1 and D-2 (see Fig. J-5 and J-10) is obviously suggestive of contamination by contact with the galvanized steel Shelby tube core barrels.

Analysis of mercury did show that (a) the concentration in the modern bottom sediment is higher at the south end of the basin just offshore from the Diversion than it is at three other locations farther north (see Fig. D-34) and (b) the surface sediment (0-2 cm) contains slightly higher amounts of Hg relative to subsurface sediment in four to six sites examined (Table 6-3) although at most of these sites the surface increase is only 10 ppb and probably is not significant. However, in core 40, which is the site nearest to the Portage Diversion, the increase is from 40 to 170 ppb. It is evident from the spatial distribution of these results that the Portage Diversion is a likely source for this higher level of mercury. However, as shown in Table 6-4, the values of Hg (as well as all other trace elements) are well below those cited in the literature for anthropogenic loading and, therefore, do not justify the designation "enrichment."

Table 6-3. Mercury content of sediment cores from the South Basin of Lake Manitoba.

Depth (cm)	Hg (ppb)
Core 9	
0-2	10
6-8	10
8-10	20
10-12	20
14-16	20
20-22	20
40-42	20
80-82	10
Core 23	
0-2	20
10-12	10
120-123	10
260-263	10
Core 34	
0-2	70
12-14	60
Core 36	
0-2	70
8-10	60
Core 40	
0-2	170
2-4	80
6-8	60
12-14	80
23-26	60
36-40	40
Core D-1	
0-2	20
340-343	20
740-743	20

Table 6-4. Trace metal content of Lake Manitoba sediment compared with sediment from other lakes. Hg content in ppb; all other values in ppm. B is the baseline value of core material either reported by the author or estimated from their data. S is the average surface sediment value. The anomalous Zn value of 1115 at site 28 in Lake Manitoba has been eliminated in calculating S. Data from Allen and Brunskill (1977; Lake Winnipeg), Frye and Shimp (1973; Lake Michigan), Nriagu et al. (1979; Lake Erie, Cu, Zn, Pb, Cd); Kemp and Thomas 1976; Lake Erie, Hg; Lake Ontario; Lake Huron), Hakanson (1977; Lakes Vanern and Vattern, Sweden).

	Lake Manitoba		Lake Winnipeg		Lake Michigan		Lake Erie		Lake Huron		Lake Ontario		Lakes Vanern & Vattern	
	B	S	B	S	B	S	B	S	B	S	B	S	B	S
Cu	28	23	38	42	20	37	29	121	58	58	44	98	25	30
Zn	77	55	195	25	66	206	142	337	94	197	104	475	100	500
Pb	<20	<20	20	203	20	88	68	113	39	129	29	220	40	97
Hg	33	60	65	101	50	200	78	855	150	210	78	2350	30	1120
Cd	<1	<1	1	2	-	-	1	5	1	2	1	5	0.5	1.6

SECTION 7

CORE CHRONOLOGY AND MODERN SEDIMENTATION RATES

7.1 RADIOCARBON DATES AND METHOD OF CORRECTION

The results of the ten radiocarbon dates of organic matter in Lake Manitoba cores are shown in Table 7.1. Also listed are two additional dates: one reported by Fenton (1970, p. 57) and Sproule (1972, p. 24) and one reported by Fenton (1970, p. 57; collected by J. A. Gilliland in 1963). The reader is referred to Gilliland (1965, p. 39) and Sproule (1972, Figure 6)for details of the stratigraphic setting of these two additional dates.

It is evident from examination of the results in Table 7-1 that several of the lab dates are considerably older than would seem reasonable, given the general chronostratigraphic picture developed in other parts of the Lake Agassiz basin by previous investigators (e.g., Teller, 1976a;Teller and Fenton, 1980; Moran et al, 1976; Arndt, 1975, 1977; Harris et al, 1974). While dates in excess of 29,000 to 30,000 years B.P. could conceivably be explained by suggesting that these lacustrine deposits represent a ponding and depositional event pre-dating Lake Agassiz (i.e., Middle Wisconsinan), it is much more reasonable, in light of the stratigraphic relationships observed in the Lake Manitoba basin and the absence of an intervening till or major unconformity, to conclude that these anomalous dates are contaminated with old carbon.

The presence of pre-Quaternary microfossils in the lower 8 m of sediment in core D-1 (E. M. V. Nambudiri, personal communication, 1979) provides evidence strongly suggesting probable old carbon contamination. As suggested by Nambudiri et al (1980), these old microfossils were

TABLE 7-1

Radiocarbon dates from Lake Manitoba sediments and adjacent areas. All dates are on finely desseminated organic material except I-1255 which is on wood. n.d. indicates not determined.

Lab date (yrs. B.P.)	Lab no.	Core location & depth of date	% old microfossils	Corrected date
2,555 ± 130	GX-5644	D-1 at 129-135 cm	0	no correction
4,465 ± 165	GX-5645	D-1 at 320-327 cm	0	no correction
9,550 ± 550	BGS-567	D-1 at 560-580 cm	16	7,000 yrs. B.P.
10,170 ± 225	GX-5646	D-1 at 716-722 cm	26	8,000 yrs. B.P.
29,300 + 2780 - 2660	GX-6300	D-1 at 1010-1040 cm	46-63	11,000 yrs. B.P.
> 37,000	GX-5647	D-1 at 1341-1352 cm	80	12,000 yrs. B.P.
6,240 ± 180	GX-5648	D-2 at 354-361 cm	0	no correction
11,075 ± 350	GX-5649	D-2 at 706-713 cm	7	7,700 yrs. B.P.
8,770 ± 220	GX-5650	D-3 at 720-730 cm	22	8,300 yrs. B.P.
10,150 ± 270	GX-5651	D-3 at 874-884 cm	5	10,000 yrs. B.P.
2,400 ± 230	S-446	Cadham Bay at 102-106 cm (Sproule, 1972)	n.d.	-
3,375 ± 250	I-1255	5.6 km S of Oakland at 6 m (Fenton, 1970, p. 57)	n.d.	-

probably derived originally from Cretaceous bedrock of the watershed. Because this sequence of Mesozoic shales also includes several particularly organic-rich zones as well as low grade coal (see Section 3.3.2), it seems reasonable that old (i.e., pre-Quaternary), finely-disseminated organic carbon could be a source of contamination in Lake Manitoba sediment. Nambudiri et al (1980), therefore, have suggested that dates obtained from sediment in Lake Manitoba which contains pre-Quaternary microfossils should be corrected using the relative abundance of these old microfossils as a guide to the amount of old non-carbonate carbon contamination (Fig. 7-1). The corrected dates using this method are shown in Table 7-1.

7.2 MODERN SEDIMENTATION RATES

7.2.1 General

Within the past ten years there have been numerous references to increased sedimentation rates and changes in the modern sedimentary regime of the South Basin of Lake Manitoba. Kennedy (1949) was one of the first to make reference to sedimentation rates and refers to "verbal information" that the lake has filled about one foot (0.3 m) in the past 50 years (= linear sedimentation rate of 0.6 cm year^{-1}). Hochbaum (1965) points toward a changing sedimentary facies distribution in the South Basin and cites fishermen's and cottage owners' claims that once-hard, sandy bottom areas of the lake are now soft and muddy. This, Hochbaum contends, is due to a significant increase in the sediment load to the lake caused by the extensive network of artificial drainage ditches surrounding the basin. Similarly, Crowe (1974a, b) points toward increased watershed erosion due to the drainage canals and also alludes to Bajkov's (1930) work which refers to Lake Manitoba's "hard" bottom. Most recently, Derksen

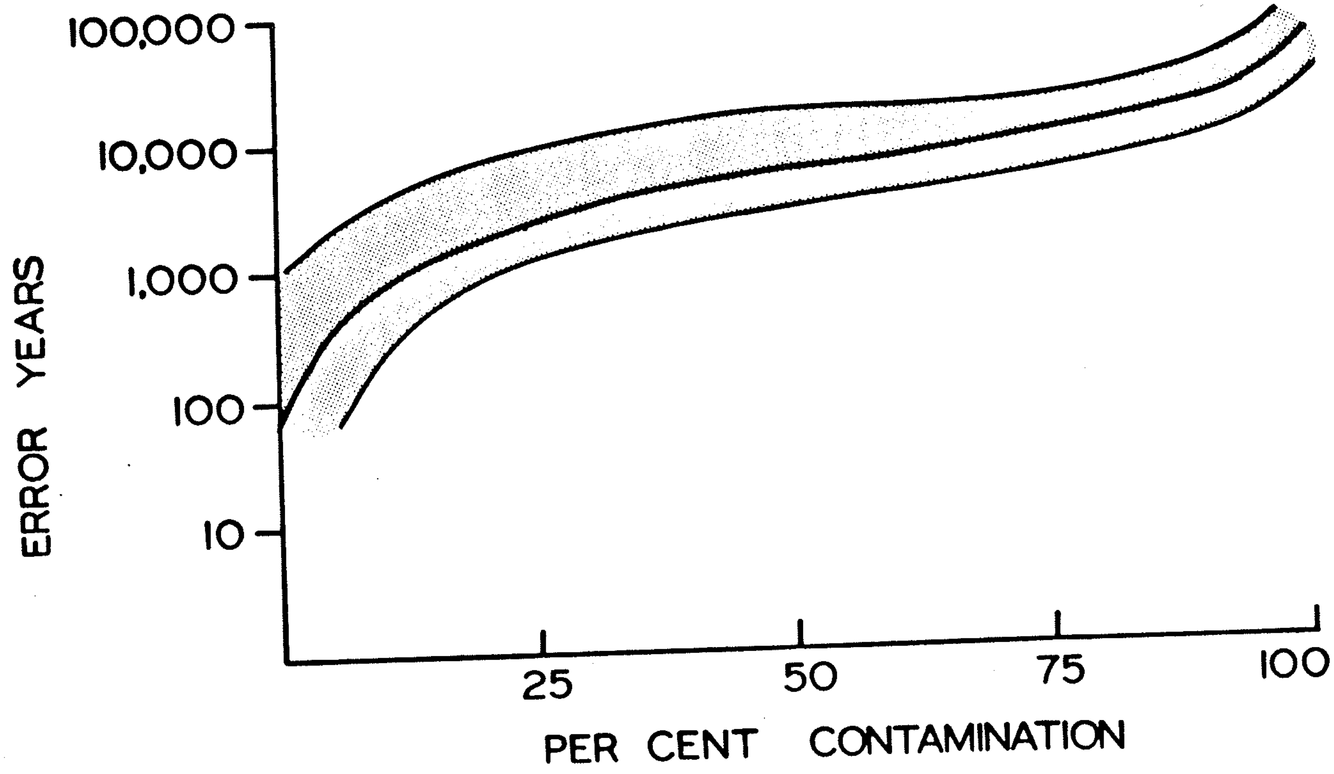

Figure 7-1. Curve used for correcting radiocarbon dates which are in error because of incorporated "old" organic carbon. The shaded area on either side of the correction curve represents the latitude of "error years" that may be used to calculate the true age.

(1978, p. 23) cites K. H. Doan (personal communication) in connection with interviews with veteran commercial fishermen of the lake. They suggest that many of the hard bottom areas of the South Basin, which previously had been excellent walleye spawning grounds, have disappeared under a thick layer of sediment - the direct result, they submit, of increased drainage from surrounding agricultural lands.

7.2.2 Ambrosia Rise Sedimentation Rates

In an attempt to help quantify these alleged changes in sedimentation characteristics and rates, six sediment cores in the South Basin were "dated" approximately by the *Ambrosia* (ragweed) pollen rise. This pollen work was done by Dr. E. M. V. Nambudiri (cores D-1, D-2, D-3, 39, and 40) and Mr. D. Slater (cores 23 and D-1). Details of the nature and sharpness of the *Ambrosia* rise horizon can be found in Nambudiri et al (in preparation).

The rise of the ragweed pollen in lake sediments has been used elsewhere as an indication of land clearing and European settlement (see Section 2.3.3). In the Lake Manitoba drainage basin area, rural settlement and cultivation of the most favorable land progressed rapidly after 1872 . This date coincides with the passing of the Dominion Lands Act which ended the fur trading era of western Canada and marked the start of extensive agricultural settlement (Warkentin and Ruggles, 1970). Weir (1960) presents a series of maps compiled by J. Warkentin showing the settlement pattern of the region between 1870 and 1901. Within this time the population of southern Manitoba increased by a factor of more than twenty (Warkentin and Ruggles, 1970) with much of the agricultural land of the Portage Plain settled by 1880. Jenkins (1974) further points out that settlement of the Whitemud River watershed area was well advanced by 1881. This settlement progress was also greatly enhanced by the construction of railways, initially linking southern Manitoba to Minnesota in 1878, and finally by completion of the CPR Transcontinental line across the southern Prairies in 1881. Thus it is evident that much of the initial settlement, land clearing and large scale agricultural development in the Lake Manitoba region occurred about 100 years ago.

Modern sedimentation rates in Lake Manitoba were calculated using the pollen data assuming the Ambrosia rise horizon represents 100 years B.P. The mean annual linear sedimentation rate is expressed in terms of millimetres of wet sediment deposited per year, and the mean annual sedimentation intensity is expressed as grams of dry sediment deposited per square metre per year. The former was derived by dividing the Ambrosia rise (in millimetres below the sediment/water interface) by 100 (that is, the number of years since the onset of agricultural activity in the watershed). The latter rate, sedimentation intensity, was calculated by dividing the dry weight of sediment per square metre column above the Ambrosia horizon by this time factor. Although the rates have been given to the nearest gram or 0.1 mm, accuracy of the determinations is probably less than this. Finally, if my previous interpretations were correct (Section 6.1), it is evident that in the relict sand areas of the basin the modern sedimentation rates will be zero. The results of these calculations, summarized in Table 7-2 and Figure 7-2, will be briefly discussed followed by several comments on the validity of these determinations in the South Basin.

Excluding the relict sand areas, post-cultural linear sedimentation rates ranged from 1.7 mm year^{-1} in core D-1 to 3.5 mm year^{-1} in core 40

TABLE 7-2

Calculated sedimentation rates based on the Ambrosia rise horizon for six cores in the South Basin of Lake Manitoba. See Figure 2-1 for core locations).

Core #	Ambrosia rise horizon depth (cm)	Uppermost marker horizon depth* (cm)	POST-SETTLEMENT		PRE-SETTLEMENT	
			Linear Sedimentation rate in mm wet sediment per year	Sedimentation intensity in g dry sediment per m^2 per year	Linear Sedimentation rate in mm wet sediment per year	Sedimentation intensity in g dry sediment per m^2 per yea
23	33	260	3.3	660	0.5	211
39	33	149	3.3	790	0.2	161
40	35	121	3.5	844	0.2	120
D-1	17	330	1.7	270	0.7	315 +
D-2	27	295	2.7	667	0.6	301
D-3	30	240	3.0	533	0.5	155

* The base of the sediment overlying this horizon is taken to be 4500 years B.P.

\+ This value represents an average of 160 g/m^2/yr for the interval 17-135 cm depth and 467 g/m^2/yr for the interval 135-330 cm depth.

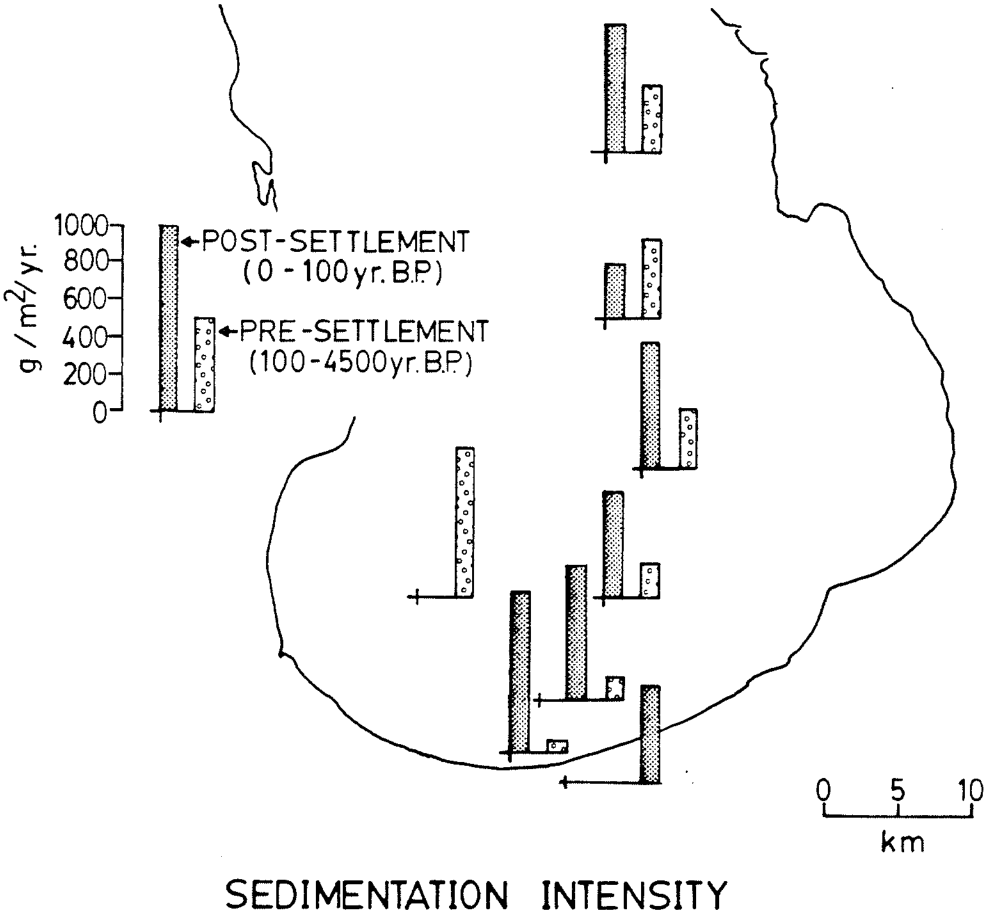

Figure 7-2. Post-settlement and pre settlement sedimentation intensities in the South Basin of Lake Manitoba calculated on the basis of Ambrosia rise horizon depth. The site located just south of the lake represents Cadham Bay, Delta Marsh. Because pollen data presented by Sproule (1972) was used for this calculation, a pre-settlement rate could not be determined. Pre-settlement sediment is defined as the core interval between the ragweed rise horizon and the uppermost marker horizon (about 4500 years B.P.). In the relict sand areas modern sediment is absent and the post-settlement rate is zero.

with the average sedimentation rate equal to 3.0 mm year^{-1}. The average rate is approximately one-half that quoted by Kennedy (1949) of 1 foot per 50 years. Modern sedimentation intensity ranged from approximately 300 g m^{-2} year^{-1} at D-1 to over 700 g m^{-2}year^{-1} in 40 ($\bar{x}$ = 627 g m^{-2}year^{-1}).

The data show that the average sedimentation rates observed in Lake Manitoba over the past 100 years are not unusually large. Estimates of Lake Erie offshore basin sedimentation intensities, which are generally believed to be the highest rates of the Great Lakes, range from 0 to over 6450 g m^{-2}year^{-1} with a basin average of approximately 1300 to 1500 g m^{-2}year^{-1} (Kemp et al, 1977, 1974; Anderson, 1974). Lake Ontario's basin receives an average of 200 (Thomas et al, 1972a, b) to 600 g m^{-2}year^{-1} (Kemp et al, 1974; Kemp and Harper, 1977a) and Lake Huron approximately 200 to 250 g m^{-2}year^{-1} (Kemp et al, 1974; Kemp and Harper, 1977b). In smaller lakes, reported sedimentation rates are extremely variable. Values as high as 25 mm year^{-1} have been reported in Long Lake, Washington (Thomas and Soltero, 1977). Brunskill and Graham (1979) quote Denis and Challies (1916) as referring to a rate of 80 mm year^{-1} sediment accumulation in Cedar Lake, Manitoba. In contrast, Canadian Shield lakes commonly deposit less than 1.0 mm of sediment per year (Hecky, 1975a, b; Brunskill et al, 1970).

There does not appear to be a consistent spatial variation in linear sedimentation rates or intensities throughout the South Basin of Lake Manitoba, although cores 39 and 40, which are closest to the Diversion entrance, do record the highest intensities. Comparison of this post-cultural sedimentation rate with the rate calculated for the immediate pre-cultural period (defined as the time period between 100 years B.P. and the first marker horizon at approximately 4500 years B.P.) shows that in all cores examined except D-1, there has been a significant increase in sedimentation rates in the most recent 100 year period.

7.2.3 Modern Sedimentation Rates based on Present-Day Sediment Influx

The contention that sedimentation rates have increased in the South Basin during historic time is apparently justified based on the ragweed pollen rise horizon. There is, however, considerable difficulty in explaining this increase in sedimentation in terms of source and transport mechanisms.

Numerous physical, chemical and/or biological conditions can lead to increased sedimentation rates in lakes and reservoirs. One of the more likely conditions is a change in the sediment load being delivered to the lake. Increased sediment loading to the lake by the fluvial systems would, in light of Hochbaum's (1965) comments on the widespread network of artificial drainage canals, seem to rank highest in importance for the Lake Manitoba situation. Outside of the extensive ditch construction within the Whitemud River watershed area, however, the remaining South Basin watershed has relatively few artificial drainage works and only seven canals are actually connected directly to the lake (see Elliott, 1978, p. 65). Making the simplifying but somewhat erroneous assumption that all sediment being delivered to the South Basin is deposited within the basin, it is possible to estimate the sedimentation rate on the basis of the two river influxes (i.e., Whitemud River and Portage Diversion) plus, of course, the authigenic organic matter and carbonate components in the record. Table 7-3 outlines these calculations.

TABLE 7-3

Calculated fluvial and authegenic sediment contribution to the South Basin of Lake Manitoba and basin sedimentation rates.

Average annual suspended load of the Whitemud River (period of 1972-1976)*	44,900 tonnes
Average annual suspended load of the Assiniboine River Diversion (period of 1970-1977)*	372,300 tonnes
Average bulk density of modern sediment (based on 0-2 cm core interval; see Section 4.2)	1.2 g/cm^2
Area of sedimentation in the South Basin	2000 km^2
Authigenic carbonate component of the modern sediment (based on an average of 22% calcite content)	173,500 tonnes per year
Authigenic organic matter component of the modern sediment (based on an average of 14% organic content	65,000 tonnes per year
Linear sedimentation rate using the detrital contribution only	0.12 mm/yr
Linear sedimentation rate using the detrital plus authigenic contributions	0.22 mm/yr
Linear sedimentation rate before the contruction of the Assiniboine River Diversion (using the detrital plus authigenic contributions)	0.034 mm/yr

* based on data in Inland Waters Directorate (1978b)

The Whitemud River and Portage Diversion together contribute about 1100 tonnes of sediment per day to the South Basin. Using an average bulk density of 1.20 g m^3 and a depositional area of approximately 2000 km^2 results in a linear sedimentation rate of about 0.2 mm $year^{-1}$. The striking difference between this calculated present-day sedimentation rate and the _Ambrosia_-based rate of about 3.0 mm $year^{-1}$ is further enhanced if the contribution by the Diversion is eliminated. That is, prior to 1970 when the Diversion was first put into operation, the sedimentation rate in the basin due to fluvial influx and authigenic carbonate precipitation and organic matter generation would have been about 0.03 mm $year^{-1}$.

7.2.4 Discussion

The discrepancy between _Ambrosia_-based and calculated sedimentation rate values can be explained in several ways:

1. This data can be used to support the suggestion that there is a source supplying a considerable quantity of sediment which was not included in the calculations. The most obvious source of sediment would be wave erosion of the shoreline. However, calculations show that in addition to the river input, a minimum shoreline recession rate of approximately 2 metres per year (or about 8 m^3 $year^{-1}$ per linear metre of shoreline) over the entire 380 km shoreline of the South Basin is necessary to account for the observed sedimentation rate (assuming a bulk density of 2.0 g m^3 for the eroded material). There have been no reports of shoreline recession or property loss of this magnitude anywhere in the South Basin and such rates do not even seem possible on the gently sloping,

low lying marshy areas or along the bedrock-bounded portion of the lakeshore. Furthermore, nearly 40% of the basin's 380 km shoreline is gravel or sand beach and thus not a potential source of fine-grained sediment.

Other possible sources of sediment are wind-transported material, sediment derived from the North Basin, and sediment derived from the reworking of relict areas by waves and currents. These potential sources are very difficult to quantify. Lacking any evidence of widespread aeolian deposits on land surrounding the lake, it seems unlikely that wind blown material has contributed significantly during the past 100 years. In Lake Balaton, Hungary, which is very similar in many hydrological and morphological respects to Lake Manitoba, Felfoldy et al (1969) estimate air fall material contributes approximately 2% (18,000 tonnes year^{-1}) of the lake's total sediment budget. Similarly low values are estimated by Kemp et al (1977) for Lake Erie (3% or 500,000 tonnes year^{-1}). For Lake Manitoba, even using the highly unlikely value of 1 X 10^{6} tonnes year^{-1} airborne contribution plus the river input still yields a sedimentation rate of only about 0.4 mm year^{-1}, almost a full order of magnitude below the observed "Ambrosia rise" rate.

The contribution of sediment to the South Basin of Lake Manitoba from the North Basin cannot be accurately assessed because of the absence of data. The numerous settling sub-basins in Lake Manitoba's North Basin as well as farther upstream in the Lake Winnipegosis basin, suggests that this northern source of sediment is probably not significant. In the south basin of Lake Winnipeg, Kushnir (1971) likewise ignored any contribution from that lake's north basin. It is probably reasonable to assume, given the Narrows' restriction in Lake Manitoba, that the influx of sediment into the South Basin from the North Basin is about equal to the sediment outflow from the South Basin into the North.

Sediment contribution by wave and current reworking of existing sediment is equally difficult to assess. While it is possible that erosion of areas similar to the offshore Marshy Point anomaly could provide a source of fine-grained sediment, the rather limited geographic extent of these regions in the mapped South Basin would argue against this being a major source of sediment. Even if the highly unlikely assumption is made that the entire 1000 km^2 of unmapped basin north of the study area is a potential source of sediment for the more southern region, and that this area yields mainly silt and clay upon erosion, a subaqueous "erosion rate" of about 8.5 to 9.0 mm $year^{-1}$ is necessary to account for the average observed sedimentation rate farther south. It is unlikely that these rates are reasonable over such a large area particularly in water depths that are not unlike those of the southern area. However, subaqueous erosion in the unmapped portion of the basin does remain a potential factor in the sediment budget.

2. Because the sedimentation rate based on the Ambrosia rise horizon is actually recording an average rate over the past 100 years, it might be argued that much higher sedimentation rates occurred early in the 100 year period and since then have dwindled to the calculated rate of about 0.1 to 0.2 mm $year^{-1}$. This would seem, on the surface, to be reasonable as the initial event of land clearing and cultivation should result in an initially high sediment load to the lake. Similarly, most of the drainage ditches were constructed during the first two decades of the 20th century (Jenkins, 1974, p. 24). However, the hydraulic capacity of the only natural large stream entering the basin, the Whitemud

River, is limited; it is not a large channel in terms of potential water and sediment discharge. Even if the largest daily sediment load on record for the river (11,973 tonnes day^{-1}, April 20, 1974) is used as a daily average for every day of the entire year, the calculated sedimentation rate of 0.13 mm year^{-1} for the basin is still more than an order of magnitude less than the *Ambrosia* rise rate. Moreover, if the variable sedimentation rate hypothesis were operative, one would expect striking differences in the concentration of pollen grains, authigenic carbonates, and organic matter within the upper 35 cm of sediment. The pollen grains, for example, which are arriving at the lake primarily by air transport in a more or less constant annual abundance, should be very dilute in the early, high sedimentation rate section of the core and more concentrated in the most recent record where contrastingly low rates prevailed. This is not the case (E. M. V. Nambudiri, personal communication, 1979).

3. The most likely explanation for the contrast in rates of sedimentation based on sediment influx and those calculated from the pollen data is that the rise in ragweed pollen is not actually contained within the sediment deposited about 100 years B.P. Instead, the increased influx of ragweed pollen that began about 100 years ago has been incorporated into older (deeper) material by sediment mixing.

Vertical sediment mixing by organisms is a common occurence in both marine and lacustrine environments (e.g., Berger and Heath, 1968; Nichols, 1974; Nichols et al, 1946; Krone, 1974; Hakanson and Kallstrom, 1978; Bortleson, 1970). Numerous detailed studies have been undertaken in an attempt to quantify the resulting sediment disturbance. Guinasso and Shink's (1975) calculations show that biologically-induced sediment mixing in the abyssal marine environment (depths greater than 1000 m) can affect over 40 cm of the sediment profile. Cole (1953) found that burrowing organisms could penetrate as deep as 24 cm into the bottom muds of a small lake in Michigan.

In Lake Manitoba numerous studies have stressed the abundance, in terms of biomass, of the benthic population. Vascatto (1969), Sieminiuk (1970), Tudorancea (1975, 1974), Tudorancea and Green (1975), and Crowe (1974a) all report high populations of the "burrowers" (e. g., Nematoda, Oligochaeta) with densities reaching as high as 25,000 individuals m^{-2}. Thus, it seems likely that bioturbation is an important mechanism of sediment disruption in the lake.

As important a role as organisms may play in the disturbance of sediment, this process of mixing is probably greatly aided by wind-generated re-suspension and sediment reworking. Kemp et al (1977) suggest that sediment mixing probably due to wave action in Lake Erie can affect as much as the upper 8 cm of the sediment profile in water depths of 8 to 10 m. Similarly, on the basis of the step-like nature of ^{210}Pb profiles in the offshore sediment of Lake Michigan, Edgington and Robbins (1976) propose that major storm-induced re-suspension has periodically affected from 4 to 8 cm of sediment in water depths greater than 60 m. Kemp et al (1977) quote Johansen and Robbins (1977) in referring to mixing of up to 11 cm of sediment in Saginaw Bay, Lake Huron (8 to 11 m water depth). Lee (1970) quotes work in Lake Erie by Skoch (1968) showing sediment mixing of 5 to 7.5 cm depth in 11 m of water attributed to wave and current action. Still within the Lake Erie Basin, Sheng and Lick (1979) show that wind-generated waves that occurred during a single storm produced sufficient bottom shear stresses in the shallow, western basin of the lake (maximum depth 7.3 m) to erode up to 0.5 cm of sediment, and further conclude that repetition of such storm events may cause bottom sediment mixing of up to 14 cm.

That sediment re-suspension is occurring in the South Basin of Lake Manitoba during the ice-free season is confirmed by the study of Kenny (National Water Resource Institute, 1978) which shows good correlation between surface wind speed and turbidity of the lake water. The bottom sediments in the South Basin are probably everywhere within wave base (wave length/2) of "normal" wind driven waves and certainly within wave base of major storm waves. Using Galay's (1964) calculated wave climate data for the South Basin (see Section 3.7; "normal" waves corresponding to winds of 25 km hour^{-1} will have heights of 75 cm and periods of 3.0 sec; "maximum storm waves" generated by winds of 85 km hour^{-1} will have heights of 150 cm and periods of 4.5 sec.), it can be shown that the maximum shear stress generated by normal waves in 6.0 m of water is capable of initiating movement of sediment grains of 0.08 mm diameter.[1]

It must be stressed, however, that this very fine sand fraction (0.04 to 0.08 mm) is probably the easiest grain size category to erode

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[1] These values were calculated using Galay's (1964) average and storm wave characteristics and the equation given by Krone (1974, p. 152). The parameter values used were coefficient of viscosity: 0.01002 poise (Weast, 1969) and water density: 0.9989 g ml^{-1} for water at 20°C; wave length: 14 m normal waves; 31 m storm waves (calculated from Friedman and Sanders, 1978, p. 468). This calculated shear stress (in dynes cm^{-2}) was then compared to Figures 2 and 7 in Miller et al (1977) and Figure 4-5 in Blatt et al (1972) to determine the grain size capable of being eroded. The failure of these works to extend into the fine silt and clay size fraction of sediment necessitated approximating the critical shear stress (or current velocity) of the cohesive fine sizes by extrapolating the data from the standard Hjulstrom's Diagram for the particular mean water content of the sediment (after Postma, 1967, p. 158).

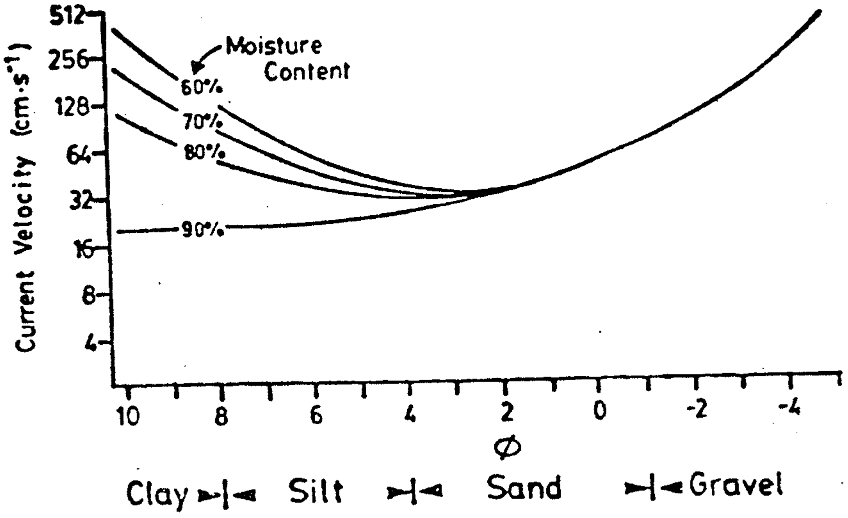
(Fig. 7-3a). Higher velocities and shear stresses are required to initiate movement of both finer and coarser materials. This is due to the strong cohesive nature of fine-grained sediment, and the fact that the smaller particles create a hydrodynamically smooth boundary layer which favors the generation of laminar flows rather than the turbulent flows created by a rough (larger grain size) boundary. Unfortunately, outside of Hjulstrom's (1939) and Sundborg's (1956) pioneer work, very little experimentally-derived empirical data has been put forth in the literature and, thus, at present, grain sizes smaller than the fine sands/coarse silts cannot be treated quantitatively with respect to critical shear stress and particle entrainment. Nonetheless, Figures 7-3b and c help convey a general feeling for the approximate size fractions that can be eroded by the calculated shear stress generated at particular depths and wave conditions in the lake. Thus, "normal" wave conditions are probably not capable of eroding the clayey silt/silty clay sediment covering much of the basin at depths of greater than 5 m.

Maximum calculated storm waves are theoretically capable of exerting enough shear stress to erode grains from coarse silt size up to sand 1 to 2 mm in diameter at most offshore locations. It must be emphasized, however, that due to a variety of complicating factors such as the basic inaccuracy of empirical wave form calculations in shallow water (Peregrine, 1972), the lack of any knowledge of the in situ bulk shear strength of the sediment (Richards, 1974), the role of high ionic concentrations in the sediment pore fluid producing stronger bonds and thus increasing the values of the critical shear stress (Terwindt, 1977), or the error of applying unidirectional critical shear stress values to oscillatory flow conditions (Komar and Miller, 1973), these values cannot be considered anything more than rough order of magnitude approximations.

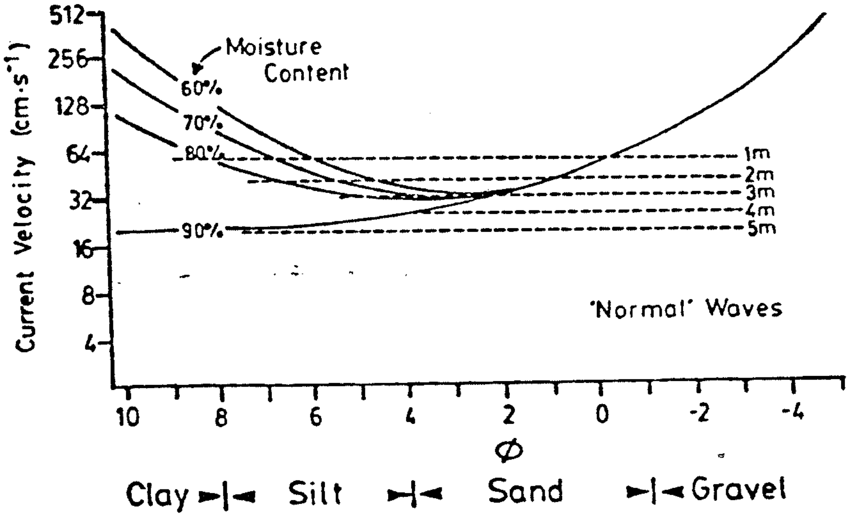
Figure 7-3a. Critical erosion velocity required for various particle sizes and moisture contents of unconsolidated sediment (data replotted from Postma, 1967).

Figure 7-3b. Sediment grain size erosion capabilities of "normal" wind generated waves (see text) at various water depths (horizontal dashed lines) in the South Basin of Lake Manitoba. The grain size capable of being eroded is indicated by the intersection of a horizontal dashed line with the critical erosion velocity curve.

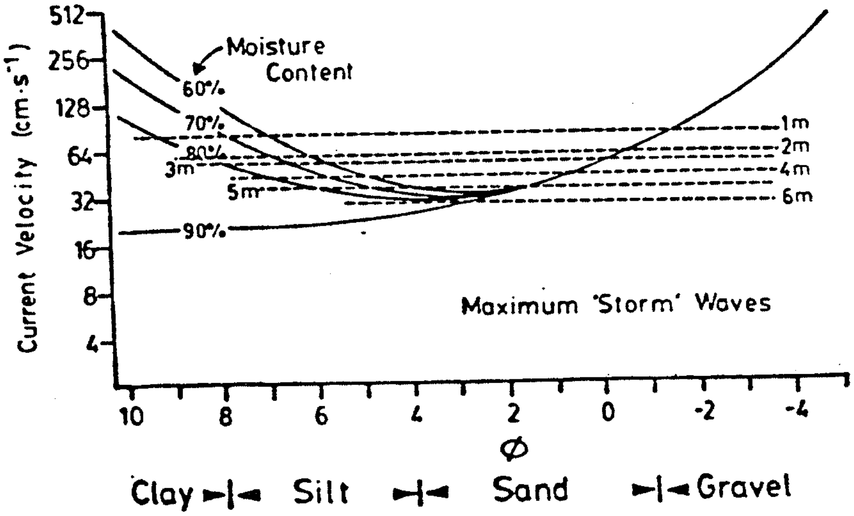
Figure 7-3c. Sediment grain size erosion capabilities of maximum "storm" generated waves (see text) at various water depths (horizontal dashed lines) in the South Basin of Lake Manitoba. The grain size capable of being eroded is indicated by the intersection of a horizontal dashed line with the critical erosion velocity curve.


512
256
128
64
32
16
8
4
Current Velocity (cm·s⁻¹)
Moisture Content
60%
70%
80%
90%
10
8
6
4
2
0
-2
-4
Ø
Clay
Silt
Sand
Gravel

7-3a


512
256
128
64
32
16
8
4
Current Velocity (cm·s⁻¹)
Moisture Content
60%
70%
80%
90%
1m
2m
3m
4m
5m
'Normal' Waves
10
8
6
4
2
0
-2
-4
Ø
Clay
Silt
Sand
Gravel

7-3b


512
256
128
64
32
16
8
4
Current Velocity (cm·s⁻¹)
Moisture Content
60%
70%
80%
90%
3m
5m
1m
2m
4m
6m
Maximum 'Storm' Waves
10
8
6
4
2
0
-2
-4
Ø
Clay
Silt
Sand
Gravel

7-3c

Likewise, probably the most critical factor, the depth of erosion, is difficult to calculate. The bottom deposits should be eroded to a depth at which the increasing shear strength of the sediment equals the decreasing shear stress being applied to it by the wave. Although a variety of sediment properties influence the material's shear strength, the degree of consolidation or compaction is one of the foremost controls in homogenous sediment.

To summarize, average sedimentation rates in the basin for the past 100 years as determined by the Ambrosia rise horizon are anomalously large when compared to the calculated sedimentation rates based on the reasonable maximum present-day river sediment influx and in situ sediment generation. Although additional sources of sediment can be suggested, it is unlikely that enough sediment can be generated, given reasonable conditions and situations, over the past century to account for the ragweed-determined sedimentation rates. Further research involving "dating" of the near-surface sediments by a variety of natural and artifical short-lived radionuclides will help to further evaluate the amount of displacement due to sediment mixing. It is most likely that the Ambrosia pollen has been mixed into older, deeper sediments by bioturbation and/or wave-generated re-suspension and mixing. While it is possible and, indeed, probable that sedimentation rates may have increased in association with the advent of agricultural activity and construction of artificial drainage works in the watershed, the magnitude of this increase cannot be established from the rise in ragweed pollen.

SECTION 8

SYNTHESIS OF INTERPRETATION OF SEDIMENT PARAMETERS BY UNIT AND CORRELATION OUTSIDE OF BASIN

8.1 UNIT A

The oldest non-glacial unit identified in Lake Manitoba sediment, Unit A, is a dark grey, firm, plastic to sticky clay and silty clay with common to abundant silty clasts, till clasts, and pebbles. The high clay content of this unit suggests that deposition occurred in the offshore portion of a deep-water stage of the lake. Grains and clasts are present throughout the unit but are particularly abundant in the lower 3 m and are interpreted as being rafted and subsequently dropped by melting icebergs calving off the nearby glacier. The upper 2 m of Unit A are not as highly clast-charged, suggesting a more distant glacier front. The angularity and sharp boundaries of inclusions similar to these in Lake Agassiz sediments near Winnipeg has lead Baracos (1977) to suggest that these features were deposited from icebergs as "cemented or lithified material which subsequently disintegrated into silt." A more likely explanation, however, considering the juxtaposition of both silt clasts and the lithified (limestone and dolomite) grains, as well as clasts of probable till origin, is that the silt and till clasts were transported and deposited in a frozen state thus allowing the unconsolidated sediment clasts to retain their angularity and undeformed shapes (Quigley, 1968; McPherson, 1970; Fenton, 1970; Teller, 1976a).

The complete absence of any macroscopic shell remains and the low organic matter content of Unit A suggests that the lake was organically unproductive or had such a high sedimentation rate that inorganic sedimentation overwhelmed and diluted any organic contribution.

The extremely low density of Quaternary pollen grains per cubic centimetre of sediment reported by Nambudiri et al (in preparation) would also suggest high inorganic sedimentation rates.

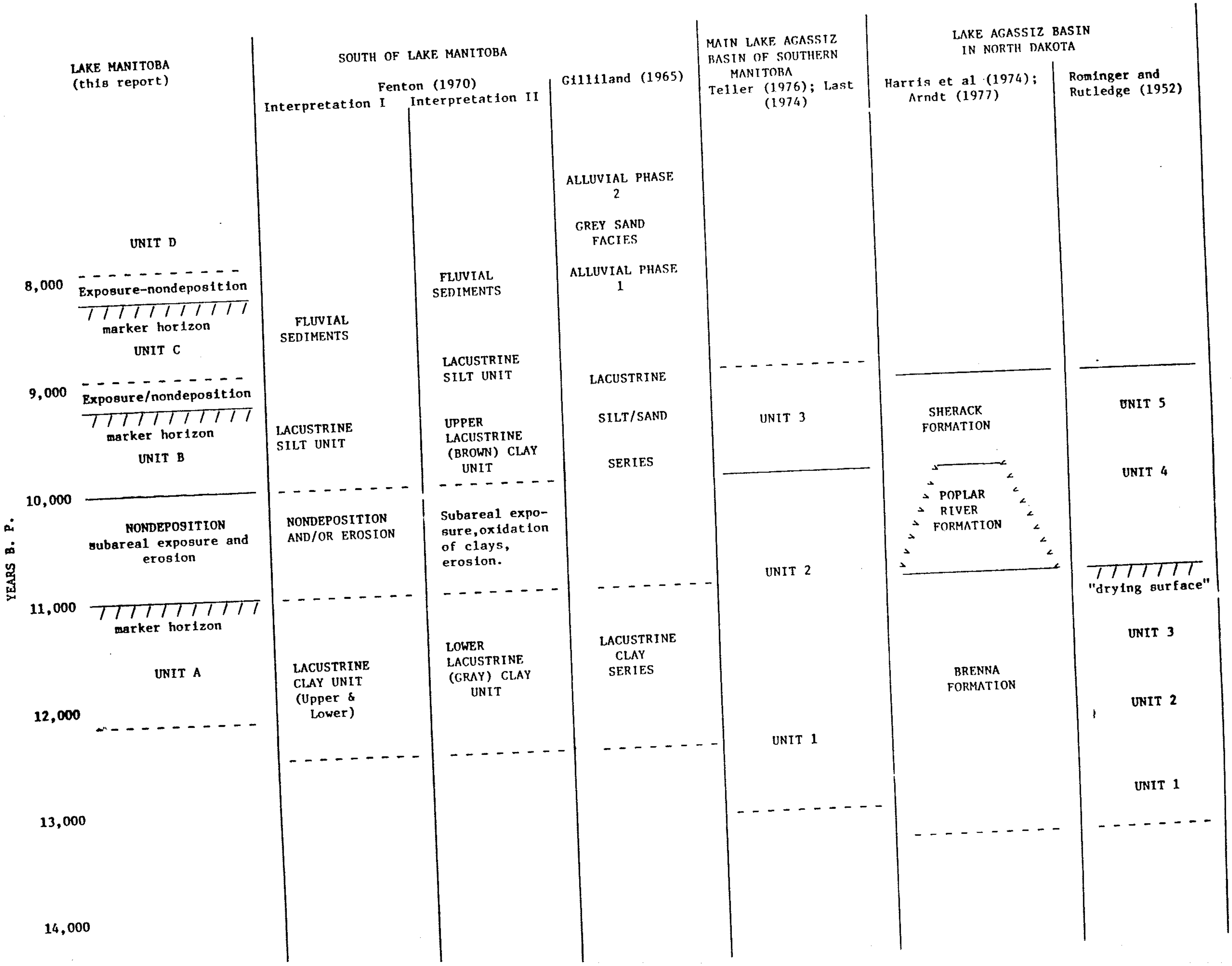
Nambudiri et al (1979; 1980) report that the palynomorph assemblage of Unit A is dominated by pre-Quaternary microfossils that probably were derived from direct shoreline wave erosion of the Cretaceous shales outcropping at the Manitoba Escarpment.

On the basis of the abundance of angular silt clasts, the dominant dark grey color, the relatively high expandable lattice clay mineral content, and the clay-rich texture, Unit A in Lake Manitoba is interpreted to be equivalent to Unit 1 and possibly the lower part of Unit 2 of Teller (1976a) and Last (1974) in the main offshore basin of Lake Agassiz in south-central Manitoba (Table 8-1). Unit A is also probably equivalent to the upper part of the Brenna Formation in North Dakota and Minnesota (Harris et al, 1974; Arndt, 1977).

The marker horizon developed in the clay-rich sediment of Unit A in core D-1 is probably correlative with Rominger and Rutledge's (1952) "old drying surface" between their units 3 and 4 in the Lake Agassiz basin in North Dakota and Minnesota (Table 8-1). As previously suggested, a period of nondeposition and probably erosion occurred between the deposition of Unit A and B. This unconformity is equivalent to the extensive unconformity recognized by Harris et al (1974) and Arndt (1977) between the Brenna Formation and the Sherack Formation in the upper Red River Valley. As pointed out by Teller (1976a), however, no equivalent horizon has yet been identified in the sediments of the main offshore basin of Lake Agassiz in southern Manitoba.

TABLE 8-1

CORRELATION OF LAKE MANITOBA UNITS WITH STRATIGRAPHY ELSEWHERE IN THE LAKE AGASSIZ BASIN


LAKE MANITOBA (this report)
SOUTH OF LAKE MANITOBA
Fenton (1970)
Interpretation I
Interpretation II
Gilliland (1965)
MAIN LAKE AGASSIZ BASIN OF SOUTHERN MANITOBA
Teller (1976); Last (1974)
LAKE AGASSIZ BASIN IN NORTH DAKOTA
Harris et al (1974); Arndt (1977)
Rominger and Rutledge (1952)
YEARS B. P.
8,000
9,000
10,000
11,000
12,000
13,000
14,000
UNIT D
Exposure-nondeposition
marker horizon
UNIT C
Exposure/nondeposition
marker horizon
UNIT B
NONDEPOSITION
subareal exposure and erosion
marker horizon
UNIT A
FLUVIAL SEDIMENTS
LACUSTRINE SILT UNIT
NONDEPOSITION AND/OR EROSION
LACUSTRINE CLAY UNIT (Upper & Lower)
FLUVIAL SEDIMENTS
LACUSTRINE SILT UNIT
UPPER LACUSTRINE (BROWN) CLAY UNIT
Subareal exposure,oxidation of clays, erosion.
LOWER LACUSTRINE (GRAY) CLAY UNIT
ALLUVIAL PHASE 2
GREY SAND FACIES
ALLUVIAL PHASE 1
LACUSTRINE
SILT/SAND
SERIES
LACUSTRINE CLAY SERIES
UNIT 3
UNIT 2
UNIT 1
SHERACK FORMATION
POPLAR RIVER FORMATION
BRENNA FORMATION
UNIT 5
UNIT 4
"drying surface"
UNIT 3
UNIT 2
UNIT 1

Precise correlation of Unit A with the post-glacial lacustrine stratigraphy identified immediately south of Lake Manitoba by Fenton (1970) and Last (1974) is somewhat problematic. In hole P-4 (location SW 22-13-7 W 1) Fenton (1970, p. 84) suggests that the 5.2 m of fine-grained, greyish brown (2.5Y 4/2), clast-charged lacustrine sediment overlying the uppermost till belongs to his Upper or Brown Clay Unit. Last (1974, p. 135) confirms this using the low montmorillonite/illite (M/I) clay mineral ratio characteristic of his Unit 3, although the uppermost sample analyzed resulted in an anomalously high M/I ratio. Thus, the 5.4 m of this study's Unit A at core location D-4, which is at approximately the same location as Fenton's P-4 site, should be equivalent to this Upper Lacustrine Clay Unit (Table 8-1, Interpretation II). However, in light of (a) the imprecise nature of the subdivision based on color, (b) the fact that Fenton's two units (i.e., Upper and Lower Lacustrine Units) could not everywhere be identified in his study area, and (c) the inconsistent clay mineralogy results, it is possible that Lake Manitoba's Unit A can be correlated to any part of Fenton's Lacustrine Clay Unit south of the lake (Table 8-1, Interpretation I).

Two radiocarbon dates have been acquired from Unit A in Lake Manitoba. On the basis of the abundance of pre-Quaternary microfossils, these two dates have been corrected to 12,000 years B.P. (from > 37,000 years B.P.; GX 5647) and 11,000 years B.P. (from 29,300 $^{+\,2780}_{-\,2660}$ years B.P.; GX 6300; see Table 7-1).[1] Unit A was probably deposited between slightly

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[1] Further evidence supporting the approximate magnitude of these corrections and the resulting chronology is the identification of a sharp decline in the abundance of Picea sp. and corresponding rapid rise in Pinus sp. in the upper metre of Unit A in core D-1 (Nambudiri et al, 1979, 1980).

before 12,000 years B.P. and about 11,000 years B.P.

Using these two corrected radiocarbon dates results in a linear sedimentation rate for Unit A of about 0.3 cm per year or a sedimentation intensity of close to 1500 g (dry weight) $m^{-2} year^{-1}$.

8.2 UNIT B

Overlying Unit A in the Lake Manitoba basin is Unit B. The unit is a clayey to sandy silt and is marked by relatively good bedding and a very high dolomite content. A marker horizon developed into the top of Unit A separates it from Unit B.

The high silt/low clay content of Unit B and the well-laminated character point toward a depositional environment of higher energy than that which was responsible for the deposition of Unit A. I interpret that Unit B was deposited during a low water phase of the lake, probably coincident with basin reflooding after development of the marker horizon in Unit A. The absence of this lowermost marker zone from core D-3 can be explained by erosion associated with the subaereal exposure of the bottom sediment at this site. Significant erosion and loss of the sediment record is further confirmed by the absence of the uppermost 1 to 2 m of relatively clast-free clayey sediment of Unit A from cores D-3 and D-2.

The Assiniboine River probably played a major role in delivering coarse-grained sediment to the Lake Manitoba basin during this time. During the deposition of Unit A, the mouth of this large river was to the west and south of the Lake Manitoba basin, and most of the coarse clastic material which it brought into Lake Agassiz was deposited in the large Assiniboine Delta (see Figure 3 in Teller, 1976a). However, coincident with the low water phase following the deposition of Unit A, the Delta's channels shifted resulting in a greater influx of coarser-grained sediment to the Lake Manitoba area.

The association of several marker horizons with Unit B suggest that periodic low water conditions and sediment desiccation occurred during the deposition of the unit. Although the record is dominated by detrital input, the presence of Mg-calcite (4 mole percent $MgCO_3$) in the upper 0.8 m of this unit indicates that minor authigenic precipitation of carbonate material occurred.

On the basis of its coarse grain size, relatively well-developed laminae, low moisture content, and stratigraphic position above deep-water, clast-rich lacustrine sediment interpreted to be correlative to the Brenna Formation, Unit B is equivalent to the Poplar River Formation and lower part of the Sherack Formation of the upper Red River Valley (Harris et al, 1974; see Table 8-1). In the offshore Lake Agassiz basin of southern Manitoba, grain size and clay mineralogy would suggest that Unit B (as well as possibly part of the overlying Unit C) be correlated to Teller's (1976a) Unit 3 and Last's (1974) Unit 3.

South of Lake Manitoba, Fenton (1970, p. 64-66) has suggested that after deposition of his Lower (Gray) Lacustrine Clay Unit, lake levels dropped sufficiently to subaerially expose and oxidize the lacustrine and ice-laid sediment in the southwestern portion of his study area as well as in the main Assiniboine River delta area. Then with higher water levels the expanded lake eroded and re-deposited this oxidized sediment to form his Upper (Brown) Lacustrine Clay Unit. The low-water phase of the lake, however, is evidently not recorded by a distinct unit of sediment in his area. Likewise, there is essentially no difference in grain size or cl mineralogy between his pre-lowering and post-lowering lacustrine sediment (see Last, 1974, p. 135-136).

An alternative interpretation for the stratigraphy south of Lake Manitoba (see Table 8-1, Interpretation I) is that all or most of the fine-grained lacustrine deposits of the Portage Plain (and West Plain) area were deposited prior to the 11,000 to 10,000 year B.P. lowering of Lake Agassiz. Thus, as shown in Table 8-1 and suggested in Section 8.1, Unit A in Lake Manitoba is equivalent to Fenton's (1970) entire (that is, both Lower Gray and Upper Brown) Lacustrine Clay Unit. Unit B in Lake Manitoba either (a) does not have an equivalent unit south of the lake due to subsequent erosion and loss of the record, or (b) is equivalent to a thin, discontinuous "offshore lacustrine silt" (Fenton, 1970, p. 25) overlying the Lacustrine Clay Unit. Gilliland (1965, p. 19) also makes reference to this "lacustrine" silt and sand deposit overlying the fine-grained lacustrine clays in the Portage la Prairie area. He attributes these silty sands and sandy silts to transport by wind from a "sand desert" to the southwest and deposition in a very shallow stage of Lake Agassiz.

One ^{14}C date was obtained from the sediment of Unit B. This date of 10,000 years B.P. (corrected from 10,150 ± 270, GX 5651; Table 7-1) from the lower few centimetres of the unit in core D-3 confirms the regional correlation and timing of this major low water phase of Lake Agassiz and also supports the contention that erosion and loss of record has occurred in core D-3 coincident with the lowering. Unit B was deposited between about 10,000 to 9,000 years B.P.

Considering the numerous periods of non-deposition implied by the marker horizons scattered throughout Unit B, it is difficult to arrive at a meaningful sedimentation rate calculation. An average linear sedimentation rate of about 0.15 cm $year^{-1}$ (or a sedimentation intensity of about 900 to 1200 g $m^{-2}year^{-1}$) can be calculated using 10,000 and 9,000 years B.P. as initiation and termination dates of Unit B. However, actual rates were probably considerably higher than this because deposition was probably not continuous over this period.

8.3 UNIT C

Overlying Unit B in the Lake Manitoba basin is Unit C. The unit is a silty clay and clayey silt with a lower dolomite content, slightly finer grain size and poorer bedding relative to Unit B. It is separated from Unit B by a marker horizon developed into the underlying unit.

Unit C represents deposition in a lacustrine environment probably quite similar to that of Unit B. The relatively high sand content of the unit in D-3 suggests either the proximity of a high energy shoreline environment or a higher energy regime associated with shallower water immediately after the development of the marker horizon in the top of Unit B. The overall finer average grain size of the unit relative to that of Unit B would imply a slightly deeper lake, a more distant source, or a decrease in the amount of coarse material being delivered by rivers (notably the Assiniboine River) and shoreline erosion.

I interpret the striking decrease in dolomite content relative to the underlying unit as reflecting the result of a combination of factors, including: (a) a decrease in the amount of coarse silt-sized material in the sediment (which is the terminal grade of detrital dolomite); (b) a decrease in the available dolomite in the watershed due to a weathering; and (c) a decrease in the contribution of streams supplying the detrital dolomite. The higher calcite content of the unit is mainly due to an increase in authigenic precipitation of this carbonate mineral. Whether the cause of this enhanced precipitation of $CaCO_3$ is due to increased organic productivity is uncertain. The total organic matter of the sediment remains rather low (unit average of 5.7%); however, the first macroscopic shell remains in the post-glacial record of Lake Manitoba are present in Unit C and are relatively common in portions of the unit in cores D-2 and D-3.

Overall, Units B and C probably represent the final phases of lacustrine sedimentation of Lake Agassiz in the Lake Manitoba basin. Whether the body of water in the Lake Manitoba basin during the deposition of Unit C was part of the northward-migrating main body of Lake Agassiz or whether the South Basin of Lake Manitoba had, by this time, achieved a more or less autonomous existence is not readily apparent from the sedimentary evidence. The low number of pre-Quaternary (mainly Cretaceous) microfossils in the sediment of Unit C (and in the upper 50 cm of Unit B) reported by Nambudiri et al (1980) would certainly imply that the lake was no longer receiving sediment contribution by direct wave erosion of the Cretaceous shales of the Manitoba Escarpment. Furthermore, if the strong decrease in dolomite content of the sediment at the base of Unit C is interpreted as a decrease in fluvial contribution to the lake, the implication is that the Assiniboine River was at this time by-passing the South Basin and entering the rapidly receding Lake Agassiz or the Red River farther eastward. It is likely that after the lowering of the lake, recorded by the marker horizon developed into the top of Unit B, the South Basin of Lake Manitoba became a large cul-de-sac of the main body of Lake Agassiz which was situated farther north and east (Fig. 8-1).

If the depositional environment and lacustrine geographic setting I have suggested above is valid, all or most of the sediment of Unit C is transitional between true Lake Agassiz sedimentation and Lake Manitoba deposition and, therefore, does not have an equivalent in most of the Lake Agassiz basin in southern Manitoba or the upper Red River Valley. Arndt (1977) indicates that Agassiz lacustrine sedimentation ceased in North Dakota about 9000 years B.P.

One radiocarbon date was acquired from the organic matter in Unit C. This date of 8300 years B.P. (corrected from 8770 ± 220; GX 5650; Table 7-1) is consistent with the belief that Lake Agassiz had withdrawn from southern Manitoba shortly after 9000 years B.P. and suggests that by about 8300 years ago the main body of Lake Agassiz had receded to a position north or east of the South Basin, West Plain and Interlake Areas as suggested by Prest (1970).

8.4 UNIT D

Overlying Unit C in the Lake Manitoba basin is Unit D. This unit is a relatively thick, dark grey, firm to soft, silty clay characterized by increasing amounts of calcite and organic matter upward in the section. The unit is separated from the underlying Unit C by a basin-wide marker horizon developed into Unit C.

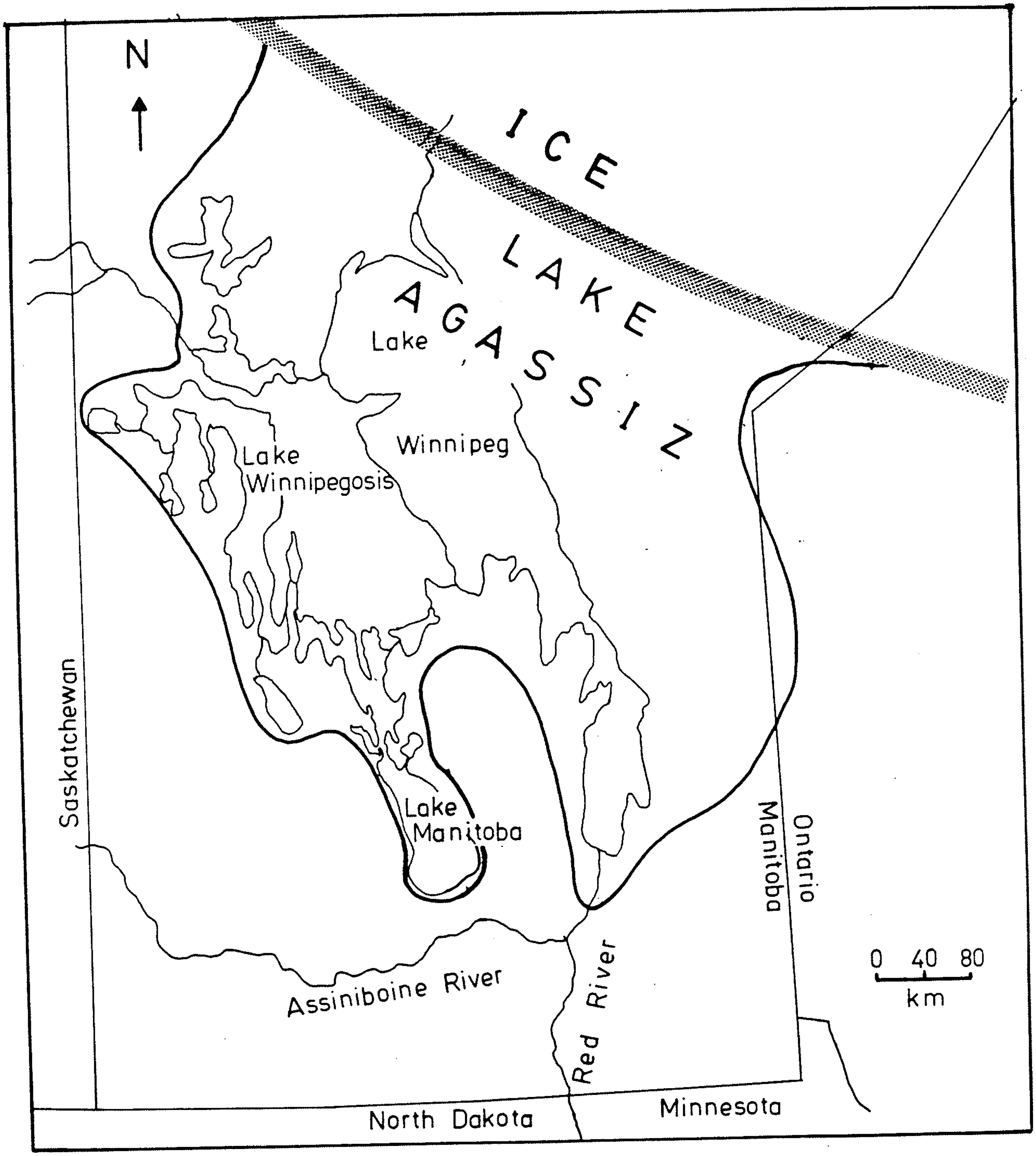

Figure 8-1. Lake Agassiz during the deposition of Unit C in the Lake Manitoba Basin. The main body of Lake Agassiz is located north and east of the South Basin, and the Assiniboine River, which previously had been a major contributor of sediment and water to the Lake Manitoba area is by-passing the lake to the south. (Location of Lake Agassiz and ice margins, in part, after Elson, 1967).

Unit D represents mainly offshore deposition in a body of water occupying the Lake Manitoba basin that was probably very similar in size and geographic extent to today's lake. This lake, however, was subjected to numerous periods of at least partial draining or drying and desiccation as evidenced by the marker zones scattered throughout the unit. Furthermore, both the frequency and duration of these low water/desiccation events increased through time. The increase in physicochemical precipitation of calcite in the lake and the higher average percent $MgCO_3$ incorporation into the calcite crystal lattice relative to the underlying units can be indicative of several things, including: warmer water temperatures, higher salinities, higher Mg/Ca ratios, and increased primary organic productivity.

Four radiocarbon dates have been acquired from the sediment of Unit D. These dates are 8000 years B.P. (corrected from 10,170 ± 225; GX 5646), 7700 years B.P. (corrected from 11,075 ± 350; GX 5649), 7000 years B.P. (corrected from 9550 ± 550; BGS 567), and 6240 ± 180 years B.P. (GX 5648, no correction required; see Table 7-1). Using dates of about 8000 years ago for the end of marker horizon development in the top of underlying Unit C and 5500 years B.P.for the beginning of most recent drying event in the basin (i.e., the end of deposition of Unit D), yields a sedimentation rate of about 0.18 to 0.2 cm $year^{-1}$ (800 to 900 g m^{-2} $year^{-1}$) for Unit D.

8.5 UNIT E

Overlying Unit D in the Lake Manitoba basin is Unit E. The unit is coarse-grained (sands, silty sands, and sandy silts) in the southern-most portion of the basin, and fine-grained clayey silts basinward. The calcite of the unit also contains the highest average $MgCO_3$ content of the postglacial sediment record. The uppermost (and best-developed) marker horizon in the basin separates Unit E from underlying Unit D.

Unit E represents a substantial change in the physical, chemical and, probably, biological conditions of Lake Manitoba. After development of the marker horizon at the top of Unit D during the final major drying event, reflooding of the lake occurred in part due to a somewhat less arid climate and, possibly more importantly, to the diversion of all or a major part of the Assiniboine River into the basin. Associated with this sudden increased fluvial contribution, the coarse-grained delta complex (i.e., relict sand area) was deposited in the southwestern portion of the basin. This deposition was probably coincident with major alluvial channel cutting and filling on shore south of the lake as suggested by Fenton (1970).

Both Fenton (1970) and Gilliland (1965) have suggested multiple stages of channel development during the post-Lake Agassiz period. In part on the basis of color differences (brown sand versus grey sand) and in part on the levels of the fluvial channel-fill sands, Gilliland proposes four distinct phases of alluvial channeling and fill controlled by fluctuations of the immediate base level of the streams (that is, fluctuations in the level of Lake Manitoba). As only his most recent phase is ^{14}C dated, the precise sequence and time of the earliest three phases and their possible correlation to the offshore stratigraphic record in Lake Manitoba is speculative. Gilliland's Alluvial Phase 1 (fluvial channel cutting) is possibly correlative with the low water-desiccation period of the lake responsible for the marker horizon development in the top of Unit

C (see Table 8-1). His Alluvial Phase 2 (channel inactivity and deposition of Grey Sand Facies) could then correspond to the reflooding of the lake and deposition of Unit D in the offshore.

After a lenghty period of flow of the Assiniboine River that by-passed the Lake Manitoba basin to the south, the river was again diverted into the lake basin (corresponding to Gilliland's Alluvial Phase 3) helping to reflood the lake after the development of the youngest basin-wide marker zone on top of Unit D. This diversion also supplied coarse-grained sediment (sand and silt) to the delta facies of Unit E (now identified on the lake bottom as the relict sand area) and clayey silt basinward. Finally, Gilliland's Alluvial Phase 4 (channel inactivity, deposition of Brown Sand Facies) which is dated at about 3400 years B.P. (see Table 7-1) corresponds to the continued regression of the lake's shoreline southward coincident with rising water levels.

Alternatively, considering the complexity of a distributary system at the mouth of a river, it is possible that all four of Gilliland's alluvial phases south of Lake Manitoba took place during the deposition of Unit E in the basin.

Sproule (1972) presents limited sedimentological data on three cores (up to 8.3 m in length) near Delta Beach in Cadham Bay of Delta March. On the basis of the grain-size results presented in his Figure 9[1], Unit E

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[1] There is some confusion as to the precise grain-size boundaries used by Sproule. On page 20, he indicates that "Sands were separated by sieving into medium (0.5-0.25 mm) and fine sand (0.25-0.1 mm)." This would imply that since the percentages of his medium sand + fine sand + silt + clay fractions apparently sum to 100% in his Figure 6, the very fine sand fraction (0.1-0.0625 mm) has been included in the silt-sized category. Similarly, he does not clearly identify what silt/clay boundary he uses. If the 0.002 m diameter division of Kline and Alexander (1949) was, indeed, used (as is implied elsewhere in his thesis) then most of Sproule's grain size distributi percentages cannot be directly compared with the results of this study.

is probably equivalent to the sediment between about 365 cm and 50 to 75 cm depths in his Core A. The strong grain-size discontinuity at 365 cm in Sproule's core probably represents the uppermost marker horizon with the relatively coarse sands overlying it corresponding to the lower coarse fluvial facies of Unit E. The clayey silt underlying 365 cm then would possibly be equivalent to Unit D.

Possible hypotheses regarding the significant increase in Mg content of the calcite in Unit E were discussed in detail in Section 6.3.4. To summarize, the higher $MgCO_3$ incorporation into the calcite is believed to record the combined effects of a substantially higher Mg/Ca ratio of the lake water and possibly higher water temperatures. The increased Mg/Ca ratio can be attributed to several physical and chemical phenomena that were probably associated with the final desiccation event of the lake and subsequent reflooding. These include: (a) precipitation and then selective dissolution of Mg-bearing evaporitic salts on the lake bottom as well as in the pore spaces of the sediment by the overlying body of water and by discharging groundwater; (b) ion exchange of Ca^{+2} for Mg^{+2} on the montmorillonitic clay minerals of the deposits; and (c) the increased relative contribution of Mg-rich surface water (Assiniboine River) and groundwater to the lake.

The results of Carter's preliminary examination of the diatom stratigraphy of Units E and D (see Appendix C) further supports the suggestion that during the earliest stages of Unit E deposition, the lake was smaller, shallower, and more saline than during the deposition of portions of the underlying Unit D.

Two radiocarbon dates have been acquired from the sediment of Unit E in this study. These dates were 4465 ± 165 years B.P. (GX 5645) and 2555 ± 130 years B.P. (GX 5644; Table 7-1). In addition, the 3375 ± 250 years B.P. (I-1255) and 2400 ± 230 years B.P. (S 446) dates reported by Fenton (1970, p. 57; see also Sproule, 1972) are from material correlative to Unit E.

Using the above two dates from this study, an average linear sedimentation rate of about 0.1 cm $year^{-1}$ (or sedimentation intensity of 460 g $m^{-2} year^{-1}$) for Unit E can be calculated. In addition, the 4465 ± 165 years B.P. date from sediment immediately overlying the uppermost marker zone in D-1 when compared to the 6240 ± 180 date from near the top of Unit D in D-2 suggests that the marker horizon records a major hiatus of as much as 1800 years of nondeposition and/or loss of the sediment column by erosion.

8.6 UNIT F

The youngest unit defined in Lake Manitoba sediment, Unit F, is characterized by a slightly finer grain size, a lower $MgCO_3$ content of the calcite, and higher organic, moisture, and calcite contents relative to Unit E.

Initiation of Unit F deposition probably occurred coincident with the diversion of the Assiniboine River out of the drainage basin of Lake Manitoba. Because of its similarity to the modern bottom sediments of the lake, the sediment of Unit F represents deposition in a lake very similar to that of today. The lake probably was considerably more organically productive relative to the 2500 year period immediately preceding the deposition of Unit F as evidenced by substantial increases in organic matter, including shell fragments, authigenically precipitated calcite, and P compared to Unit E.

No ^{14}C dates were acquired from Unit F. The 2555 ± 130 date from the upper several centimetres of Unit E can be used to estimate the time of diversion of the Assiniboine River out of the basin. Using a linear sedimentation rate of 0.1 cm $year^{-1}$ calculated for Unit E, this diversion occurred about 2000 to 1900 years ago. Using this 2000 year B.P. date for the initiation of Unit F sedimentation, a linear sedimentation rate of approximately 0.03 to 0.07 cm $year^{-1}$ (sedimentation intensity of 140 to 300 g $m^{-2} year^{-1}$) can be calculated for the unit. This lower sedimentation rate relative to the immediately preceding unit is in keeping with the loss of fluvial sediment input by the diversion of the Assiniboine River.

SECTION 9

POST-GLACIAL HISTORY OF LAKE MANITOBA

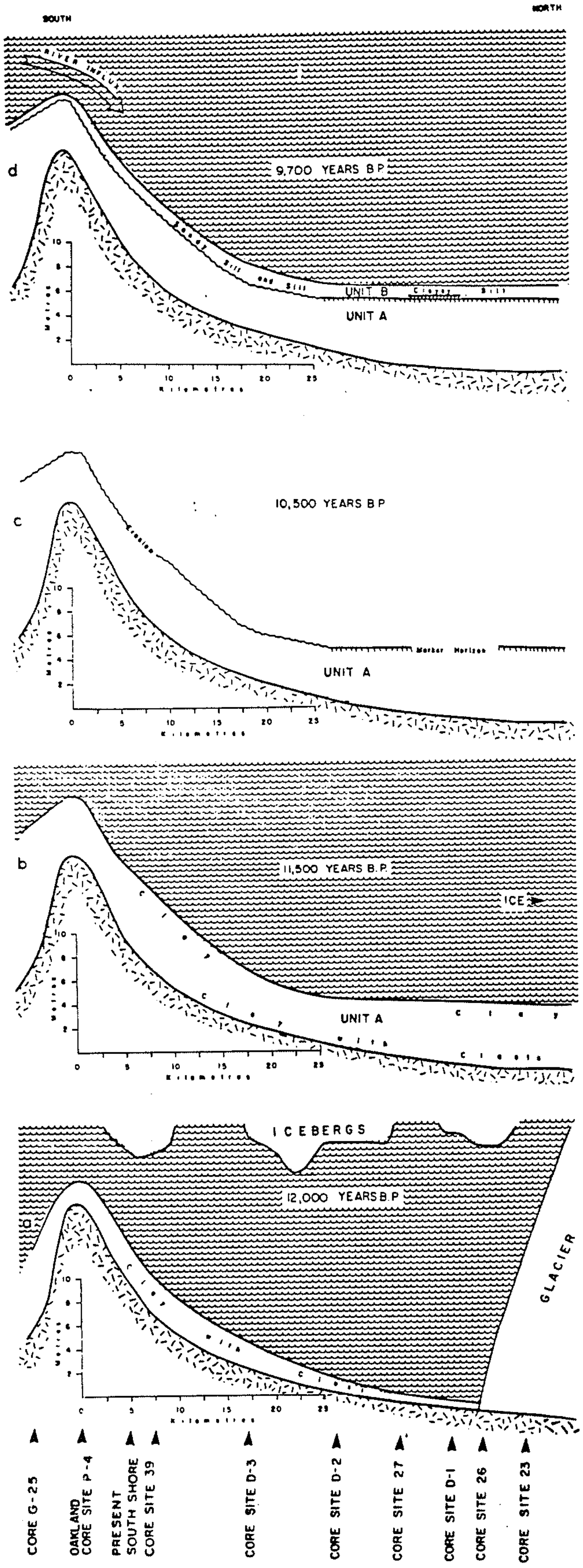
9.1 INTRODUCTION

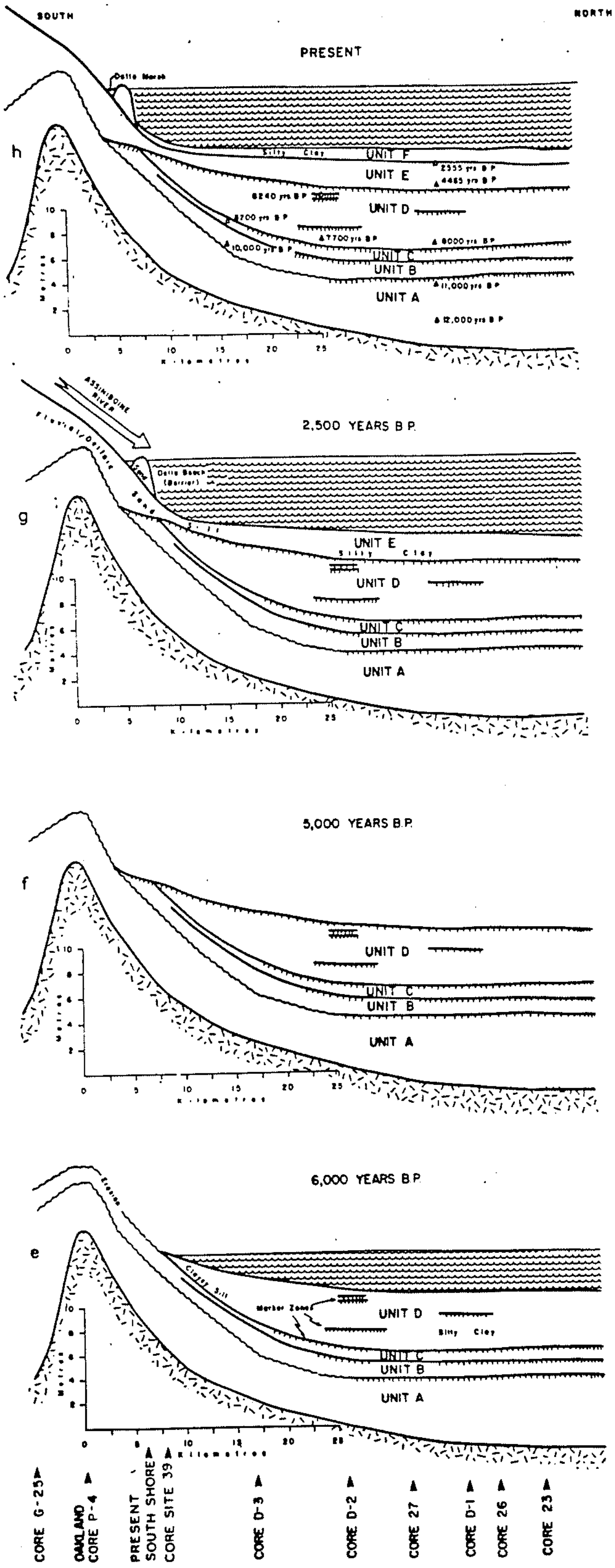
On the basis of the lithostratigraphy, the chronological framework, and the correlations with units and events outside of the immediate study area, the following history of Lake Manitoba can be constructed. The major depositional events responsible for producing the stratigraphic units are shown in a series of south to north cross-sections (Fig. 9-1) and maps (Fig. 9-2) of the South Basin.

9.2 LATE PLEISTOCENE TO EARLY HOLOCENE - LAKE AGASSIZ PHASE

As Late Wisconsinan ice began to recede from the region, Lake Agassiz was formed by the trapping of meltwater between the ice front to the north and higher elevations to the south and west. As previously demonstrated and reviewed by numerous authors (e.g., Moran et al, 1976; Teller, 1976a; Harris et al, 1976; Arndt, 1977), Lake Agassiz sedimentation began about 13,500 years ago in North Dakota with the deposition of the Wylie Formation. After a re-advance of the ice into this southern portion of the basin sometime before 12,800 B.P., which deposited the clayey Whitemouth Lake till in southeastern Manitoba (Teller and Fenton, 1980) and the Upper Till Unit of Fenton (1970; and Gilliland, 1965) immediately south of Lake Manitoba, Lake Agassiz rapidly expanded northward into southern Manitoba. Whether the retreat prior to this minor advance was sufficient to allow lacustrine sedimentation to occur in the Lake Manitoba basin is unknown as the till was not penetrated in any of the long cores in the basin.

Figure 9-1. Cross-sections showing conditions in the Lake Manitoba basin between 12,000 years B.P. and today. Refer to Figures 2-1 or 6-2 for location of section in the South Basin. Locations G-25 and P-4 at the southern end of the sections refer to wells described by Gilliland (1965) and Fenton (1970),respectively.


SOUTH
NORTH
RIVER INFLUX
d
9,700 YEARS B.P.
Sandy Silt and Silt
UNIT B
Clayey Silt
UNIT A
c
10,500 YEARS B.P.
Erosion
Marker Horizon
UNIT A
b
11,500 YEARS B.P.
ICE
Clay
UNIT A
Clay with Clasts
a
ICEBERGS
12,000 YEARS B.P.
GLACIER
Clay with Clasts
Metres
2
4
6
8
10
0
5
10
15
20
25
Kilometres
CORE G-25
OAKLAND CORE SITE P-4
PRESENT SOUTH SHORE
CORE SITE 39
CORE SITE D-3
CORE SITE D-2
CORE SITE 27
CORE SITE D-1
CORE SITE 26
CORE SITE 23


SOUTH
NORTH
PRESENT
h
Delta Marsh
Silty Clay
UNIT F
UNIT E
2335 yrs B.P.
4465 yrs B.P.
6240 yrs B.P.
UNIT D
8700 yrs B.P.
7700 yrs B.P.
8000 yrs B.P.
10,000 yrs B.P.
UNIT C
UNIT B
11,000 yrs B.P.
UNIT A
12,000 yrs B.P.
Metres
Kilometres
2,500 YEARS B.P.
g
ASSINIBOINE RIVER
Fluvial/Deltaic
Sand
Delta Beach (Barrier)
Silt
UNIT E
Silty Clay
UNIT D
UNIT C
UNIT B
UNIT A
5,000 YEARS B.P.
f
UNIT D
UNIT C
UNIT B
UNIT A
6,000 YEARS B.P.
e
Erosion
Clayey Silt
Marker Zones
UNIT D
Silty Clay
UNIT C
UNIT B
UNIT A
0
5
10
15
20
25
CORE G-25
OAKLAND CORE P-4
PRESENT SOUTH SHORE
CORE SITE 39
CORE D-3
CORE D-2
CORE 27
CORE D-1
CORE 26
CORE 23

By about 12,000 years ago, the ice did retreat far enough northward to permit fine-grained offshore lacustrine sedimentation in the southern two-thirds of the Lake Manitoba basin (Fig. 9-1a). The highly clast-charged nature of the lower several metres of Unit A suggests an initially close ice margin in direct contact with the lake. Sediment-laden icebergs calving off this glacier front and density currents eminating from the ice provided source and transport mechanisms for the coarser grains and clasts in addition to the normal clay-rich sediment being supplied by rivers draining the newly deglaciated Prairies to the west. In addition, wave erosion along the lake's western shoreline provided abundant fine-grained sediment including pre-Quaternary microfossils and "old" organic carbon. An average linear sedimentation rate of about 0.3 cm year^{-1} is calculated for this stage of Lake Manitoba.

Over the next 1000 to 1500 years, offshore deposition continued in all portions of the southern Lake Agassiz basin while the ice continued to retreat northward in response to the moderating climate. In the Upper Red River Valley of North Dakota and Minnesota, the clay-rich Brenna Formation and numerous sandy deltas on the western side of the lake were deposited (Arndt, 1977; Elson, 1967). In Manitoba, sediments equivalent to the Brenna Formation were deposited in the offshore portion of the basin, with the Assiniboine River forming a major (6500 km^2) delta in the western portion of the basin (Elson, 1967). As pointed out by Johnston (1946), Elson (1967), and Teller (1976a), various lake-level fluctuations occurred during this time in response to changes in the elevation of the lake's southern outlet, crustal rebound, and position and movement of the ice margin.

Within and immediately south of the Lake Manitoba basin, offshore sedimentation continued with the deposition of the upper part of Unit A and Fenton's (1970) Lacustrine Clay Unit (Fig. 9-1b). However, the total thickness of this phase of Agassiz sediment is unknown because erosion associated with the following low level stages of the lake may have removed a portion of the record.

The overall climate of the region during this early Lake Agassiz Phase of Lake Manitoba was probably a few degrees cooler and slightly more humid than today's conditions (Moran et al, 1976). Nambudiri et al (1979) suggest a spruce-dominated boreal forest covered much of the land surface surrounding the lake. This is further confirmed by numerous other palynological studies of correlable lacustrine sediment in and around the Lake Agassiz basin (e.g., Shay, 1967; Wright, 1971, Ritchie, 1976; Ritchie and Lichti-Fedorovich, 1968).

About 11,000 years ago, ice retreat was sufficient to open a lower, eastern outlet into the Lake Superior basin, resulting in significantly lower lake levels (Moran et al, 1976; Teller, 1976a; Saarnisto, 1974). In portions of North Dakota and Minnesota, this drop exposed much of the lake floor to desiccation as well as erosion by newly developed drainage networks (Arndt, 1977; Rominger and Rutledge, 1952). Coarse-grained alluvial channel-fill and finer-grained overbank sediments of the Poplar River Formation were deposited on the clays of the Brenna Formation in the Upper Red River Valley (Harris et al, 1974; Arndt, 1977). In the main part of the offshore basin in south-central Manitoba, however, this low water phase of Lake Agassiz has not yet been identified in the sediment record (Last, 1974). In the Lake Manitoba basin (Fig. 9-1c), this lowering event is recorded by: (a) a marker horizon developed into the top of Unit A and (b) a loss of sediment record due to erosion.

A reflooding of the lake caused by a re-advance of the ice across the eastern outlets about 9900 years ago brought an end to this low water stage (Teller, 1976a; Arndt, 1977; Harris et al, 1974), and deposition of the lower coarse-grained portion of Unit B in the Lake Manitoba basin took place (Fig. 9-1d). As higher water levels were attained, sedimentation of the relatively finer, upper sections of Unit B occurred. In the Upper Red River Valley, the renewed water levels were responsible for deposition of the laminated silt and clays of the Sherack Formation over the Poplar River and Brenna Formations (Harris et al, 1974; Arndt, 1977).

Most authorities conclude that the newly reflooded lake attained nearly the same water levels (i.e., Campbell beach level) as the previous phase (e.g., Arndt, 1977; Teller, 1976a;Klassen and Elson, 1972; Moran et al, 1976; Elson, 1967; Delorme, 1971; Ashworth et al, 1972). The relatively low amount of pre-Quaternary microfossils in the upper part of Unit B, however, suggests that by this time the lake basin had constricted sufficiently to eliminate any major contribution of Cretaceous shales from the Manitoba Escarpment. This means that lake levels were probably considerably below the Campbell beach level during the latter stage of deposition of Unit B.

This final sedimentation event of glacial Lake Agassiz in the Lake Manitoba basin was short-lived. Opening of lower eastern outlets due to northward retreat of the ice in Manitoba and Ontario occurred by about 9500 years B.P. (Saarnisto, 1974; Teller, 1976a),and the lake rapidly drained in a series of stages. In southern Manitoba, Lake

Agassiz may have persisted until about 9000 years ago, at which time complete withdrawal of water from the Lake Manitoba basin and subaerial exposure of Unit B occurred over the next several hundred years. This 9000 to 8500 year draining/drying event marks the end of the Lake Agassiz Phase of sedimentation in Lake Manitoba.

Roughly coincident with these final sedimentological events of the Lake Agassiz Phase in Lake Manitoba, Nambudiri et al (1979) recognize the onset of relatively warm and dry conditions (the Hypsithermal interval) evidenced by the establishment of a Prairie-type of vegetation in the region. Ritchie (1976) and Wright (1970, 1971) also note a shift from a spruce-dominated boreal forest to the Prairie-type vegetation in the region.

9.3 MIDDLE HOLOCENE - EARLY LAKE MANITOBA PHASE

The southern shoreline of Lake Manitoba during the next 4000 years fluctuated from a position north of the study area to probably very close to today's configuration. Lake level fluctuations were in response to several controlling factors:

(a) Minor variations in the rate of retreat of the ice front to the north during the earliest stages of this phase, in part, controlled the levels of water in the Lake Manitoba-Lake Agassiz system (Ringrose, 1975; Grice, 1970; Elson, 1967);

(b) Greater rates of crustal rebound of the lake's outlet area in the north relative to the South Basin had two complimentary effects: namely, (1) an increase in the elevation of the Fairford River outlet without a corresponding downcutting would increase the effectiveness of the outlet in ponding water behind it, thereby raising the water levels, and (2) the differential rebound would cause a tilting of the basins resulting in a gradual southward transgression of the lake's shoreline;

(c) The warmer and drier climate of the region during this phase, as evidenced by the pollen record of Lake Manitoba (Nambudiri et al, 1979 and in preparation), would cause a constriction and possibly complete drying of the lake by increasing the evaporation/precipitation ratio over the basin and decreasing the fluvial and shallow (local) groundwater input.

Thus, when these factors interacted to create very low (or no) water conditions in the South Basin, marker zones developed in the sediment on the floor of the lake. When conditions favored higher water levels in the basin, the lacustrine sediment of Units C and D accumulated (Fig. 9-1e).

This long 4000-year period of oscillating low water to dry lake conditions which began about 9200 years B.P. was evidently a regional phenomenon. Callender (1967, 1968) and Owen et al (1973) have suggested that Devil's Lake, North Dakota (200 km south of Lake Manitoba) completely dried at about 6000 years ago. Likewise, Moran et al (1976) and Clayton et al (1976) estimate that the climate in North Dakota was considerably warmer and drier relative to today during the 8500 to 4500 year period, with many small lakes and streams completely drying. Furthermore, Ringrose (1975) alludes to evidence of subaerial exposure and weathering on till that is today submerged below the waters of Lake Winnipeg, and implies that the low water necessary for this exposure occurred sometime after 8300 years B.P.

Finally, the tendency toward a relatively warmer and drier climate during this period is further confirmed by paleobiological studies in the region in addition to those in the Lake Manitoba basin. For example, Ritchie and Hadden (1975) identify the period of 7200 to 6200 B.P. as warmer and drier than present on the basis of the pollen stratigraphy of a small lake on The Pas moraine about 100 km north of Lake Manitoba. This warm, dry period is coincident with the culmination of Prairie-type vegetation and conditions over much of the Western Interior Plains region (Ritchie, 1976). Ritchie and Koivo (1975) offer further confirmation of this warm, dry episode by identifying a corresponding rise in brackish water diatoms at this Grand Rapids core site. In a small lake on the Pembina Upland about 80 km south of Lake Manitoba, Delorme (1971) interprets the ostracod stratigraphy as indicating relatively lower but significantly fluctuating water levels, higher salinities, lower precipitation and higher evaporation at about 5500 years B.P.

During this 4000-year phase of Lake Manitoba, organic productivity in the basin increased substantially causing an increase in the authigenic components within the sediment record (i.e., organic matter and physicochemically precipitated calcite).

By about 6000 to 5500 years ago, the higher mean annual temperatures and the lower precipitation and inflow finally overwhelmed the tendency of crustal rebound to cause southward basin flooding, and the southern two-thirds of the Lake Manitoba basin underwent a major period of drying and desiccation (Fig. 9-1f). This final desiccation episode of Lake Manitoba lasted until about 4500 years ago and marks the culmination of the Early Lake Manitoba Phase of lacustrine sedimentation and the beginning of the final,Late Lake Manitoba Phase.

9.4 LATE HOLOCENE - LATE LAKE MANITOBA PHASE

The 1000-year period of desiccation and non-deposition in the Lake Manitoba basin between about 5500 and 4500 years B.P. was terminated by the diversion of at least part of the Assiniboine River into the Lake Manitoba watershed. This diversion resulted in the deposition of the sandy fluvial-deltaic complex of Unit E in and immediately south of the basin (Fig. 9-2a). With continued rising water levels due, in part, to the added fluvial contribution and, in part, to the decreasing aridity of the region, the lake gradually expanded during the next 500 to 1000 years (Fig. 9-2b). Salinities in the newly developing lake were probably high, in response to the gradual dissolution of soluble, evaporitic salts deposited during the previous 1000 years of more arid conditions and, probably, to a higher solute load of the inflowing streams. Higher water temperatures and, in particular, higher Mg/Ca ratios in the lake water permitted elevated levels of $MgCO_3$ incorporation into the authigenic calcite. In addition, the lake became more organically productive resulting in higher levels of organic matter in the sediment as well as more abundant calcite precipitation.

The decline in non-arboreal, Prairie-type pollen in the Lake Manitoba sediment reported by Nambudiri et al (1979, in preparation) indicates that the climate had begun a gradual shift toward cooler and wetter conditions after about 6000 years ago, thereby supplementing the added discharge of water into the basin. In addition, differential crustal rebound also probably continued to affect the region and help raise the level of the water in the South Basin.

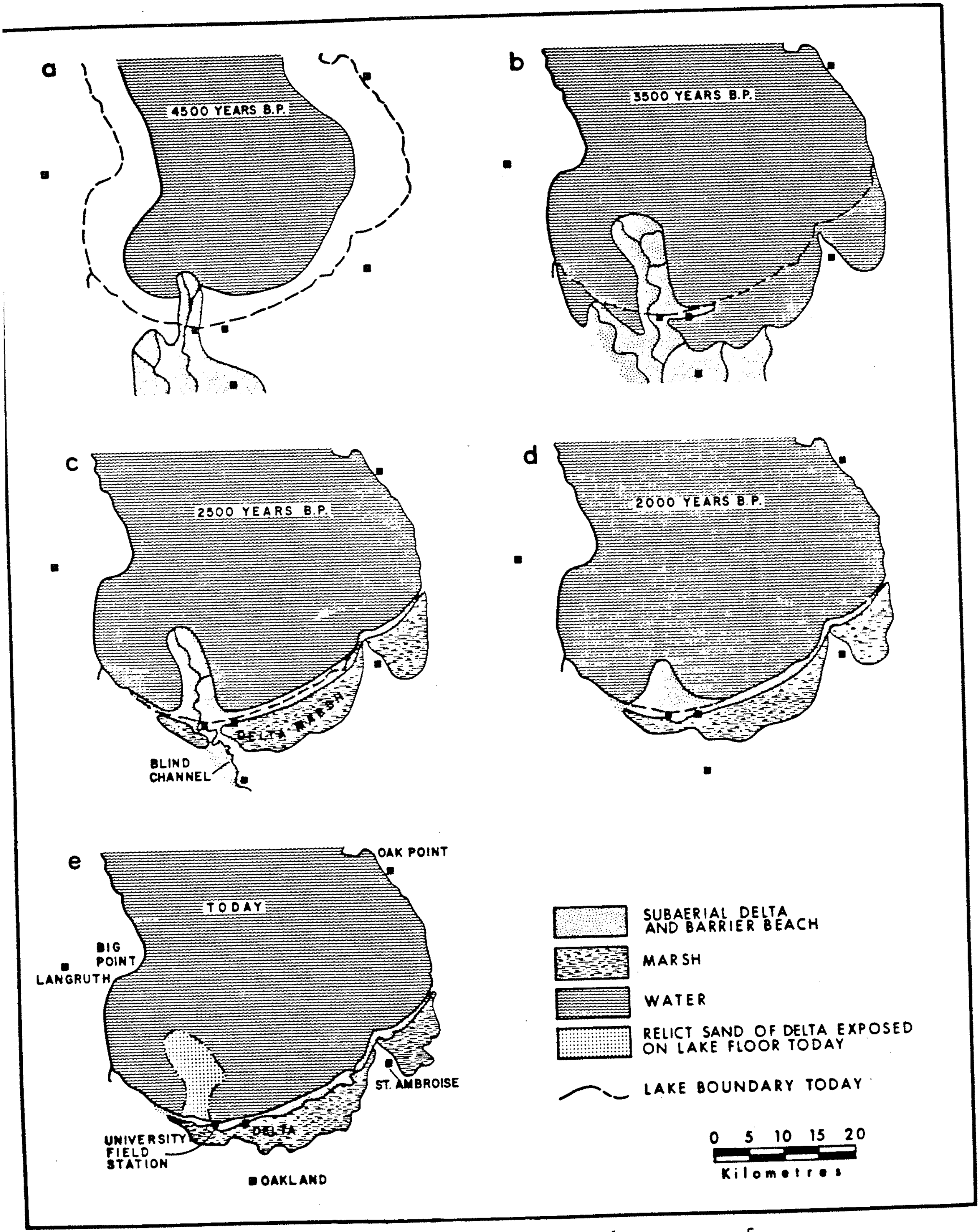


Figure 9-2. Maps showing the time and sequence of development of the Assiniboine Delta in Lake Manitoba. During construction of the delta, which began about 4500 years ago and ended about 2000 years ago, Delta Marsh was formed as a barrier beach was built by longshore drift.

Wave erosion of the coarse-grained fluvial-deltaic sands of Unit E by the southward transgressing lake, as well as continued influx of the Assiniboine River sediment provided sources of clastic material for the development of a barrier beach at the south end of the lake (Figs. 9-1g and 9-2c to 9-2e). The initiation of marsh vegetation conditions behind this barrier in Delta Marsh took place about 2400 years ago (Sproule, 1972). The presence of two distinct parallel beach ridges immediately north of Cadham Bay on the Delta Marsh barrier (see Fenton, 1970, Figure 5; and Gilliland, 1965, Figure 12) suggests two stages of barrier beach construction corresponding to slightly different lake levels over the next 2400 years.

By about 2000 years ago, the gradient of the Assiniboine River, which has been supplying water, sediment, and ions to the lake since 4500 years B.P., decreased to the point that the northward-trending channel(s) between the lake and the Portage la Prairire area was completely abandoned (Fig. 9-2d) and the river assumed its present-day eastward flow. This decreased gradient and subsequent abandonment was due to channel sedimentation, a rising base level, and continued differential crustal rebound.

The most recent 2000-year history recorded in the offshore sediments of Lake Manitoba reflects a period of considerable stability. Over this time, the productivity of the lake has continued to increase resulting in higher levels of organic matter and calcite in the record. However, due to the lack of major fluvial input, overall sedimentation rates for this final period are comparatively very low, averaging about 0.05 cm year^{-1} versus about 0.1 cm year^{-1} during the preceding 2500 years. In spite of the decrease in fluvial input via the Assiniboine River, the South Basin has maintained a stable lake level during the past 2000 years. Apparently, increasing precipitation and cooler temperatures combined with the effect of continued differential crustal rebound have been able to offset the loss. Similarly, Nambudiri et al (1979 and in preparation) suggest that, with the exception of an increase in *Ambrosia* which resulted from agricultural development in the watershed, vegetation patterns have not altered significantly during the last 3000 years.

Human activities and manipulation of the lake's drainage basin have not significantly affected the sediment record. Although pollen data would suggest a large increase in sedimentation rates in the basin during the last 100 years, there is considerable doubt as to the reliability of using the *Ambrosia* rise horizon as a time marker in the sediment record of Lake Manitoba.

9.5 SUMMARY OF THE POST-GLACIAL SEDIMENTARY HISTORY OF LAKE MANITOBA

Deposition of lacustrine sediment in the Lake Manitoba basin began about 12,000 years ago as meltwater from the retreating glacier was impounded in front of the ice (Fig. 9-3). High rates of sedimentation prevailed for about 1000 years as clayey sediment brought in by major rivers draining the newly deglaciated Prairies to the west, as well as by shoreline erosion, accumulated in the offshore basins of this large, deep, proglacial lake. In the initial part of this Lake Agassiz phase, the glacier itself also provided an abundance of coarse grains, pebbles, and till clasts. Organic productivity in the lake during this early phase was low, and the sediment record is dominated by detrital components.

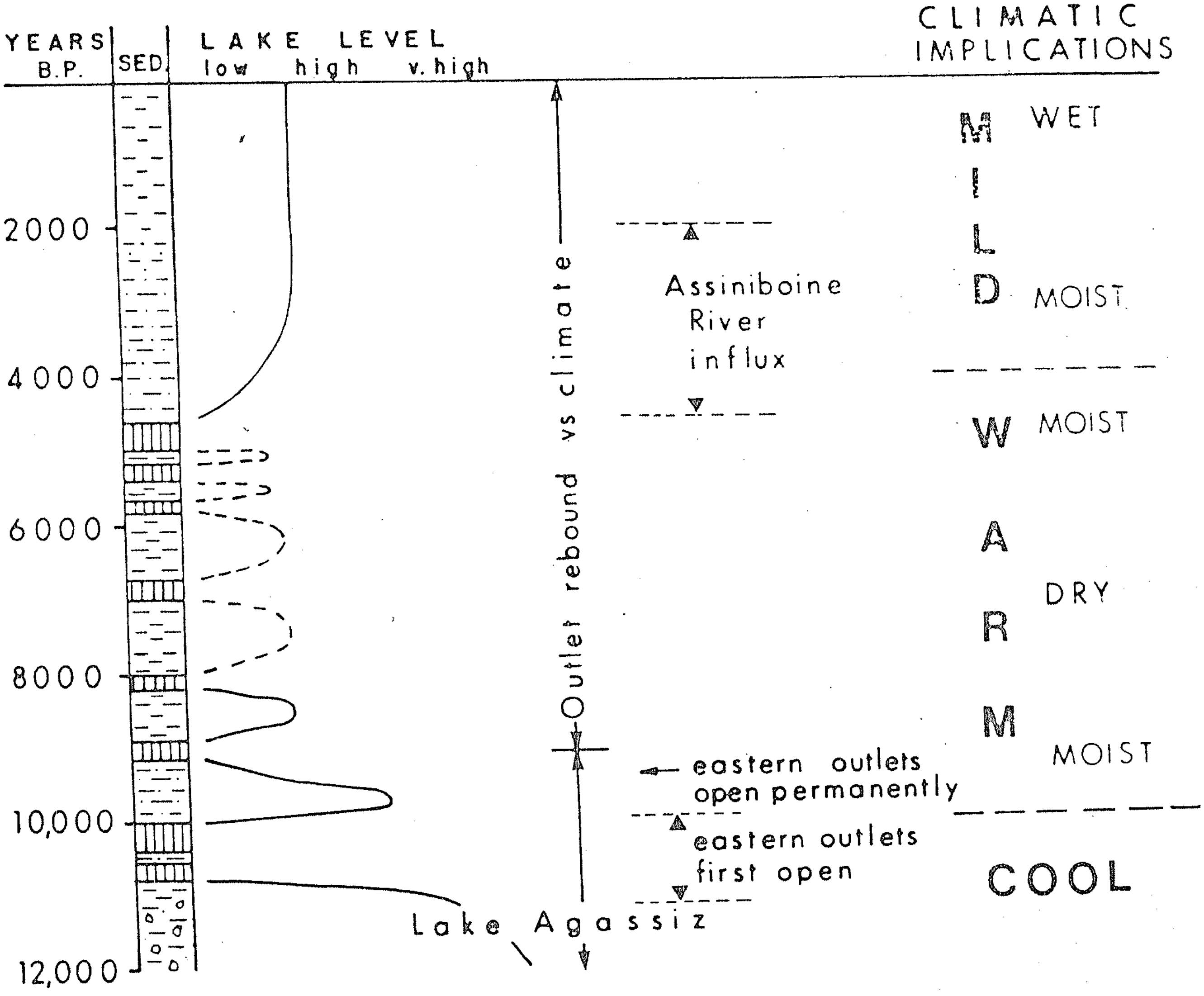


Figure 9-3. Chronology of lake level fluctuations and their climatic implications. Vertically lined segments of the "sed" column represent non-deposition and formation of marker zones (modified from Teller and Last, 1979).

By 11,000 years ago, continued retreat of the ice sheet in response to the moderating climate opened significantly lower eastern outlets and much of Lake Agassiz, including the Lake Manitoba basin, drained. However, water levels again rose at about 10,000 years B.P. due to a re-advance of ice over the eastern outlets. This final episode of Lake Agassiz was short-lived and by about 9500 years ago the lake began to drain in a series of stages as the eastern outlets were undammed. The South Basin of Lake Manitoba was again dry by about 9000 years B.P.

Alternating wet and dry conditions prevailed in the Lake Manitoba basin for the next 4500 years mainly in response to the interaction of a warmer and drier climate in which evaporation greatly exceeded precipitation plus inflow and differential crustal rebound which tended to increase the depth of the South Basin in relation to the North Basin. During the driest of these periods, distinctive marker horizons developed in the exposed mud on the lake floor, while during "wet" periods deposition of both authigenic (magnesian calcite and organic matter) and detrital components took place. At about 6000 years ago the South Basin entered the final and probably longest period of dominantly dry conditions.

The second most recent episode of sedimentation in Lake Manitoba was initiated when all or part of the Assiniboine River began to discharge into the south end of the Basin about 4500 years B.P. In addition to helping reflood the lake, this added fluvial input supplied coarse-grained sediment. Moreover, high Mg/Ca ratios in the newly developing lake, probably in response to the gradual dissolution of evaporitic salts in the bottom sediments and possibly supplemented and maintained by a high Mg/Ca ratio of the inflowing Assiniboine River, resulted in the precipitation of magnesian calcite with a considerably higher $MgCO_3$ content than that of the previously deposited sediment.

The Assiniboine River was diverted out of the South Basin watershed about 2000 years ago resulting in lower offshore lacustrine sedimentation rates and deposition of finer-grained material. Calcite precipitation in the lake and accumulation of organic matter in the sediment has continued to steadily increase over the past 3500 to 4500 years. Erosion and redistribution of the sandy deltaic sediments of the Assiniboine River by wave action has created a barrier beach separating Delta Marsh from the main lake at the south end of the basin. Except for these developments, however, there has been little change in the lake over the past 2000 years.

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APPENDIX A

Field Equipment List and Description of Operation of Livingstone Corer

A.1 Livingstone Coring

A.1.1 Equipment Requirements

Livingstone corer including: (a) 5 cm diameter, 20-guage stainless steel, 122 cm long core barrel(s) with bevelled cutting edge and holes for connection screws, and escape of water at upper end; (b) a piston assembly consisting of two rubber stoppers, a conical aluminum point, a slotted threaded shaft, washers and nuts; (c) a 15 m long, 3.0 mm plastic-coated piston wire; (d) a stainless steel sampler head with threaded core barrel attachment holes and a slotted, square central shaft; (e) screws for attachment of (a) to (d); (f) a 126 cm long, 1.5 cm diameter, square, steel piston rod threaded at upper and lower ends, with metal stops or flanges 24 cm from lower end (Further specifications of the Livingstone sampler can be found in Wright, 1967).

Lowering cable: 30 m long, 5 mm diameter, plastic coated.

Connecting (or drive) rods: variable lengths of 2.24 cm diameter, seamless 4130 chrome-molybdenum steel alloy threaded pipe.

T-handle

Screw driver(s)

Pliers

Vise-grip pliers (2)

Crescent wrench

Tape measure (30 m length) and metre sticks

Wire brush

Methyl hydrate (de-icer)

Tape, markers and plastic for labeling and sealing core.

Ice auger: 15 cm diameter capable of penetrating the maximum expected ice thickness.

Board or unflexible rod for piston wire surface attachment.

Small sledge or hammer

Shovel

Tarp

Rubberized gloves

A.1.2 Field Procedure

(a) Before arriving at sampling site, assemble corer. Adjust piston diameter by compressing or expanding the rubber stoppers such that the assembly fits tightly inside the core barrel but movement is still possible by pulling the piston wire.

(b) At the sampling site, place all required tools on tarp, auger a hole through the ice and measure water depth with weighted tape measure. Lay out the corer in extended position (that is, the lower end of the piston rod is at the upper end of the sampler head and the entire unit measures about 237 cm from the end of the piston at the base to the top of the piston rod) on the ice and connect the appropriate lengths of drive rods to the upper end of the piston rod. Mark the sediment/water interface on the assembly by placing a vise-grip wrench at the water depth distance measured from the base of the core barrel. Measure and likewise mark exactly 1 m above this point.

(c) Slowly lower the apparatus through the ice to the level of the first wrench, making sure that the piston is positioned at the very end of the core barrel and that no tension is applied to the piston wire. The corer should be at the sediment/water interface. Carefully remove the wrench that is at the water surface. Rotate the drive rods such that the flanges on the lower end of the piston rod do not coincide with the grooves in the top of the sampler head. Carefully take up any slack on the piston wire and secure it to the board near the auger hole. Apply slow, even, downward pressure to the top of the drive rods (T-handle) stopping at the level of the second vise grip wrench. Pull out the assembly, disconnect the filled core tube from the sampler head and piston, seal, label and place upright in vehicle.

(d) Carefully remove all ice and sediment from the piston, piston wire, square rod and sampler head using the wire brush and methyl hydrate. Insert the piston and piston wire into a new core barrel. Thread the lowering cable through the two water vent holes in the upper end of the new barrel and attach the sampler head. Lay out the corer in the compressed position (that is, the lower end of the piston rod is at the base of the corer and the entire unit measures about 137 cm from the end of the piston at the base to the top of the piston rod) on the ice and connect an additional drive rod for sampling of 1-2 m depth below sediment-water interface. Mark with the vise grip wrenches the sediment/water interface and exactly 1 m above it.

(e) Slowly lower the apparatus through the ice using the lowering cable to the level of the first wrench. Remove this wrench. The sampler (which is still in the compressed position) is now at the sediment/water interface. Push the sampler to the level of the second wrench by applying downward force on the drive rods. Do not remove this second wrench. It is somewhat helpful, but not necessary, to attempt to re-enter the previous core hole. The piston and the end of the core barrel are now at a position 1 m below the sediment/water interface. Pull up on the drive rods and rotate the rods to the position such that the flanges do not coincide with the grooves in the sampler head. The wrench is now 1 m above the water level and markes the position the sampler should be driven to. The lowering cable is no longer of use and can be released. Proceed as above; secure the piston wire at the surface, drive 1 m to the level of the wrench, pull out and disconnect the filled core barrel. Each additional 1 m core length attempted will require the appropriate positioning of the second wrench above the one marking the sediment/water interface.

A.1.3 Extrusion of Livingstone cores

Extrusion of the filled Livingstone core barrels is accomplished by re-attaching the piston, sampler head and piston rod (in extended position) out the top of the filled core barrel. The sediment is extruded out the base of the barrel by applying force onto the top of the piston rod.

Required equipment for this procedure includes: split 7.6 cm diameter rigid plastic pipe, plastic sheeting, tape, markers, styrofoam cups (for end plugs) in addition to the Livingstone assembly and assorted tools.

APPENDIX B

Number and frequency of analyses per core.

The value outside of the parentheses is the total number of analyses of that parameter within the particular core; the value inside the parentheses is the frequency of analysis (one analysis per x cm of core) of that parameter within the core. For example, in core 1 the moisture content of 21 subsamples was determined which results in one moisture content analysis approximately every 2 cm. The total number of analyses for all the cores is given on the final page of this Appendix.

CORE	MOISTURE CONTENT	SAND	SILT	CLAY	MEAN GRAIN SIZE	STANDARD DEVIATION	SKEWNESS	KURTOSIS	ORGANIC MATTER	BULK DENSITY CALCULATED	BULK DENSITY EXPERIMENTAL	POROSITY
1	21(2)	7(7)	7(7)	7(7)	7(7)	7(7)	7(7)	7(7)	21(2)	1(52)	-	1(52)
2	10(2)	4(5)	4(5)	4(5)	4(5)	4(5)	4(5)	4(5)	10(2)	1(20)	-	1(20)
3	21(3)	3(21)	3(21)	3(21)	2(31)	1(63)	1(63)	1(63)	9(7)	1(63)	1(63)	1(63)
4	9(9)	1(80)	1(80)	1(80)	1(80)	1(80)	1(80)	1(80)	9(9)	1(80)	-	1(80)
5	31(3)	1(92)	1(92)	1(92)	1(92)	1(92)	1(92)	1(92)	11(8)	1(92)	-	1(92)
6	3(32)	1(96)	1(96)	1(96)	1(96)	1(96)	1(96)	1(96)	3(32)	1(96)	-	1(96)
7	30(3)	5(17)	5(17)	5(17)	1(86)	1(86)	1(86)	1(86)	13(6)	12(7)	-	12(7)
8	10(7)	2(35)	2(35)	2(35)	1(69)	1(69)	1(69)	1(69)	8(8)	1(69)	-	1(69)
9	12(7)	1(83)	1(83)	1(83)	1(83)	1(83)	1(83)	1(83)	11(7)	1(83)	-	1(83)
10	12(7)	1(90)	1(90)	1(90)	1(90)	1(90)	1(90)	1(90)	12(7)	1(90)	-	1(90)
11	4(25)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	4(25)	1(100)	-	1(100)
12	34(3)	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	34(3)	7(14)	-	7(14)
13	34(3)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	34(3)	4(25)	-	4(25)
14	3(33)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	3(33)	1(100)	-	1(100)
15	3(28)	1(84)	1(84)	1(84)	1(84)	1(84)	1(84)	1(84)	3(28)	1(84)	-	1(84)
16	10(7)	1(73)	1(73)	1(73)	1(73)	1(73)	1(73)	1(73)	10(7)	1(73)	-	1(73)
17	12(8)	1(96)	1(96)	1(96)	1(96)	1(96)	1(96)	1(96)	12(8)	1(96)	-	1(96)
18	15(6)	1(94)	1(94)	1(94)	1(94)	1(94)	1(94)	1(94)	15(6)	1(94)	-	1(94)
19	33(3)	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	33(3)	1(98)	-	1(98)
20	3(3)	2(5)	2(5)	2(5)	2(5)	2(5)	2(5)	2(5)	3(3)	-	-	-

CORE	QUARTZ	FELDSPAR	TOTAL CALCITE	Mg-CALCITE	MOLE % $MgCO_3$ in CALCITE	DOLOMITE	TOTAL CARBONATE (L.O.C.)	TOTAL CLAY MINERALS	EXPANDABLE CLAY MINERALS	ILLITE	KAOLINITE + CHLORITE
1	1(52)	1(52)	1(52)	-	-	1(52)	21(2)	1(52)	-	-	-
2	1(20)	1(20)	1(20)	-	-	1(20)	10(2)	1(20)	-	-	-
3	1(63)	1(63)	1(63)	1(63)	1(63)	1(63)	9(7)	1(63)	-	-	-
4	1(80)	1(80)	1(80)	-	-	1(80)	9(9)	1(80)	1(80)	1(80)	1(80)
5	1(92)	1(92)	1(92)	1(92)	1(92)	1(92)	11(8)	1(92)	1(92)	1(92)	1(92)
6	1(96)	1(96)	1(96)	-	-	1(92)	3(32)	1(92)	1(92)	1(92)	1(92)
7	1(86)	1(86)	1(86)	1(86)	1(86)	1(86)	13(6)	1(86)	1(86)	1(86)	1(86)
8	1(69)	1(69)	1(69)	-	-	1(69)	8(8)	1(69)	1(69)	1(69)	1(69)
9	1(83)	1(83)	1(83)	1(83)	1(83)	1(83)	11(7)	1(83)	1(83)	1(83)	1(83)
10	1(90)	1(90)	1(90)	-	-	1(90)	12(7)	1(90)	1(90)	1(90)	1(90)
11	1(100)	1(100)	1(100)	-	-	1(100)	4(25)	1(100)	1(100)	1(100)	1(100)
12	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	34(3)	1(98)	1(98)	1(98)	1(98)
13	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	34(3)	1(100)	1(100)	1(100)	1(100)
14	1(100)	1(100)	1(100)	1(100)	1(100)	1(100)	3(33)	1(100)	1(100)	1(100)	1(100)
15	1(84)	1(84)	1(84)	1(84)	1(84)	1(84)	3(28)	1(84)	1(84)	1(84)	1(84)
16	1(73)	1(73)	1(73)	-	-	1(73)	10(7)	1(73)	1(73)	1(73)	1(73)
17	1(96)	1(96)	1(96)	1(96)	1(96)	1(96)	12(8)	1(96)	1(96)	1(96)	1(96)
18	1(94)	1(94)	1(94)	1(94)	1(94)	1(94)	15(6)	1(94)	1(94)	1(94)	1(94)
19	1(98)	1(98)	1(98)	1(98)	1(98)	1(98)	33(3)	1(98)	1(98)	1(98)	1(98)
20	1(11)	1(11)	1(11)	-	-	1(11)	3(3)	1(11)	-	-	-

CORE	pH	Eh	TOTAL CARBON	CARBONATE CARBON	ORGANIC CARBON	POTASSIUM	SODIUM	CALCIUM	MAGNESIUM	IRON
1	-	-	-	-	-	1(52)	1(52)	1(52)	1(52)	1(52)
2	1(20)	1(20)	-	-	-	1(20)	1(20)	1(20)	1(20)	1(20)
3	12(5)	12(5)	-	-	-	1(63)	1(63)	1(63)	1(63)	1(63)
4	10(8)	10(8)	-	-	-	1(80)	1(80)	1(80)	1(80)	1(80)
5	32(3)	32(3)	-	-	-	1(92)	1(92)	1(92)	1(92)	1(92)
6	3(32)	-	-	-	-	1(92)	1(92)	1(92)	1(92)	1(92)
7	30(3)	30(3)	-	-	-	1(86)	1(86)	1(86)	1(86)	1(86)
8	10(7)	10(7)	-	-	-	1(69)	1(69)	1(69)	1(69)	1(69)
9	12(7)	12(7)	-	-	-	-	-	-	-	-
10	12(7)	12(7)	-	-	-	1(90)	1(90)	1(90)	1(90)	1(90)
11	4(25)	4(25)	-	-	-	-	-	-	-	-
12	34(3)	34(3)	4(25)	4(25)	4(25)	1(98)	1(98)	1(98)	1(98)	1(98)
13	34(3)	34(3)	-	-	-	1(100)	1(100)	1(100)	1(100)	1(100)
14	3(33)	3(33)	-	-	-	-	-	-	-	-
15	3(28)	3(28)	-	-	-	-	-	-	-	-
16	10(7)	10(7)	-	-	-	-	-	-	-	-
17	12(8)	12(8)	-	-	-	1(96)	1(96)	1(96)	1(96)	1(96)
18	15(6)	15(6)	-	-	-	1(94)	1(94)	1(94)	1(94)	1(94)
19	33(3)	33(3)	-	-	-	1(98)	1(98)	1(98)	1(98)	1(98)
20	3(3)	3(3)	-	-	-	1(11)	1(11)	1(11)	1(11)	1(11)

CORE	MANGANESE	PHOSPHOROUS	ZINC	CADMIUM	COPPER	LEAD	MERCURY	CHLORIDE	TOTAL SULFUR	SULFATE SULFUR	SOLUBLE SALT
1	1(52)	1(52)	1(52)	-	1(52)	-	-	-	-	-	-
2	1(20)	1(20)	1(20)	-	1(20)	-	-	-	-	-	-
3	1(63)	1(63)	1(63)	-	1(63)	-	-	-	-	-	-
4	1(80)	1(80)	1(80)	-	1(80)	-	-	-	-	-	-
5	1(92)	1(92)	1(92)	-	1(92)	-	-	-	-	-	-
6	1(92)	1(92)	1(92)	-	1(92)	-	-	-	-	-	-
7	1(86)	1(86)	1(86)	-	1(86)	-	-	-	-	-	-
8	1(69)	1(69)	1(69)	-	1(69)	-	1(69)	-	-	-	-
9	-	-	-	-	-	8(10)	-	-	-	-	-
10	1(90)	1(90)	1(90)	-	1(90)	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	1(98)	1(98)	1(98)	-	1(98)	-	-	-	-	-	-
13	1(100)	1(100)	1(100)	-	1(100)	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	1(84)	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-
17	1(96)	1(96)	1(96)	-	1(96)	-	-	-	-	-	-
18	1(94)	1(94)	1(94)	-	1(94)	-	-	-	-	-	-
19	1(98)	1(98)	1(98)	-	1(98)	-	-	-	-	-	-
20	1(11)	1(11)	1(11)	-	1(11)	-	-	-	-	-	-

CORE	MOISTURE CONTENT	SAND	SILT	CLAY	MEAN GRAIN SIZE	STANDARD DEVIATION	SKEWNESS	KURTOSIS	ORGANIC MATTER	BULK DENSITY, CALCULATED	BULK DENSITY EXPERIMENTAL	POROSITY
21	8(3)	1(27)	1(27)	1(27)	1(27)	1(27)	1(27)	1(27)	8(3)	1(27)	-	1(27)
22	5(39)	1(197)	1(197)	1(197)	1(197)	1(197)	1(197)	1(197)	5(39)	-	-	-
23	54(5)	22(12)	22(12)	22(12)	1(265)	1(265)	1(265)	1(265)	54(5)	13(20)	-	13(20)
24	24(8)	1(200)	1(200)	1(200)	1(200)	1(200)	1(200)	1(200)	2(100)	-	-	-
25	37(3)	1(126)	1(126)	1(126)	1(126)	1(126)	1(126)	1(126)	37(3)	-	-	-
26	58(5)	1(325)	1(325)	1(325)	1(325)	1(325)	1(325)	1(325)	41(8)	31(10)	-	31(10)
27	51(5)	1(257)	1(257)	1(257)	1(257)	1(257)	1(257)	1(257)	34(7)	27(9)	-	27(9)
28	51(5)	6(58)	6(58)	6(58)	1(296)	1(296)	1(296)	1(296)	32(9)	-	-	-
29	1(100)	-	-	-	-	-	-	-	1(100)	-	-	-
30	1(-)	1(-)	1(-)	1(-)	1(-)	1(-)	1(-)	1(-)	-	-	-	-
31	18(3)	1(49)	1(49)	1(49)	1(49)	1(49)	1(49)	1(49)	9(5)	1(49)	-	1(49)
32	29(3)	1(72)	1(72)	1(72)	1(72)	1(72)	1(72)	1(72)	15(5)	1(72)	-	1(72)
33	15(5)	1(25)	1(25)	1(25)	1(25)	1(25)	1(25)	1(25)	7(3)	1(25)	-	1(25)
34	46(3)	1(105)	1(105)	1(105)	1(105)	1(105)	1(105)	1(105)	31(3)	1(105)	-	1(105)
35	19(3)	1(53)	1(53)	1(53)	1(53)	1(53)	1(53)	1(53)	9(6)	9(6)	-	9(6)
36	4(22)	-	-	-	-	-	-	-	-	-	-	-
37	51(5)	1(291)	1(291)	1(291)	1(291)	1(291)	1(291)	1(291)	51(5)	-	-	-
38	52(5)	8(235)	8(235)	8(235)	1(285)	1(285)	1(285)	1(285)	45(6)	-	-	-
39	39(3)	9(18)	9(18)	9(18)	1(160)	1(160)	1(160)	1(160)	39(3)	-	-	-
40	38(4)	5(25)	5(25)	5(25)	1(127)	1(127)	1(127)	1(127)	9(14)	-	-	-

CORE	QUARTZ	FELDSPAR	TOTAL CALCITE	Mg-CALCITE	MOLE % $MgCO_3$ in CALCITE	DOLOMITE	TOTAL CARBONATE (L.O.C.)	TOTAL CLAY MINERALS	EXPANDABLE CLAY MINERALS	ILLITE	KAOLINITE + CHLORITE
21	1(27)	1(27)	1(27)	-	-	1(27)	8(3)	1(27)	-	-	-
22	1(197)	1(197)	1(197)	1(197)	1(197)	1(197)	5(39)	1(197)	-	-	-
23	18(14)	18(14)	18(14)	7(38)	7(38)	18(14)	54(5)	18(14)	1(265)	1(265)	1(265)
24	1(200)	1(200)	1(200)	-	-	1(200)	2(100)	1(200)	1(200)	1(200)	1(200)
25	1(126)	1(126)	1(126)	1(126)	1(126)	1(126)	37(3)	1(126)	1(126)	1(126)	1(126)
26	1(325)	1(325)	1(325)	-	-	1(325)	41(8)	1(325)	1(325)	1(325)	1(325)
27	1(257)	1(257)	1(257)	-	-	1(257)	34(7)	1(257)	1(257)	1(257)	1(257)
28	1(296)	1(296)	1(296)	1(296)	1(296)	1(296)	32(9)	1(296)	1(296)	1(296)	1(296)
29	-	-	-	-	-	-	1(100)	-	-	-	-
30	1(-)	1(-)	1(-)	-	-	1(-)	-	1(-)	-	-	-
31	1(49)	1(49)	1(49)	1(49)	1(49)	1(49)	9(5)	1(49)	1(49)	1(49)	1(49)
32	1(72)	1(72)	1(72)	1(72)	1(72)	1(72)	15(5)	1(72)	1(72)	1(72)	1(72)
33	1(25)	1(25)	1(25)	1(25)	1(25)	1(25)	7(3)	1(25)	1(25)	1(25)	1(25)
34	1(105)	1(105)	1(105)	1(105)	1(105)	1(105)	31(3)	1(105)	1(105)	1(105)	1(105)
35	1(53)	1(53)	1(53)	1(53)	1(53)	1(53)	9(6)	1(53)	-	-	-
36	1(89)	1(89)	1(89)	-	-	1(89)	-	1(89)	-	-	-
37	1(291)	1(291)	1(291)	1(291)	1(291)	1(291)	51(5)	1(291)	1(291)	1(291)	1(291)
38	13(22)	13(22)	13(22)	1(285)	1(285)	13(22)	45(6)	13(22)	1(285)	1(285)	1(285)
39	1(160)	1(160)	1(160)	1(160)	1(160)	1(160)	39(3)	1(160)	1(160)	1(160)	1(160)
40	1(127)	1(127)	1(127)	-	-	1(127)	9(14)	1(127)	1(127)	1(127)	1(127)

CORE	pH	Eh	TOTAL CARBON	CARBONATE CARBON	ORGANIC CARBON	POTASSIUM	SODIUM	CALCIUM	MAGNESIUM	IRON
21	5(5)	5(5)	-	-	-	-	-	-	-	-
22	5(39)	5(39)	-	-	-	-	-	-	-	-
23	56(5)	56(5)	2(132)	2(132)	2(132)	4(66)	4(66)	4(66)	4(66)	4(66)
24	24(8)	24(8)	-	-	-	1(200)	1(200)	1(200)	1(200)	1(200)
25	15(19)	15(19)	-	-	-	1(126)	1(126)	1(126)	1(126)	1(126)
26	39(8)	39(8)	1(325)	1(325)	1(325)	1(325)	1(325)	1(325)	1(325)	1(325)
27	34(7)	34(7)	-	-	-	1(257)	1(257)	1(275)	1(257)	1(257)
28	46(6)	46(6)	1(296)	1(296)	1(296)	1(296)	1(296)	1(296)	1(296)	1(296)
29	1(100)	1(100)	-	-	-	-	-	-	-	-
30	1(-)	1(-)	-	-	-	-	-	-	-	-
31	17(3)	17(3)	-	-	-	1(49)	1(49)	1(49)	1(49)	1(49)
32	13(5)	13(5)	-	-	-	1(72)	1(72)	1(72)	1(72)	1(72)
33	9(3)	9(3)	-	-	-	-	-	-	-	-
34	16(6)	16(6)	-	-	-	1(105)	1(105)	1(105)	1(105)	1(105)
35	11(5)	11(5)	-	-	-	-	-	-	-	-
36	4(22)	4(22)	-	-	-	-	-	-	-	-
37	32(9)	32(9)	-	-	-	1(291)	1(291)	1(291)	1(291)	1(291)
38	38(7)	38(7)	-	-	-	1(285)	1(285)	1(285)	1(285)	1(285)
39	39(3)	39(3)	-	-	-	9(18)	9(18)	9(18)	9(18)	9(18)
40	18(7)	18(7)	-	-	-	-	-	-	-	-

CORE	MANGANESE	PHOSPHOROUS	ZINC	CADMIUM	COPPER	LEAD	MERCURY	CHLORIDE	TOTAL SULFUR	SULFATE SULFUR	SOLUBLE SALT
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	4(66)	4(66)	4(66)	1(265)	4(66)	1(265)	4(66)	-	-	-	-
24	1(200)	1(200)	1(200)	-	1(200)	-	-	-	-	-	-
25	1(126)	1(126)	1(126)	-	1(126)	-	-	-	-	-	-
26	1(325)	1(325)	1(325)	-	1(325)	-	-	-	-	-	-
27	1(257)	1(257)	1(257)	-	1(257)	30(85)	-	-	-	-	-
28	1(296)	1(296)	1(296)	-	1(296)	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-
31	1(49)	1(49)	1(49)	-	1(49)	-	-	-	-	-	-
32	1(72)	1(72)	1(72)	-	1(72)	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-
34	1(105)	1(105)	1(105)	1(105)	1(105)	1(105)	2(52)	-	-	-	-
35	-	-	-	-	-	--	-	-	-	-	-
36	-	-	-	-	-	-	1(89)	-	-	-	-
37	1(291)	1(291)	1(291)	-	1(291)	-	-	-	-	-	-
38	1(285)	1(285)	1(285)	-	1(285)	-	-	-	-	-	-
39	9(18)	9(18)	9(18)	-	9(18)	-	-	-	-	-	-
40	-	-	6(21)	-	6(21)	3(42)	6(21)	-	-	-	-

CORE	MOISTURE CONTENT	SAND	SILT	CLAY	MEAN GRAIN SIZE	STANDARD DEVIATION	SKEWNESS	KURTOSIS	ORGANIC MATTER	BULK DENSITY CALCULATED	BULK DENSITY EXPERIMENTAL	POROSITY
41	-	2(18)	2(18)	2(18)	1(36)	1(36)	1(36)	1(36)	1(36)	-	-	-
42	19(9)	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	-	-	-
43	8(9)	8(9)	8(9)	8(9)	8(9)	8(9)	8(9)	8(9)	1(75)	1(75)	-	1(75)
44	6(10)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	-	-	-
45	5(7)	1(36)	1(36)	1(36)	1(36)	1(36)	1(36)	1(36)	1(36)	-	-	-
47	8(7)	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	-	-	-
D-1	105(12)	50(27)	50(27)	50(27)	1(1359)	1(1359)	1(1359)	1(1359)	95(14)	10(136)	10(136)	-
D-2	88(12)	43(25)	43(25)	43(25)	1(1068)	1(1068)	1(1068)	1(1068)	88(12)	78(13)	14(76)	78(13)
D-3	104(9)	50(19)	50(19)	50(19)	3(319)	3(319)	3(319)	3(319)	104(9)	12(79)	10(95)	-
D-4	-	4(167)	4(167)	4(167)	-	-	-	-	-	-	-	-
TOTALS	1244	261	261	261	68	68	68	68	983	256	34	232

CORE	QUARTZ	FELDSPAR	TOTAL CALCITE	Mg-CALCITE	MOLE % $MgCO_3$ in CALCITE	DOLOMITE	TOTAL CARBONATE (L.O.C.)	TOTAL CLAY MINERALS	EXPANDABLE CLAY MINERALS	ILLITE	KAOLINITE + CHLORITE
41	1(36)	1(36)	1(36)	-	-	1(36)	1(36)	1(36)	-	-	-
42	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	1(180)	-	-	-
43	1(75)	1(75)	1(75)	-	-	1(75)	1(75)	1(75)	-	-	-
44	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)	1(59)
45	1(36)	1(36)	1(36)	-	-	1(36)	1(36)	1(36)	-	-	-
47	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	1(54)	-	-	-
D-1	70(19)	70(19)	70(19)	37(37)	37(37)	70(19)	95(14)	70(19)	38(35)	38(35)	38(35)
D-2	40(26)	40(26)	40(26)	11(97)	11(97)	40(26)	88(12)	40(26)	36(30)	36(30)	36(30)
D-3	41(23)	41(23)	41(23)	9(106)	9(106)	41(23)	104(9)	41(23)	37(26)	37(26)	37(26)
D-4	-	-	-	-	-	-	-	-	-	-	-
TOTALS	225	225	225	89	89	225	983	225	165	165	165

CORE	pH	Eh	TOTAL CARBON	CARBONATE CARBON	ORGANIC CARBON	POTASSIUM	SODIUM	CALCIUM	MAGNESIUM	IRON
41	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-	-
45	1(36)	-	-	-	-	-	-	-	-	-
47	-	-	-	-	-	-	-	-	-	-
D-1	103(13)	103(13)	9(148)	9(148)	9(148)	37(37)	37(37)	37(37)	37(37)	37(37)
D-2	84(13)	84(13)	8(122)	8(122)	8(122)	34(31)	34(31)	34(31)	34(31)	34(31)
D-3	98(10)	98(10)	-	-	-	34(28)	34(28)	34(28)	34(28)	34(28)
D-4	-	-	-	-	-	-	-	-	-	-
TOTALS	983	983	25	25	25	143	143	143	143	143

CORE	MANGANESE	PHOSPHOROUS	ZINC	CADMIUM	COPPER	LEAD	MERCURY	CHLORIDE	TOTAL SULFUR	SULFATE SULFUR	SOLUBLE SALT
41	-	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-
47	-	-	-	-	-	-	-	-	-	-	-
D-1	37(37)	37(37)	37(37)	-	37(37)	-	3(450)	37(37)	-	-	-
D-2	34(31)	34(31)	34(31)	5(213)	34(31)	**9(118)**	-	-	27(29)	27(29)	32(33)
D-3	34(28)	34(28)	34(28)	4(239)	34(28)	1(957)	-	-	-	-	-
D-4	-	-	-	-	-	-	-	-	-	-	-
TOTALS	143	143	143	12	143	**18**	26	37	27	27	32

APPENDIX C

Biological Data

Table C-1	Lake Manitoba plankton species list (summarized from Bajkov, 1930).
Table C-2	Results of reconnaissance investigation of mollusks in cores from the South Basin (reported by Dr. I. Lubinsky, Department of Zoology, University of Manitoba, 1979).
Table C-3	Results of reconnaissance investigation of diatoms in core D-1 (reported by Dr. R. Carter, Anthropology Department, University of Manitoba, 1979).

Table C-1. Lake Manitoba plankton species list (summarized from Bajkov, 1930). a = abundant; vc = very common; c = common; lc = less common; r = rare

MYXOPHYCEAE

Anabaena flos-aquae Breb: c

Aphanocapsa elachista West:

Chroococcus limneticus Lemm: c

Merismopedia glauca Nag: lc

Microcystis aeruginosa (Kutz): c

Nostoc commune Vauch: c

Rivularia pisum (Ag.): a

CHLOROPHYCEAE

Actinastrum gracillimum G. M. Smith: lc

Botryococcus brauni Kutz: c

Cladophora sp.: r

Closterium moniliferum Ehrb: c

Closterium sp.: r

Coelastrum microporum Nag.: lc

Cosmarium botrytis Uneg.: lc

Cosmarium meneghinii Breb.: lc

Cosmarium reniforme (Ralfs.): lc

Cosmarium sp.: lc

Crucigenia quadrata Morren: c

Distyosphaerium pulchellum Wood: vc

Euastrum sp.: r

Eudorina elegans Ehrb.: c

Microspora sp.: lc

Mougeotia sp.: r

Oocystis lacustris Chad.: c

Pediastrum boryanum Uneg.: vc

Pediastrum duplex Uneg.: vc

Pediastrum duplex var.: vc

Pediastrum integrum Nag.: r
Pediastrum simplex Meyer.: c
Pediastrum simplex Meyer. var.: c
Pediastrum tetras (Ehrb.): c
Rhizoclonium hieroglyphicum Kutz.: c
Scenedesmus quadricauda Breb.: a
Selenastrum sp.: lc
Spirogyra sp.: r
Staurastrum brevis pinum Breb.: r
Staurastrum leptocladum Nordst.: r
Staurastrum sp.: lc
Tetraspora gelatinosa (Vauch): c
Tribonema sp.: r
Ulothrix zonata Kutz.: lc
Zygnema sp.: lc

BACILLARIACEAE

Amphora ovalis Ehrb.: lc
Asterionella formosa Hass.: r
Cyclotella antiqua, W. Sm.: c
Cymatopleura sp.: c
Epithemia turgida (Ehrb.): c
Eunotia sp.: lc
Fragilaria crotonensis Kitton: vc
Melosira grannulata Ehrb.: vc
Melosira varians (Ag.): vc
Navicula radiosa Kutz, var. acuta. W. Smith: c
Navicula sp.: lc
Pleurosigma attenautum W. Smith: c
Rhizosolenia morsa W. & G. West: r
Stephanodiscus niagareoe Ehrb.: lc
Surirella ovalis Breb. var. ovata Kutz.: lc
Surirella sp.: lc
Synedra salina W. Smith: r

Synedra sp.: lc
Tabellaria *fenestrata* Kutz.: vc
Tabellaria *flocculosa* Kutz.: lc

FLATELLATA

Ceratium *hirundinella* O. F. Mull.: lc
Dinobryon *sertularia* Ehrb.: c
Dinobryon *stipitatum* Stein.: lc
Glenodinium *pulvisculus* Stein.: lc
Peridinium *tabulatum* Ehrb.: r

ROTATORIA

Anuraea *aculeata* Ehrb.: vc
Anuraea *cochlearis* Gosse: vc
Asplanchna *priodonta* Gosse: vc
Brachionus *bakeri*, Mull.: lc
Brachionus *bakeri*, Mull. var. *entzii* (Frande): c
Brachionus *bakeri*, Mull. var. *brevispinus* Ehrb.: c
Cathypna *luna* Ehrb.: c
Colurus *grallator* Gosse: c
Monostyla *quadridentata* Ehrb.: c
Noteus *quadricornis* Ehrb.:
Notholca *longispina* Kellic: a
Polyarthra *platyptera* Ehrb.: a
Triathra sp.: a

COPEPODA

Canthocampus sp.: vc
Cyclops *bisucpidatus* Claus: lc
Cyclops sp.: c
Diaptomus *shoshone* Forbes: vc
Diaptomus sp.: c

PHYLLOPODA

Acroperus *harpae* Baird: c

Alona quadrangularis O. F. Mull.: c
Bosmina longirostris O. F. Mull.: c
Ceriodaphinia sp.: c
Chydorus sphaericus O. F. Mull: c
Daphnia longispina O. F. Mull: vc
Daphnia longispina O. F. Mull. var. *hyalina*: a
Daphnia pulex de Geer: c
Diaphanosoma brachyurum Lieven: c
Diaphanosoma leuchtenbergianum Fisch.: lc
Kurzia latissima Kutz: c
Moina sp.: lc
Sida crystallina O. F. Mull: c
Simocephalus vetulus O. F. Mull: lc

OSTRACODA
Candona sp.: r
Cypria sp.: c
Limnicythere reticulata Sharpe: lc

PROTOZOA
Tintinnopsis sp.: c

Table C-2. Results of reconnaissance investigation of mollusks in cores from the South Basin (reported by Dr. I. Lubinsky, Department of Zoology, University of Manitoba, 1979).

Core D-1, 200 to 208 cm depth:

Valvata tricarinata (Say)	3 specimen
Sphaerium striatulum (Lam.)	1 specimen
Amnicola limosa (Say)	10 specimen
Lymnaea (*Stagnicola*) *catascopium* (Say)	1 specimen
Lymnaea (*Stagnicola*) *elodes* (Say)	2 specimen
Pisidium sp.	23 specimen

Core D-1, 625 to 645 cm depth:

Few small fragments of *Amnicola* and *Pisidium* sp.

Core D-2, 590 to 600 cm depth:

No mollusks.

Core 13, 27 to 27.5 cm depth:

Valvata tricarinata (Say)	35 specimen
Marstonia (*Amnicolidae*) *decepta* (Baker)	120specimen
Lymnaea sp.	1 specimen
Pisidium sp.	345specimen

Core 29, 17 to 25 cm depth:

Valvata tricarinata (Say)	47 specimen
Lymnaea sp.	45 specimen
Marstonia (*Amnicolidae*) *decepta* (Baker)	29 specimen
Pisidium sp.	119 specimen

Table C-3. Results of reconnaissance investigation of diatoms in core D-1 (reported by Dr. R. Carter, Anthropology Department, University of Manitoba, 1979).

Core D-1. 290 cm.

Valves counted: 321
Preservation: generally poor. Many valves were badly corroded.

	No.	%
Cyclotella kutzingiana?	89	28
Cyclotella sp..	81	25
Diploneis sp.	38	12
Surirella peisonis	22	7
Navicula (3 sp.)	15	5
Nitzschia (2 sp.)	15	5
Stephanodiscus hantzschii + *S. minutus?*	14	4
Nitzschia hungarica	10	3
Diatoma sp.	4	1
Stephanodiscus niagarae	4	1
Epithemia sp.	3	1
Cocconeis sp.	3	1
Fragilaria sp.	3	1
Achnanthes sp.	1	
Cymatopleura sp.	1	
Gomphonema sp.	1	
Melosira sp.	1	
Amphora sp.	1	
Indeterminate centric	1	
Indeterminate pennate	14	4

Conclusions and Interpretation (R. Carter): lake relatively smaller, shallower, littoral zone poorly developed, alkaline, quite saline. May be shallow enough to permit a widespread epipelic bottom flora.

Core D-1. 580 cm.

Valves counted: 167
Preservation: excellent.

	No.	%
Microsiphona? sp.	41	25
Fragilaria construens var. *venter*	33	20
Cyclotella sp.	27	16
Stephanodiscus niagarae	16	10
Nitzschia cf. *kutzingiana*	11	07
Nitzschia (4 sp.)	10	06
Stephanodiscus hantzschii + *S. minutus*?	8	5
Navicula (2 sp.)	7	4
Melosira granulata var. *angustissima*	3	2
Melosira granulata	2	1
Gyrosigma sp.	2	1
Surirella ovata var. *pinnata*	1	1
Fragilaria sp.	1	1
Nitzschia cf. *apiculata*	1	1
Nitzschia cf. *dissipata*	1	1
Cymbella sp.	1	1
Amphora sp.	1	1
Stauroneis? sp.	1	1

Conclusions and Interpretation (R. Carter): lake relatively larger, deeper, well-developed littoral zone, alkaline, some salinity.

Core D-1. 620 cm.

Valves counted: 172
Preservation: good, a few etched or corroded valves.

	No.	%
Fragilaria construens var. *venter*	40	23
Stephanodiscus niagarae	25	15
Microsiphona? sp.	22	13
Cyclotella sp.	17	10
Diatoma sp.	13	8
Navicula (2 sp.)	11	6
Stephanodiscus hantzschii + *S. minutus*?	6	3
Nitzschia hungarica	5	3
Synedra sp.	3	2
Diploneis sp.	2	1
Stephanodiscus subtilis?	2	1
Pleurosigma sp.	2	1
Cyclotella kutzingiana?	2	1
Amphora sp.	1	1
Pinnularia sp.	1	1
Surirella peisonis	1	1
Melosira granulata	1	1
Indeterminate pennate	9	5

Conclusions and Interpretation (R. Carter): lake relatively larger, deeper, well-developed littoral zone, alkaline, moderate salinity.

APPENDIX D

Distribution of characteristics of surface sediment. Refer to Figure 2-1 for number and location of sample sites. For contoured maps, the dots represent control points.

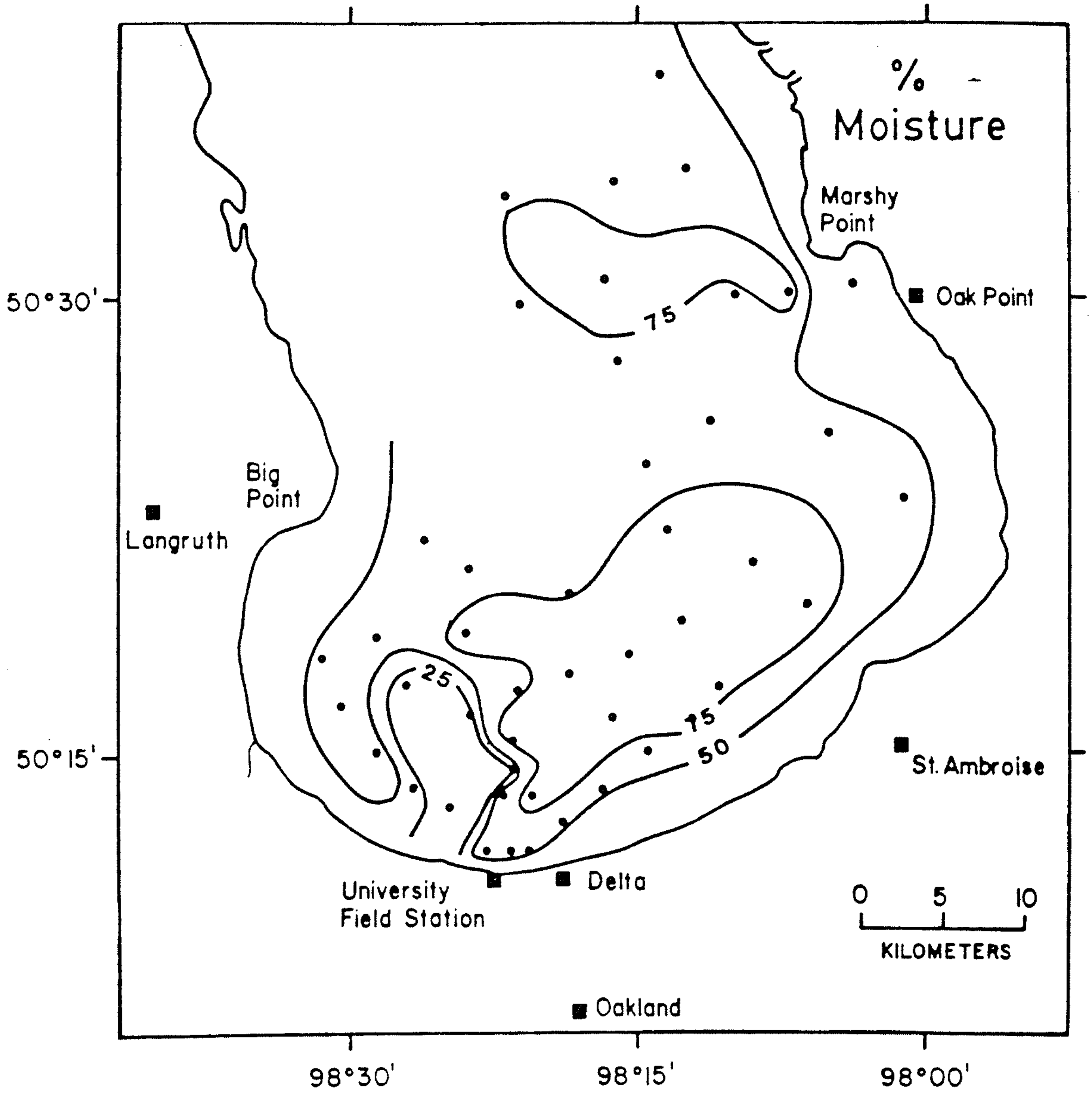


Figure D-1. Moisture content of surface sediment.

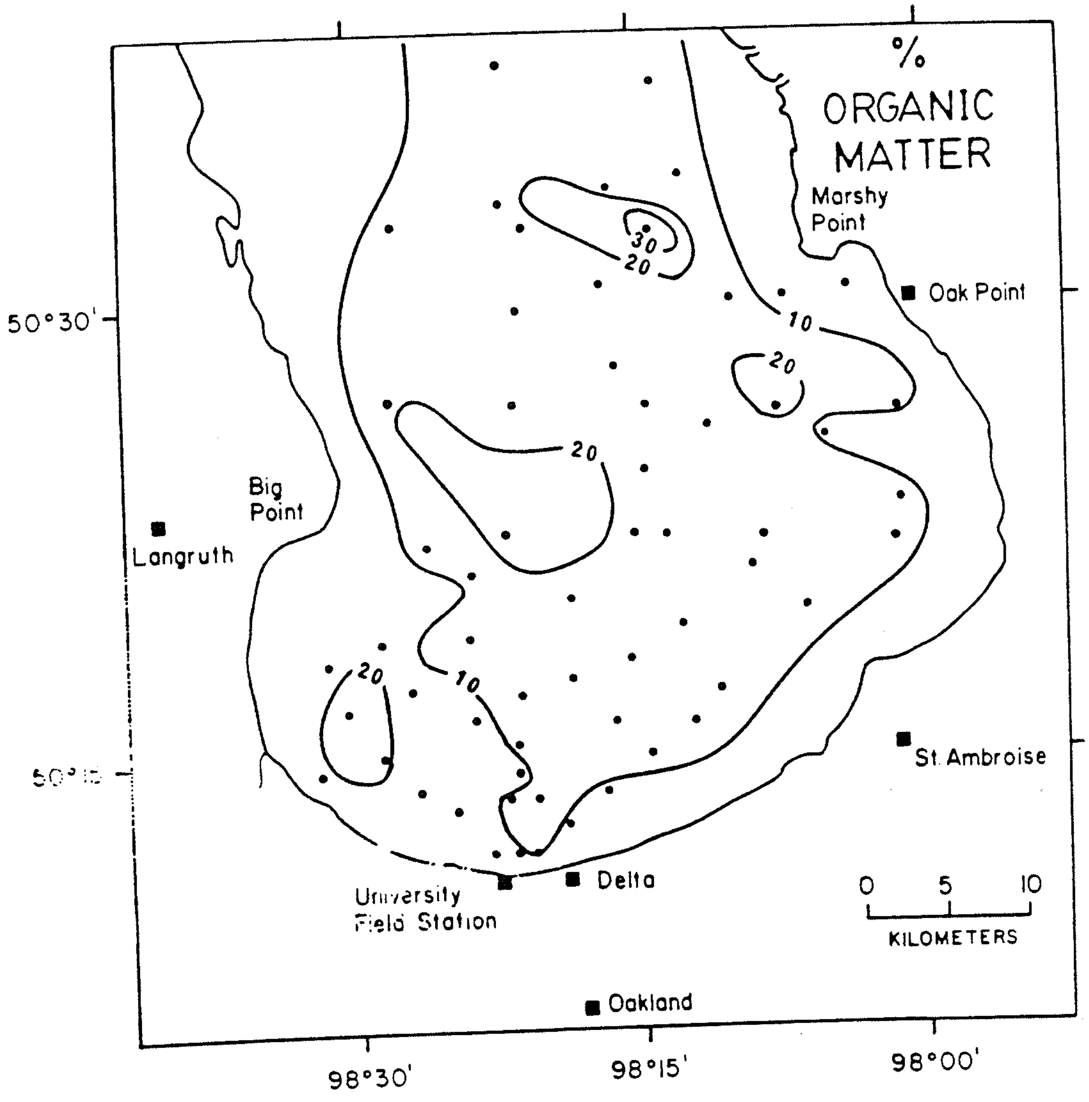


Figure D-2. Organic content of surface sediment. Additional data supplied by J. Crowe (personal communication, 1978) are included (see Appendix F).

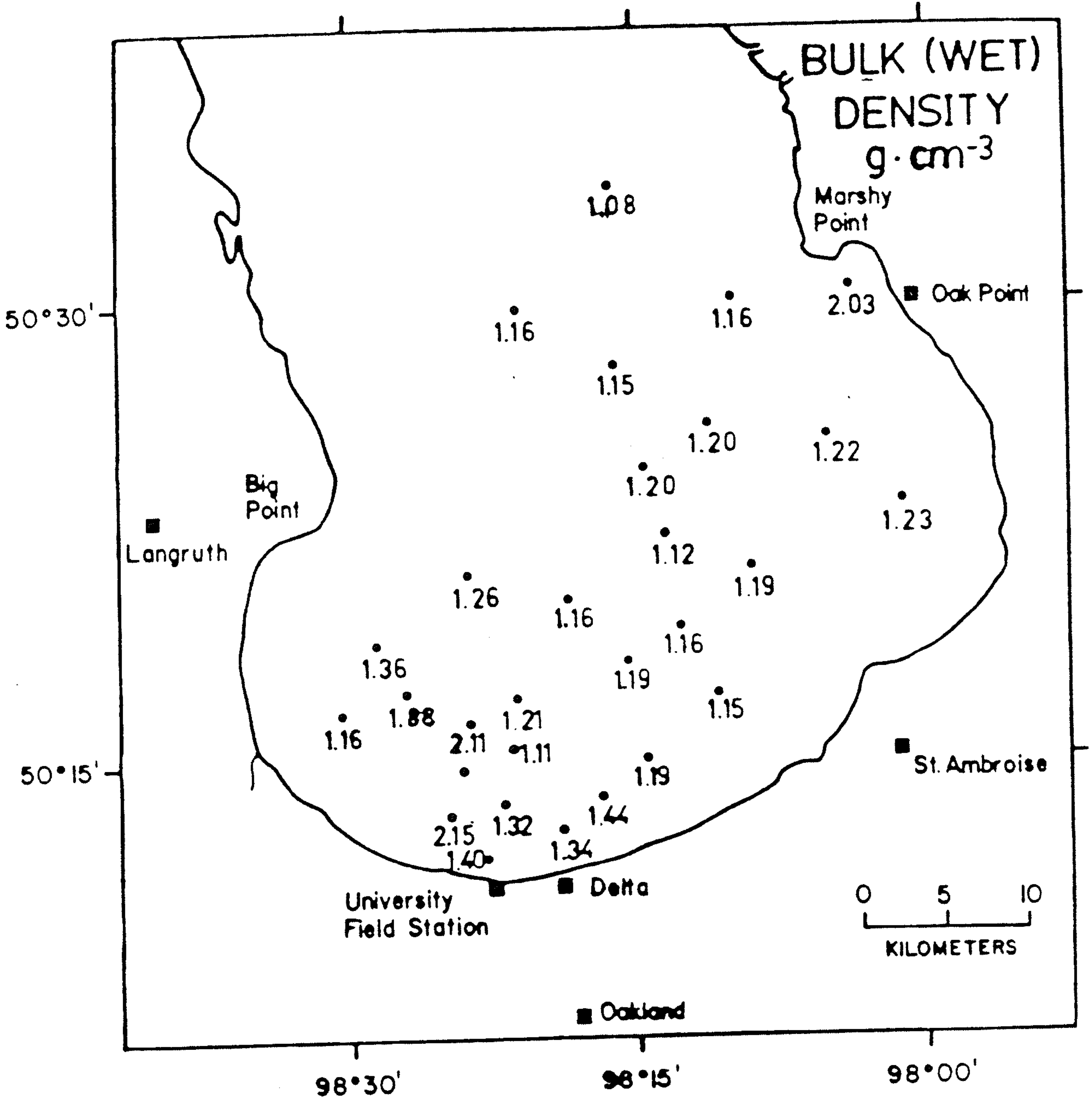


Figure D-3. Calculated bulk (wet) density of surface sediment.

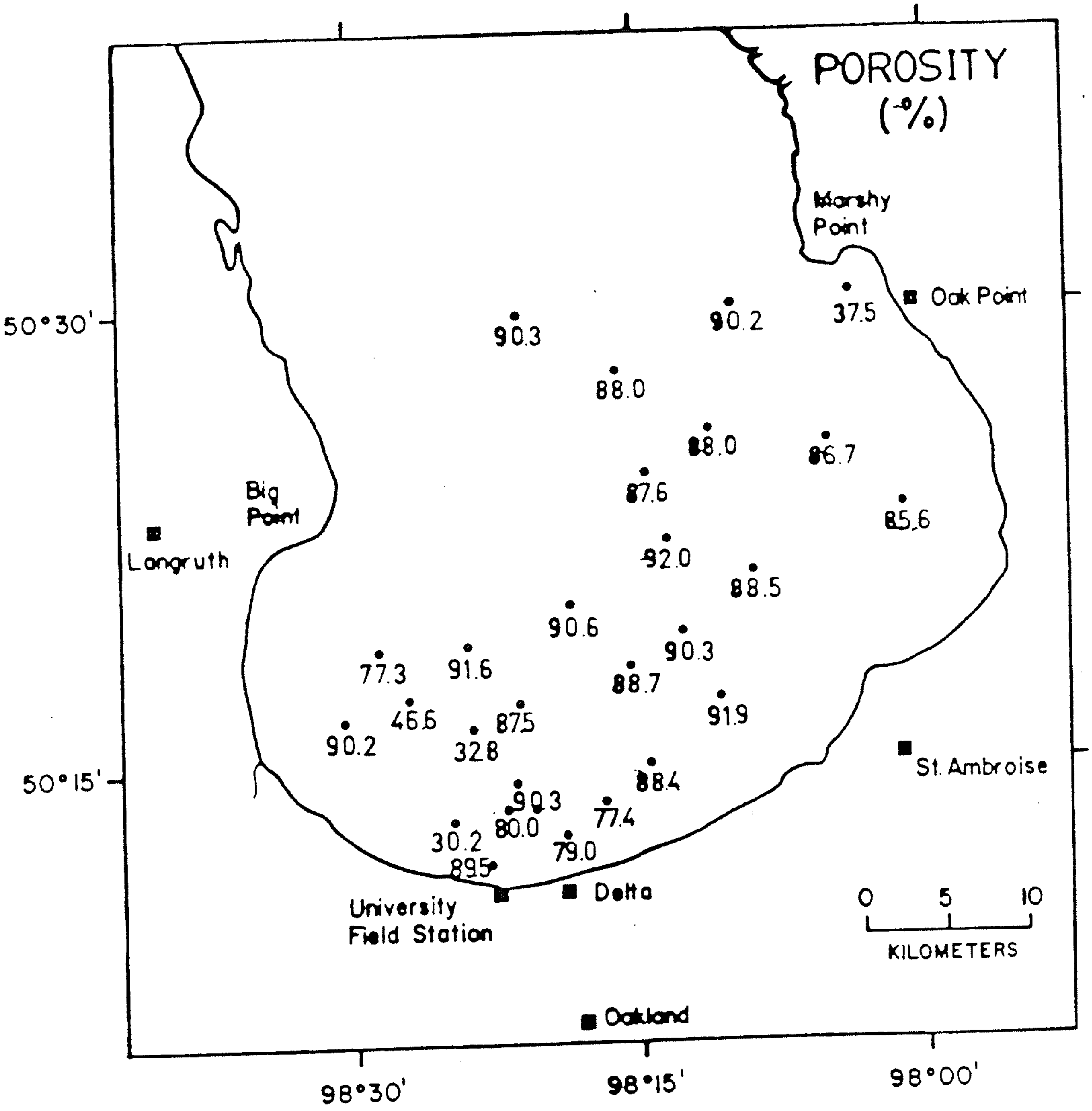


Figure D-4. Calculated porosity of surface sediment.

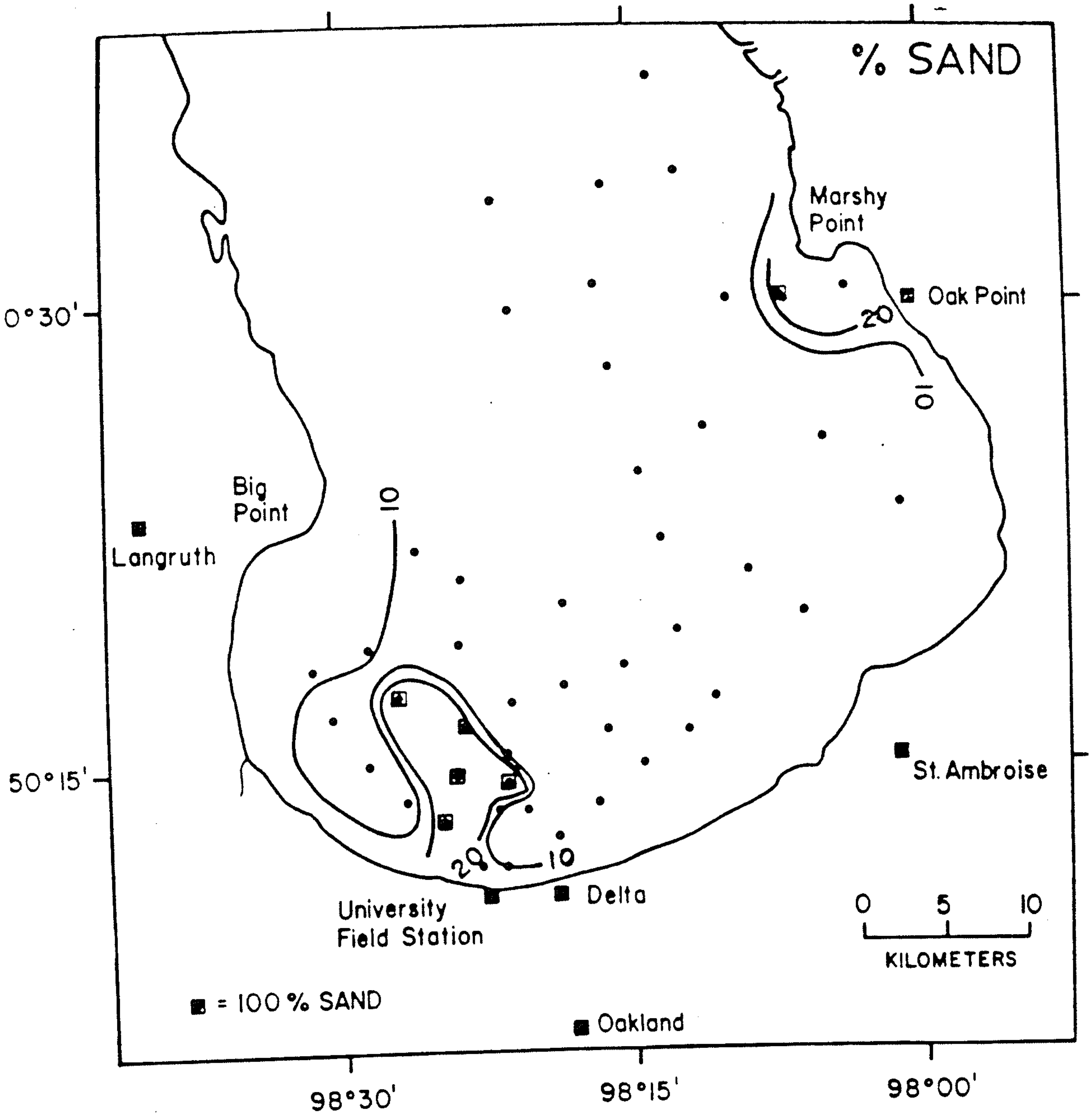


Figure D-5. Distribution of sand-size material in surface sediment.

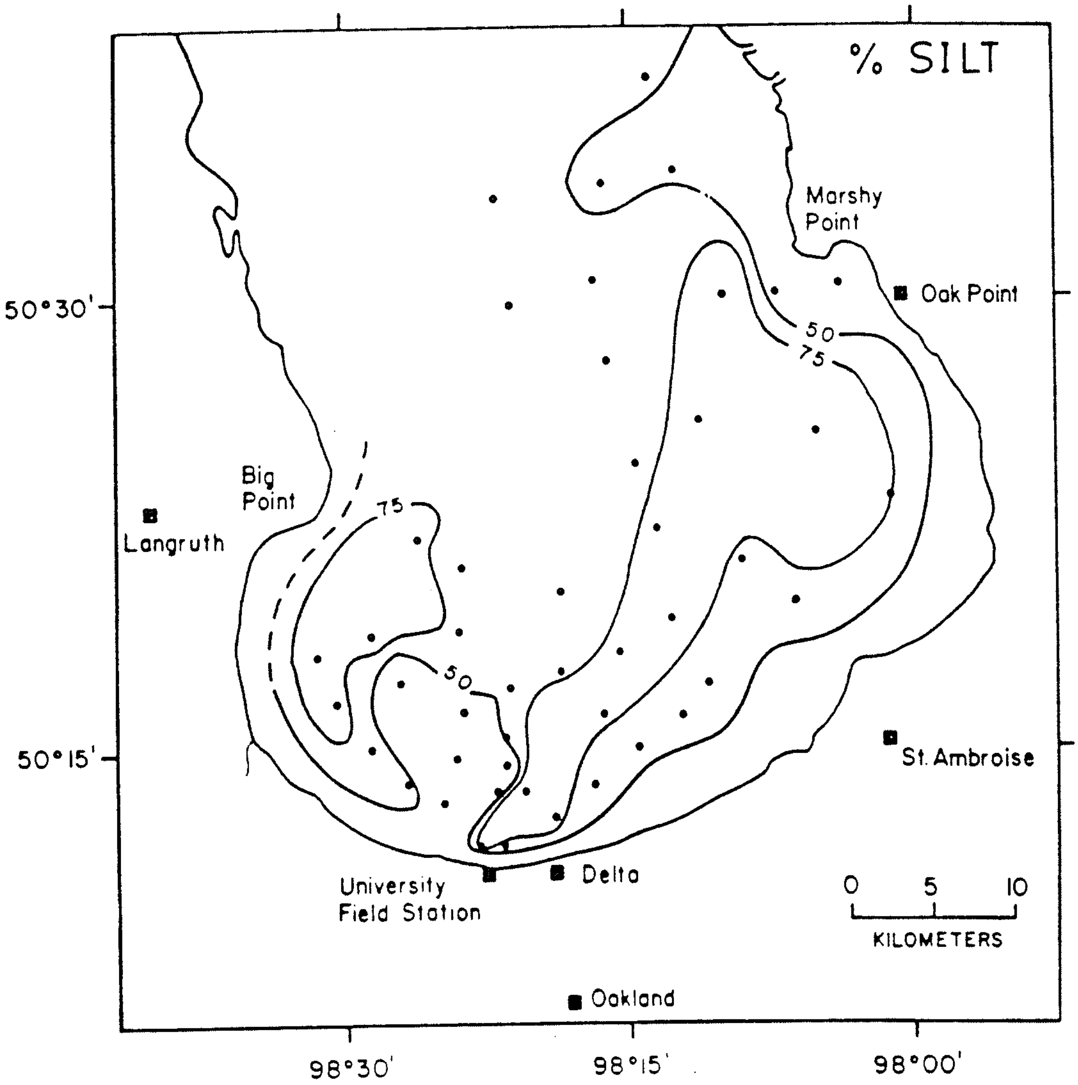


Figure D-6. Distribution of silt-sized material in surface sediment.

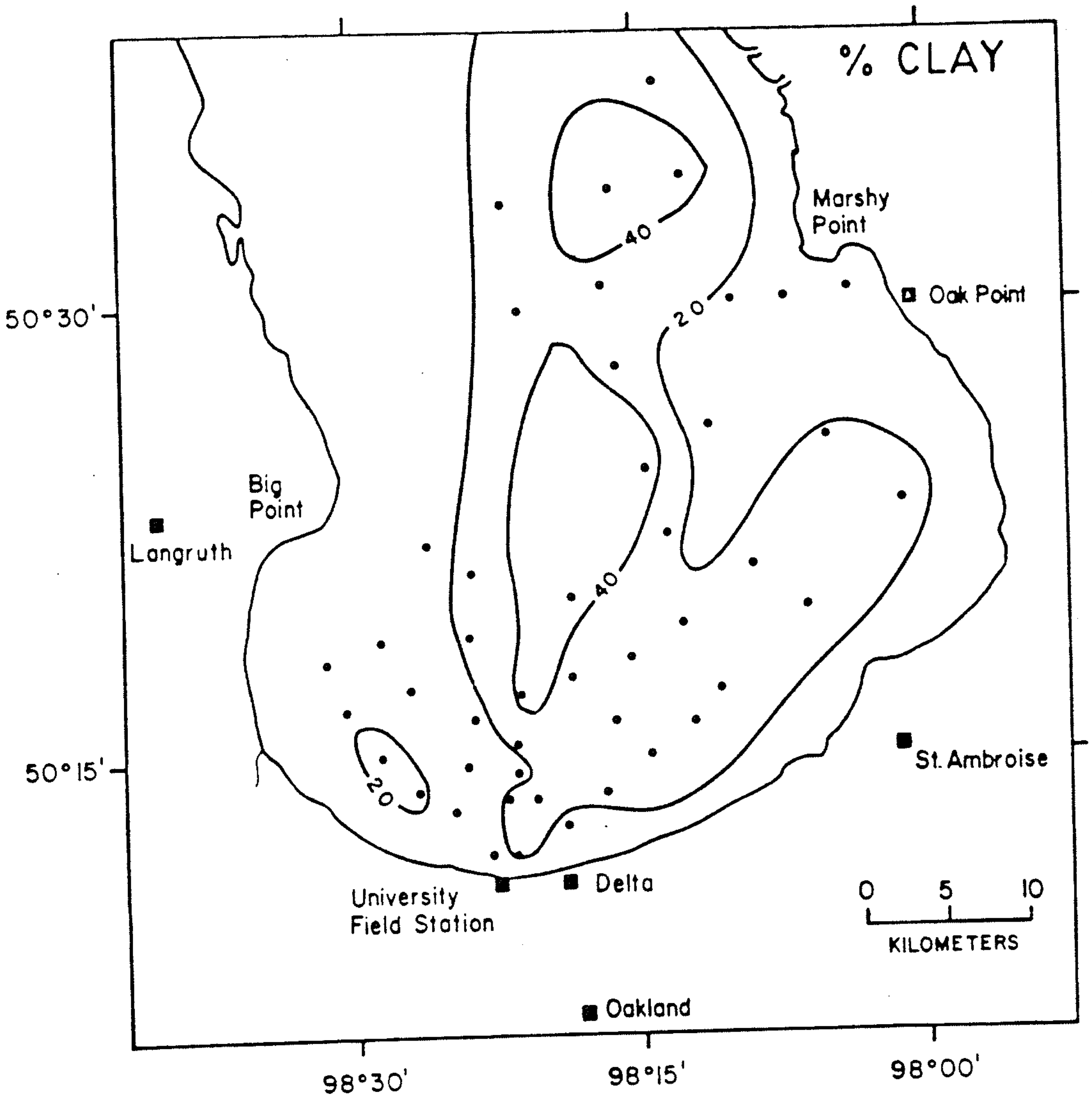


Figure D-7. Distribution of clay-sized material in surface sediment.

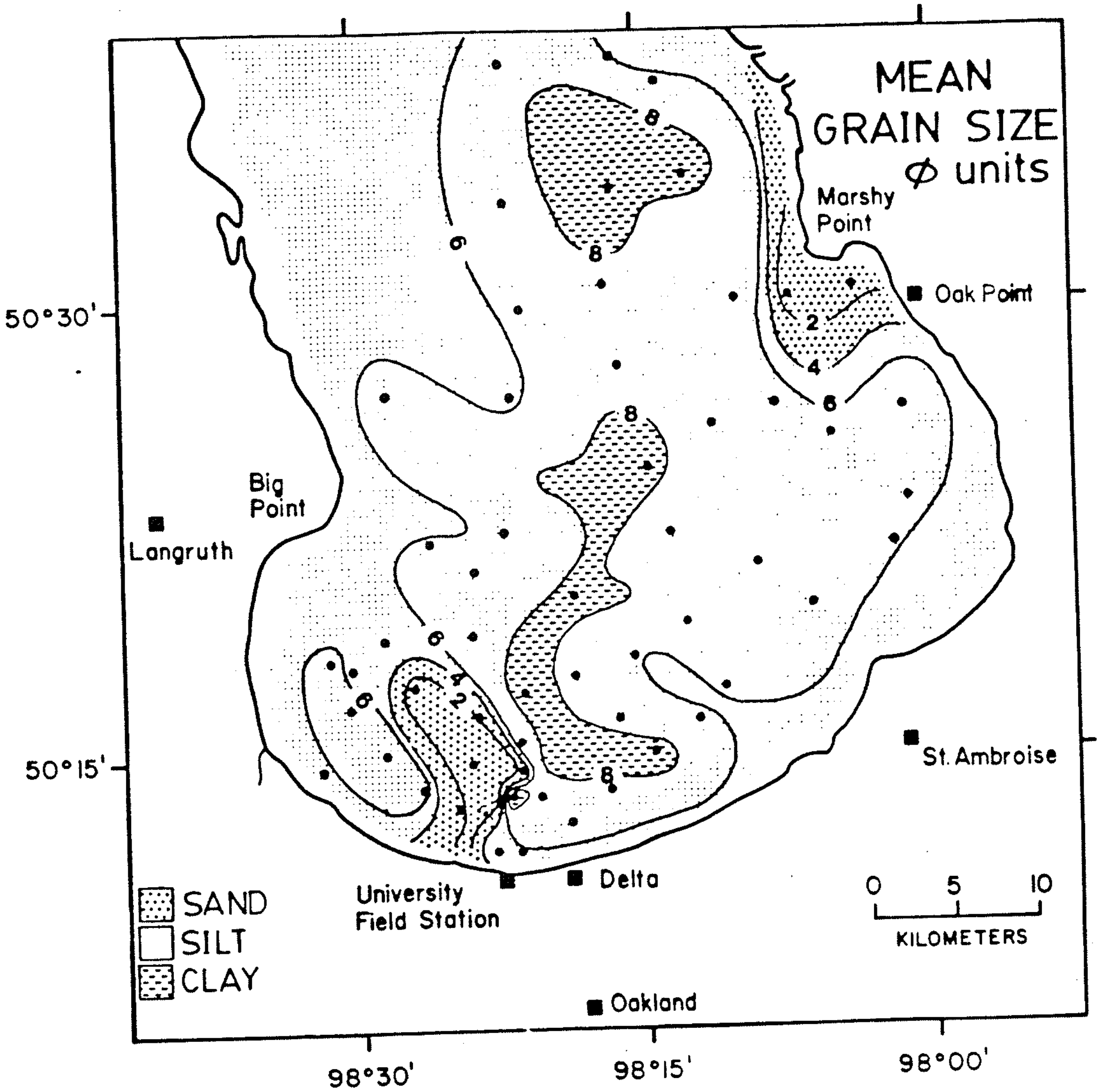


Figure D-8. Mean grain size of surface sediment. Additional data supplied by J. Crowe (see Appendix F).

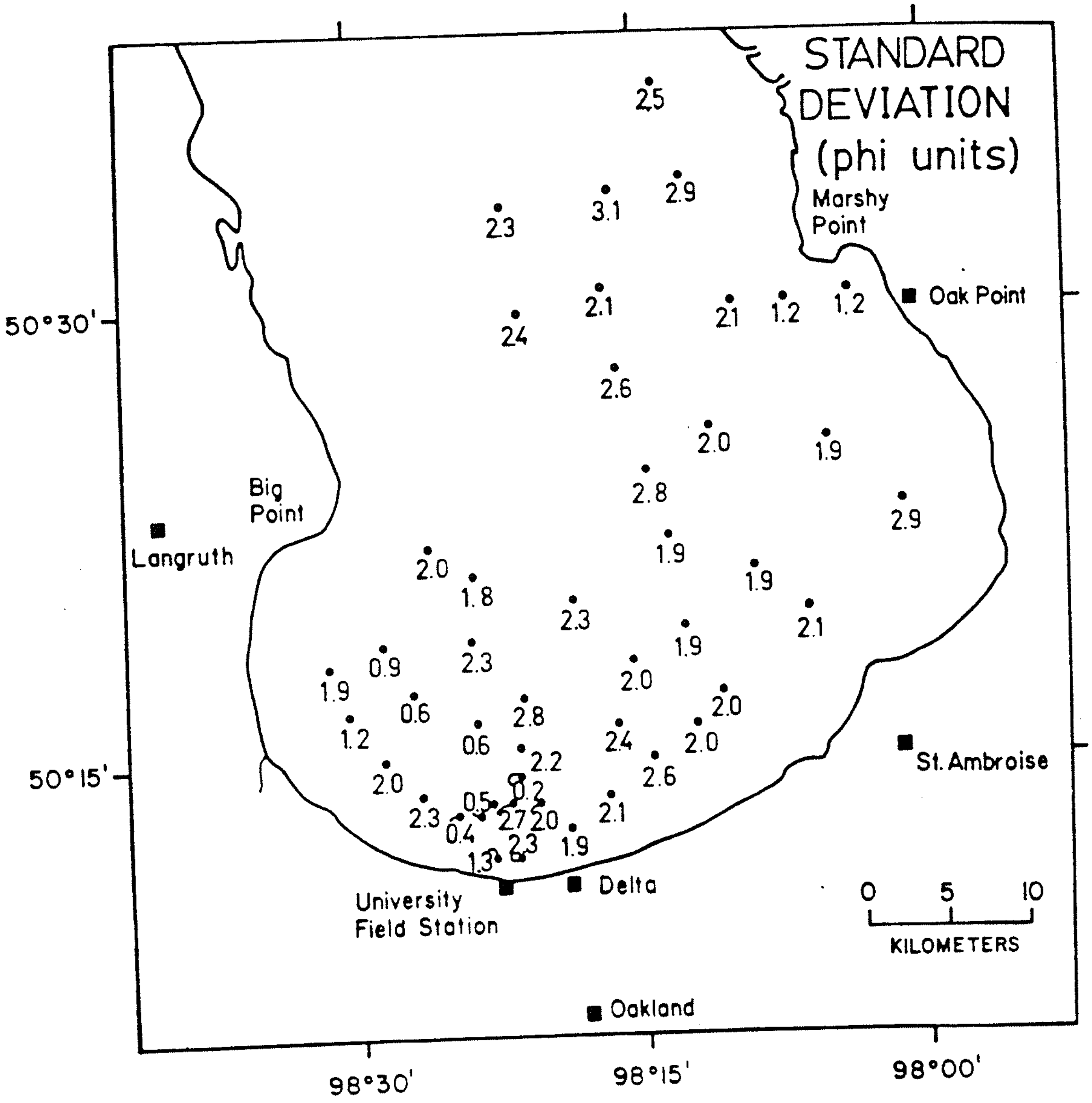


Figure D-9. Surface sediment grain size distribution standard deviation (second moment about the mean).

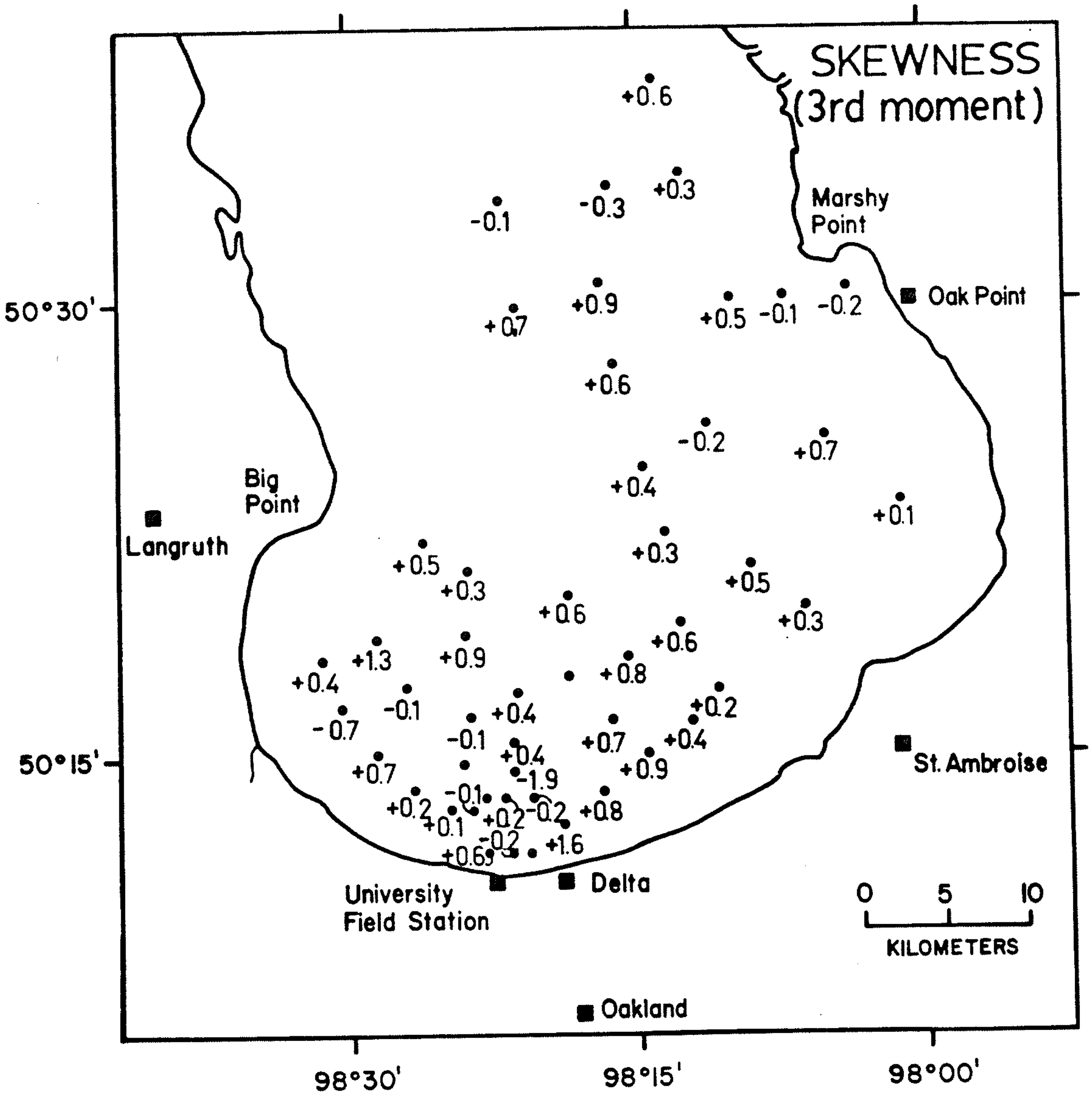


Figure D-10. Surface sediment grain size distribution skewness (third moment about the mean).

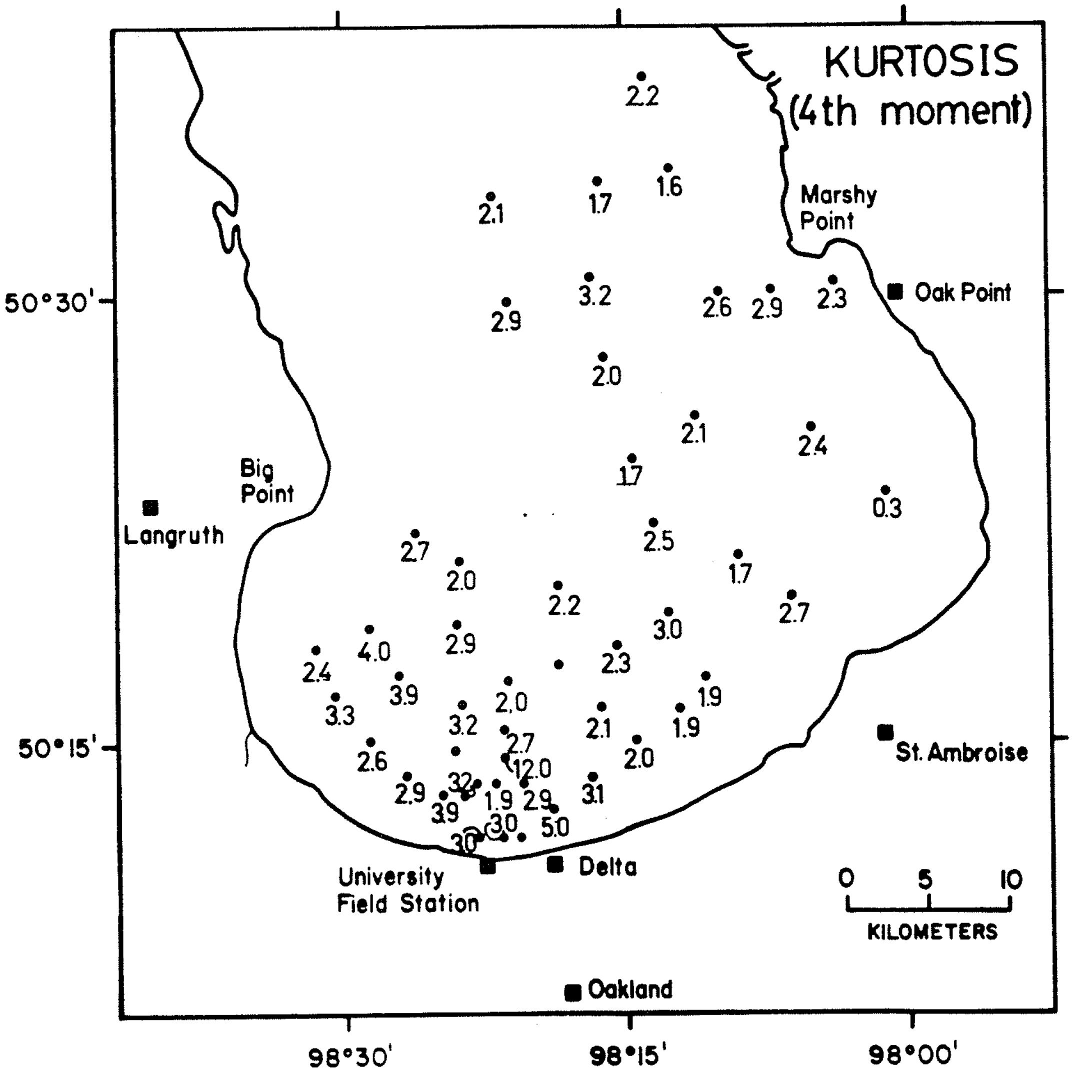


Figure D-11. Surface sediment grain size distribution kurtosis (fourth moment about the mean).

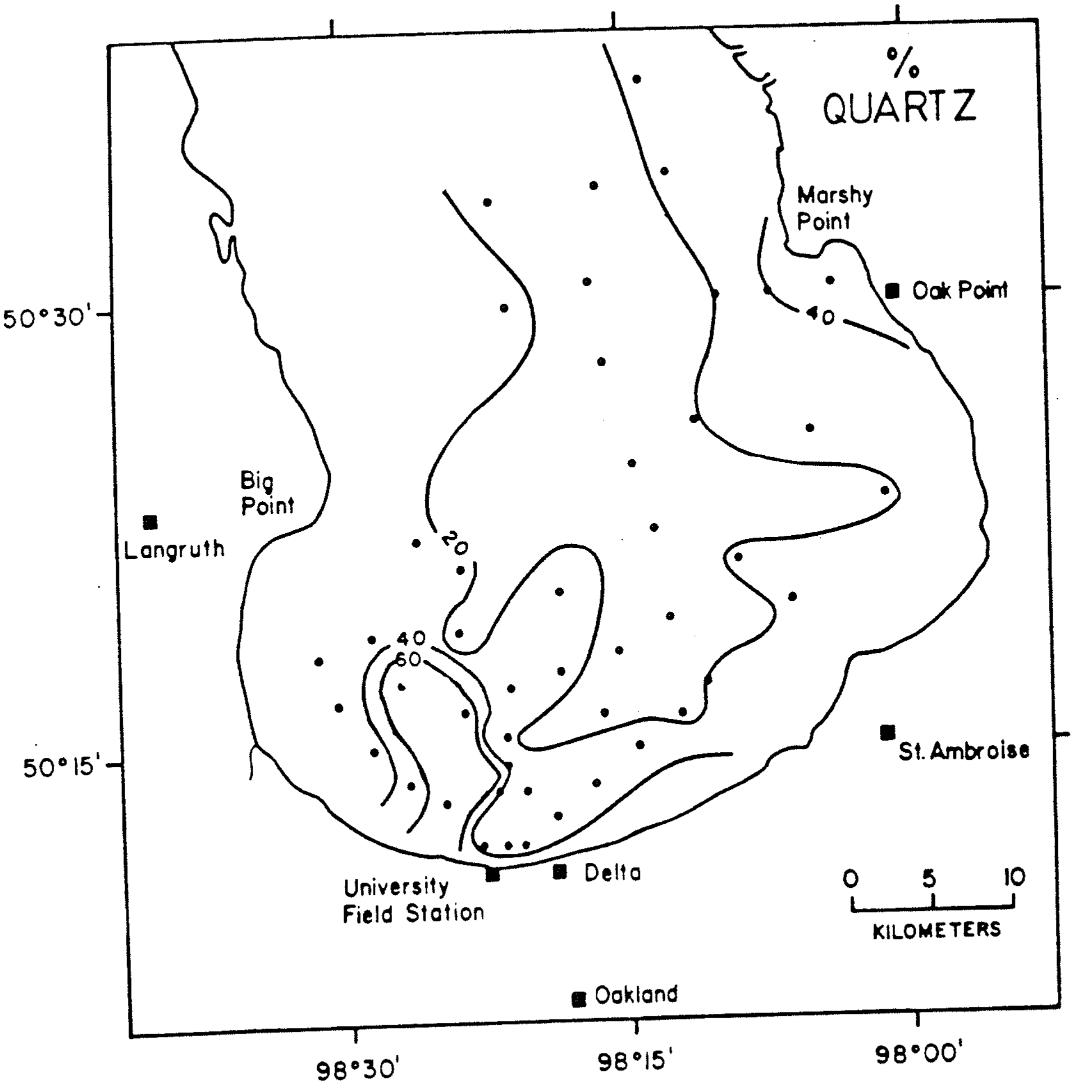


Figure D-12. Distribution of quartz in surface sediment.

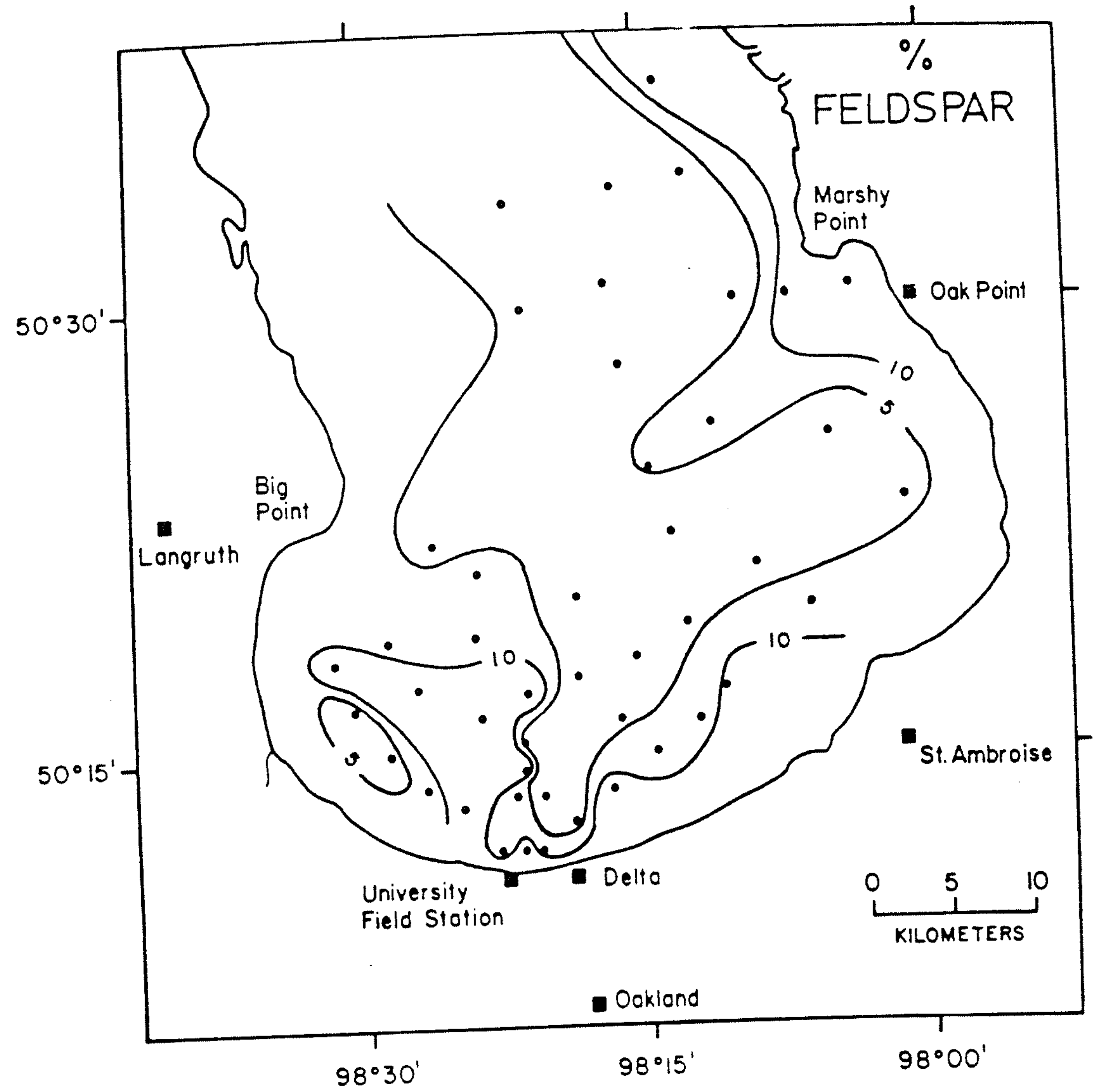


Figure D-13. Distribution of feldspar in surface sediment.

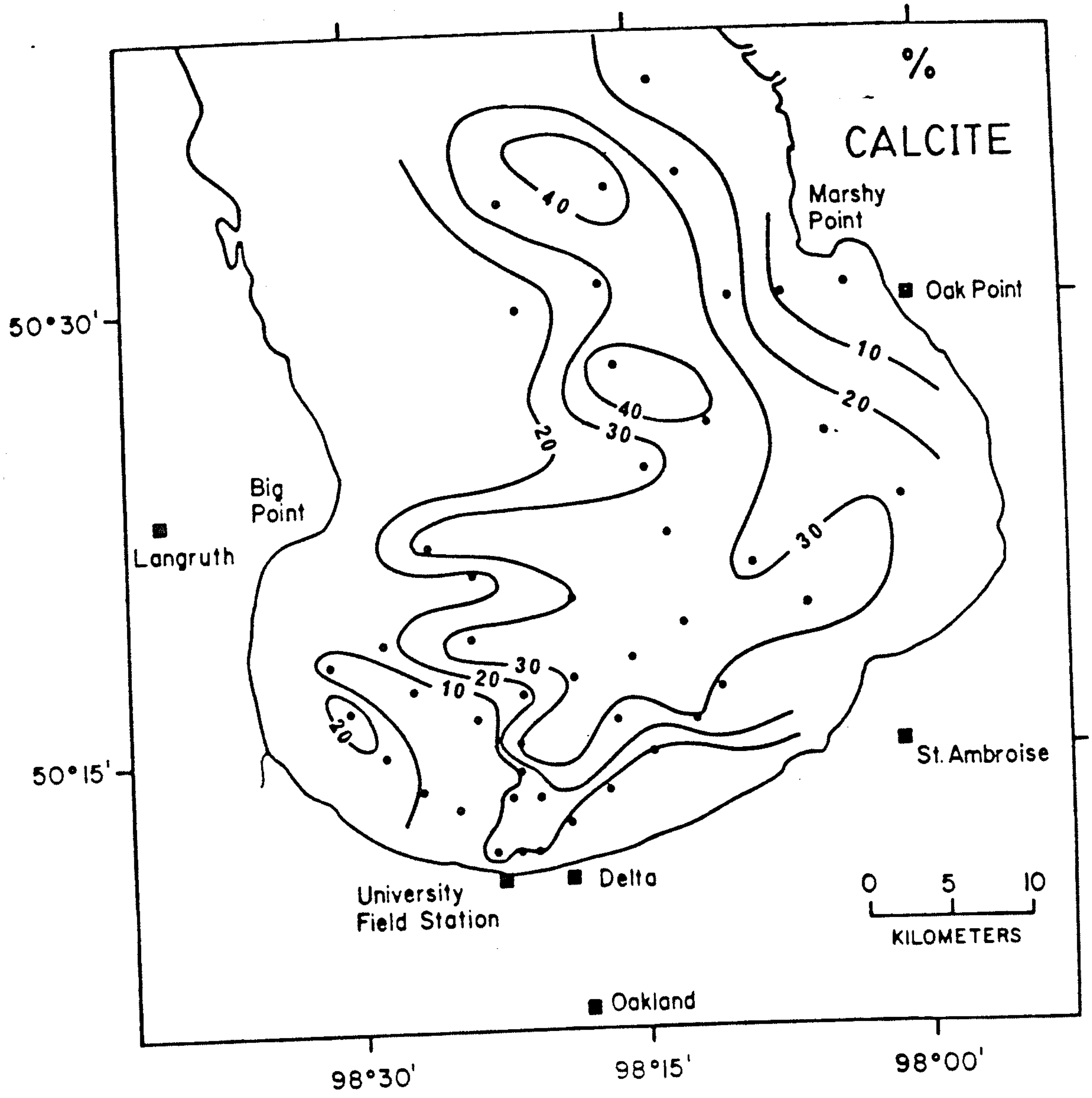


Figure D-14. Distribution of calcite in surface sediment.

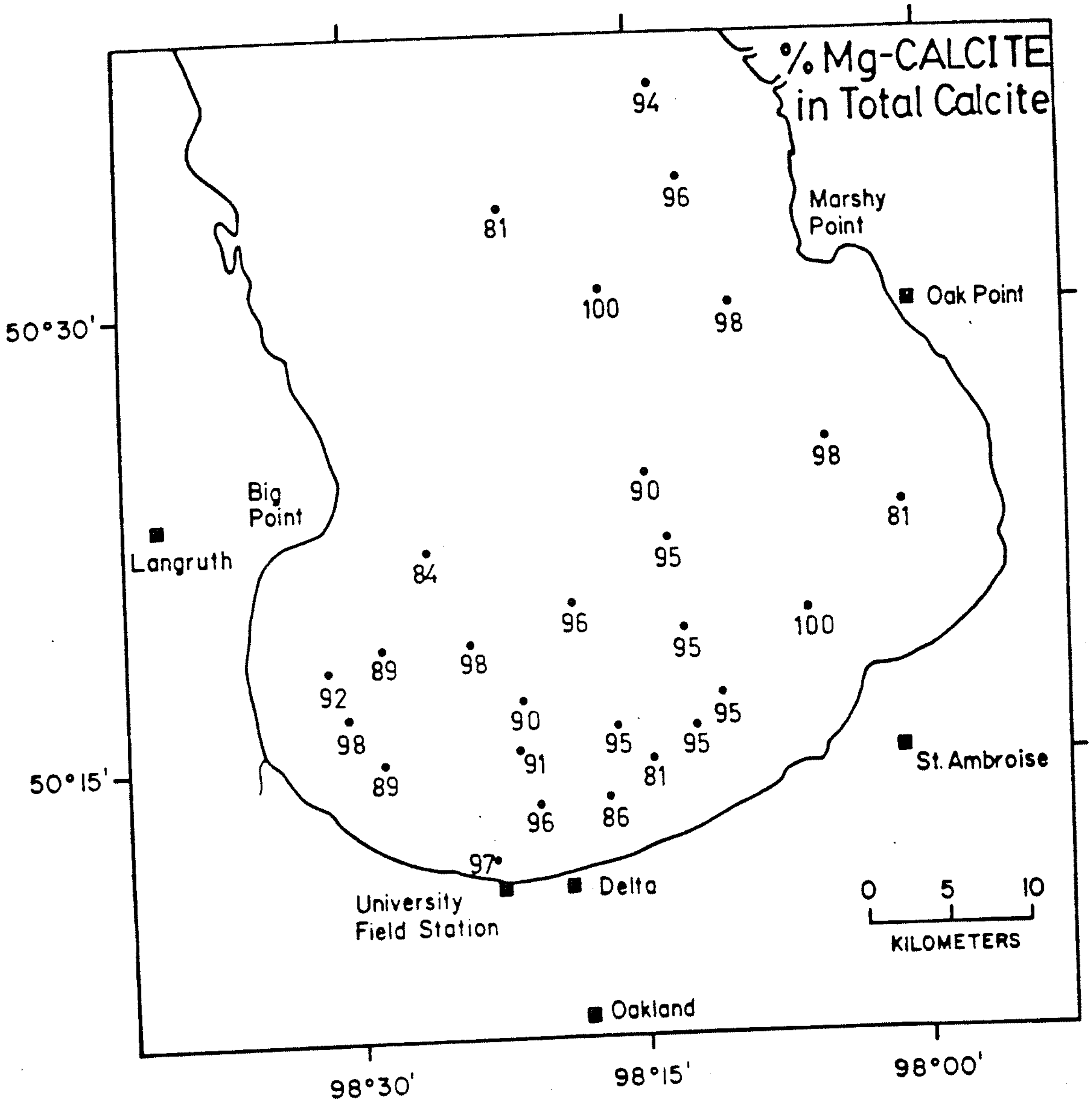


Figure D-15. Percentage of high Mg-calcite in total calcite in surface sediment.

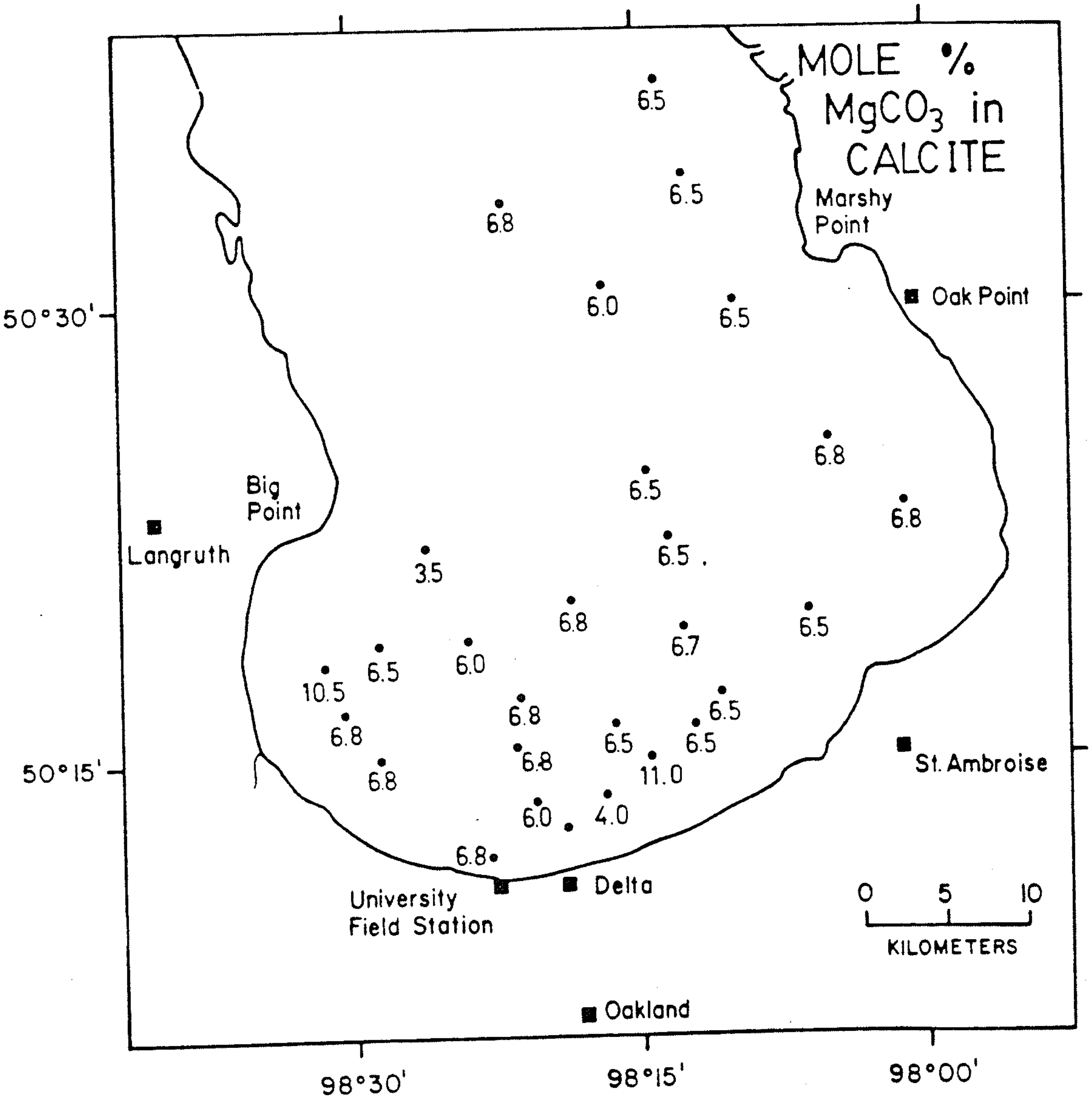


Figure D-16. Mole percent $MgCO_3$ in calcite in surface sediment.

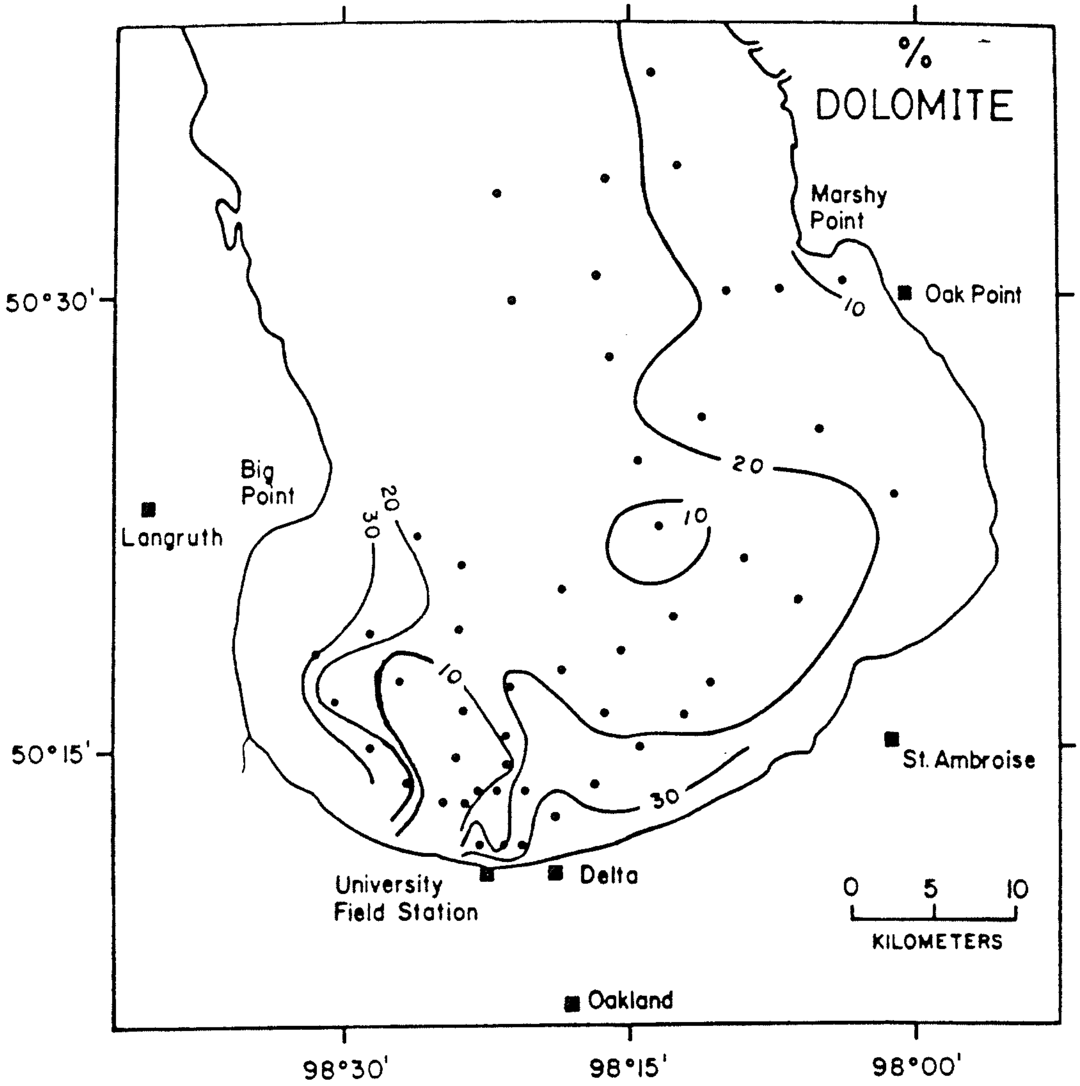


Figure D-17. Distribution of dolomite in surface sediment.

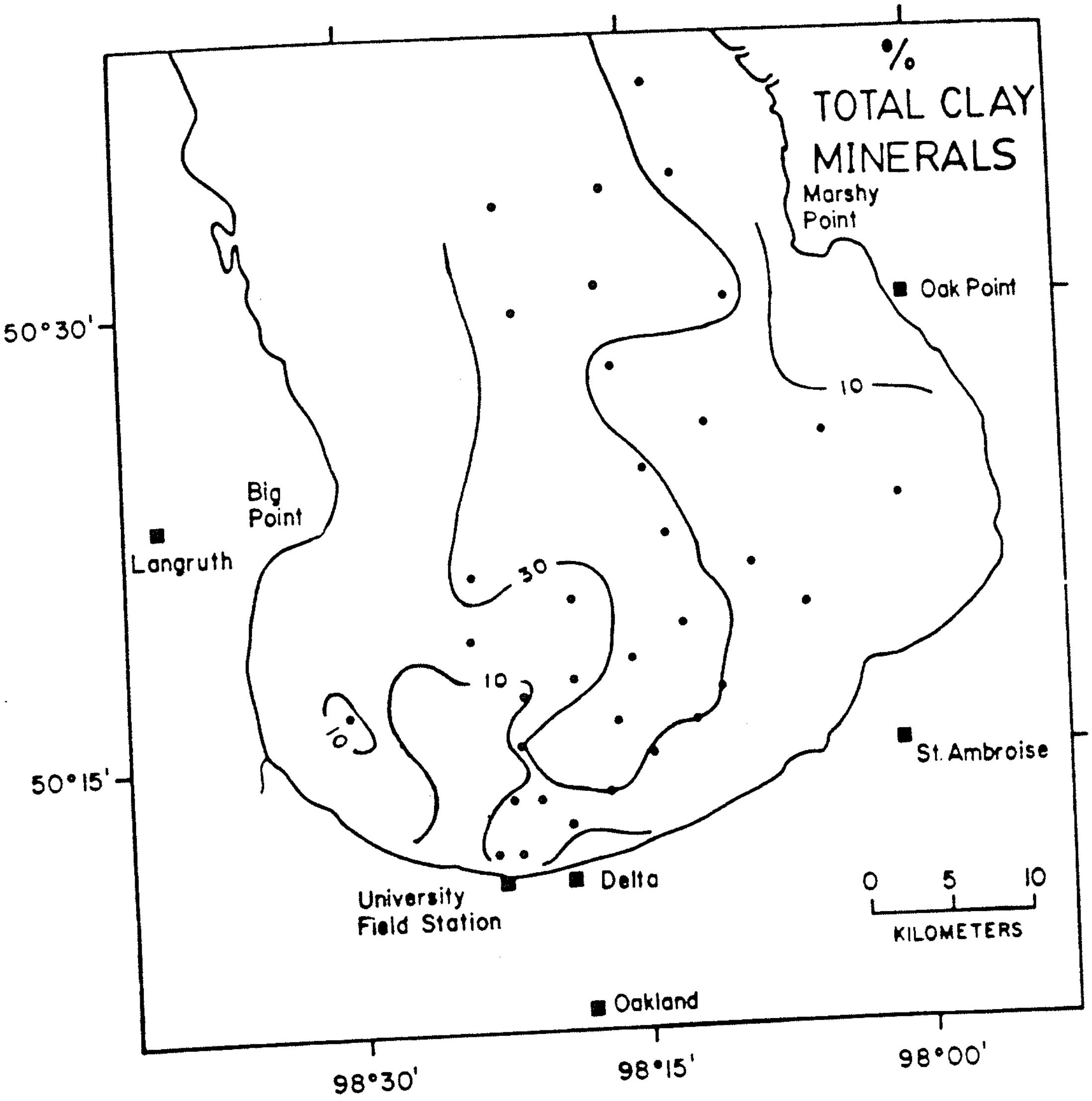


Figure D-18. Percentage of clay minerals in surface sediment.

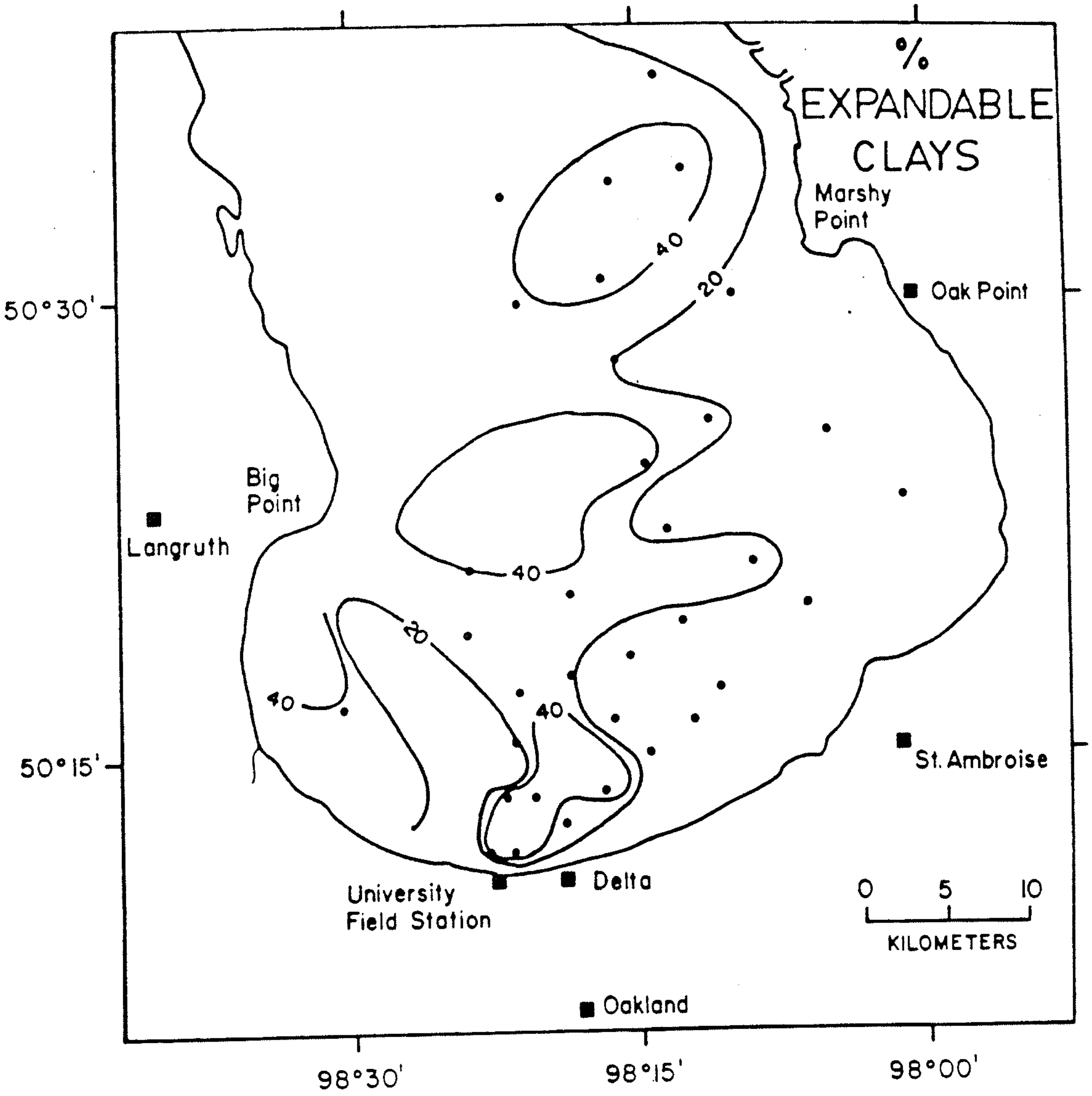


Figure D-19. Distribution of expandable lattice clay minerals in surface sediment.

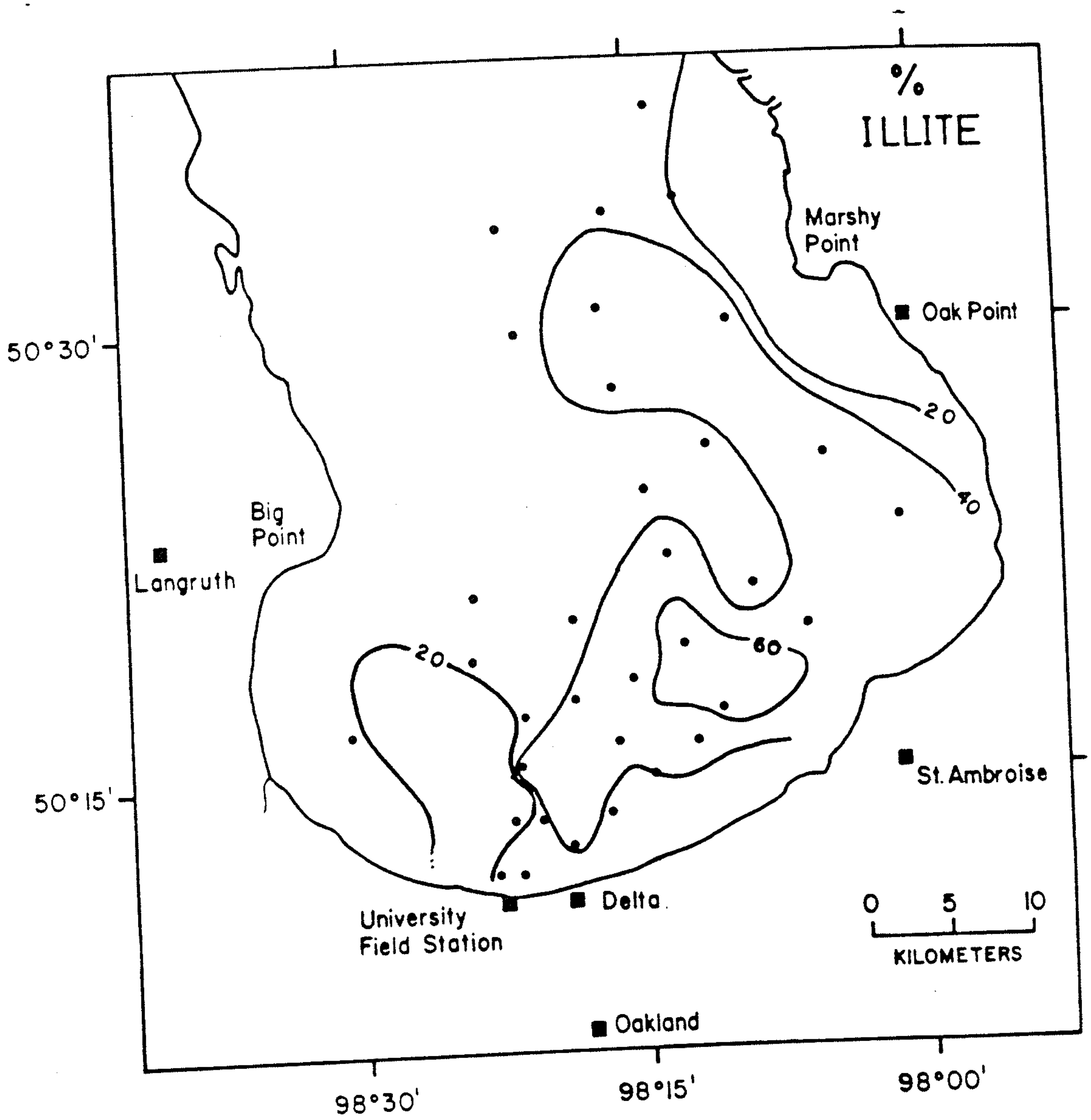


Figure D-20. Distribution of illite in surface sediment.

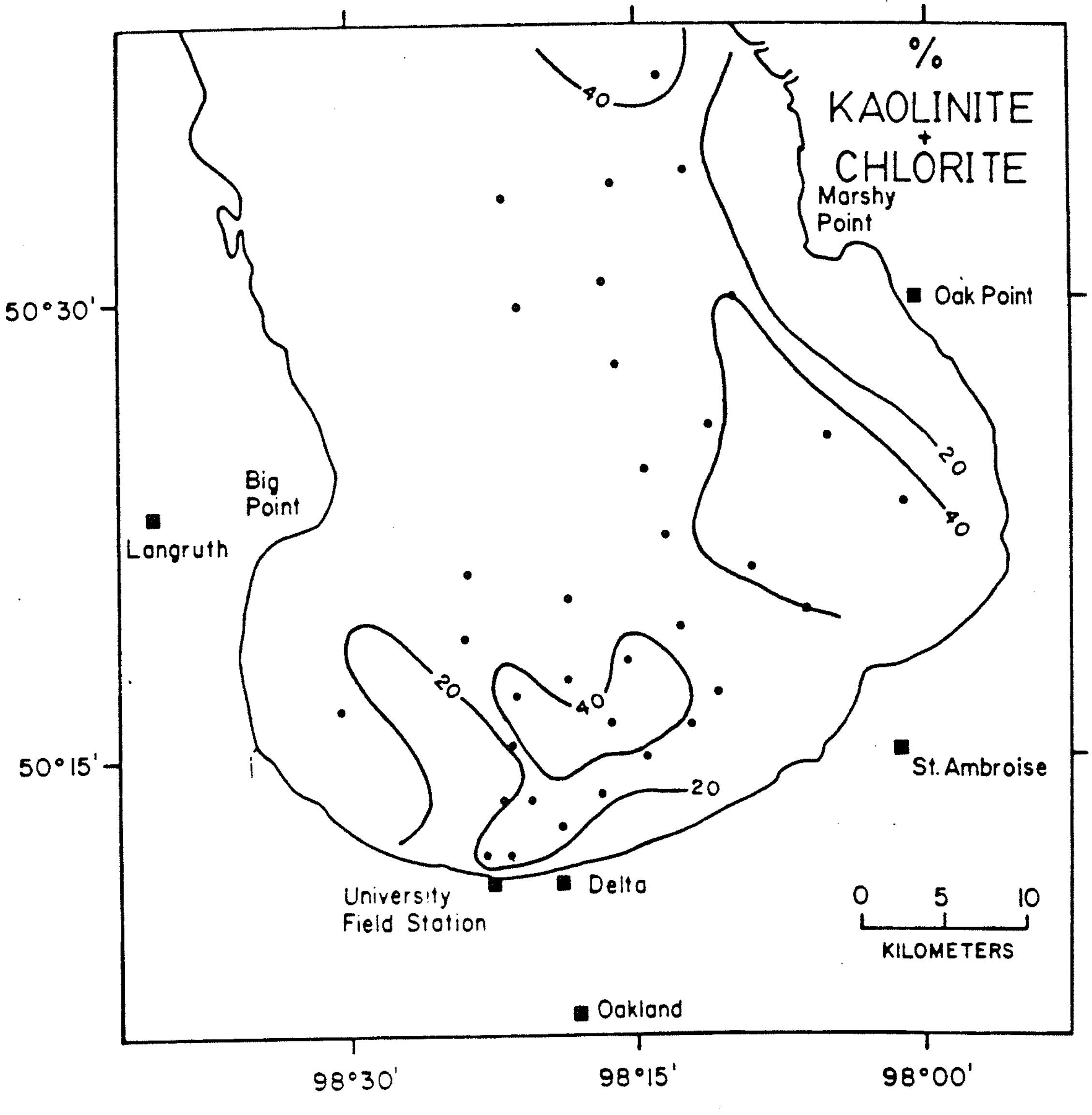


Figure D-21. Distribution of kaolinite plus chlorite in surface sediment.

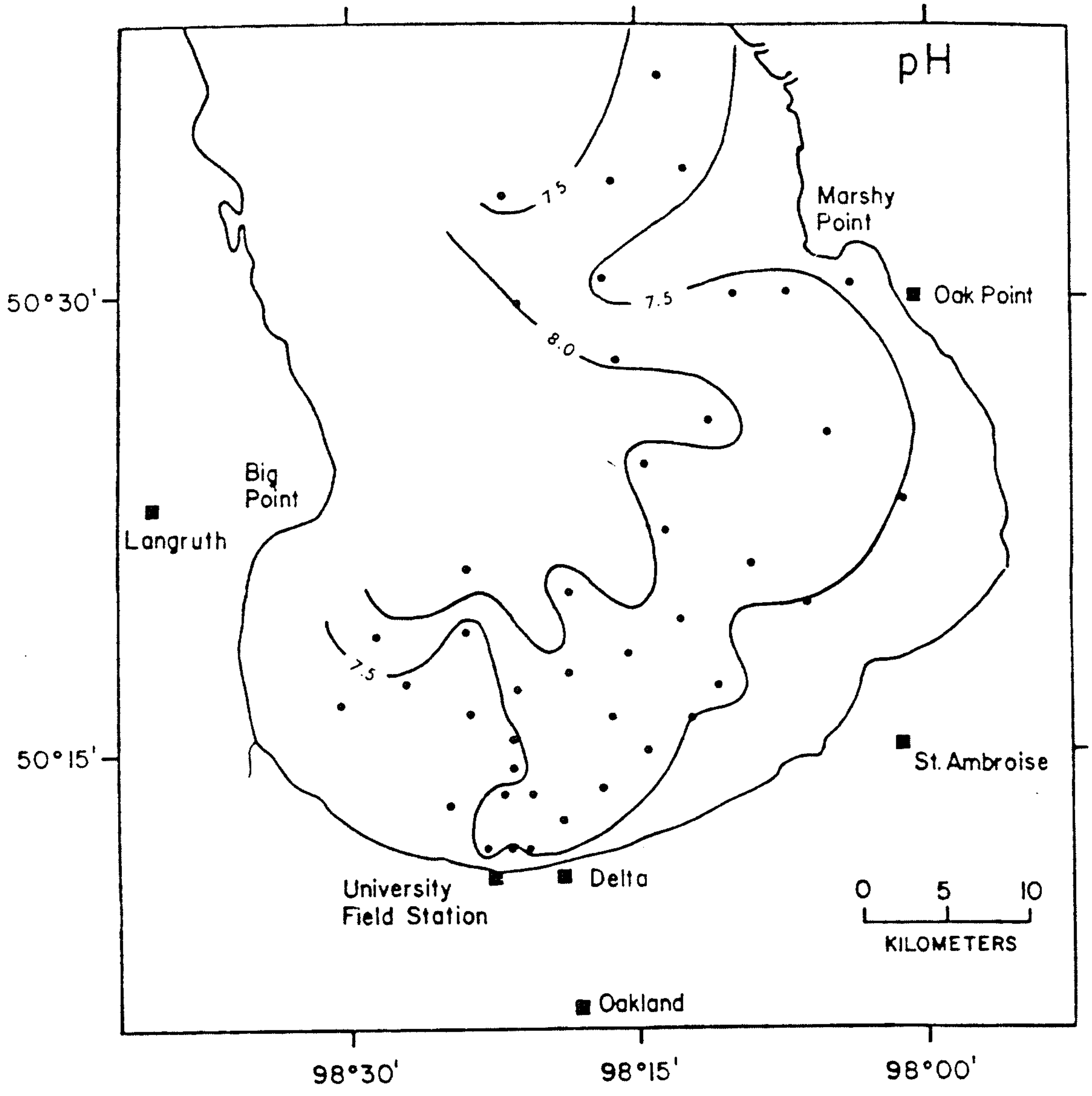


Figure D-22. pH of surface sediment.

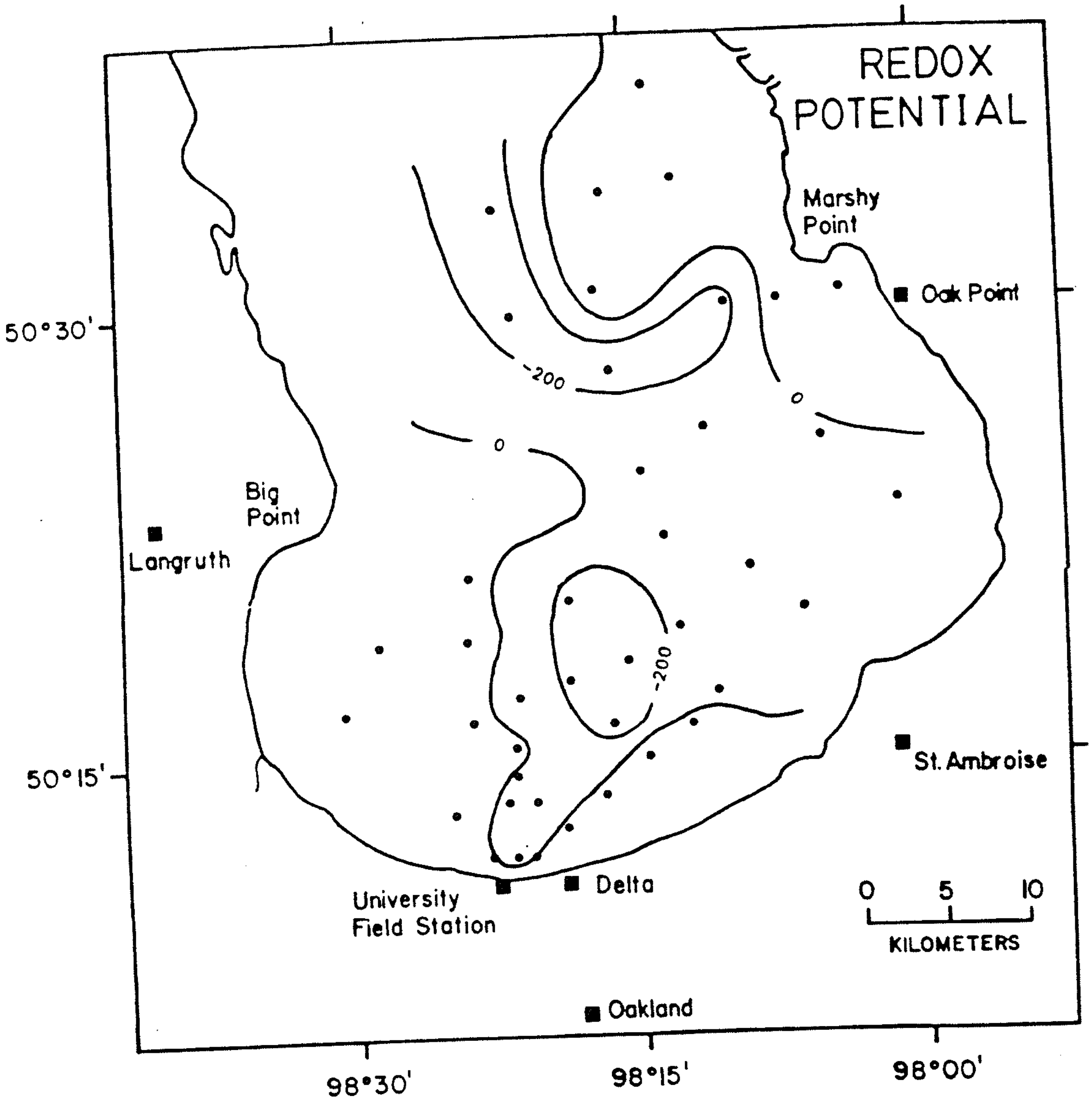


Figure D-23. Redox potential (Eh) of surface sediment.

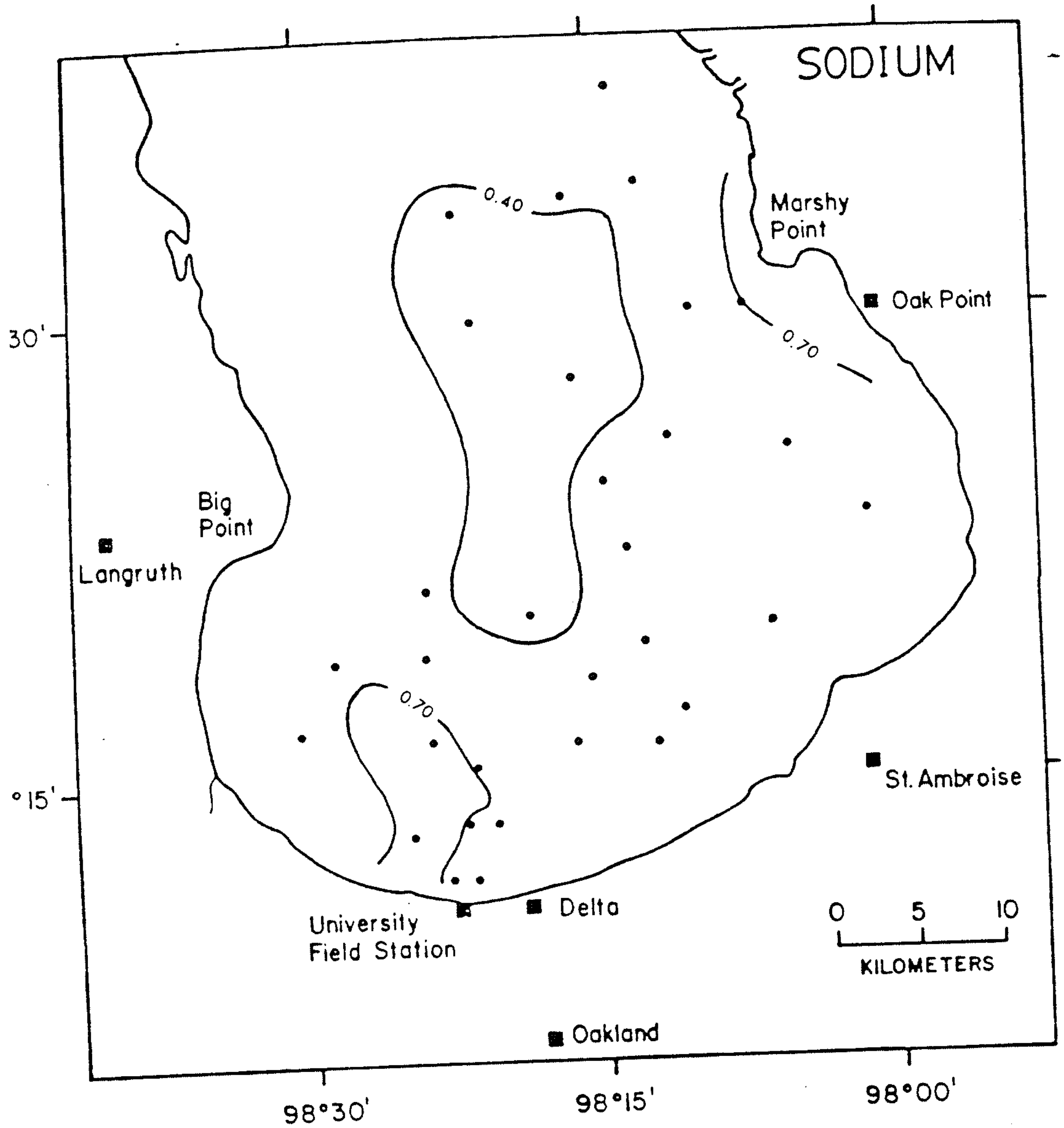


Figure D-24. Distribution of sodium in surface sediment.

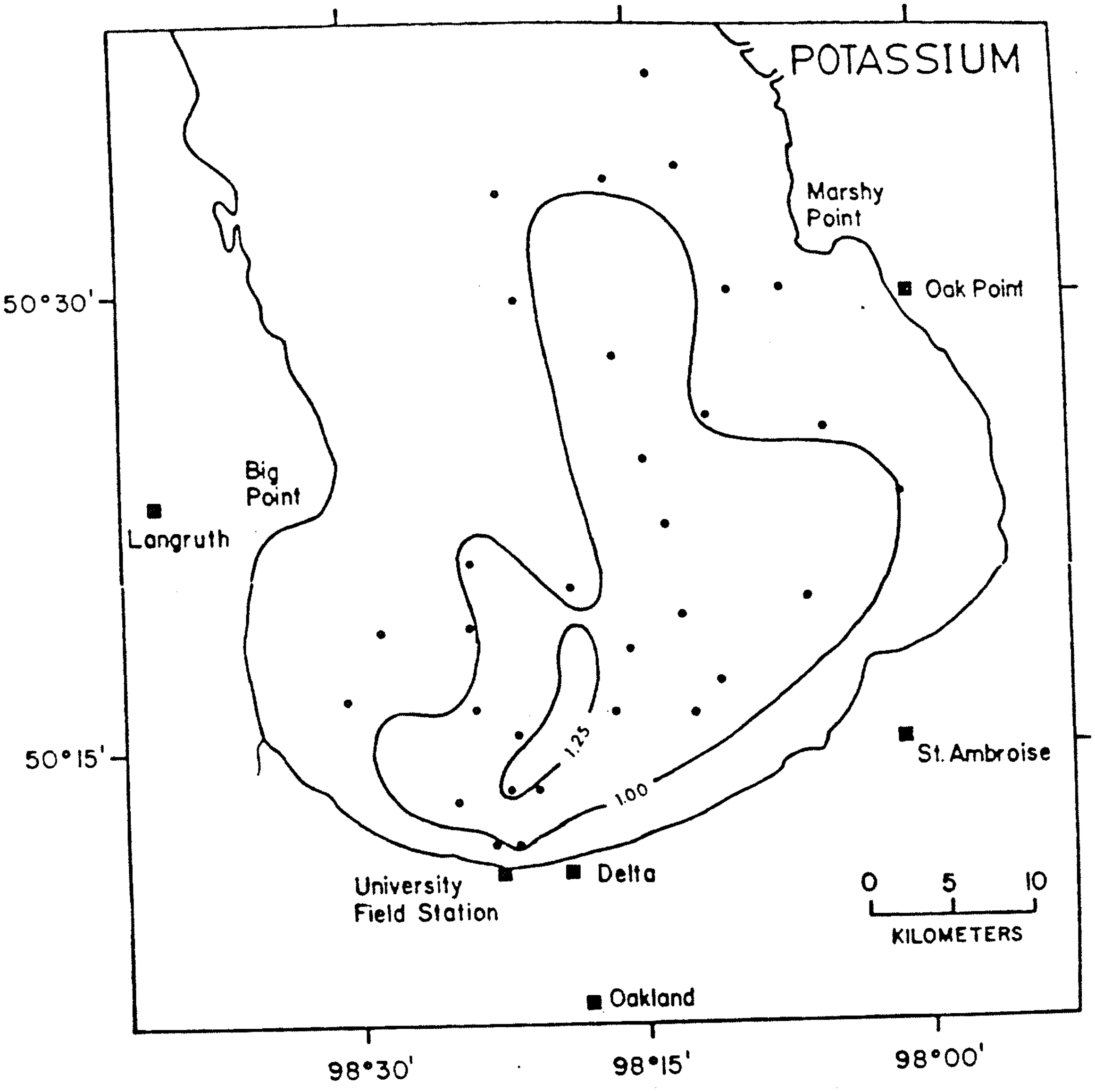


Figure D-25. Distribution of potassium in surface sediment.

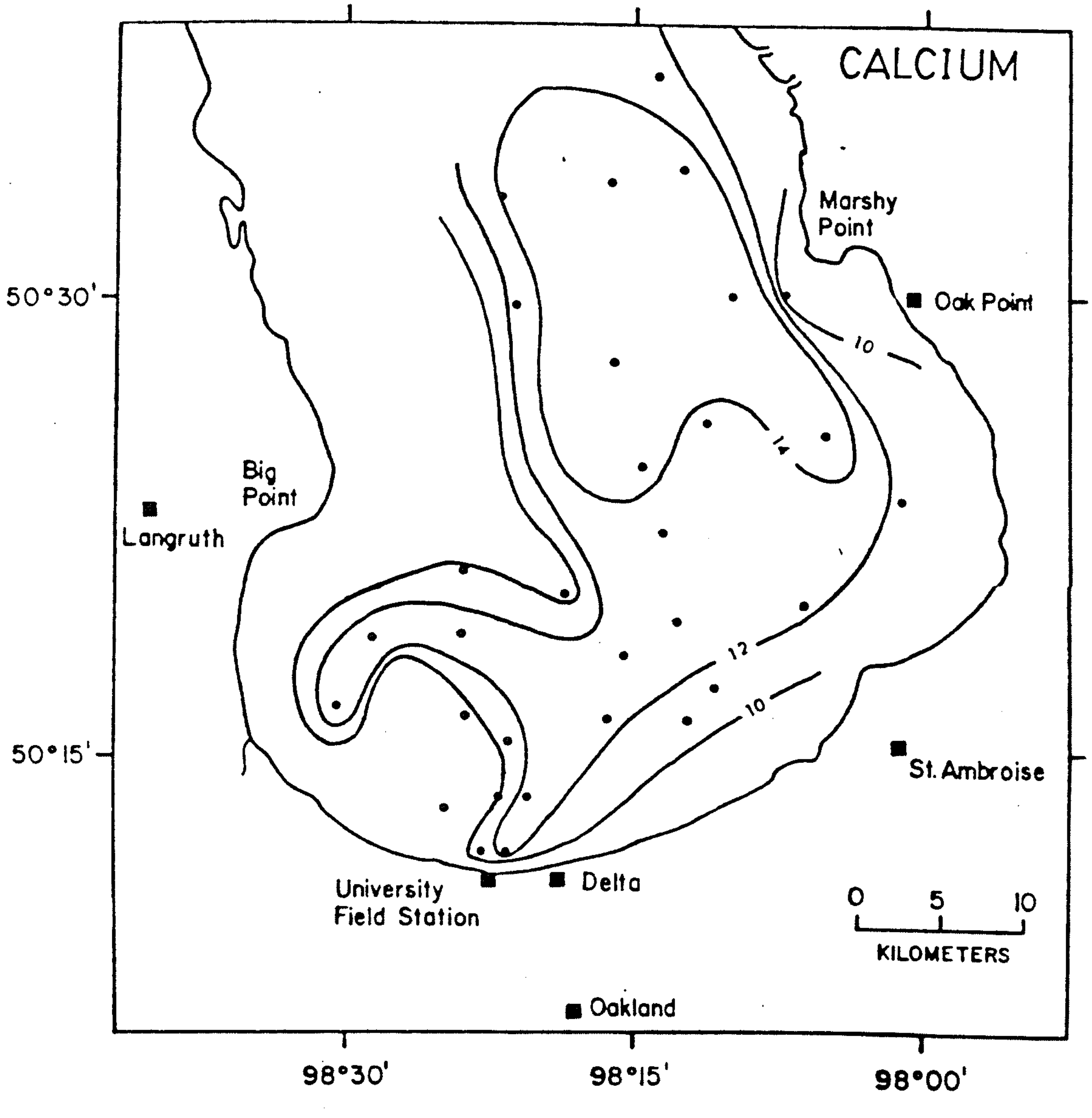


Figure D-26. Distribution of calcium in surface sediment.

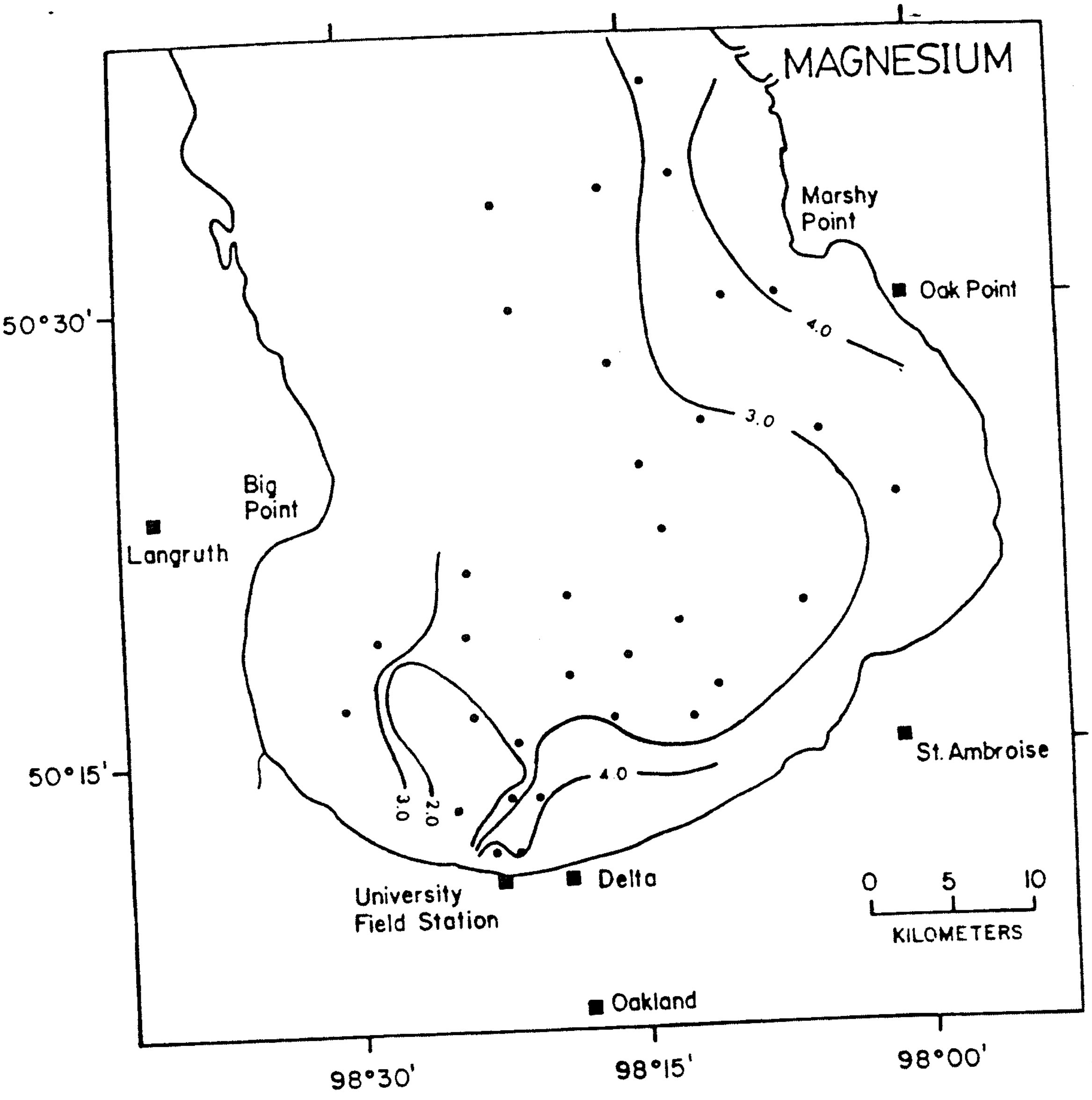


Figure D-27. Distribution of magnesium in surface sediment.

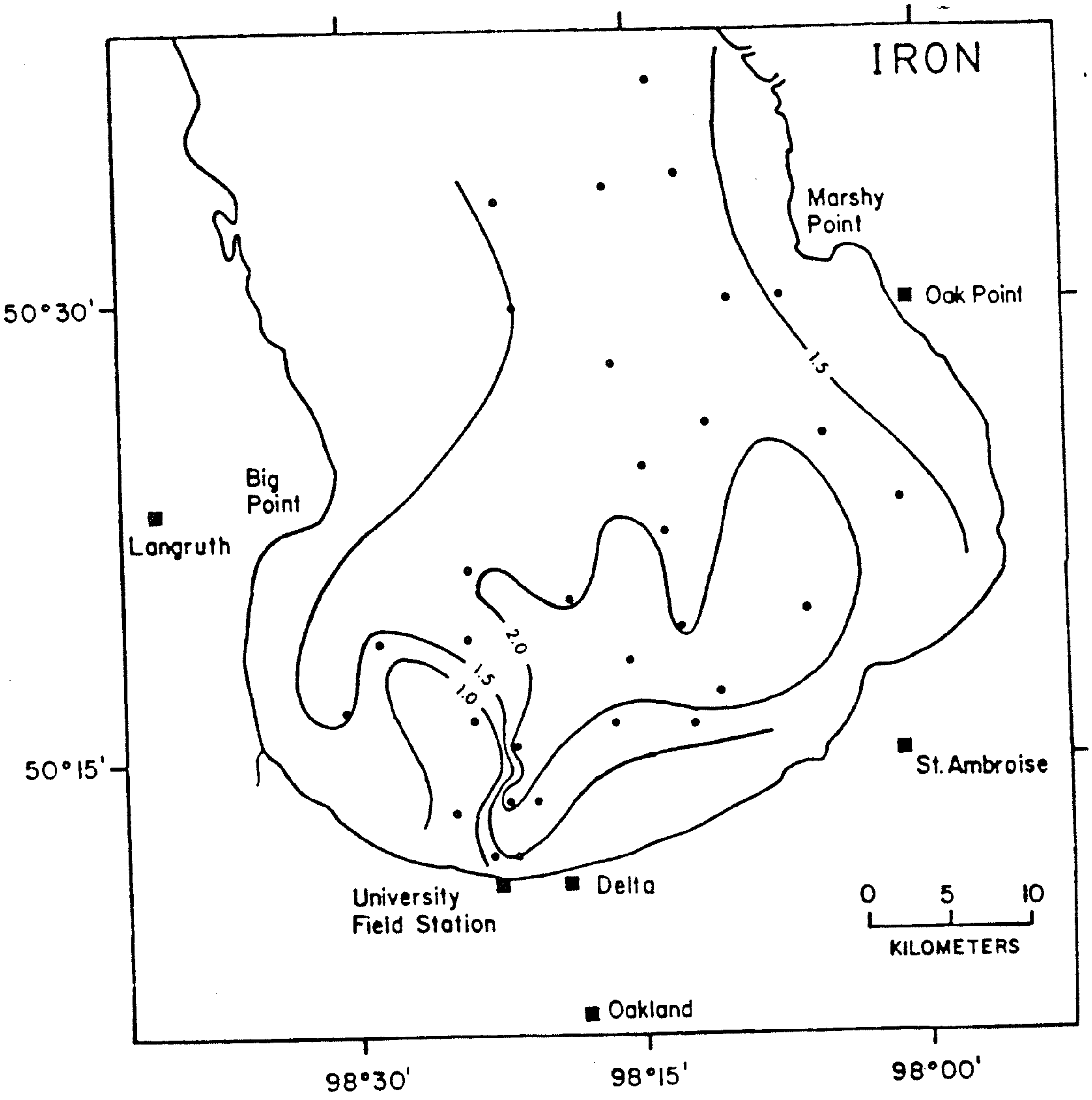


Figure D-28. Distribution of iron in surface sediment.

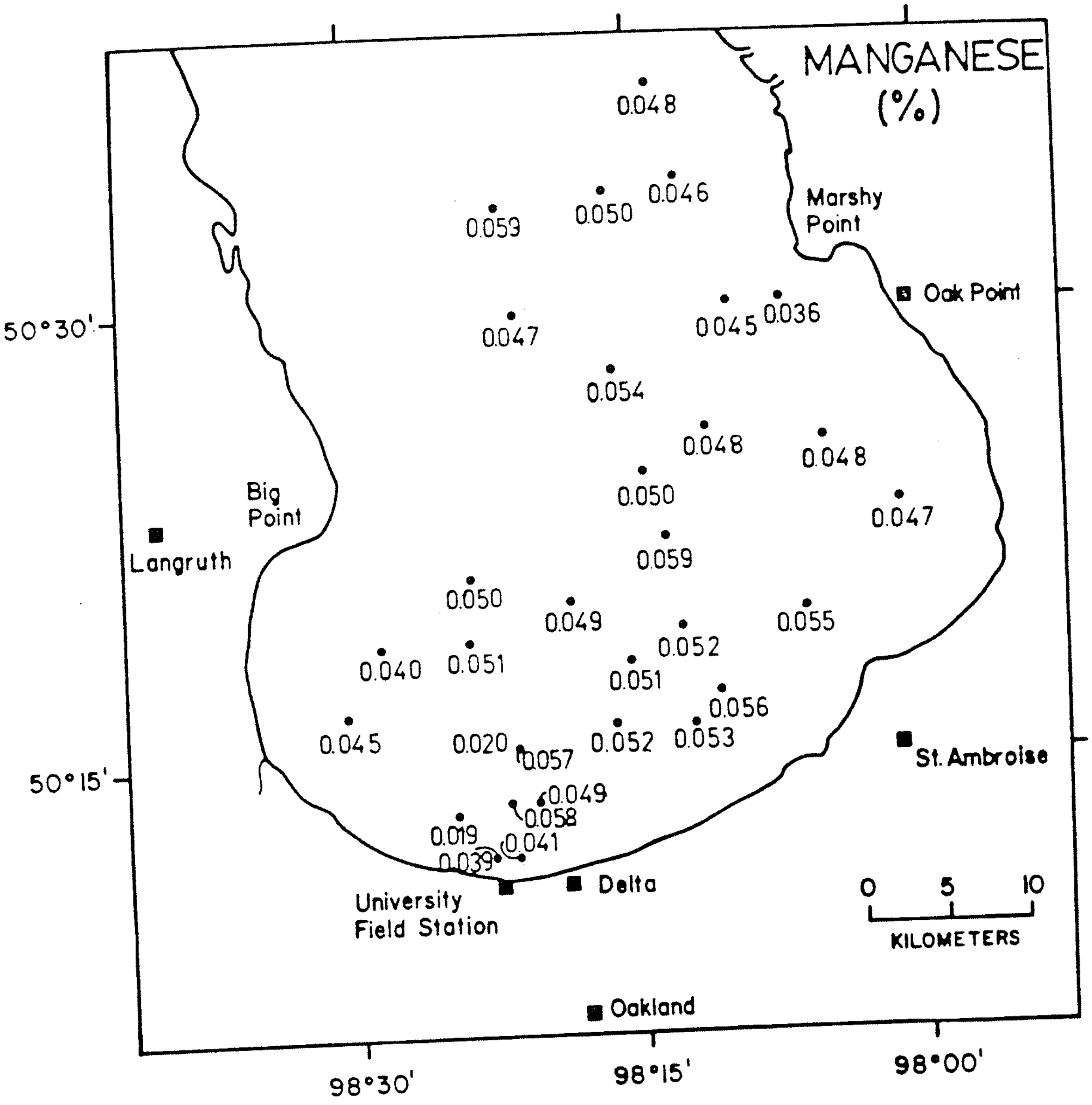


Figure D-29. Distribution of manganese in surface sediment.

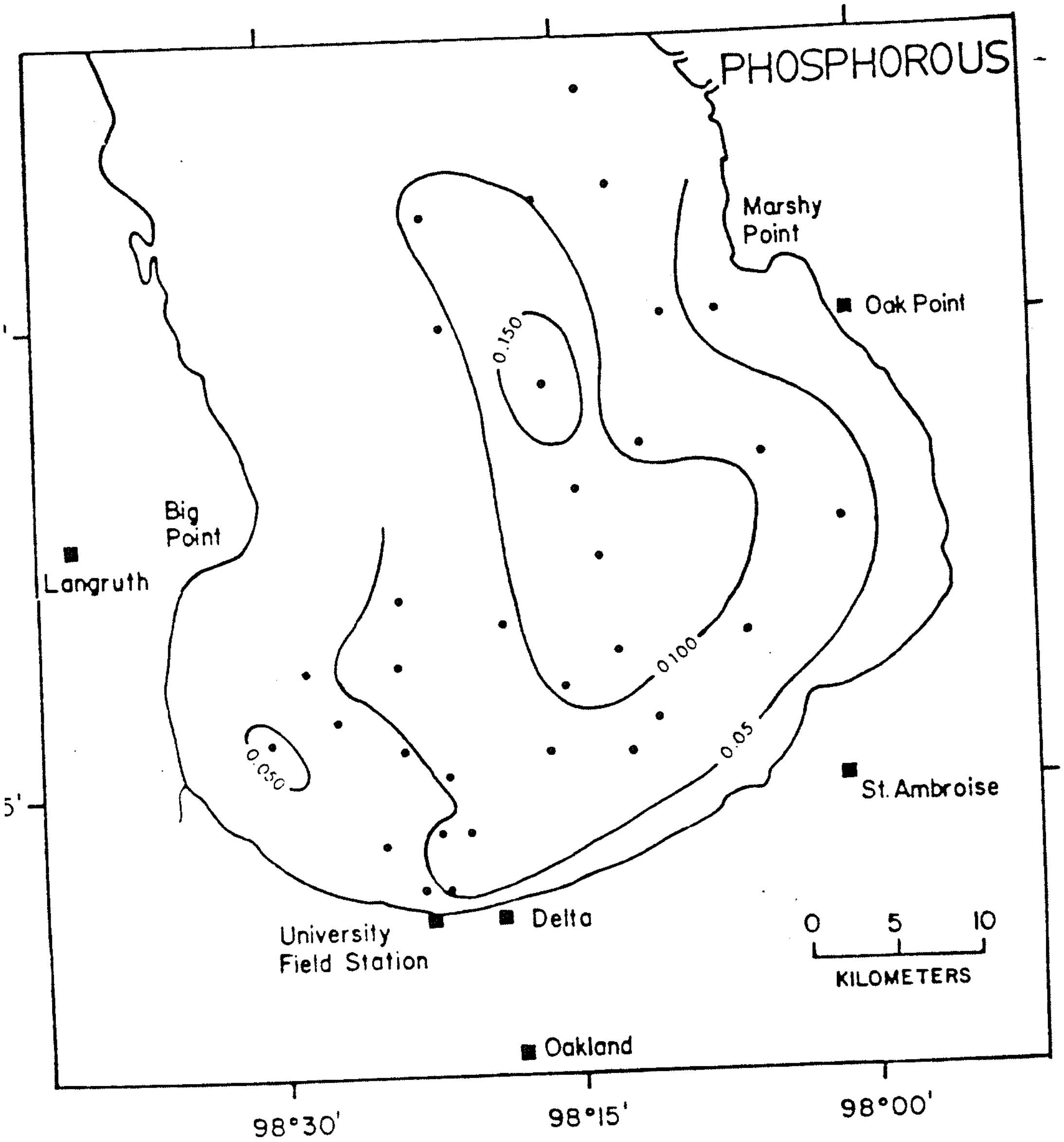


Figure D-30. Distribution of phosphorous in surface sediment.

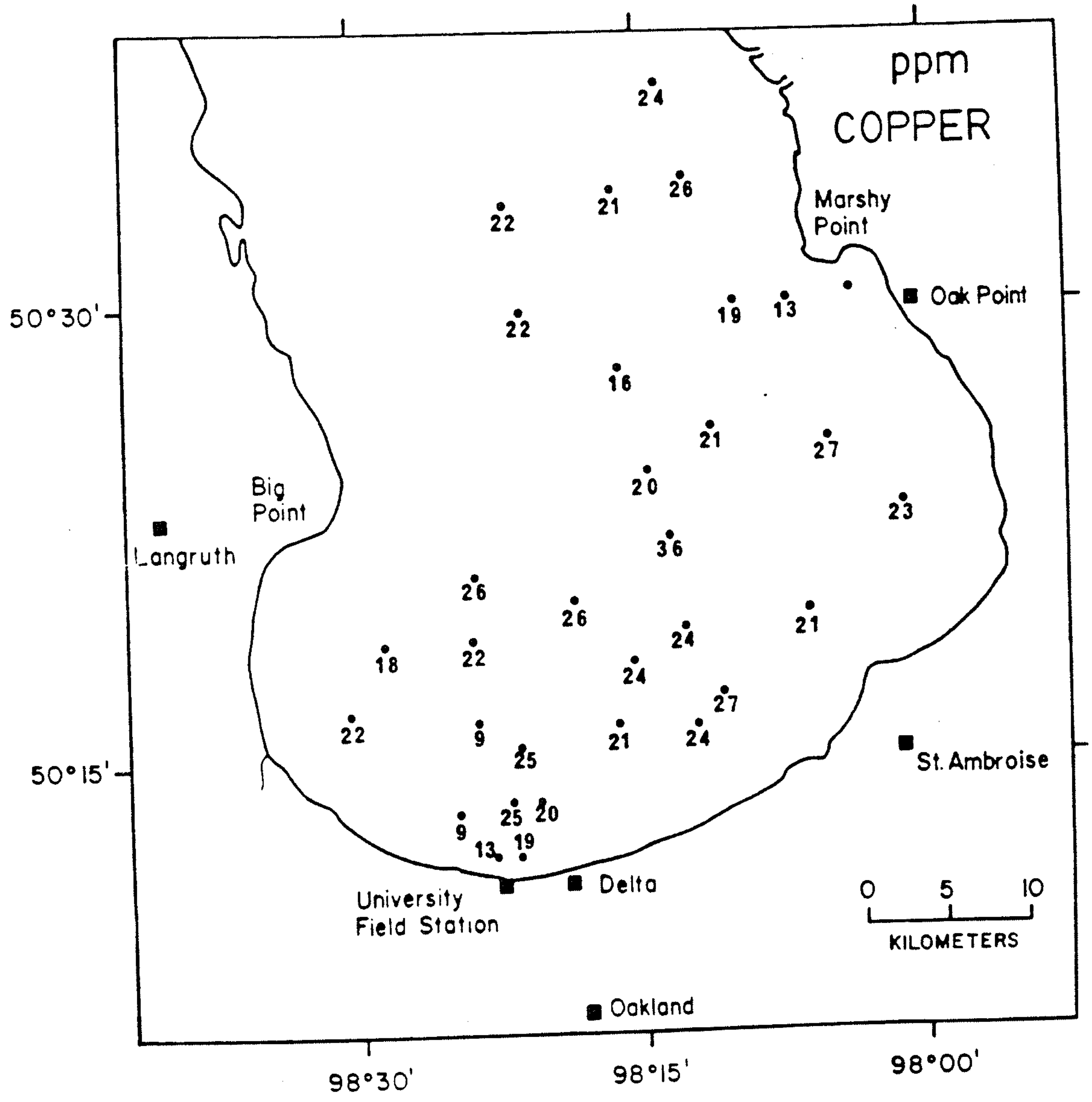


Figure D-31. Distribution of copper in surface sediment.

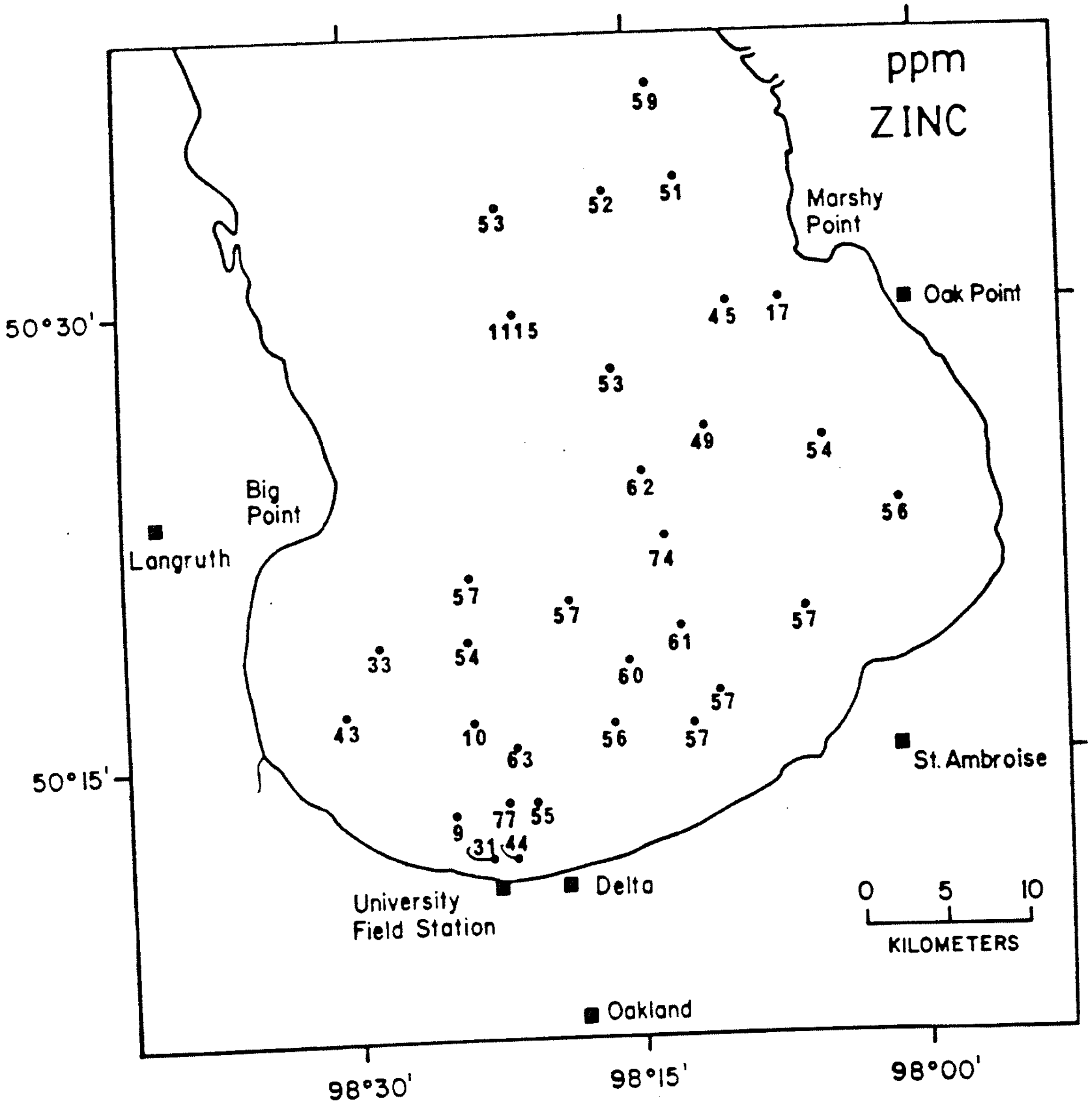


Figure D-32. Distribution of zinc in surface sediment.

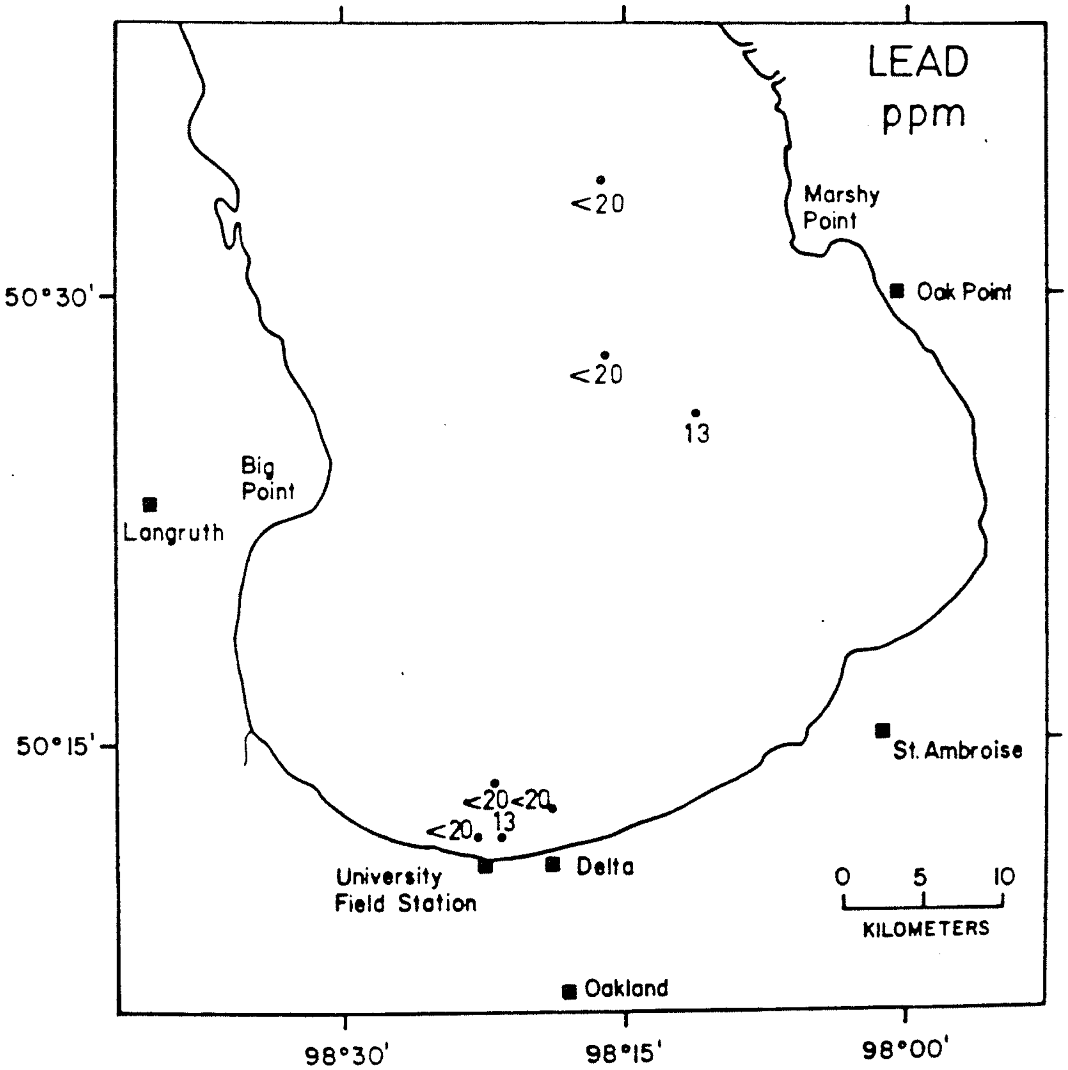


Figure D-33. Distribution of lead in surface sediment.

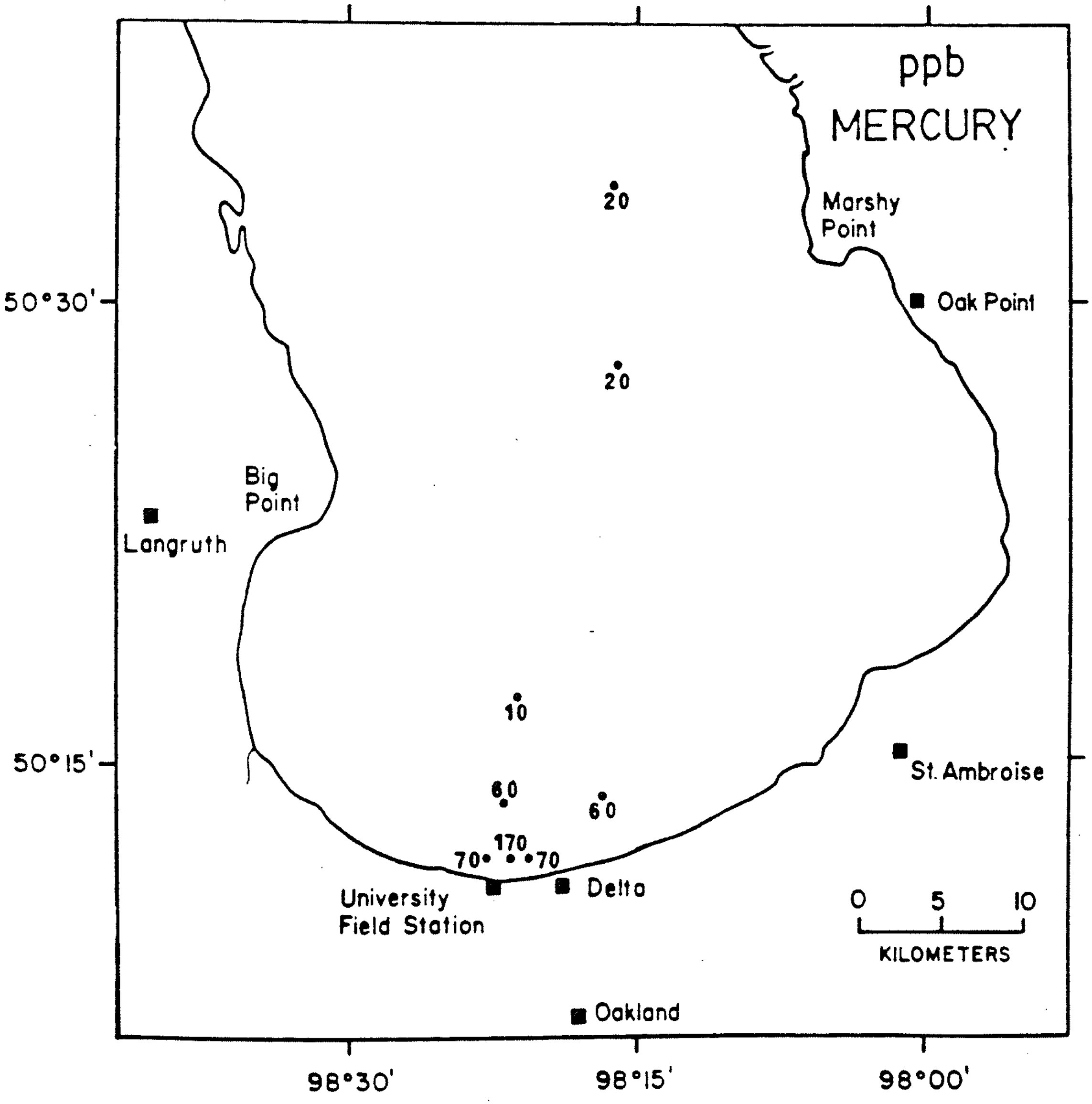


Figure D-34. Distribution of mercury in surface sediment.

APPENDIX E

Results of analyses of physical, chemical and mineralogical parameters.

The following table lists, in numerical order starting with core 1, the results of analysis of samples of sediment cores taken from Lake Manitoba and immediate surrounding area; refer to Figure 2-1 in the text for the location of these cores.

A blank on the table indicates that the analysis was not done. The percentages of quartz + feldspar + total calcite + dolomite + total clay minerals were normalized to equal 100%. The amount of magnesian calcite (Mg-calcite) in the sample is, in all cases, reported as a percentage of the total mineralogy. The amount of magnesian calcite subtracted from the amount of total calcite is equal to the percentage of low-Mg or normal calcite. The individual clay mineral percentages (i.e., expandable clay minerals, illite, kaolinite plus chlorite) are relative values summing to 100%.

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
1	0-2	13.6	100.0	0.0	0.0	2.3	0.5	+0.10	3.85	0.4	2.15		30.2
	2-4	14.7	99.0	1.0	0.0	2.0	0.9	-0.09	4.20	0.4			
	4-6	15.3								0.4			
	6-8	16.6								0.3			
	8-10	15.4								0.7			
	10-12	15.2	98.0	2.0	0.0	1.9	0.7	-0.12	6.90	0.6			
	12-14	15.6								0.6			
	14-16	16.8								0.6			
	16-18	16.9								0.4			
	18-20	17.8								0.5			
	20-23	16.3	100.0	0.0	0.0	2.1	0.5	-0.01	4.12	0.6			
	23-26	15.1								0.4			
	26-30	16.9								0.3			
	30-33	15.6	99.0	1.0	0.0	2.2	0.6	-0.12	4.95	0.4			
	33-36	17.1								0.5			
	36-39	17.6								0.5			
	39-40	21.0								0.8			
	40-43	17.2	100.0	0.0	0.0	2.3	0.6	-0.09	3.60	0.3			
	43-46	17.2								0.5			
	46-50	16.8								0.4			
	50-52	16.6	99.0	1.0	0.0	2.3	0.9	-0.62	2.87	0.6			
2	0-2	14.9	99.0	1.0	0.0	2.2	0.5	-1.40	3.23	0.6	2.11		32.8
	2-4	15.2								0.6			
	4-6	17.8	98.0	2.0	0.0	2.5				0.6			
	6-8	16.8								0.6			
	8-10	17.5								0.6			
	10-12	17.1	99.0	1.0	0.0	2.0				0.5			
	12-14	17.2								0.6			
	14-16	17.9								0.5			
	16-18	16.9								0.6			
	18-20	16.7	99.0	1.0	0.0	2.4				0.5			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
1	0-2	78.6	14.4	4.8			2.0	3.4	0.0			
	2-4							3.4				
	4-6							3.3				
	6-8							3.3				
	8-10							3.4				
	10-12							3.6				
	12-14							3.7				
	14-16							3.2				
	16-18							3.4				
	18-20							3.2				
	20-23							3.2				
	23-26							6.5				
	26-30							3.2				
	30-33							3.2				
	33-36							2.9				
	36-39							3.2				
	39-40							9.1				
	40-43							2.6				
	43-46							3.3				
	46-50							3.2				
	50-52							4.4				
2	0-2	71.6	17.7	3.9			6.6	6.8	0.0			
	2-4							6.2				
	4-6							5.9				
	6-8							6.0				
	8-10							6.1				
	10-12							6.9				
	12-14							6.2				
	14-16							6.1				
	16-18							6.0				
	18-20							7.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
1	0-2						1.08	1.05	3.52	0.47	0.55
	2-4										
	4-6										
	6-8										
	8-10										
	10-12										
	12-14										
	14-16										
	16-18										
	18-20										
	20-23										
	23-26										
	26-30										
	30-33										
	33-36										
	36-39										
	39-40										
	40-43										
	43-46										
	46-50										
	50-52										
2	0-2	7.3	+40				1.01	1.10	3.91	1.27	0.87
	2-4										
	4-6										
	6-8										
	8-10										
	10-12										
	12-14										
	14-16										
	16-18										
	18-20										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
1	0-2	0.019	0.026	9		9						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-39											
	39-40											
	40-43											
	43-46											
	46-50											
	50-52											
2	0-2	0.020	0.031	10		9						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
3	0-2	54.9	11.7	88.3	0.0	5.1	0.9	+1.93	4.00	5.9	1.36	1.46	78.3
	2-4	52.8											
	4-6	50.2								5.7			
	6-8	51.5											
	8-11	50.6											
	11-12	27.6								1.3			
	12-14	25.1											
	14-16	23.3											
	16-18	21.8								0.9			
	18-20	20.9											
	20-23	21.8	79.2	16.2	4.6	3.3				0.8			
	26-30	21.8											
	30-33	22.8								1.1			
	36-40	21.5											
	40-43	24.7								2.0			
	43-46	21.2											
	46-50	23.7											
	50-53	23.0								2.3			
	53-56	27.5											
	56-60	29.6											
	60-63	29.7	1.4	31.7	66.9					4.9			
4	0-2	62.6	5.0	67.0	28.0	6.6	1.8	+0.29	2.05	10.7	1.26	1.38	84.0
	4-6	68.1								12.2			
	10-12	63.4								9.8			
	21-23	62.1								12.2			
	30-33	60.2								9.9			
	40-43	62.1								9.2			
	50-53	61.9								10.4			
	60-63	63.5								12.9			
	70-71	60.4								8.7			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
3	0-2	22.9	8.1	18.8	16.7	6.5	25.4	20.1	24.5			
	2-4											
	4-6							18.1				
	6-8											
	8-11											
	11-12							9.5				
	12-14											
	14-16											
	16-18							5.2				
	18-20											
	20-23							4.5				
	26-30											
	30-33							5.1				
	36-40											
	40-43							6.8				
	43-46											
	46-50											
	50-53							7.1				
	53-56											
	56-60											
	60-63							6.4				
4	0-2	23.8	7.1	15.6			17.2	17.5	32.8	40.0	30.0	30.0
	4-6							12.7				
	10-12							16.4				
	21-23							22.9				
	30-33							16.8				
	40-43							16.8				
	50-53							15.7				
	60-63							12.4				
	70-71							22.0				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
3	0-2	7.9	+80				0.87	0.56	13.11	3.68	1.41
	2-4	7.9	+30								
	4-6	7.9	+50								
	6-8	7.9	+10								
	8-11	7.9	-100								
	11-12										
	12-14	7.9	-200								
	14-16										
	16-18	7.9	-150								
	18-20										
	20-23	7.9	-135								
	26-30										
	30-33	7.9	-210								
	36-40										
	40-43	7.8	-180								
	43-46										
	46-50	7.8	-200								
	50-53	7.8	-200								
	53-56										
	56-60										
	60-63	8.1	-180								
4	0-2	8.0	+20				1.02	0.44	10.42	2.30	1.85
	4-6	7.8	0								
	10-12	7.7	+40								
	21-23	7.8	++30								
	30-33	7.8	+20								
	40-43	7.8	+10								
	50-53	7.9	+20								
	60-63	7.9	+40								
	70-71	7.8	+60								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
3	0-2	0.040	0.044	33		18						
	2-4											
	4-6											
	6-8											
	8-11											
	11-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	26-30											
	30-33											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
4	0-2	0.050	0.065	57		26						
	4-6											
	10-12											
	21-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-71											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
5	0-2	73.7	1.6	52.9	45.5	8.1	2.3	+0.57	2.22	16.9	1.15		90.5
	2-4	73.5											
	4-6	72.7								18.2			
	6-8	72.7											
	8-10	74.8											
	10-12	71.9								16.8			
	12-14	71.6											
	14-16	71.2											
	16-18	70.8											
	18-20	69.7											
	20-23	69.8								12.6			
	23-26	70.2											
	26-30	71.2											
	30-33	69.4								13.7			
	33-36	68.3											
	36-40	67.4											
	40-43	65.2								11.8			
	43-46	66.1											
	46-50	67.2											
	50-53	66.1								9.8			
	53-56	66.1											
	56-60	65.2											
	60-63	66.8								8.4			
	63-66	66.9											
	66-70	66.8											
	70-73	70.1								8.9			
	73-76	65.4											
	76-80	64.1											
	80-83	63.2								12.2			
	83-86	60.9											
	86-90	60.8											
	90-92	61.2								9.9			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
5	0-2	34.8	3.9	29.4	28.2	6.8	13.9	16.8	17.8	29.6	37.0	33.3
	2-4											
	4-6							16.9				
	6-8											
	8-10											
	10-12							16.5				
	12-14											
	14-16											
	16-18											
	18-20											
	20-23							17.2				
	23-26											
	26-30											
	30-33							16.8				
	33-36											
	36-40											
	40-43							16.4				
	43-46											
	46-50											
	50-53							16.0				
	53-56											
	56-60											
	60-63							12.4				
	63-66											
	66-70											
	70-73							19.2				
	73-76											
	76-80											
	80-83							18.1				
	83-86											
	86-90											
	90-92							8.5				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
5	0-2	7.5	-210				0.89	0.39	9.90	2.23	1.69
	2-4	7.5	-210								
	4-6	7.5	-200								
	6-8	7.5	-200								
	8-10	7.5	-200								
	10-12	7.5	-180								
	12-14	7.6	-150								
	14-16	7.6	-150								
	16-18	7.6	-100								
	18-20	7.6	- 90								
	20-23	7.6	-100								
	23-26	7.6	- 90								
	26-30	7.6	-100								
	30-33	7.7	- 80								
	33-36	7.7	- 80								
	36-40	7.7	- 80								
	40-43	7.8	- 80								
	43-46	7.8	- 60								
	46-50	7.7	- 40								
	50-53	7.7	- 80								
	53-56	7.8	- 80								
	56-60	7.8	- 80								
	60-63	7.8	- 70								
	63-66	7.8	- 80								
	66-70	7.8	- 80								
	70-73	7.8	- 80								
	73-76	7.7	- 80								
	76-80	7.8	- 70								
	80-83	7.8	- 80								
	83-86	7.8	- 80								
	86-90	7.8	- 80								
	90-92	7.8	- 70								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
5	0-2	0.049	0.087	57		26						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-92											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
6	0-2	69.8	0.2	78.1	21.7	6.1	1.9	+0.85	2,32	16.2	1.19		88.7
	4-6									15.8			
	10-12									17.1			
7	0-2	80.1	0.1	78.3	21.6					14.6	1.12		92.9
	2-4	80.9											
	4-6	78.4								14.6	1.11		92.6
	6-8	80.2											
	8-10	81.6								14.6			
	10-12	80.3	0.6	83.2	16.2					14.8	1.14		90.7
	12-14	79.6											
	14-16	78.7											
	16-18	79.7								13.9	1.13		90.1
	18-20	82.6											
	20-23	79.3											
	23-26	79.2	0.5	70.1	29.4					13.0	1.14		88.6
	26-30	58.1											
	30-33	78.3								12.8	1.13		82.1
	33-36	82.8											
	36-40	83.0											
	40-43	79.4								13.9	1.12		88.1
	43-46	77.9											
	46-50	78.2											
	50-53	78.9								12.7	1.13		82.9
	53-56	77.9											
	56-60	80.2											
	60-63	79.1								12.7	1.13		84.3
	63-66	77.3											
	66-70	76.5											
	70-73	72.6								9.9	1.15		82.1
	73-76	72.1											
	76-80	77.6											
	80-83	77.4	0.9	68.6	30.5					11.2	1.15		82.0
	83-86	72.4								10.8	1.15		81.9

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
6	0-2	17.0	3.8	32.8			12.1	16.8	34.1	0	54.5	45.5
	4-6											
	10-12											
7	0-2	19.9	4.4	27.0	25.9	6.5	14.6	16.9	33.8	16.0	42.0	42.0
	2-4											
	4-6							17.0				
	6-8											
	8-10							17.0				
	10-12							17.1				
	12-14											
	14-16											
	16-18							17.9				
	18-20											
	20-23											
	23-26							18.2				
	26-30											
	30-33							19.2				
	33-36											
	36-40											
	40-43							18.3				
	43-46											
	46-50											
	50-53							18.5				
	53-56											
	56-60											
	60-63							18.6				
	63-66											
	66-70											
	70-73							18.4				
	73-76											
	76-80											
	80-83							20.5				
	83-86							16.6				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
6	0-2	7.7					1.02	0.49	12.51	2.40	2.00
	4-6	7.9									
	10-12	7.8									
7	0-2	7.6	-240				1.02	0.51	12.36	3.00	1.81
	2-4	7.5	-210								
	4-6	7.5	-240								
	6-8	7.6	-240								
	8-10	7.8	-210								
	10-12	7.5	-200								
	12-14	7.6	-250								
	14-16	7.8	-260								
	16-18	7.6	-280								
	18-20	7.6	-240								
	20-23	7.6	-210								
	23-26	7.5	-200								
	26-30	7.3	-200								
	30-33	7.5	- 40								
	33-36	7.7	-170								
	36-40	7.7	- 55								
	40-43	7.7	-175								
	43-46	7.6	-175								
	46-50	7.5	- 85								
	50-53	7.8	-100								
	53-56	7.7	-150								
	56-60	7.7	-180								
	60-63	7.7	-170								
	63-66	7.7	- 40								
	66-70	7.5	- 35								
	70-73	7.6	-110								
	73-76	7.8	-135								
	76-80	7.7	- 15								
	80-83	7.7	+ 15								
	83-86	7.9	0								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
6	0-2	0.051	0.102	60		24						
	4-6											
	10-12											
7	0-2	0.052	0.083	56		21						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
8	0-2	59.2	1.4	48.3	50.3	8.4	2.7	+0.27	1.91	10.8	1.32		41.7
	2-4	62.0											
	4-6	69.2											
	10-12	70.1								12.2			
	20-23	68.1								11.9			
	30-33	72.2								10.8			
	40-43	68.1								9.6			
	50-53	60.2								9.9			
	60-63	60.4	0.9	52.6	46.5					10.4			
	66-69	62.1								9.4			
9	0-2	68.5	2.6	55.2	42.2	8.1	2.8	+0.41	2.02	13.7	1.21		87.5
	2-4	68.9								15.2			
	4-6	68.6								12.6			
	10-12	69.4								10.8			
	14-16	67.2											
	20-23	68.1								10.2			
	30-33	67.2								9.8			
	40-43	67.1								9.9			
	50-53	68.1								9.4			
	60-63	67.0								10.3			
	70-73	66.8								6.5			
	80-83	60.4								9.4			
10	0-2	68.2	1.0	53.8	45.2	8.2	2.8	+0.43	1.76	15.4	1.20		87.6
	4-6	68.8								13.2			
	10-12	68.4								12.1			
	14-16	67.2								12.8			
	20-23	69.1								12.8			
	30-33	68.2								14.2			
	40-43	68.1								16.8			
	50-53	68.1								14.1			
	60-63	68.4								10.1			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
8	0-2	41.7	6.7	12.5			26.3	12.3	14.0	64.9	17.5	17.5
	2-4											
	4-6											
	10-12							12.9				
	20-23							12.2				
	30-33							14.1				
	40-43							16.3				
	50-53							10.5				
	60-63							11.2				
	66-69							14.8				
9	0-2	36.9	16.2	18.8	17.1	6.8	20.6	17.8	7.2	27.7	27.8	44.4
	2-4							17.9				
	4-6							18.2				
	10-12							17.8				
	14-16											
	20-23							17.4				
	30-33							17.4				
	40-43							18.2				
	50-53							17.1				
	60-63							16.5				
	70-73							19.2				
	80-83							10.4				
10	0-2	19.7	5.5	27.9			16.5	18.3	30.1	40.4	29.8	29.8
	4-6							18.4				
	10-12							18.3				
	14-16							17.1				
	20-23							16.8				
	30-33							15.4				
	40-43							18.1				
	50-53							16.4				
	60-63							16.3				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
8	0-2	8.0	- 30				1.44	0.56	8.66	2.99	2.60
	2-4	7.9	-200								
	4-6	7.9	-220								
	10-12	7.9	-210								
	20-23	7.8	- 80								
	30-33	7.8	- 40								
	40-43	7.7	- 20								
	50-53	7.7	0								
	60-63	7.6	- 10								
	66-69	7.7	- 10								
9	0-2	7.8	- 20								
	2-4	7.7	- 90								
	4-6	7.7	-110								
	10-12	7.7	- 60								
	14-16	7.7	- 30								
	20-23	7.7	0								
	30-33	7.8	+ 10								
	40-43	7.8	0								
	50-53	7.8	+ 10								
	60-63	7.8	+ 10								
	70-73	7.8	- 10								
	80-83	7.8	- 20								
10	0-2	7.9	- 40				1.04	0.50	14.8	2.2	1.97
	4-6	7.9	- 30								
	10-12	7.9	- 60								
	14-16	7.9	- 40								
	20-23	7.9	- 80								
	30-33	7.9	- 80								
	40-43	7.9	- 30								
	50-53	7.9	- 30								
	60-63	7.9	- 10								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
8	0-2	0.058	0.074	72	1	35	20	60				
	2-4											
	4-6											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	66-69											
9	0-2						10					
	2-4						10					
	4-6						10					
	10-12						20					
	14-16						20					
	20-23						20					
	30-33											
	40-43						20					
	50-53											
	60-63											
	70-73											
	80-83						10					
10	0-2	0.050	0.120	62		20						
	4-6											
	10-12											
	14-16											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
10	70-73	62.9								9.8			
	80-83	67.9								10.4			
	86-90	67.5								10.1			
11	0-2	70.4	0.7	66.2	33.1	7.1	1.9	+0.50	1.71	18.1	1.19		88.5
	2-4	71.9								18.1			
	4-6	70.9								15.4			
	8-10	68.8								16.3			
12	0-2	75.3	1.7	77.8	20.5	7.2	1.9	+0.61	3.01	18.7	1.16		90.3
	2-4	74.5								16.7			
	4-6	73.1								16.4			
	6-8	73.2								11.8	1.15		90.0
	8-10	73.1								14.2			
	10-12	73.5								16.2			
	12-14	73.4								15.4			
	14-16	73.2								12.9	1.17		88.1
	16-18	73.3								12.8			
	18-20	74.0								14.3			
	20-23	73.2								12.9	1.16		80.2
	23-26	73.1								16.1	1.17		89.1
	26-30	72.0								14.5	1.16		81.3
	30-33	73.4								15.8			
	33-36	72.6								14.1			
	36-40	71.2								13.6			
	40-43	70.3								13.4			
	43-46	71.5								13.3	1.18		84.1
	46-50	70.8								13.2			
	50-53	72.0								11.9			
	53-56	70.1								12.5			
	56-60	69.7								11.2			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
10	70-73							18.2				
	80-83							15.1				
	86-90							22.1				
11	0-2	24.3	4.1	28.6			15.0	17.3	27.7	32.6	25.0	42.3
	2-4							22.1				
	4-6							18.5				
	8-10							16.1				
12	0-2	15.0	4.7	35.7	34.0	6.7	13.1	14.9	31.3	12.2	62.0	25.8
	2-4							16.4				
	4-6							15.8				
	6-8							21.0				
	8-10							17.8				
	10-12							16.7				
	12-14							17.3				
	14-16							19.4				
	16-18							19.5				
	18-20							18.6				
	20-23							16.4				
	23-26							17.2				
	26-30							16.8				
	30-33							16.9				
	33-36							17.4				
	36-40							17.1				
	40-43							16.1				
	43-46							16.4				
	46-50							16.8				
	50-53							16.9				
	53-56							17.4				
	56-60							15.9				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
10	70-73	7.9	- 20								
	80-83	7.9	- 30								
	86-90	7.9	- 40								
11	0-2	7.9	+100								
	2-4	7.6	+ 90								
	4-6	7.5	- 40								
	8-10	7.4	- 10								
12	0-2	7.6	-180				1.07	0.44	12.54	2.30	1.96
	2-4	7.5	-210								
	4-6	7.6	-210								
	6-8	7.7	-200								
	8-10	7.9	-210								
	10-12	8.0	-200								
	12-14	8.0	-190								
	14-16	8.1	-175								
	16-18	8.0	-190								
	18-20	8.0	-140								
	20-23	8.0	-160								
	23-26	8.1	-190	11.6	5.2	6.4					
	26-30	8.0	-210	10.9	5.4	5.5					
	30-33	8.0	-220	11.6	5.0	6.6					
	33-36	8.0	-200								
	36-40	8.1	-190								
	40-43	8.1	-160								
	43-46	8.1	-200								
	46-50	8.1	-190	10.4	5.2	5.2					
	50-53	8.0	-140								
	53-56	8.0	-150								
	56-60	8.1	-190								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
10	70-73											
	80-83											
	86-90											
11	0-2											
	2-4											
	4-6											
	8-10											
12	0-2	0.052	0.110	61		24						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
12	60-63	68.2								10.8			
	63-66	66.8								11.9			
	66-70	67.4								11.0			
	70-73	67.4								10.8			
	73-76	65.9								10.8			
	76-80	65.0								9.6			
	80-83	63.8								9.9			
	83-86	64.1								9.7			
	86-90	64.5								9.6			
	90-93	64.4								10.6			
	93-96	65.8								10.5			
	96-98	62.2								10.4			
13	0-2	75.6	2.6	66.1	31.3	6.8	2.0	+0.24	1.89	15.8	1.15		91.2
	2-4	73.2								13.9			
	4-6	71.8								13.8			
	6-8	71.6								13.2			
	8-10	70.1								13.9			
	10-12	71.2								14.3			
	12-14	70.0								14.1			
	14-16	71.7								13.7			
	16-18	72.9								13.7	1.16		
	18-20	70.7								13.7			
	20-23	71.7								14.9			
	23-26	73.8								13.8			
	26-30	72.3								14.1			
	30-33	72.7								13.0	1.16		
	33-36	71.3								13.0			
	36-40	71.7								12.9			
	40-43	69.2								12.2			
	43-46	68.8								12.8			
	46-50	67.7								12.8			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
12	60-63							16.0				
	63-66							16.9				
	66-70							16.1				
	70-73							16.3				
	73-76							15.9				
	76-80							15.9				
	80-83							17.2				
	83-86							16.5				
	86-90							17.3				
	90-93							16.8				
	93-96							11.2				
	96-98							11.2				
13	0-2	22.4	11.7	28.0	26.6	6.5	15.2	15.7	22.4	4.7	66.6	28.5
	2-4							17.5				
	4-6							17.2				
	6-8							17.0				
	8-10							17.4				
	10-12							16.7				
	12-14							17.1				
	14-16							17.5				
	16-18							17.1				
	18-20							17.2				
	20-23							17.3				
	23-26							17.3				
	26-30							21.0				
	30-33							19.0				
	33-36							19.1				
	36-40							18.1				
	40-43							17.9				
	43-46							18.0				
	46-50							19.0				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
12	60-63	8.0	-170								
	63-66	8.1	-180								
	66-70	8.2	-180								
	70-73	8.2	-180								
	73-76	8.1	-190								
	76-80	8.1	-200								
	80-83	8.2	-210								
	83-86	8.0	-180								
	86-90	7.9	-170								
	90-93	8.0	-200								
	93-96	8.0	- 80								
	96-98	8.0	- 50								
13	0-2	7.7	- 40				1.10	0.50	11.46	2.70	2.04
	2-4	7.6	-100								
	4-6	7.7	-140								
	6-8	7.6	-180								
	8-10	7.7	-200								
	10-12	7.8	-210								
	12-14	7.6	-260								
	14-16	7.8	-280								
	16-18	7.8	-260								
	18-20	7.7	-260								
	20-23	7.9	-250								
	23-26	8.0	-200								
	26-30	7.9	-220								
	30-33	7.8	-280								
	33-36	7.6	-230								
	36-40	7.9	-260								
	40-43	7.9	-310								
	43-46	7.9	-260								
	46-50	7.8	-290								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
12	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											
	96-98											
13	0-2	0.058	0.079	57		27						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
13	50-53	68.9								12.8			
	53-56	68.6								12.9	1.18		79.9
	56-60	67.0								11.9			
	60-63	65.6								10.8			
	63-66	65.4								9.9			
	66-71	65.5								9.9			
	71-73	63.0								9.8			
	73-76	62.9								9.1			
	76-80	62.9								9.0			
	80-83	63.7								9.0			
	83-86	62.9								9.1			
	86-90	60.9								10.3			
	90-93	60.7								10.3			
	93-96	60.8								10.4			
	96-100	61.5								9.7			
14	0-2	69.6	0.4	51.7	47.9	8.4	2.6	+0.79	2.04	14.6	1.19		88.3
	4-6	69.5								15.0			
	10-12	69.6								14.9			
15	0-2	49.9	2.5	69.0	28.5	7.1	2.02	+0.84	3.08	6.7	1.44		73.4
	4-6	52.4								6.9			
	10-12	56.9								9.2			
16	0-2	55.8	0.5	84.5	15.0	6.5	1.9	+1.55	5.08	8.1	1.34		79.0
	2-4	56.3								8.0			
	4-6	55.4								8.0			
	10-12	54.9								9.2			
	20-23	56.8								8.7			
	30-33	54.4								9.2			
	40-43	54.6								9.9			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
13	50-53							20.9				
	53-56							21.0				
	56-60							19.0				
	60-63							16.6				
	63-66							18.0				
	66-71							20.1				
	71-73							17.1				
	73-76							18.2				
	76-80							21.2				
	80-83							17.3				
	83-86							21.3				
	86-90							17.0				
	90-93							15.2				
	93-96							16.4				
	96-100							15.8				
14	0-2	32.7	8.1	9.0	7.8	11.0	22.8	15.7	27.1	18.0	44.0	38.0
	4-6							14.8				
	10-12							15.8				
15	0-2	33.0	12.4	2.2	1.8	4.0	23.0	10.0	30.3	57.3	20.0	22.6
	4-6							12.1				
	10-12							9.8				
16	0-2	30.1	3.1	4.7			39.4	16.9	30.1	25.0	43.7	31.2
	2-4							17.5				
	4-6							16.8				
	10-12							16.7				
	20-23							16.9				
	30-33							18.2				
	40-43							12.7				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
13	50-53	7.9	-280								
	53-56	7.8	-280								
	56-60	7.8	-280								
	60-63	7.8	-280								
	63-66	7.8	-260								
	66-71	7.8	-240								
	71-73	7.8	-240								
	73-76	7.7	-240								
	76-80	7.7	-240								
	80-83	7.8	-270								
	83-86	7.8	-230								
	86-90	7.8	-230								
	90-93	7.8	-250								
	93-96	7.9	-110								
	96-100	7.9	-100								
14	0-2	7.8	+ 90								
	4-6	7.4	- 30								
	10-12	7.3	-200								
15	0-2	7.9	+100								
	4-6	7.6	+ 80								
	10-12	7.6	+ 40								
16	0-2	8.0	+ 20								
	2-4	7.6	-200								
	4-6	7.6	-200								
	10-12	7.6	-200								
	20-23	7.6	-120								
	30-33	7.7	-110								
	40-43	7.7	- 80								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
13	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-71											
	71-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											
	96-100											
14	0-2											
	4-6											
	10-12											
15	0-2							60				
	4-6											
	10-12											
16	0-2											
	2-4											
	4-6											
	10-12											
	20-23											
	30-33											
	40-43											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
16	50-53	59.8											
	60-63	58.7											
	70-73	58.9											
17	0-2	65.5	1.4	75.0	23.6	6.9	2.9	+0.13	0.29	11.7	1.23		85.6
	2-4	65.4								12.8			
	4-6	65.4								10.5			
	10-12	65.3								12.8			
	20-23	63.4								9.0			
	30-33	62.5								9.4			
	40-43	61.9								9.8			
	50-53	60.8								10.4			
	60-63	61.8								10.1			
	70-73	60.9								10.9			
	80-83	61.8								9.9			
	93-96	60.9								9.8			
18	0-2	66.5	5.7	73.4	20.9	6.2	1.9	+0.66	2.39	7.6	1.22		86.8
	4-6	66.1								7.9			
	6-8	65.2								7.8			
	10-12	65.9								8.2			
	14-16	66.2								9.3			
	20-23	67.1								9.8			
	23-26	64.5								10.4			
	26-30	64.9								10.2			
	30-33	65.1								10.4			
	40-43	65.2								10.2			
	50-53	64.1								10.2			
	60-63	59.2								12.1			
	70-73	60.1								9.1			
	80-83	61.1								9.0			
	90-94	60.9								8.0			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
16	50-53							18.6				
	60-63							22.1				
	70-73							9.5				
17	0-2	18.9	3.3	21.9	28.5	6.8	21.9	18.8	29.8	9.8	45.2	45.0
	2-4							18.8				
	4-6							18.5				
	10-12							18.9				
	20-23							16.4				
	30-33							12.8				
	40-43							18.9				
	50-53							16.4				
	60-63							17.1				
	70-73							18.1				
	80-83							19.2				
	93-96							8.7				
18	0-2	32.6	4.5	26.0	23.9	6.8	23.0	18.4	15.0	8.6	43.4	47.8
	4-6							19.2				
	6-8							19.2				
	10-12							20.1				
	14-16							18.2				
	20-23							16.2				
	23-26							17.2				
	26-30							17.1				
	30-33							18.2				
	40-43							16.1				
	50-53							11.1				
	60-63							15.2				
	70-73							15.4				
	80-83							16.3				
	90-94							17.1				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
16	50-53	7.6	- 80								
	60-63	7.6	- 90								
	70-73	7.6	- 70								
17	0-2	7.4	-150				1.00	0.55	12.74	3.34	1.67
	2-4	7.6	-210								
	4-6	7.7	-200								
	10-12	7.7	-240								
	20-23	7.6	-210								
	30-33	7.7	-100								
	40-43	7.7	- 50								
	50-53	7.7	- 10								
	60-63	7.6	+ 10								
	70-73	7.6	- 10								
	80-83	7.6	- 10								
	93-96	7.7	+ 10								
18	0-2	7.7	- 50				0.95	0.51	14.17	3.08	1.69
	4-6	7.8	-110								
	6-8	7.5	-200								
	10-12	7.4	-200								
	14-16	7.4	-150								
	20-23	7.3	-120								
	23-26	7.3	- 80								
	26-30	7.4	+ 80								
	30-33	7.4	+ 40								
	40-43	7.7	+ 40								
	50-53	7.6	+ 30								
	60-63	7.7	+ 40								
	70-73	7.7	+ 40								
	80-83	7.7	+ 40								
	90-94	7.7	+ 30								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
16	50-53											
	60-63											
	70-73											
17	0-2	0.047	0.065	46		23						
	2-4											
	4-6											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	80-83											
	93-96											
18	0-2	0.048	0.087	54		27						
	4-6											
	6-8											
	10-12											
	14-16											
	20-23											
	23-26											
	26-30											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	80-83											
	90-94											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
19	0-2	72.7	0.6	82.3	17.1	6.4	2.1	+0.48	2.65	11.5	1.16		90.2
	2-4	72.8								11.3			
	4-6	75.2								11.8			
	6-8	71.9								11.7			
	8-10	72.5								11.3			
	10-12	70.6								11.4			
	12-14	73.9								12.1			
	14-16	72.3								12.2			
	16-18	72.9								12.9			
	18-20	72.3								11.8			
	20-23	67.2								10.6			
	23-26	66.1								10.6			
	26-30	66.3								10.9			
	30-33	65.5								10.0			
	33-36	64.5								10.0			
	36-40	63.0								10.1			
	40-43	62.5								9.2			
	43-46	62.3								9.8			
	46-50	63.7								9.2			
	50-53	62.2								8.3			
	53-56	60.9								9.1			
	56-60	60.2								8.9			
	60-63	61.6								8.8			
	63-66	62.5								8.4			
	66-70	62.3								8.3			
	70-73	59.5								7.7			
	73-76	57.2								7.9			
	76-80	57.9								7.9			
	80-83	58.3								7.5			
	83-86	63.9								7.6			
	86-90	59.8								8.0			
	90-93	62.6								8.9			
	93-96	63.7								8.1			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
19	0-2	19.9	3.2	22.3	21.8	6.5	21.9	14.7	32.4	18.6	41.0	40.4
	2-4							19.8				
	4-6							20.3				
	6-8							20.1				
	8-10							20.1				
	10-12							19.8				
	12-14							19.2				
	14-16							19.6				
	16-18							19.7				
	18-20							19.9				
	20-23							26.2				
	23-26							20.1				
	26-30							20.5				
	30-33							20.5				
	33-36							20.5				
	36-40							19.9				
	40-43							19.6				
	43-46							19.9				
	46-50							19.8				
	50-53							20.2				
	53-56							19.2				
	56-60							19.5				
	60-63							19.8				
	63-66							18.6				
	66-70							18.5				
	70-73							19.0				
	73-76							19.0				
	76-80							18.5				
	80-83							18.9				
	83-86							17.6				
	86-90							18.1				
	90-93							13.5				
	93-96							17.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
19	0-2	7.6	-210				0.96	0.51	14.59	3.32	1.64
	2-4	7.5	-240								
	4-6	7.5	-250								
	6-8	7.7	-230								
	8-10	7.6	-180								
	10-12	7.5	-210								
	12-14	7.7	-200								
	14-16	7.6	-200								
	16-18	7.7	-200								
	18-20	7.6	-200								
	20-23	7.3	-210								
	23-26	7.7	-260								
	26-30	7.5	-220								
	30-33	7.6	-130								
	33-36	7.6	- 80								
	36-40	7.8	- 30								
	40-43	7.9	- 30								
	43-46	7.8	- 20								
	46-50	7.7	-100								
	50-53	7.6	- 30								
	53-56	7.8	-110								
	56-60	7.8	- 70								
	60-63	7.7	- 60								
	63-66	7.7	- 20								
	66-70	7.7	-100								
	70-73	7.7	- 50								
	73-76	7.6	-150								
	76-80	7.8	- 50								
	80-83	7.7	-210								
	83-86	7.7	-230								
	86-90	7.7	-220								
	90-93	7.6	-170								
	93-96	7.7	- 60								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
19	0-2	0.045	0.061	45		19						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
20	0-5	77.6	99.6	0.4	0	1.0	1.2	-0.09	2.94	1.4			
	5-10	78.9	100	0.0	0	0.8	2.9	-0.91	2.01	0.6			
	10-11	54.6								7.2			
21	0-2	17.5	98.1	1.9	0	1.7	1.2	-0.19	2.25	1.2	2.03		37.4
	6-8	18.5								2.4			
	10-12	27.1								4.2			
	14-16	31.0								5.0			
	16-18	23.0								6.1			
	20-23	24.1								5.7			
	23-26	22.9								5.7			
	26-27	24.7								6.2			
22	0-2	74.4	1.1	68.1	30.8	7.5	2.1	+0.84	3.19	16.8			
	2-4	72.1								16.9			
	4-6	73.6								16.2			
	8-10	71.9								18.1			
	10-12	69.9								17.9			
23	0-2	80.1	0	35.7	64.3	9.3	3.1	-0.33	1.71	19.2	1.08		94.7
	2-4	80.9								19.9			
	4-6	89.9	0.8	42.6	56.6					20.8	1.07		94.2
	6-8	80.1								19.4			
	8-10	79.5								18.1			
	10-12	79.6	1.1	44.4	54.5					17.9			
	12-14	79.5								18.2			
	14-16	79.2								17.3			
	16-18	78.2								19.2			
	18-20	77.8								15.0			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
20	0-5	40.8	31.0	6.8			20.9	28.9	0			
	5-10							29.5				
	10-11							18.1				
21	0-2	47.1	38.9	1.1			12.7	9.8	0			
	6-8							17.0				
	10-12							27.2				
	14-16							16.6				
	16-18							18.0				
	20-23							14.7				
	23-26							13.1				
	26-27							11.6				
22	0-2	14.4	1.9	27.8	27.2	6.0	11.1	16.9	46.4			
	2-4							15.5				
	4-6							12.1				
	8-10							18.2				
	10-12							19.1				
23	0-2	12.5	3.0	48.2			13.6	16.2	22.7	40.1	34.0	25.9
	2-4							17.2				
	4-6							13.8				
	6-8							14.2				
	8-10							16.2				
	10-12	15.8	5.4	31.9			19.1	16.0	27.6			
	12-14							18.1				
	14-16							16.6				
	16-18							18.4				
	18-20							18.9				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
20	0-5	7.6	+ 80				0.91	1.33	9.88	4.32	1.37
	5-10	7.7	+ 90								
	10-11	8.0	+ 90								
21	0-2	7.6	+ 20								
	6-8	7.7	+ 10								
	10-12										
	14-16										
	16-18										
	20-23	8.0	- 90								
	23-26	8.0	- 80								
	26-27	7.9	-110								
22	0-2	7.3	+ 10								
	2-4	7.4	0								
	4-6	7.4	- 10								
	8-10	7.4	0								
	10-12	7.4	+ 10								
23	0-2	7.7	+240				0.96	0.44	11.11	2.27	1.64
	2-4	7.9	+150								
	4-6	8.0	+ 70				0.96	0.45	9.52	2.52	1.62
	6-8	7.9	+ 60								
	8-10	8.0	+ 40	10.8	5.2	5.6					
	10-12	8.0	+ 20								
	12-14	8.0	+ 10								
	14-16	8.0	+ 60				0.93	0.41	10.90	2.61	1.75
	16-18	8.0	0								
	18-20	8.0	+ 60								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
20	0-5	0.036	0.022	17		13						
	5-10											
	10-11											
21	0-2											
	6-8											
	10-12											
	14-16											
	16-18											
	20-23											
	23-26											
	26-27											
22	0-2											
	2-4											
	4-6											
	8-10											
	10-12											
23	0-2	0.043	0.092	49		24		20				
	2-4											
	4-6	0.045	0.083	58		20						
	6-8											
	8-10							10				
	10-12											
	12-14											
	14-16	0.050	0.074	55		20						
	16-18											
	18-20											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
23	20-23	77.9	2.6	50.1	47.3					16.9	1.11		93.2
	23-26	78.2	2.9	54.9	42.2					15.4	1.06		93.5
	26-30	78.4								14.2			
	30-33	78.6	2.3	51.8	45.9					14.0	1.22		96.1
	33-36	77.8								13.8			
	36-40	77.9								13.9			
	40-43	77.8	1.1	33.0	65.9					13.9	1.11		86.2
	43-46	77.9								14.1			
	46-50	77.8								14.0			
	50-53	77.9	2.0	37.5	60.1					14.1	1.19		93.1
	53-56	77.6								14.5			
	56-60	77.5								14.2			
	60-63	76.5								12.1	1.19		88.4
	63-66	71.3								10.2			
	66-70	74.9								12.0			
	70-73	72.8								11.9	1.20		87.6
	73-76	70.0	0.5	38.7	60.8					10.5			
	76-80	71.9								10.4			
	80-83	70.8								9.6	1.21		87.9
	83-86	70.0								8.8			
	86-90	70.9								9.4			
	90-93	70.5								9.1			
	93-96	69.9								9.3			
	96-100	68.5	0.8	41.9	57.3					9.2			
	100-103	66.9								9.6			
	110-113	67.6								12.0			
	120-123	63.3	0.5	59.0	40.5					10.3			
	130-133	66.0								11.5			
	140-143	65.6								13.0			
	150-153	63.5	0.4	57.6	41.9					10.7			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
23	20-23	10.2	29.1	26.4			11.4	18.2	22.5			
	23-26							18.6				
	26-30							18.7				
	30-33	16.6	4.3	37.7			12.1	19.4	29.0			
	33-36							19.8				
	36-40							22.1				
	40-43							20.3				
	43-46							20.2				
	46-50							21.4				
	50-53	12.0	5.3	38.6	32.8	8.0	13.3	19.8	30.5			
	53-56							19.2				
	56-60							19.1				
	60-63							17.2				
	63-66							18.2				
	66-70							16.9				
	70-73							16.0				
	73-76	18.0	4.6	36.9	31.3	8.0	13.2	18.0	27.0			
	76-80							18.7				
	80-83							19.8				
	83-86							18.8				
	86-90							19.9				
	90-93							19.1				
	93-96							18.9				
	96-100	18.6	9.2	29.8			16.1	19.2	25.7			
	100-103							19.3				
	110-113							16.8				
	120-123	20.0	7.8	31.4	26.7	8.8	17.1	17.1	23.3			
	130-133							16.7				
	140-143							19.3				
	150-153	24.4	4.8	26.8			16.8	19.3	26.8			

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
23	20-23	8.0	+ 20								
	23-26	8.0	+ 10								
	26-30	7.9	+ 40								
	30-33	8.0	+ 80				1.06	0.43	14.25	2.67	1.74
	33-36	8.0	+ 90								
	36-40	8.0	+ 20								
	40-43	8.0	+ 40								
	43-46	8.0	+ 30								
	46-50	8.0	+ 40								
	50-53	8.0	+ 50								
	53-56	7.9	+ 50								
	56-60	7.9	+ 10								
	60-63	8.0	+ 30								
	63-66	7.9	+ 10								
	66-70	7.9	+ 10								
	70-73	7.9	+ 20								
	73-76	7.8	+ 20								
	76-80	7.8	+ 20								
	80-83	8.0	+ 80								
	83-86	7.8	+ 80								
	86-90	7.8	+ 70								
	90-93	8.0	+ 50								
	93-96	7.8	+ 50								
	96-100	8.0	+ 50								
	100-103	8.2	- 20								
	110-113	8.2	- 10								
	120-123	8.3	- 80								
	130-133	8.2	-120								
	140-143	8.1	- 50								
	150-153	8.2	- 60								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
23	20-23											
	23-26											
	26-30											
	30-33	0.055	0.100	109	<1	24	< 20					
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											
	96-100											
	100-103											
	110-113							10				
	120-123											
	130-133											
	140-143											
	150-153											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
23	160-163	55.0								8.1			
	170-173	55.5	0.2	49.6	50.2					8.2			
	180-183	55.0								8.0			
	190-193	52.3	0	38.4	61.6					8.0			
	195-200	51.9								7.8			
	200-203	50.7	0	48.6	51.4					7.8			
	210-213	52.0	0	49.9	50.1					7.8			
	220-223	55.2								7.8			
	230-233	55.0	0.5	43.2	56.3					5.9			
	240-243	53.9								2.9			
	250-253	51.3	0	18.3	81.7					6.5			
	254-257	47.4	0	34.8	65.2					6.4			
	260-263	43.8	0	36.4	63.6					6.5			
	263-265	43.6	0.2	34.8	65.0								
24	0-2	67.5	0.1	69.0	30.9	6.9	2.5	+0.66	2.23	14.9			
	2-4	68.1								11.8			
	4-6	68.0											
	8-10	67.2											
	10-12	65.7											
	20-23	66.2											
	30-33	64.2											
	40-43	65.1											
	50-53	64.0											
	60-63	63.2											
	70-73	62.1											
	80-83	62.9											
	90-93	63.1											
	100-103	63.0											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
23	160-163											
	170-173	25.6	7.0	16.0	11.2	11.5	22.6	15.4	28.2			
	180-183							14.3				
	190-193	23.1	7.3	12.7	10.1	10.2	17.4	14.5	39.1			
	195-200							13.0				
	200-203	29.2	7.3	15.5			23.5	9.4	24.3			
	210-213	25.1	4.6	15.4			16.2	14.4	38.5			
	220-223							15.1				
	230-233	20.2	9.3	22.4			14.1	16.2	33.6			
	240-243							16.0				
	250-253	20.9	5.7	24.9			10.0	16.5	38.3			
	254-257	21.1	8.4	25.3	17.7	3.8	13.3	15.0	31.6			
	260-263	21.1	6.2	22.3	17.8	2.5	12.6	14.4	37.3			
	263-265	24.3	7.5	28.5			14.1	19.6	25.2			
24	0-2	22.7	11.0	18.3	17.3	6.5	22.7	19.8	25.0	21.2	34.0	44.6
	2-4							22.1				
	4-6											
	8-10											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	80-83											
	90-93											
	100-103											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
23	160-163	8.3	-160								
	170-173	8.4	-150								
	180-183	8.3	-100								
	190-193	8.2	- 90								
	195-200	8.1	-100								
	200-203	8.5	+ 20	5.9	4.2	1.7					
	210-213	8.4	- 50								
	220-223	8.4	+ 10								
	230-233	8.2	+ 20								
	240-243	8.4	0								
	250-253	8.4	- 10								
	254-257	8.1	+ 10								
	260-263	8.6	+ 20								
	263-265	8.6	+ 20								
24	0-2	7.7	+ 90				0.95	0.52	12.84	3.04	1.70
	2-4	7.7	+ 80								
	4-6	7.6	+ 90								
	8-10	7.7	+ 90								
	10-12	7.8	+100								
	20-23	7.8	+ 10								
	30-33	7.8	+ 10								
	40-43	7.7	- 10								
	50-53	7.7	0								
	60-63	7.7	+ 10								
	70-73	7.7	+ 90								
	80-83	7.8	+ 10								
	90-93	7.7	+ 70								
	100-103	7.7	+ 50								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
23	160-163											
	170-173											
	180-183											
	190-193											
	195-200											
	200-203											
	210-213											
	220-223											
	230-233											
	240-243											
	250-253											
	254-257											
	260-263							10				
	263-265											
24	0-2	0.048	0.084	59		24						
	2-4											
	4-6											
	8-10											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	80-83											
	90-93											
	100-103											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
24	110-113	60.1											
	120-123	59.7											
	130-133	59.9											
	140-143	60.1											
	150-153	60.2											
	160-163	59.7											
	170-173	58.7											
	180-183	58.4											
	190-193	56.2											
	198-200	58.1											
25	0-2	70.5	0.6	47.5	51.9	8.7	2.9	+0.29	1.60	12.2			
	2-4	70.1								14.3			
	4-6	69.6								12.9			
	6-8	69.8								12.3			
	8-10	69.5								13.5			
	10-12	71.0								14.1			
	12-14	68.4								11.6			
	14-16	69.5								13.1			
	16-18	69.2								13.6			
	18-20	65.1								9.7			
	20-23	69.9								10.7			
	23-26	63.2								10.1			
	26-30	62.1								8.2			
	30-33	62.1								8.0			
	33-36	62.1								10.1			
	36-40	62.0								10.0			
	40-43	65.9								11.5			
	43-46	60.9								11.1			
	46-50	61.0								9.9			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
24	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	190-193											
	198-200											
25	0-2	20.7	3.3	28.6	27.4	6.5	25.3	21.0	22.0	53.3	20.0	26.6
	2-4							19.2				
	4-6							20.6				
	6-8							20.9				
	8-10							19.9				
	10-12							19.5				
	12-14							22.5				
	14-16							20.1				
	16-18							19.7				
	18-20							23.6				
	20-23							22.2				
	23-26							22.7				
	26-30							21.6				
	30-33							22.3				
	33-36							22.2				
	36-40							22.5				
	40-43							21.0				
	43-46							21.1				
	46-50							21.3				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
24	110-113	7.7	+ 50								
	120-123	7.8	+ 80								
	130-133	7.7	+100								
	140-143	7.7	+100								
	150-153	7.8	+150								
	160-163	7.7	+180								
	170-173	7.7	+180								
	180-183	7.8	+180								
	190-193	7.7	+180								
	198-200	7.7	+170								
25	0-2	7.8	+ 70				0.95	0.48	15.10	3.74	1.64
	2-4	7.8	+ 80								
	4-6	7.7	- 20								
	6-8										
	8-10	7.6	- 80								
	10-12	7.6	- 60								
	12-14										
	14-16										
	16-18										
	18-20										
	20-23	7.8	- 60								
	23-26										
	26-30										
	30-33	7.9	- 30								
	33-36										
	36-40										
	40-43	8.0	- 50								
	43-46										
	46-50										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
24	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	190-193											
	198-200											
25	0-2	0.064	0.074	51		26						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
25	50-53	63.8								10.8			
	53-56	62.0								10.0			
	56-60	62.1								9.0			
	60-63	62.9								9.7			
	63-66	62.5								10.7			
	66-70	62.4								8.6			
	70-73	63.3								11.4			
	73-76	62.1								10.6			
	76-80	62.5								10.9			
	80-83	62.6								10.6			
	83-86	62.8								9.2			
	86-90	60.9								7.4			
	90-93	58.2								8.4			
	93-96	59.9								9.1			
	100-103	53.2								7.7			
	110-113	41.6								6.2			
	120-123	33.1								5.2			
	125-126	34.6								4.8			
26	0-2	72.7	2.9	6.76	29.5	6.9	2.4	+0.71	2.85	18.5	1.15		90.3
	2-4	70.9								19.1	1.15		90.3
	4-6	72.5											
	6-8	71.5											
	8-10	71.9											
	10-12	72.3											
	12-14	71.6								18.5			
	14-16	70.9											
	16-18	71.5											
	18-20	70.8								16.5	1.20		87.2
	20-23	70.4											
	23-26	70.9								15.0			
	26-30	70.1											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
25	50-53							19.9				
	53-56							19.8				
	56-60							21.9				
	60-63							20.5				
	63-66							19.6				
	66-70							21.6				
	70-73							18.7				
	73-76							23.6				
	76-80							19.3				
	80-83							19.2				
	83-86							20.0				
	86-90							23.3				
	90-93							20.8				
	93-96							19.6				
	100-103							18.1				
	110-113							23.7				
	120-123							24.9				
	125-126							21.0				
26	0-2	28.7	4.7	11.9			14.9	17.0	39.6	38.2	34.0	27.8
	2-4											
	4-6							16.3				
	6-8											
	8-10											
	10-12											
	12-14											
	14-16							17.1				
	16-18											
	18-20											
	20-23							18.3				
	23-26											
	26-30							19.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
25	50-53	8.1	- 60								
	53-56										
	56-60										
	60-63	8.1	- 30								
	63-66										
	66-70										
	70-73	8.0	- 50								
	73-76										
	76-80										
	80-83	8.1	- 30								
	83-86										
	86-90										
	90-93	7.9	- 40								
	93-96	8.1	+ 90								
	100-103	7.9	+ 50								
	110-113										
	120-123										
	125-126										
26	0-2	8.0	-220				0.78	0.32	11.95	2.15	1.50
	2-4	7.9	-240								
	4-6	7.9	-200								
	6-8	7.9	-210								
	8-10	7.9	-190								
	10-12	7.9	-250								
	12-14										
	14-16	7.9	-200	13.0	5.2	7.8					
	16-18										
	18-20										
	20-23	8.0	-210								
	23-26										
	26-30										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
25	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											
	100-103											
	110-113											
	120-123											
	125-126											
26	0-2	0.047	0.083	1115		22						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
26	30-33	69.9								14.1	1.21		86.5
	33-36	68.8											
	36-40	67.8								13.6			
	40-43	67.8								13.5	1.23		86.4
	43-46	68.1											
	46-50	67.2											
	50-53	66.3								13.7	1.24		86.7
	53-56	66.1											
	56-60	65.0								12.9			
	60-63	64.5								12.7	1.26		87.5
	63-66	65.9											
	66-70	65.8											
	70-73	66.8								12.7	1.25		86.2
	73-76	65.9											
	76-80	65.2								12.6			
	80-83	65.9								13.2	1.25		86.4
	83-86	64.8											
	86-90	65.0								12.6			
	90-93	65.0								13.2	1.26		85.3
	93-98	65.9								11.0	1.26		84.2
	100-103	65.3								11.2	1.26		84.1
	110-113	66.1								10.8	1.25		85.2
	120-123	67.0								9.5	1.32		80.1
	130-133	59.2								10.4	1.32		80.4
	140-143	58.4								9.8	1.32		80.1
	150-153	58.6								9.5	1.35		80.1
	160-163	57.3								9.2	1.38		77.4
	170-173	54.2								8.7	1.38		77.1
	180-183	54.5								8.7	1.37		81.0
	190-192	55.5								8.4	1.31		83.4

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
26	30-33							19.6				
	33-36											
	36-40							19.5				
	40-43							18.3				
	43-46											
	46-50											
	50-53							17.0				
	53-56											
	56-60							17.7				
	60-63							18.3				
	63-66											
	66-70											
	70-73							17.6				
	73-76											
	76-80							17.7				
	80-83							17.8				
	83-86											
	86-90							18.1				
	90-93							17.6				
	93-98							18.3				
	100-103							17.7				
	110-113							17.6				
	120-123							16.9				
	130-133							16.0				
	140-143							15.1				
	150-153							14.7				
	160-163							14.6				
	170-173							14.9				
	180-183							14.9				
	190-192							14.4				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
26	30-33	8.0	-140								
	33-36										
	36-40										
	40-43	8.0	-110								
	43-46										
	46-50										
	50-53	8.0	- 90								
	53-56										
	56-60										
	60-63	7.9	- 90								
	63-66										
	66-70										
	70-73	8.0	- 80								
	73-76										
	76-80										
	80-83	8.1	- 60								
	83-86										
	86-90										
	90-93	8.1	- 80								
	93-98	8.0	- 90								
	100-103	7.9	- 60								
	110-113	7.9	+ 10								
	120-123	7.8	- 30								
	130-133	7.9	-200								
	140-143	7.9	-180								
	150-153	7.9	-200								
	160-163	7.9	-180								
	170-173	8.0	-150								
	180-183	8.2	-150								
	190-192	8.1	- 30								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
26	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-98											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	190-192											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
										12.0			
26	200-203	61.8								8.8	1.29		84.2
	210-213	59.8								8.7			
	220-223	63.6								9.2	1.27		83.1
	230-233	60.8								9.0			
	240-243	64.8								9.2	1.29		79.0
	250-253	61.2								9.9			
	260-263	62.6								8.6	1.35		80.1
	270-273	59.9								8.2	1.34		75.4
	280-283	57.4								8.1	1.41		75.6
	290-293	57.5								7.3	1.51		66.4
	300-303	50.9								7.3	1.55		67.2
	310-313	42.8								8.1	1.55		67.1
	313-316	40.6								7.5	1.55		67.2
	318-321	40.6											
	321-324	40.6											
27	0-2	68.9	2.8	90.3	6.9	6.4	2.0	-0.16	2.05	14.77	1.20		88
	2-4	69.0								16.6	1.18		89
	4-6	69.5											
	6-8	69.5											
	8-10	69.4								14.6	1.21		87
	10-12	69.3											
	12-14	68.4								14.2	1.22		87
	14-16	66.5											
	16-18	66.8											
	18-20	67.5								14.4	1.22		87
	20-23	67.2											
	23-26	68.1								13.8			
	26-30	66.9								15.2	1.22		87
	30-33	66.4											
	33-36	66.9								12.7			
	36-40	62.1											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
26	200-203							14.6				
	210-213							14.0				
	220-223							14.1				
	230-233							12.5				
	240-243							13.3				
	250-253							11.9				
	260-263							14.4				
	270-273							14.3				
	280-283							14.7				
	290-293							15.7				
	300-303							14.0				
	310-313							13.7				
	313-316							13.2				
	318-321							13.8				
	321-324											
27	0-2	20.0	5.2	38.0			20.1	18.6	20.0	24.1	38.0	32.9
	2-4											
	4-6							17.9				
	6-8											
	8-10											
	10-12							18.5				
	12-14											
	14-16							18.7				
	16-18											
	18-20											
	20-23							18.5				
	23-26											
	26-30							19.0				
	30-33							17.9				
	33-36											
	36-40							19.8				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
26	200-203	8.0	- 80								
	210-213	7.9	- 90								
	220-223	7.9	- 90								
	230-233	8.0	- 80								
	240-243	8.0	- 50								
	250-253	7.9	-110								
	260-263	7.9	- 90								
	270-273	7.9	- 80								
	280-283	7.9	- 90								
	290-293	8.0	-120								
	300-303	8.1	-180								
	310-313	8.0	+ 10								
	313-316										
	318-321	8.0	-140								
	321-324										
27	0-2	8.1	-110				0.96	0.45	13.51	2.94	1.71
	2-4	7.9	-130								
	4-6	7.8	-220								
	6-8	7.7	-260								
	8-10	7.7	-240								
	10-12	7.7	-210								
	12-14										
	14-16	7.7	-190								
	16-18										
	18-20	7.8	-150								
	20-23	7.7	-110								
	23-26	7.7	-130								
	26-30										
	30-33	7.7	-200								
	33-36										
	36-40										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
26	200-203											
	210-213											
	220-223											
	230-233											
	240-243											
	250-253											
	260-263											
	270-273											
	280-283											
	290-293											
	300-303											
	310-313											
	313-316											
	318-321											
	321-324											
27	0-2	0.048	0.083	49		21	8					
	2-4											
	4-6											
	6-8											
	8-10						13					
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
27	40-43	63.0								13.8	1.25		85
	43-46	66.5											
	46-50	66.0								13.4			
	50-53	65.5								13.7	1.23		86
	53-56	64.1											
	56-60	69.2								10.8			
	60-63	63.5								13.1	1.25		85
	63-66	62.0											
	66-70	61.3								10.0			
	70-73	61.4								10.8	1.27		84
	73-76	61.5											
	76-80	60.4								10.6			
	80-83	59.9								11.1	1.29		83
	83-86	59.1											
	86-90	60.1								13.2			
	90-93	61.4								11.0	1.27		84
	100-103	56.8								9.2	1.32		81
	110-113	58.1								8.6	1.31		81
	120-123	58.1								11.2	1.31		81
	130-133	55.5								9.3	1.33		80
	140-143	55.3								9.8	1.33		80
	150-153	55.0								9.7	1.33		80
	160-163	52.5								8.9	1.37		77
	170-173	51.4								8.9	1.38		77
	180-183	50.7											
	200-203	54.0								6.8	1.36		78
	210-213	56.1								6.9	1.34		79
	220-223	55.3								8.1	1.34		79
	230-233	52.2								7.6	1.38		77
	240-243	36.5								6.7	1.59		64
	250-253	46.6								6.7	1.45		72
	254-257	47.9								7.4	1.43		74

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
27	40-43							18.6				
	43-46											
	46-50							19.2				
	50-53							18.9				
	53-56											
	56-60							19.4				
	60-63							18.1				
	63-66											
	66-70							18.0				
	70-73							16.9				
	73-76											
	76-80							19.5				
	80-83							16.1				
	83-86											
	86-90							17.2				
	90-93							16.4				
	100-103							17.9				
	110-113							19.4				
	120-123							15.9				
	130-133							16.2				
	140-143							15.7				
	150-153							15.4				
	160-163							15.3				
	170-173							14.6				
	180-183											
	200-203							15.5				
	210-213							16.4				
	220-223							15.0				
	230-233							15.1				
	240-243							15.3				
	250-253							19.7				
	254-257							14.9				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
27	40-43	7.8	-200								
	43-46										
	46-50										
	50-53	7.8	-200								
	53-56										
	56-60										
	60-63	7.8	-200								
	63-66										
	66-70										
	70-73	7.8	-190								
	73-76										
	76-80										
	80-83	7.9	-140								
	83-86										
	86-90										
	90-93	7.8	-210								
	100-103	7.9	+ 30								
	110-113	8.0	- 80								
	120-123	8.0	-200								
	130-133	7.9	-210								
	140-143	8.0	-150								
	150-153	8.1	-210								
	160-163	8.0	-150								
	170-173	8.0	-110								
	180-183	8.0	-120								
	200-203	7.9	-200								
	210-213	7.6	-180								
	220-223	7.6	-240								
	230-233	7.7	-190								
	240-243	7.6	-180								
	250-253	7.4	-160								
	254-257	7.6	-170								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
27	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80						15					
	80-83											
	83-86											
	86-90											
	90-93											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	200-203											
	210-213											
	220-223											
	230-233											
	240-243											
	250-253											
	254-257											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
28	0-2	73.4	5.8	71.5	22.7	6.8	2.2	-0.10	2.14	17.6			
	2-4	72.4								18.8			
	4-6	73.5								17.9			
	6-8	72.1											
	8-10	73.5								17.7			
	10-12	74.8											
	12-14	71.2											
	14-16	72.1											
	16-18	71.1											
	18-20	69.0											
	20-23	69.4								13.2			
	23-26	69.8											
	26-30	69.4											
	30-33	71.9								9.2			
	33-36	69.9											
	36-40	69.2											
	40-43	63.6								29.3			
	43-46	65.1											
	46-50	68.2											
	50-53	67.0	0	52.4	47.6					9.9			
	53-56	67.1											
	56-60	67.2											
	60-63	65.1								8.2			
	63-66	65.4											
	66-70	63.2											
	70-73	62.8								9.2			
	73-76	63.1											
	76-80	63.2											
	80-83	60.0								8.8			
	83-86	60.1											
	86-90	61.5											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
28	0-2	17.3	3.3	32.6	30.9	6.8	12.9	17.4	33.7	36.0	29.0	25.0
	2-4							17.7				
	4-6							17.4				
	6-8											
	8-10							17.3				
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23							18.4				
	23-26											
	26-30											
	30-33							25.1				
	33-36											
	36-40											
	40-43							14.6				
	43-46											
	46-50											
	50-53							17.6				
	53-56											
	56-60											
	60-63							19.3				
	63-66											
	66-70											
	70-73							17.8				
	73-76											
	76-80											
	80-83							17.5				
	83-86											
	86-90											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
28	0-2	7.4	-240				0.97	0.39	14.0	2.38	1.84
	2-4	7.4	-240								
	4-6	7.3	-260								
	6-8	7.3	-240								
	8-10	7.9	-260	13.2	5.1	8.1					
	10-12	7.4	-260								
	12-14	7.5	-270								
	14-16	7.7	-270								
	16-18	7.8	-270								
	18-20	7.8	-240								
	20-23	7.9	-230								
	23-26	7.9	-210								
	26-30	7.9	-180								
	30-33	8.0	-170								
	33-36										
	36-40	8.0	-160								
	40-43	7.9	-120								
	43-46	7.9	-180								
	46-50										
	50-53	7.9	-100								
	53-56	7.9	-100								
	56-60										
	60-63	8.0	- 90								
	63-66	7.9	-100								
	66-70										
	70-73	7.9	-180								
	73-76	8.0	-180								
	76-80										
	80-83	8.0	-150								
	83-86	8.0	-150								
	86-90										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
28	0-2	0.059	0.110	53		22						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
28	90-93	64.7								8.6			
	100-103	62.9	0.4	69.1	30.5					10.9			
	110-113	63.1								9.4			
	120-123	59.2								8.5			
	130-133	60.7								7.6			
	140-143	60.2								7.9			
	150-153	60.2								7.1			
	160-163	60.6								7.1			
	170-173	59.6								7.8			
	180-183	55.7								7.6			
	190-193	53.6								7.5			
	200-203	54.1	0.2	60.5	39.3					15.6			
	210-213	54.2								1.3			
	220-223	54.3								7.3			
	230-233	54.7								7.4			
	240-243	55.8								7.6			
	250-253	56.8								6.9			
	260-263	56.6								6.7			
	270-273	55.3								7.7			
	280-283	54.7	0	61.2	38.8					7.0			
	290-293	45.3	0	29.9	70.1					7.0			
29	0-2	70.5								14.1			
30	0-2	26.3	99.7	0.3	0	2.0	0.2	-1.93	12.2				
31	0-2	80.7	2.0	68.6	29.4	7.3	2.2	+0.74	2.65	15.6	1.11		93.2
	2-4	80.1											
	4-6	80.3								15.5			
	6-8	80.0											
	8-10	80.5											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
28	90-93							17.5				
	100-103							16.9				
	110-113							18.2				
	120-123							16.9				
	130-133							17.5				
	140-143							17.2				
	150-153							16.8				
	160-163							16.8				
	170-173							16.8				
	180-183							15.3				
	190-193							14.7				
	200-203							16.7				
	210-213							21.2				
	220-223							14.8				
	230-233							14.9				
	240-243							14.4				
	250-253							15.0				
	260-263							14.7				
	270-273							15.1				
	280-283							15.7				
	290-293							14.7				
29	0-2							18.8				
30	0-2	49.6	41.0	4.8			4.4		0			
31	0-2	20.1	3.7	31.0	29.2	6.8	15.2	15.8	30.0	20.5	44.1	35.2
	2-4											
	4-6							16.1				
	6-8											
	8-10											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
28	90-93	8.0	-140								
	100-103	8.0	- 50								
	110-113	8.0	-190								
	120-123	7.8	-140								
	130-133	7.8	-170								
	140-143	7.9	- 60								
	150-153	7.9	- 90								
	160-163	8.0	-160								
	170-173	7.8	- 60								
	180-183	7.9	-120								
	190-193	7.9	-210								
	200-203	8.0	-160								
	210-213	8.1	-170								
	220-223	8.2	-120								
	230-233	8.0	-100								
	240-243	8.2	-120								
	250-253	8.2	-100								
	260-263	8.2	-150								
	270-273	8.2	-210								
	280-283	8.0	-150								
	290-293	8.4	- 20								
29	0-2	7.9	-200								
30	0-2	7.0	-240								
31	0-2	7.3	+110				1.12	0.54	11.26	2.74	2.08
	2-4	7.4	+ 60								
	4-6	7.4	+ 60								
	6-8	7.4	- 10								
	8-10	7.3	0								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
28	90-93											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	190-193											
	200-203											
	210-213											
	220-223											
	230-233											
	240-243											
	250-253											
	260-263											
	270-273											
	280-283											
	290-293											
29	0-2											
30	0-2											
31	0-2	0.057	0.092	63		25						
	2-4											
	4-6											
	6-8											
	8-10											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
31	10-12	84.3								18.0			
	12-14	79.8											
	14-16	79.1											
	16-18	76.5											
	18-20	74.1											
	20-23	74.6								13.5			
	23-26	74.2											
	26-30	74.1								12.8			
	30-33	71.0								10.8			
	33-36	73.0											
	36-40	71.5								10.9			
	40-43	69.6								11.4			
	43-46	62.6								8.1			
32	0-2	76.4	0.6	73.0	26.4	7.2	2.3	+0.75	2.94	17.0	1.13		91.6
	2-4	75.1											
	4-6	76.2								15.7			
	6-8	74.2											
	8-10	76.1											
	10-12	77.3								17.5			
	12-14	75.2											
	14-16	71.9								17.0			
	16-18	72.8											
	18-20	70.6								18.0			
	20-23	66.0											
	23-26	69.0											
	26-30	72.0								16.1			
	30-33	73.0								12.8			
	33-36	70.1											
	36-40	71.0								12.1			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
31	10-12							15.0				
	12-14											
	14-16											
	16-18											
	18-20											
	20-23							20.3				
	23-26											
	26-30							17.0				
	30-33							16.0				
	33-36											
	36-40							15.4				
	40-43							14.4				
	43-46							14.4				
32	0-2	11.9	7.3	36.1	35.3	6.0	17.1	16.1	27.3	34.1	17.1	7.3
	2-4											
	4-6							16.7				
	6-8											
	8-10											
	10-12							15.5				
	12-14											
	14-16							12.2				
	16-18											
	18-20							17.0				
	20-23											
	23-26											
	26-30							21.0				
	30-33							25.5				
	33-36											
	36-40							19.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
31	10-12	7.3	- 20								
	12-14	7.4	- 50								
	14-16	7.4	- 80								
	16-18	7.4	-100								
	18-20	7.4	- 50								
	20-23	7.4	- 60								
	23-26	7.4	- 80								
	26-30	7.4	-100								
	30-33	7.6	- 40								
	33-36	7.5	- 30								
	36-40	7.6	- 20								
	40-43	7.8	- 20								
	43-46										
32	0-2	7.4	+ 20				1.00	0.48	13.14	2.70	1.89
	2-4	7.4	+ 60								
	4-6	7.3	+ 60								
	6-8	7.3	+ 80								
	8-10	7.4	+ 60								
	10-12	7.4	+ 50								
	12-14										
	14-16	7.4	+ 40								
	16-18										
	18-20										
	20-23	7.4	+ 20								
	23-26										
	26-30										
	30-33	7.4	+ 50								
	33-36										
	36-40										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
31	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
32	0-2	0.051	0.070	54		22						
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
32	40-43	68.6								11.0			
	43-46	69.8											
	46-49	60.2								14.0			
	49-53	21.4								1.3			
	53-56	18.5											
	56-60	21.0								1.9			
	60-63	19.9								2.3			
	63-66	19.4											
	66-70	25.1								4.1			
	70-73	24.4								3.0			
33	0-2	73.8	1.6	81.2	17.2	6.6	1.2	-0.74	2.98	14.5	1.16		90.2
	2-4	74.0											
	4-6	75.9								16.5			
	6-8	75.1											
	8-10	73.0											
	10-12	72.2								13.2			
	12-14	71.5											
	14-16	71.2								14.1			
	16-18	70.9											
	18-20	71.9								11.8			
	20-22	72.9								12.9			
	22-25	22.0								1.9			
34	0-2	50.9								6.3	1.40		89.5
	2-4	59.8											
	4-6	58.1								9.3			
	6-8	56.8											
	8-10	60.9								10.2			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
32	40-43							16.0				
	43-46											
	46-49							18.1				
	49-53							4.1				
	53-56											
	56-60							6.0				
	60-63							5.7				
	63-66											
	66-70							6.2				
	70-73							7.1				
33	0-2	23.0	4.7	21.0	20.5	6.8	15.4	17.5	35.7	38.0	31.0	31.0
	2-4											
	4-6							17.2				
	6-8											
	8-10											
	10-12							18.1				
	12-14											
	14-16							19.2				
	16-18											
	18-20							17.9				
	20-22							17.9				
	22-25							20.1				
34	0-2	37.5	6.9	12.3	10.8	6.8	28.6	19.2	17.0	42.1	24.0	33.9
	2-4											
	4-6							18.8				
	6-8											
	8-10							17.3				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
32	40-43	7.6	+ 30								
	43-46										
	46-49										
	49-53	7.8	+ 10								
	53-56										
	56-60										
	60-63	7.8	+ 50								
	63-66										
	66-70										
	70-73	7.9	+ 30								
33	0-2	7.2	+ 80								
	2-4	7.3	+ 10								
	4-6	7.4	- 10								
	6-8	7.5	+ 20								
	8-10	7.6	+ 20								
	10-12	7.4	+ 20								
	12-14	7.5	+ 10								
	14-16										
	16-18	7.5	+ 10								
	18-20										
	20-22	7.4	+ 10								
	22-25										
34	0-2	7.6	+ 10				0.96	0.68	11.48	4.48	1.24
	2-4	7.6	-110								
	4-6	7.7	- 90								
	6-8	7.7	- 90								
	8-10										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
32	40-43											
	43-46											
	46-49											
	49-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
33	0-2											
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-22											
	22-25											
34	0-2	0.039	0.059	31	<1	13	<20	70				
	2-4											
	4-6											
	6-8											
	8-10											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
34	10-12	61.1								14.1			
	12-14	60.5								12.4			
	14-16	59.8								15.3			
	16-18	58.2								12.1			
	18-20	58.1								7.3			
	20-23	56.8								4.2			
	23-26	57.9								4.1			
	26-30	49.8								2.9			
	30-33	33.5								3.1			
	33-36	38.7								4.7			
	36-40	39.4								4.5			
	40-43	46.8								6.0			
	43-46	41.9								4.2			
	46-50	40.6								2.5			
	50-53	38.1								3.0			
	53-56	39.2								3.2			
	56-60	40.6								1.5			
	60-63	29.6								1.5			
	63-66	24.6								1.5			
	66-70	29.4								2.0			
	70-73	35.0								2.5			
	73-76	36.8								2.1			
	76-80	34.0								2.3			
	80-83	35.4								2.1			
	83-86	39.4								2.0			
	86-90	38.6								3.6			
	90-93	38.0								3.5			
	93-96	38.1								1.7			
	96-100	33.8											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
34	10-12							15.4				
	12-14							16.2				
	14-16							18.1				
	16-18							14.2				
	18-20							17.9				
	20-23							10.0				
	23-26							13.0				
	26-30							13.4				
	30-33							14.1				
	33-36							14.5				
	36-40							17.4				
	40-43							15.1				
	43-46							12.5				
	46-50							13.1				
	50-53							11.0				
	53-56							12.0				
	56-60							10.0				
	60-63							10.1				
	63-66							9.8				
	66-70							10.3				
	70-73							10.0				
	73-76							11.5				
	76-80							11.4				
	80-83							10.1				
	83-86							12.9				
	86-90							19.9				
	90-93							9.2				
	93-96							15.8				
	96-100											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
34	10-12	7.9	- 80								
	12-14										
	14-16	7.8	- 60								
	16-18										
	18-20										
	20-23	7.7	- 20								
	23-26										
	26-30										
	30-33	7.7	- 30								
	33-36										
	36-40										
	40-43	7.7	- 40								
	43-46										
	46-50										
	50-53	7.7	- 30								
	53-56										
	56-60										
	60-63	7.8	- 40								
	63-66										
	66-70										
	70-73	7.9	+ 10								
	73-76										
	76-80										
	80-83	8.0	- 10								
	83-86										
	86-90										
	90-93	7.9	+ 50								
	93-96										
	96-100	8.1	+ 70								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHORUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
34	10-12							60				
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	93-96											
	96-100											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
35	0-2	41.1								7.3	1.52		68
	2-4												
	4-6	33.5								2.7	1.65		61
	6-8												
	8-10												
	10-12	28.6								2.8	1.76		54
	12-14	27.2											
	14-16	26.3								3.0	1.81		51
	16-18	26.1											
	18-20	25.2											
	20-23	24.4								3.1	1.84		49
	23-26	24.1											
	26-30	24.0											
	30-33	23.0								2.5	1.88		47
	33-36	24.1											
	36-40	24.8								2.3	1.85		48
	40-43	25.4								2.1	1.84		49
	43-46	25.9											
	46-50	25.8											
	50-53	27.6								3.3	1.77		53
36	0-2	58.5											
	2-4	56.9											
	4-6	56.8											
	10-12	58.2											
37	0-2	80.2	0.6	70.5	28.9	6.7	1.9	+0.40	1.85	16.3			
	2-4	79.8								15.5			
	4-6	79.7								15.8			
	6-8	78.5								14.8			
	8-10	78.4								15.0			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
35	0-2	39.4	24.0	5.9	5.5	11.0	10.0	9.7	20.5			
	2-4											
	4-6							9.3				
	6-8											
	8-10											
	10-12							9.3				
	12-14											
	14-16							5.6				
	16-18											
	18-20											
	20-23							9.8				
	23-26											
	26-30											
	30-33							9.9				
	33-36											
	36-40							10.6				
	40-43							16.7				
	43-46											
	46-50											
	50-53							10.4				
36	0-2	34.8	4.8	15.0			24.8		20.3			
	2-4											
	4-6											
	10-12											
37	0-2	16.3	9.2	29.8	28.3	6.5	13.7	17.0	16.3	12.8	48.0	39.2
	2-4							15.3				
	4-6							16.0				
	6-8							17.1				
	8-10							16.8				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
35	0-2	7.9	-120								
	2-4	7.9	-210								
	4-6	7.8	-210								
	6-8	7.7	-200								
	8-10	7.7	-120								
	10-12	7.6	-100								
	12-14										
	14-16	7.6	-140								
	16-18										
	18-20										
	20-23	7.6	-190								
	23-26										
	26-30										
	30-33	7.8	-100								
	33-36										
	36-40										
	40-43	7.7	- 80								
	43-46										
	46-50										
	50-53	7.7	- 70								
36	0-2	7.5	+110				1.12	0.53	11.64	2.63	2.00
	2-4	7.6	+ 90								
	4-6	7.6	+ 80								
	10-12	7.5	+ 80								
37	0-2	7.5	+140								
	2-4	7.6	+140								
	4-6	7.5	+140								
	6-8	7.6	+100								
	8-10										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
35	0-2											
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
36	0-2							70				
	2-4											
	4-6											
	10-12											
37	0-2	0.053	0.120	59		26						
	2-4											
	4-6											
	6-8											
	8-10											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
37	10-12	78.6								14.7			
	12-14	78.9								14.3			
	14-16	79.2								14.8			
	16-18	78.6								14.7			
	18-20	78.5								15.1			
	20-23	78.4								16.2			
	23-26	79.2								16.3			
	26-30	78.5								17.8			
	30-33	78.1								16.3			
	33-36	77.6								16.3			
	36-40	77.5								16.4			
	40-43	77.1								16.3			
	43-46	78.1								15.8			
	46-50	76.9								16.2			
	50-53	75.0								14.6			
	53-56	75.8								13.4			
	56-60	74.0								12.1			
	60-63	70.4								12.0			
	63-66	72.8								13.6			
	66-70	73.9								15.5			
	70-73	70.7								15.9			
	73-76	70.8								11.5			
	76-80	69.4								12.8			
	80-83	67.3								11.0			
	83-86	63.1								11.6			
	100-103	67.0								11.0			
	110-113	66.9								10.4			
	120-123	68.2								9.9			
	130-133	63.0								12.0			
	140-143	66.5								9.4			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
37	10-12							16.7				
	12-14							16.8				
	14-16							16.9				
	16-18							17.1				
	18-20							17.1				
	20-23							15.7				
	23-26							15.9				
	26-30							15.7				
	30-33							16.1				
	33-36							17.2				
	36-40							16.2				
	40-43							16.0				
	43-46							17.2				
	46-50							17.0				
	50-53							17.3				
	53-56							17.3				
	56-60							15.7				
	60-63							15.8				
	63-66							15.5				
	66-70							15.9				
	70-73							15.8				
	73-76							15.5				
	76-80							14.5				
	80-83							15.1				
	83-86							14.9				
	100-103							15.4				
	110-113							15.1				
	120-123							15.6				
	130-133							15.8				
	140-143							14.7				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
37	10-12	7.6	+100								
	12-14										
	14-16										
	16-18										
	18-20										
	20-23	7.6	+ 90								
	23-26										
	26-30										
	30-33	7.6	+ 80								
	33-36										
	36-40										
	40-43										
	43-46	7.6	+ 90								
	46-50										
	50-53										
	53-56	7.6	+100								
	56-60										
	60-63										
	63-66	7.6	+120								
	66-70										
	70-73										
	73-76	7.7	+100								
	76-80										
	80-83										
	83-86	7.7	+ 90								
	100-103										
	110-113	7.7	+180								
	120-123	7.7	+210								
	130-133	7.7	+200								
	140-143	7.8	+180								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
37	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
37	150-153	65.5								9.7			
	160-163	63.6								8.2			
	170-173	66.5								9.2			
	180-183	60.7								5.5			
	190-193	63.8								7.9			
	200-203	48.8								4.9			
	210-213	60.5								6.9			
	220-223	54.7								5.8			
	230-233	59.7								8.5			
	240-243	50.8								4.6			
	250-253	51.5								5.1			
	260-263	50.5								5.4			
	270-273	51.8								5.7			
	276-279	39.3								4.6			
	280-283	42.6								9.3			
	289-291	43.3								5.9			
38	0-2	77.4	4.4	70.0	25.6	7.2	2.1	+0.26	2.65	13.5			
	2-4	79.2								15.7			
	4-6	80.4								18.1			
	6-8	79.4											
	8-10	78.6								15.6			
	10-12	79.6											
	12-14	79.2	0.6	64.8	34.6					15.2			
	14-16	78.1											
	16-18	79.2								15.6			
	18-20	78.1								15.1			
	20-23	78.2								15.2			
	23-26	77.5								15.1			
	26-30	77.6											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
37	150-153							14.9				
	160-163							14.4				
	170-173							13.2				
	180-183							16.0				
	190-193							14.3				
	200-203							13.4				
	210-213							13.9				
	220-223							13.5				
	230-233							14.1				
	240-243							15.0				
	250-253							13.7				
	260-263							13.2				
	270-273							13.0				
	276-279							12.1				
	280-283							7.4				
	289-291							12.7				
38	0-2	20.5	5.5	32.9	32.9	6.5	12.7	18.1	28.2	6.0	53.3	40.0
	2-4							17.1				
	4-6							15.2				
	6-8											
	8-10							17.3				
	10-12											
	12-14							18.1				
	14-16	19.1	4.1	28.7			15.2		32.9			
	16-18							19.2				
	18-20							18.1				
	20-23							17.2				
	23-26							16.9				
	26-30	15.9	2.0	20.1			14.9		47.1			

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
37	150-153	7.8	+150								
	160-163	7.8	+150								
	170-173	7.8	+180								
	180-183	7.8	+180								
	190-193	7.8	+120								
	200-203	7.8	+150								
	210-213	7.8	+150								
	220-223	7.8	+120								
	230-233	7.8	+100								
	240-243	7.8	+120								
	250-253	7.8	+ 50								
	260-263	7.8	+ 30								
	270-273	7.9	+ 20								
	276-279	7.9	+ 50								
	280-283	7.9	+ 40								
	289-291	8.0	+ 20								
38	0-2	7.5	- 85				1.09	0.48	12.14	2.59	1.92
	2-4	7.6	-105								
	4-6	7.4	- 90								
	6-8	7.4	-100								
	8-10	7.5	- 70								
	10-12	7.6	- 60								
	12-14										
	14-16	7.6	- 20								
	16-18										
	18-20										
	20-23	7.7	+ 40								
	23-26										
	26-30	7.6	+ 10								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
37	150-153											
	160-163											
	170-173											
	180-183											
	190-193											
	200-203											
	210-213											
	220-223											
	230-233											
	240-243											
	250-253											
	260-263											
	270-273											
	276-279											
	280-283											
	289-291											
38	0-2	0.055	0.087	43	< 1	22	< 20					
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23											
	23-26											
	26-30											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
38	30-33	77.6								15.0			
	33-36	77.1								15.1			
	36-40	77.9											
	40-43	76.6								14.3			
	43-46	76.4								15.0			
	46-50	77.1											
	50-53	76.1	2.8	46.9	50.3					14.1			
	53-56	78.2								14.8			
	56-60	76.0								14.0			
	60-63	73.9								12.5			
	63-66	74.1								14.1			
	66-70	72.9								12.8			
	70-73	71.6								15.5			
	73-76	70.8								12.8			
	76-80	69.4								11.2			
	80-83	69.9								10.4			
	83-86	69.8								10.8			
	86-90	70.2								10.9			
	90-93	70.1	1.0	50.0	49.0					10.9			
	100-103	68.7								9.9			
	110-113	69.9								10.2			
	120-123	68.9								9.5			
	130-133	69.4											
	140-143	67.1								10.5			
	150-153	65.8	0.6	58.9	40.5					9.7			
	160-163	63.7								9.2			
	170-173	65.1								8.5			
	180-183	62.1								16.1			
	190-193	65.1								7.4			
	200-203	64.4	1.8	59.2	39.0					7.8			
	210-213	61.8								6.9			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
38	30-33							17.1				
	33-36							16.9				
	36-40											
	40-43							16.6				
	43-46							16.9				
	46-50											
	50-53	18.2	7.9	27.6			14.2	16.4	32.5			
	53-56							15.8				
	56-60							16.0				
	60-63							16.9				
	63-66							17.2				
	66-70							18.1				
	70-73							11.2				
	73-76							11.9				
	76-80	19.9	4.9	24.2			12.9	15.8	38.1			
	80-83							16.6				
	83-86							15.5				
	86-90							15.6				
	90-93							15.6				
	100-103	18.1	7.4	24.5			13.8	16.5	36.2			
	110-113							16.5				
	120-123							17.4				
	130-133											
	140-143							16.8				
	150-153	20.9	8.2	25.1			19.2	17.4	26.6			
	160-163							17.2				
	170-173	22.8	5.1	20.8			15.6	17.5	35.7			
	180-183							23.1				
	190-193							14.3				
	200-203	21.9	7.6	24.0			18.1	13.7	28.5			
	210-213							13.9				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
38	30-33	7.6	- 10								
	33-36										
	36-40	7.6	- 20								
	40-43	7.6	- 20								
	43-46										
	46-50	7.6	- 20								
	50-53	7.7	- 10								
	53-56										
	56-60										
	60-63	7.7	+ 20								
	63-66										
	66-70										
	70-73	7.7	- 10								
	73-76										
	76-80										
	80-83	7.7	- 10								
	83-86										
	86-90										
	90-93	7.6	- 20								
	100-103	7.9	+150								
	110-113	7.7	+ 40								
	120-123	7.7	+ 20								
	130-133	7.7	+ 20								
	140-143	7.8	+ 50								
	150-153	7.7	+ 20								
	160-163	7.7	+ 40								
	170-173	7.7	+ 90								
	180-183	7.7	+100								
	190-193	7.7	+ 95								
	200-203	7.6	+120								
	210-213	7.8	+140								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
38	30-33											
	33-36											
	36-40											
	40-43											
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73											
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	90-93											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
	190-193											
	200-203											
	210-213											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
38	220-223	58.1								6.4			
	230-233	63.6								7.6			
	240-243	61.4								7.9			
	250-253	62.2								8.2			
	260-263	59.8	0.9	60.2	38.2					3.6			
	270-273	59.4								7.1			
	280-282	54.7								6.2			
	282-285	33.7	0.4	39.8	59.8					6.0			
39	0-2	73.8	1.0	79.5	19.5	6.9	1.9	-0.16	2.91	10.5			
	2-4	76.4								10.5			
	4-6	73.8								12.6			
	6-8	72.9								6.5			
	8-10	72.7								10.4			
	10-12	74.0								11.1			
	12-14	74.5								13.6			
	14-16	73.1								13.3			
	16-18	70.4								11.6			
	18-20	64.8								10.9			
	20-23	71.3	10.7	69.1	20.2					10.7			
	23-26	72.7								11.8			
	26-30	69.3								9.6			
	30-33	72.7								11.2			
	33-36	72.9								11.7			
	36-40	72.2								9.2			
	40-43	76.1	0.5	63.0	36.5					12.3			
	43-46	74.8								12.8			
	46-50	68.1								9.0			
	50-53	67.0								8.8			
	53-56	67.0								8.8			
	56-60	70.9								10.6			
	60-63	65.6								9.5			
	63-66	70.6	5.1	57.8	37.1					11.0			
	66-70	62.6								7.2			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
38	220-223	24.6	7.0	18.0			20.9	14.9	29.5			
	230-233							14.5				
	240-243							14.5				
	250-253	25.9	5.4	12.8			15.8	14.4	40.1			
	260-263							14.1				
	270-273	24.1	8.3	15.2			16.9	13.6	38.5			
	280-282							15.1				
	282-285	19.8	3.9	16.8			14.2	14.5	45.3			
39	0-2	25.8	4.6	17.3	16.6	6.0	24.1	17.7	27.8	41.0	30.0	29.0
	2-4							17.2				
	4-6							17.1				
	6-8							18.8				
	8-10							18.4				
	10-12							17.8				
	12-14							17.4				
	14-16							17.5				
	16-18							16.7				
	18-20							17.8				
	20-23							17.4				
	23-26							18.8				
	26-30							19.1				
	30-33							18.1				
	33-36							17.3				
	36-40							18.2				
	40-43							20.2				
	43-46							15.5				
	46-50							18.1				
	50-53							16.8				
	53-56							19.7				
	56-60							16.2				
	60-63							14.9				
	63-66							15.5				
	66-70							12.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBCN (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
38	220-223	7.9	+ 95								
	230-233	7.9	+ 80								
	240-243	8.0	+ 10								
	250-253	7.9	+ 30								
	260-263	7.8	+ 40								
	270-273	7.9	+ 40								
	280-282	8.0	+ 40								
	282-285	8.1	+ 10								
39	0-2	7.6	-100				1.20	0.65	12.03	3.91	1.75
	2-4	7.6	-150								
	4-6	7.5	-230				1.15	0.63	11.04	3.61	1.77
	6-8	7.5	-200								
	8-10	7.7	-290								
	10-12	7.7	-290								
	12-14	7.6	-240								
	14-16	7.7	-210								
	16-18	7.7	-200								
	18-20	7.6	-220								
	20-23	7.7	-200				1.18	0.63	11.64	3.35	1.82
	23-26	7.7	-175								
	26-30	7.7	-230								
	30-33	7.7	-210								
	33-36	7.7	-260								
	36-40	7.7	-260								
	40-43	7.9	-270				1.15	0.57	11.86	2.68	2.03
	43-46	7.8	-250								
	46-50	7.8	-270								
	50-53	7.8	-200								
	53-56	7.9	-250								
	56-60	7.8	-230								
	60-63	7.9	-280								
	63-66	8.1	-140								
	66-70	8.2	-220								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHORCUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
38	220-223											
	230-233											
	240-243											
	250-253											
	260-263											
	270-273											
	280-282											
	282-285											
39	0-2	0.058	0.11	44		19						
	2-4											
	4-6	0.053	0.10	50		20						
	6-8											
	8-10											
	10-12											
	12-14											
	14-16											
	16-18											
	18-20											
	20-23	0.051	0.10	51		23						
	23-26											
	26-30											
	30-33											
	33-36											
	36-40											
	40-43	0.060	0.11	60		29						
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
39	70-73	47.4	51.6	23.5	24.9					4.8			
	73-76	39.1								3.4			
	76-80	42.6								3.8			
	80-83	37.3								4.2			
	83-86	37.8								2.2			
	86-90	36.6								3.3			
	100-105	37.9	53.7	28.7	17.5					2.9			
	105-110	37.1								2.7			
	110-115	44.2								3.7			
	115-120	53.6								6.1			
	120-125	57.9								7.0			
	125-130	54.5								6.7			
	130-135	45.4								4.0			
	135-140	44.5								4.4			
	140-146	50.9	19.9	43.1	37.0					4.9			
	146-149	40.3								3.8			
	149-155	39.2	28.8	44.9	26.3					5.2			
	155-160	40.1	16.0	48.8	35.1					6.5			
40	0-2	51.1	10.4	67.9	21.7	6.9	2.4	-0.20	3.01	7.4			
	2-4	51.2											
	4-6	54.7											
	6-8	52.1								8.0			
	8-10	51.2											
	10-12	54.7											
	12-14	55.2								6.2			
	14-16	60.4											
	16-18	61.0											
	18-20	59.8											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
39	70-73							10.0				
	73-76							9.2				
	76-80							10.3				
	80-83							10.0				
	83-86							10.4				
	86-90							9.9				
	100-105							11.9				
	105-110							11.7				
	110-115							12.5				
	115-120							14.3				
	120-125							14.7				
	125-130							13.8				
	130-135							15.4				
	135-140							11.6				
	140-146							14.2				
	146-149							13.3				
	149-155							12.9				
	155-160							9.9				
40	0-2	33.7	13.2	4.4			19.2	8.9	29.3	48.2	24.1	27.5
	2-4											
	4-6							8.9				
	6-8											
	8-10											
	10-12							19.8				
	12-14											
	14-16											
	16-18											
	18-20											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
39	70-73	8.2	-200				1.21	0.95	7.31	1.98	1.36
	73-76	8.1	-210								
	76-80	8.1	-210								
	80-83	8.2	-220								
	83-86	8.2	-200								
	86-90	8.1	-170								
	100-105	8.0	-160				1.23	1.04	5.49	1.51	0.91
	105-110	8.0	- 80								
	110-115	8.0	-120								
	115-120	8.0	-110								
	120-125	7.9	-130								
	125-130	7.9	-210								
	130-135	8.0	-140				1.19	0.73	8.56	2.40	2.01
	135-140	7.9	-100								
	140-146	8.0	-180								
	146-149	8.0	-150								
	149-155	7.9	-120				1.21	0.74	8.02	2.50	1.67
	155-160	7.9	- 80				2.42	0.79	7.55	2.70	1.80
40	0-2	7.0	- 90								
	2-4	7.1	-140								
	4-6	7.1	-140								
	6-8	6.9	-130								
	8-10	7.1	-140								
	10-12	7.2	-150								
	12-14										
	14-16										
	16-18	7.2	- 80								
	18-20										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
39	70-73	0.039	0.079	37		16						
	73-76											
	76-80											
	80-83											
	83-86											
	86-90											
	100-105	0.033	0.065	23		11						
	105-110											
	110-115											
	115-120											
	120-125											
	125-130											
	130-135	0.066	0.074	73		26						
	135-140											
	140-146											
	146-149											
	149-155	0.060	0.074	58		26						
	155-160	0.059	0.083	49		27						
40	0-2			85		30	17	170				
	2-4							80				
	4-6			65		25	13	80				
	6-8											
	8-10											
	10-12			50		28						
	12-14							60				
	14-16											
	16-18											
	18-20											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
40	20-23	59.0	12.0	58.0	30.0					7.4			
	23-26	59.9											
	26-30	62.0											
	30-33	65.0								10.2			
	33-36	66.0											
	36-40	61.0											
	40-43	59.7								8.2			
	43-46	59.8											
	46-50	50.8											
	50-53	47.6	4.2	51.0	44.8					5.5			
	53-56	61.0											
	56-60	60.8											
	60-63	56.9								7.6			
	63-66	59.2											
	66-70	54.1											
	70-73	54.0								5.9			
	73-76	55.2											
	76-80	50.2											
	80-83	48.7											
	100-103	41.3											
	110-113	56.3	7.9	49.8	42.3								
	119-122	35.4											
	123-126	30.9	0.9	41.9	57.7								
41	0-2		100	0	0	2.0	0.6	-0.12	6.2	0.5			
	20-23		98	2	0	2.6							
42	0-2	78.0	7.8	76.2	16.0	6.1	1.9	+1.51	2.7	15.8			
	4-6	78.8											
	10-12	78.1											
	20-23	78.5											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
40	20-23							18.2				
	23-26											
	26-30											
	30-33							16.3				
	33-36											
	36-40											
	40-43							17.0				
	43-46											
	46-50											
	50-53							16.4				
	53-56											
	56-60											
	60-63							15.8				
	63-66											
	66-70											
	70-73							17.4				
	73-76											
	76-80											
	80-83											
	100-103											
	110-113											
	119-122											
	123-126											
41	0-2	72.1	14.2	5.2			7.1	5.1	0			
	20-23											
42	0-2	23.4	3.7	33.8	29.3	3.5	14.4	18.9	21.5			
	4-6											
	10-12											
	20-23											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
40	20-23	7.4	- 20								
	23-26										
	26-30										
	30-33	7.4	- 20								
	33-36										
	36-40										
	40-43	7.3	0								
	43-46										
	46-50										
	50-53	7.4	+ 20								
	53-56										
	56-60										
	60-63	7.3	- 20								
	63-66										
	66-70										
	70-73	7.4	- 10								
	73-76										
	76-80										
	80-83	7.4	+ 10								
	100-103	7.7	+ 60								
	110-113	7.6	- 10								
	119-122	7.7	+ 20								
	123-126	7.7	- 20								
41	0-2										
	20-23										
42	0-2										
	4-6										
	10-12										
	20-23										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
40	20-23			55		20	22	60				
	23-26											
	26-30											
	30-33											
	33-36							40				
	36-40											
	40-43			35		25						
	43-46											
	46-50											
	50-53											
	53-56											
	56-60											
	60-63											
	63-66											
	66-70											
	70-73			29		20						
	73-76											
	76-80											
	80-83											
	100-103											
	110-113											
	119-122											
	123-126											
41	0-2											
	20-23											
42	0-2											
	4-6											
	10-12											
	20-23											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
42	30-33	75.3											
	40-43	75.1											
	50-53	70.1											
	60-63	72.0											
	70-73	68.1											
	76-80	68.4											
	100-103	68.7											
	110-113	58.6											
	120-123	63.3											
	130-133	59.3											
	140-143	58.7											
	150-153	58.6											
	160-163	58.8											
	170-173	52.1											
	180-183	56.1											
43	0-2	15.1	98.1	1.9	0	1.9	0.6	-0.14	3.81	0.7	1.88		46.6
	10-12	15.9	99.8	0.2	0	2.2	0.5	-0.10	5.78				
	20-23	16.2	99.6	0.4	0	2.1	0.4						
	30-33	17.1	99.6	0.4	0	2.2	0.5						
	40-43	16.6	99.1	0.9	0	2.3	0.5						
	50-53	17.5	98.9	1.1	0	2.4	0.5	-0.75	4.21				
	60-63	15.4	98.7	1.3	0	1.9	0.9						
	70-73	15.3	97.9	2.1	0	2.3	1.1	-0.24	3.89				
44	0-2	61.6	8.0	69.2	22.8	6.4	2.0	+0.80	2.61	11.3			
	10-12	72.1											
	20-23	75.1											
	30-33	71.2											
	40-43	33.6											
	50-53	29.7											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
42	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	76-80											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
43	0-2	76.0	15.4	4.2			5.6	4.2	0			
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
44	0-2	34.8	3.6	15.5	13.9	6.8	21.4	8.6	24.5	36.1	35.2	28.7
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
42	30-33										
	40-43										
	50-53										
	60-63										
	70-73										
	76-80										
	100-103										
	110-113										
	120-123										
	130-133										
	140-143										
	150-153										
	160-163										
	170-173										
	180-183										
43	0-2										
	10-12										
	20-23										
	30-33										
	40-43										
	50-53										
	60-63										
	70-73										
44	0-2										
	10-12										
	20-23										
	30-33										
	40-43										
	50-53										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
42	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
	76-80											
	100-103											
	110-113											
	120-123											
	130-133											
	140-143											
	150-153											
	160-163											
	170-173											
	180-183											
43	0-2											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											
	60-63											
	70-73											
44	0-2											
	10-12											
	20-23											
	30-33											
	40-43											
	50-53											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
45	0-2	45.9	5.5	8.0			21.9	20.5	18.5			
	8-10											
	18-20											
	23-26											
	33-36											
47	0-2	35.4	13.8	7.5	7.3	10.5	30.0	24.8	12.5			
	4-6											
	10-12											
	18-20											
	26-30											
	30-33											
	40-43											
	50-53											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
45	0-2	40.8	6.0	71.6	22.4	6.2	2.3	+0.17	2.8	2.1			
	8-10	29.7											
	18-20	31.4											
	23-26	30.6											
	33-36	29.6											
47	0-2	52.4	12.2	78.0	9.8	6.1	1.9	+0.44	2.4	2.9			
	4-6	41.8											
	10-12	56.7											
	18-20	48.8											
	26-30	31.5											
	30-33	32.9											
	40-43	36.5											
	50-53	37.0											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
45	0-2	7.8									
	8-10										
	18-20										
	23-26										
	33-36										
47	0-2										
	4-6										
	10-12										
	18-20										
	26-30										
	30-33										
	40-43										
	50-53										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
45	0-2											
	8-10											
	18-20											
	23-26											
	33-36											
47	0-2											
	4-6											
	10-12											
	18-20											
	26-30											
	30-33											
	40-43											
	50-53											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
D-1	0-2	70.9	0.5	69.3	30.2	7.1	2.5	+0.64	1.98	14.5	1.15	1.21	8.8
	2-4	70.2								13.8			
	4-6	70.9								15.1			
	6-8	70.3											
	8-10	71.5											
	10-12	71.5	1.0	40.6	58.3					14.9	1.17	1.24	
	12-14	71.0								15.1			
	14-16	70.5											
	16-18	71.7											
	18-20	70.5								14.0			
	20-23	70.8								14.37	1.18	1.21	
	23-26	69.8	0.8	50.0	49.2								
	26-30	69.3								14.2			
	30-33	67.9								12.6	1.21	1.23	
	33-36	68.0	1.1	48.3	50.6								
	36-40	69.1								13.6			
	40-43	69.1	0.8	42.9	56.3					14.5			
	43-46	68.2											
	46-50	67.8								13.3			
	50-53	66.7	1.5	47.8	50.7					11.9			
	53-56	66.3											
	56-60	62.0								11.2			
	60-63	63.3	1.9	49.1	49.0					11.6			
	63-66	62.3											
	66-70	61.5								10.4			
	70-73	62.5	0.6	51.6	47.8					10.8			
	73-76	62.5											
	76-80	63.3								11.2			
	80-83	64.2	0.2	46.8	51.0					11.8			
	83-86	62.1											
	86-90	61.6								19.2			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-1	0-2	20.0	4.1	41.1			18.7	18.1	22.1	15.0	50.0	35.0
	2-4							19.6				
	4-6							18.7				
	6-8	16.6	1.1	39.0	36.6	5.8	19.2		23.8	15.0	50.0	35.0
	8-10											
	10-12	13.4	4.1	37.2			7.8	18.6	37.2			
	12-14							18.2				
	14-16											
	16-18											
	18-20							19.2				
	20-23	16.6	3.0	35.5	31.2	6.5	12.0	18.2	32.6	11.1	55.0	33.0
	23-26											
	26-30							17.5				
	30-33							19.0				
	33-36	17.4	4.7	40.3			14.3		22.9			
	36-40							18.4				
	40-43	16.4	5.4	37.2			13.3	17.2	27.2	21.7	34.7	43.5
	43-46											
	46-50							17.9				
	50-53	18.6	4.7	38.7	37.1	6.8	18.6	18.4	23.7			
	53-56											
	56-60							16.5				
	60-63	19.3	6.4	26.4	24.9	8.0	13.4	15.8	34.1	20.0	40.0	40.0
	63-66											
	66-70							16.7				
	70-73	17.4	3.9	33.2			14.6	17.2	30.6			
	73-76											
	76-80							16.4				
	80-83	22.0	5.5	27.8	25.3	6.8	11.5	16.9	33.0	50.0	33.3	16.6
	83-86											
	86-90							16.2				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-1	0-2	7.9	-200				1.02	0.39	15.20	2.69	1.92
	2-4	8.1	-257								
	4-6	8.1	-253				0.86	0.45	12.16	2.14	1.48
	6-8	8.2	-257								
	8-10	8.2	-237								
	10-12	8.2	-200				0.95	0.45	12.49	2.14	1.67
	12-14			11.6	5.4	6.2					
	14-16	8.2	-140								
	16-18										
	18-20	8.4	-190								
	20-23	8.2	-210	11.4	5.4	6.0	1.06	0.41	15.14	2.59	2.02
	23-26										
	26-30	8.4	-160								
	30-33	8.3	-140	10.8	5.3	5.5	1.10	0.40	13.48	2.80	2.00
	33-36										
	36-40	8.4	-120								
	40-43	8.5	-140				0.98	0.41	9.25	2.54	1.74
	43-46										
	46-50	8.3	-200								
	50-53	8.4	-220				0.94	0.43	13.51	2.41	1.66
	53-56										
	56-60										
	60-63	8.3	-220				1.23	0.53	12.16	2.90	2.32
	63-66										
	66-70										
	70-73	8.4	-160				1.21	0.50	12.07	2.79	2.10
	73-76										
	76-80										
	80-83	8.3	-130				1.25	0.49	12.12	2.90	2.18
	83-86										
	86-90	8.2	-250								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-1	0-2	0.054	0.170	53		16		20	<30			
	2-4											
	4-6	0.048	0.096	62		32			<30			
	6-8											
	8-10											
	10-12	0.053	0.110	69		32			<30			
	12-14											
	14-16											
	16-18											
	18-20											
	20-23	0.058	0.100	57		21			<30			
	23-26											
	26-30											
	30-33	0.058	0.110	51		18			<30			
	33-36											
	36-40											
	40-43	0.053	0.061	50		22			<30			
	43-46											
	46-50											
	50-53	0.050	0.092	61		25			<30			
	53-56											
	56-60											
	60-63	0.059	0.087	62		25			<30			
	63-66											
	66-70											
	70-73	0.057	0.096	54		24			<30			
	73-76											
	76-80											
	80-83	0.058	0.096	62		28			<30			
	83-86											
	86-90											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
										10.0			
D-1	90-93	66.6	1.1	70.5	28.4					7.7			
	93-96	62.2								9.8			
	96-100	64.2								10.9			
	100-103	68.2	2.3	72.9	24.8					10.9			
	105-108	68.4								10.4	1.22	1.24	
	110-113	67.9								12.5			
	115-119	69.2	1.3	62.7	36.0					11.0			
	123-125	68.6		65.0	35.0					10.7			
	130-132	67.0	1.9	70.5	27.5					9.2			
	135-138	64.5								9.6			
	140-143	63.5	1.0	61.0	38.0					9.1			
	145-148	67.8								8.8			
	150-153	62.5								9.2			
	155-158	63.2	0.7	58.9	40.4					9.0			
	200-203	58.0	0.3	55.7	44.0					9.0			
	210-213	65.2								8.6	1.25	1.21	
	220-223	63.4								8.8			
	230-233	68.0	0.6	64.7	34.7					8.1			
	240-243	64.3								8.6			
	260-263	65.3								7.9			
	270-273									7.6			
	280-283	65.3								7.5			
	290-293	64.3	0.3	64.8	34.9					6.9			
	300-303	65.0	1.3	69.2	29.5					6.6	1.23	1.21	
	310-313	67.8								7.1			
	316-319	64.7	Tr	78.9	21.9					5.2			
	331-334	40.4	0.4	40.6	59.0					5.3			
	340-343	41.4	Tr	27.0	73.0					5.2			
	390-393	39.8	0.4	37.0	62.6					5.9			
	400-403	40.5	0.5	32.3	67.2					6.5			
	450-453	50.7											

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-1	90-93	24.6	3.9	28.0	26.1	9.5	21.2	17.3	21.9	20.0	40.0	40.0
	93-96							16.0				
	96-100	20.8	7.5	27.0	25.9	9.8	15.7	16.2	29.0			
	100-103							17.2				
	105-108	18.8	6.0	26.4	24.9	9.8	16.8	17.5	32.0	0	50.0	50.0
	110-113	20.2	5.1	30.9			13.4	17.3	30.0	15.0	45.0	40.0
	115-119	21.4	5.0	29.2			15.4	15.5	27.3	20.0	45.0	35.0
	123-125	22.9	5.2	28.8			16.5	16.9	26.2			
	130-132	22.7	5.1	28.9	23.0	9.9	16.7	17.2	26.2			
	135-138							16.3				
	140-143	23.4	7.1	20.6			22.4	15.3	25.8			
	145-148							15.1				
	150-153	24.0	4.8	18.4	18.1	9.8	16.0	15.0	36.1			
	155-158	22.9	5.8	26.2	24.7	10.3	20.4	15.1	24.3	20.0	50.0	30.0
	200-203	25.2	4.5	21.5	17.2	9.9	18.4	15.3	30.7	16.6	50.0	33.3
	210-213	26.5	7.3	21.1	19.6	9.8	20.4	13.6	24.3			
	220-223							14.9				
	230-233	26.3	5.1	14.2			14.3	14.1	39.8	10.0	60.0	30.0
	240-243	26.7	6.3	10.4	8.3	10.8	18.0	14.6	38.1			
	260-263	23.2	6.1	24.5			20.4	15.2	25.5	35.7	28.5	35.7
	270-273							19.3				
	280-283	27.4	4.2	15.1	13.5	9.2	19.9	14.7	33.1			
	290-293	26.2	7.4	11.7			18.1	14.9	36.2	18.1	50.0	31.8
	300-303	25.9	7.1	17.1	15.4	11.0	16.0	14.5	33.4			
	310-313							14.6				
	316-319							14.8				
	331-334	29.3	3.0	24.6	21.6	2.1	14.7	14.9	28.1	47.2	24.8	27.6
	340-343	25.7	7.1	21.8	18.7	3.0	10.0	13.8	34.9	52.0	25.3	22.6
	390-393	10.3	5.6	20.6			12.7	15.2	37.9	37.5	25.0	36.0
	400-403	19.2	5.4	18.6	16.3	3.9	11.4	14.0	45.2	47.0	24.4	23.5
	450-453	20.5	3.6	20.1	17.1	4.0	15.2	14.6	40.3			

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-1	90-93	8.0	-250				1.25	0.56	12.11	3.21	2.31
	93-96	8.0	-225								
	96-100	8.0	-250								
	100-103										
	105-108	8.3	-360								
	110-113	8.1	-320	8.6	4.8	3.8					
	115-119	7.9	-225				1.24	0.50	11.82	2.98	2.20
	123-125	8.1	-220				1.23	0.46	11.32	2.68	2.10
	130-132	8.0	-260								
	135-138	8.2	-290								
	140-143	8.2	-290								
	145-148	8.3	-240								
	150-153	8.2	-220								
	155-158	7.9	-280				0.95	0.34	7.45	2.06	1.66
	200-203	8.3	-230				1.23	0.53	9.66	2.70	2.45
	210-213	8.0	-260								
	220-223	7.9	-240	6.6	4.1	2.5					
	230-233	7.9	-280								
	240-243	8.0	-310				1.53	0.53	10.82	3.05	2.76
	260-263	8.1	-270								
	270-273	8.0	-290								
	280-283	8.0	-310								
	290-293	8.0	-290								
	300-303	8.3	-360				1.55	0.59	9.81	2.82	2.82
	310-313	8.2	-320	5.9	3.9	2.0					
	316-319	8.1	-300				1.47	0.59	9.23	3.03	2.82
	331-334	7.9	-200				1.46	0.45	10.28	2.51	2.91
	340-343	8.0	-200				1.49	0.51	9.58	2.38	3.10
	390-393	8.1	-170								
	400-403	8.1	-210				1.56	0.44	10.11	2.21	2.92
	450-453	8.3	-210								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-1	90-93	0.067	0.14	73		37			< 30			
	93-96											
	96-100											
	100-103											
	105-108											
	110-113											
	115-119	0.065	0.099	75		34			<30			
	123-125	0.063	0.096	73		31			<30			
	130-132											
	135-138											
	140-143											
	145-148											
	150-153											
	155-158	0.043	0.061	906		22			<30			
	200-203	0.066	0.083	76		29			<30			
	210-213											
	220-223											
	230-233											
	240-243	0.067	0.070	1304		23			<30			
	260-263											
	270-273											
	280-283											
	290-293											
	300-303	0.063	0.074	111		22			<30			
	310-313											
	316-319	0.062	0.070	878		30			<30			
	331-334	0.073	0.070	72		38			<30			
	340-343	0.076	0.074	81		22		40	<30			
	390-393											
	400-403	0.077	0.079	53		21			<30			
	450-453											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
D-1	460-463	55.9								6.5			
	480-483	41.9	0.2	34.8	65.0					5.2			
	493-496	44.8	0.9	33.1	66.0					5.4	1.49	1.57	81
	510-513	48.7								5.9			
	530-533	51.3	0.6	35.8	63.6					6.3			
	550-553	52.4								6.3			
	578-581	52.8	0.2	31.6	68.2					10.0			
	600-603	50.3								7.2			
	611-614	46.9								5.7			
	620-623	50.6								6.6			
	640-643	50.1	0.2	38.9	60.9					5.8			
	660-663	51.2								6.0			
	677-680	43.3	0.5	46.0	53.5					6.0			
	710-713	42.9	0.2	45.5	54.3					5.9			
	730-733	46.0	0.2	40.4	59.4					7.7			
	740-743	28.3	1.8	43.5	54.7					5.8			
	760-763	21.9	0.9	40.2	59.8					6.4			
	780-783	31.0								5.2			
	820-823	36.7	0.2	39.2	60.6					5.4			
	833-836	22.7	Tr	53.7	46.3					3.9			
	900-903	28.9	0.4	43.1	56.5					3.9			
	906-909	23.2	Tr	43.5	56.5					4.8			
	925-928	25.0	0.2	36.5	63.3					4.9			
	940-943	22.5								4.6			
	960-963	19.9	0.7	67.2	32.1					3.6	1.93		24
	970-971									14.0			
	971-973	17.7	3.5	65.5	31.0					2.3	1.99		21
	978-981	23.6	1.0	30.4	68.6					4.3			
	1037-1040	24.4	1.2	33.0	65.8					5.0			
	1050-1053	28.4								5.2			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-1	460-463											
	480-483	21.1	4.8	16.2			14.5	8.1	28.5	49.2	25.3	25.3
	493-496	28.5	7.8	10.4	9.1	2.8	13.7	12.1	39.2	48.0	21.1	30.7
	510-513	24.1	5.1	17.1			19.0	15.3	34.3			
	530-533	26.6	6.6	11.9			19.0	12.1	35.5	36.3	27.2	36.3
	550-553											
	578-581	21.5	7.5	11.8			15.1	9.7	43.8	42.0	28.0	29.9
	600-603											
	611-614	25.4	5.6	15.9	13.9	4.0	26.3	15.3	26.5			
	620-623											
	640-643	32.1	2.8	16.2	14.2	5.8	21.1	14.6	47.8	32.8	34.3	32.8
	660-663											
	677-680	29.3	7.0	9.0	6.2	5.6	28.5	13.1	25.8	45.6	28.2	26.0
	710-713	33.2	6.9	7.9	6.3	8.0	25.1	13.0	26.5	2.5	50.0	47.5
	730-733	27.8	6.2	8.6	6.4	2.8	20.0	8.8	37.2	45.0	25.0	30.0
	740-743	34.4	4.8	7.3			27.6	17.6	25.5	21.5	46.5	31.8
	760-763	28.0	7.5	7.3	5.8	4.0	25.9	12.6	30.9	5.7	57.1	37.1
	780-783	27.6	4.6	10.9			25.4	13.0	31.2			
	820-823	20.7	4.9	6.6			24.9	14.1	42.7	27.2	46.5	41.8
	833-836	21.0	3.4	0.8	0.0	2.5	24.4	17.0	50.4	36.6	30.1	33.3
	900-903	20.3	3.9	4.5	3.1	4.0	26.0	15.0	45.2	36.6	35.7	27.5
	906-909	25.6	3.6	1.2			21.6	14.5	48.0	46.1	28.8	25.0
	925-928	34.8	8.7	0.9			38.3	13.4	17.4	42.7	27.2	30.0
	940-943	25.8	6.8	0.0	0.0	0.0	27.5	13.9	39.7			
	960-963	18.6	3.4	1.3			35.4	17.9	9.3			
	970-971	41.5	9.3	0.6			42.1	19.3	6.2			
	971-973	28.2	8.1	1.0			49.4	22.5	13.1			
	978-981	36.0	10.9	2.1			23.7	8.9	26.8	27.3	35.6	36.9
	1037-1040	27.4	11.8	0.0			18.5	8.5	42.0			
	1050-1053											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-1	460-463	8.2	-200								
	480-483	8.2	-200								
	493-496	8.2	-200	4.2	3.3	0.9	1.49	0.46	6.85	2.48	2.93
	510-513	8.2	-280								
	530-533	8.0	-250								
	550-553	8.0	-250								
	578-581	8.2	-210				1.75	0.53	7.19	2.55	3.53
	600-603	8.0	-260								
	611-614	8.0	-290								
	620-623	8.2	-280								
	640-643	8.0	-200				1.35	0.55	8.45	3.02	2.88
	660-663	8.0	-140								
	677-680	7.9	-250								
	710-713	8.0	-290				1.65	0.70	8.20	3.71	2.95
	730-733	8.0	-120				1.54	0.66	5.56	2.55	2.89
	740-743	8.0	-200				1.79	0.77	8.10	3.95	3.18
	760-763	7.9	-250				2.03	0.71	7.88	2.23	3.37
	780-783	7.9	-120								
	820-823	7.9	-220								
	833-836	8.0	-250				1.69	0.78	8.73	5.44	2.86
	900-903	8.1	-200				1.82	0.68	8.35	3.79	2.97
	906-909	8.1	-210				1.80	0.79	7.93	5.25	3.19
	925-928	8.0	-250				1.80	0.82	4.58	4.16	3.22
	940-943	8.2	-220								
	960-963	8.2	-220	5.3	4.9	0.4					
	970-971										
	971-973	8.4	-100	6.6	6.1	0.5					
	978-981	8.3	-200								
	1037-1040	8.0	-250				1.91	0.86	4.38	3.06	3.40
	1050-1053										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-1	460-463											
	480-483											
	493-496	0.064	0.057	468		23			<30			
	510-513											
	530-533											
	550-553											
	578-581	0.070	0.061	90		24			<30			
	600-603											
	611-614											
	620-623											
	640-643	0.070	0.082	74		28			<30			
	660-663											
	677-680											
	710-713	0.064	0.061	75		36			<30			
	730-733	0.059	0.079	91		31			<30			
	740-743	0.053	0.070	82		22		20	<30			
	760-763	0.057	0.065	81		34			<30			
	780-783											
	820-823											
	833-836	0.053	0.079	80		20			<30			
	900-903	0.064	0.057	73		33			<30			
	906-909	0.048	0.061	67		35			<30			
	925-928	0.048	0.070	1588		33			<30			
	940-943											
	960-963											
	970-971											
	971-973											
	978-981											
	1037-1040	0.046	0.070	100		40			<30			
	1050-1053											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
D-1	1060-1063	26.2								4.5			
	1080-1083	30.1	3.4	27.7	68.9					4.5			
	1110-1113	34.6								5.9			
	1130-1133	34.8	Tr	25.6	74.4					6.1			
	1158-1161	38.7								4.9			
	1173-1176	46.5								7.0			
	1240-1243	45.5	1.4	12.8	85.8					6.2			
	1260-1263	50.0								7.7			
	1290-1293	46.2	2.8	11.3	85.9					5.5			
	1310-1313	41.6								5.9			
	1330-1333	39.5	Tr	30.2	69.8					6.4			
	1351-1354	41.9	0.0	38.5	61.5					6.1			
D-2	0-2	81.2	1.2	78.2	20.6	6.95	1.9	+0.34	2.45	16.2	1.12		92
	2-4	80.6								16.2	1.11	1.08	93
	4-6	80.1								15.5	1.12		92
	6-8	79.7								16.7	1.12		92
	8-10	79.0								15.1	1.12		92
	10-12	78.1	0.4	33.8	65.8					15.0	1.13	1.15	92
	12-14	77.1								14.1	1.13		91
	14-16	77.1								13.7	1.14		91
	16-18	75.5								13.1	1.14		90
	18-20	75.6	0.3	20.3	79.4					12.0	1.15		90
	20-23	75.5								25.7	1.15		92
	23-26	74.7								12.0	1.13		90
	26-30	74.6								12.0	1.16		90
	30-33	72.7	0.2	45.2	54.6					9.5	1.16		89
	33-36	77.3								12.4	1.18	1.15	89
	36-40	74.0								11.5	1.17		89

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-1	1060-1063	23.3	3.8	1.9	0.0	0.0	12.6	8.5	58.3	30.6	27.8	41.7
	1080-1083	31.2	7.5	1.2			26.5	12.8	24.0			
	1110-1113	35.8	7.9	1.3			15.1	6.5	39.5			
	1130-1133	34.4	11.2	5.6			20.6	9.2	28.0			
	1158-1161	26.9	8.9	0.0			12.8	7.2	51.3	48.3	22.5	29.0
	1173-1176	27.4	1.5	1.2			8.1	3.7	45.4			
	1240-1243	30.0	13.5	0.0	0.0	0.0	7.3	4.7	50.0			
	1260-1263	32.0	8.8	2.9			4.5	3.5	51.4			
	1290-1293	26.6	17.6	2.2			9.2	6.1	44.0	45.3	29.8	24.7
	1310-1313											
	1330-1333	23.1	3.4	2.4	0.0	0.0	3.9	5.3	67.3	60.3	15.0	24.6
	1351-1354	49.0	7.6	5.5	0.0	0.0	9.7	4.6	27.9			
D-2	0-2	16.5	4.1	32.9			9.6	16.9	36.6	12.5	50.0	37.5
	2-4											
	4-6											
	6-8											
	8-10											
	10-12											
	12-14	17.7	5.8	36.5			11.9	18.6	28.0			
	14-16											
	16-18											
	18-20											
	20-23											
	23-26	20.4	6.0	29.1			13.6	15.9	21.2	14.2	50.0	35.7
	26-30											
	30-33	24.2	3.8	32.8			18.2	19.6	20.5	13.5	49.0	35.7
	33-36											
	36-40											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-1	1060-1063										
	1080-1083	8.0	-250				1.69	0.81	5.05	3.10	3.23
	1110-1113										
	1130-1133										
	1158-1161	8.0	-250				2.01	0.91	3.91	2.99	3.42
	1173-1176										
	1240-1243	7.9	-250				2.37	0.88	3.24	2.58	4.19
	1260-1263	7.9	-260								
	1290-1293	8.0	-260								
	1310-1313										
	1330-1333	8.0	-140				1.90	0.62	2.94	1.85	4.16
	1351-1354										
D-2	0-2	7.6	-120				1.05	0.53	13.27	2.14	1.81
	2-4	7.6	-145								
	4-6	7.5	-230				1.23	0.42	16.13	2.27	1.95
	6-8	7.5	-175	11.6	5.1	6.5					
	8-10	7.5	-180								
	10-12	7.6	-190				0.95	0.43	13.17	2.27	1.68
	12-14	7.7	-205								
	14-16	7.7	-230								
	16-18	7.6	-220	10.4	5.0	5.4					
	18-20	7.4	-240								
	20-23	7.6	-220				1.49	0.67	17.10	3.35	2.96
	23-26	7.9	-160								
	26-30	7.9	-180	9.8	4.9	4.9					
	30-33	8.0	-170				1.07	0.44	13.01	2.79	1.72
	33-36	8.1	-170								
	36-40	8.1	-160	9.6	4.8	4.8					

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-1	1060-1063											
	1080-1083	0.046	0.070	88		40			<30			
	1110-1113											
	1130-1133											
	1158-1161	0.044	0.065	98		44			<30			
	1173-1176											
	1240-1243	0.052	0.083	105		40			<30			
	1260-1263											
	1290-1293											
	1310-1313											
	1330-1333	0.064	0.070	101		38			<30			
	1351-1354											
D-2	0-2	0.059	0.140	74		36						
	2-4	0.062	0.150	46		54						
	4-6						<20					
	6-8									0.65	<0.005	30.9
	8-10											
	10-12	0.056	0.120	59		31						
	12-14											
	14-16											
	16-18											
	18-20									0.61	<0.005	24.0
	20-23	0.077	0.210	91		40						25.2
	23-26											
	26-30									0.65	<0.005	25.1
	30-33	0.050	0.100	58		29	<20					
	33-36											
	36-40											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
D-2	40-43	71.8	0.3	47.6	52.1					4.8	1.20	1.30	87
	43-46	71.4								11.0	1.19		88
	46-50	71.9								11.7	1.18		89
	50-53	72.0								9.7	1.18		89
	53-56	71.1								10.2	1.18		89
	56-60	70.1	1.4	63.9	34.7					8.9	1.20		88
	60-63	69.3								9.3	1.21		87
	63-66	67.7								6.1	1.23		86
	66-70	63.2								8.6	1.26	1.31	84
	70-73	62.2	0.2	60.3	39.5					22.9	1.22		86
	73-76	67.3								8.3	1.23		86
	76-80	66.2								8.7	1.23		86
	80-83	69.6								9.0	1.21		87
	83-86	70.5								8.7	1.20		88
	86-90	68.8								10.7	1.20		88
	90-91	68.0	0.3	48.2	51.5					11.3	1.22		86
	100-105	70.3	3.4	64.4	32.2					22.9	1.17		89
	105-110	70.9								12.3	1.18		89
	110-115	67.4								9.8	1.22		86
	115-120	71.9								12.7	1.18		89
	120-125	70.0	0.2	49.9	49.9					10.0	1.20		88
	125-130	71.3								12.5	1.19		88
	130-135	68.4								9.4	1.22		86
	135-140	66.7								9.4	1.23		86
	140-145	65.8								8.3	1.25		85
	145-150	63.7								9.0	1.27		83
	150-155	63.5								9.9	1.25		85
	155-160	63.6	0.9	59.5	39.6					8.6	1.26		84
	160-165	66.4								9.1	1.24		85
	165-170	64.5								8.2	1.26		84

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-2	40-43											
	43-46											
	46-50											
	50-53	23.4	5.0	29.5			17.5	16.8	25.0	8.0	44.0	28.0
	53-56											
	56-60											
	60-63					8.0						
	63-66											
	66-70											
	70-73											
	73-76											
	76-80	26.3	6.2	18.2	17.2	8.2	24.3	16.4	24.8	12.0	46.0	28.0
	80-83											
	83-86											
	86-90											
	90-91											
	100-105	28.9	5.1	31.0			18.1	18.4	17.2	20.0	30.0	50.0
	105-110											
	110-115											
	115-120											
	120-125											
	125-130	20.8	2.8	32.5	28.8	9.8	15.0	15.1	28.6	25.0	30.0	45.0
	130-135											
	135-140											
	140-145											
	145-150											
	150-155											
	155-160											
	160-165	26.4	1.7	24.8			14.6	13.9	32.3	50.0	25.0	25.0
	165-170											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-2	40-43	7.8	-200				1.06	0.47	11.50	2.39	1.93
	43-46	7.8	-170								
	46-50	7.9	-210								
	50-53	7.8	-210				1.03	0.45	11.89	2.56	2.00
	53-56	7.8	-180								
	56-60	7.7	-190								
	60-63	7.6	-200				1.14	0.45	10.77	2.81	2.25
	63-66	7.8	-200								
	66-70	7.8	-160								
	70-73	7.8	-180				1.03	0.55	10.49	3.66	1.65
	73-76	7.7	-150								
	76-80	7.8	-140								
	80-83	7.8	-210				1.05	0.49	11.87	2.52	2.13
	83-86	7.8	-150								
	86-90	8.2	-160								
	90-91	8.1	-170				1.11	0.47	10.28	2.43	2.05
	100-105	7.7	- 60				1.06	0.47	10.99	2.42	2.02
	105-110	7.6	-100								
	110-115	7.8	- 70								
	115-120	7.7	- 40								
	120-125	7.6	- 50								
	125-130	7.7	- 60								
	130-135	7.9	- 75				1.25	0.51	11.39	2.73	2.30
	135-140	7.9	- 85								
	140-145	8.0	-100								
	145-150	8.0	-120								
	150-155	7.8	-190								
	155-160	7.7	-140								
	160-165	7.7	-200				1.41	0.53	11.17	2.71	2.68
	165-170	7.8	-170								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-2	40-43	0.047	0.100	56		26						28.1
	43-46											
	46-50											
	50-53	0.051	0.087	55		23	< 20			0.81	< 0.005	33.5
	53-56											
	56-60											
	60-63	0.057	0.083	73		23						
	63-66											
	66-70											
	70-73	0.046	0.074	51		25	< 20			0.64	< 0.005	23.0
	73-76											
	76-80											
	80-83	0.053	0.092	64		33	< 20			0.79	< 0.005	27.5
	83-86											
	86-90											
	90-91	0.054	0.100	64		30	< 20			0.81	< 0.005	
	100-105	0.061	0.110	70		28						28.8
	105-110											
	110-115											
	115-120											
	120-125											
	125-130											
	130-135	0.059	0.092	69		33				0.84	< 0.005	31.9
	135-140											
	140-145											
	145-150											
	150-155											
	155-160											
	160-165	0.067	0.079	68		28				0.89	< 0.005	20.3
	165-170											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
D-2	170-175	63.3								10.5	1.27		83
	175-180	64.3	0.0	45.7	54.3					10.2	1.26		84
	180-185	63.2								11.1	1.26		84
	185-190	61.9								10.5	1.28	1.28	83
	192-195	63.0								8.7	1.26		84
	197-200	66.0								9.5	1.23		86
	207-210	63.6	1.9	64.1	34.0					8.1	1.26		84
	217-220	62.6								8.8	1.27	1.31	83
	227-230	64.6								8.6	1.25		85
	235-238	63.2	0.0	46.1	53.8					8.4	1.26		84
	250-253	56.4	0.0	49.0	51.0					7.5	1.33	1.41	80
	260-263	60.9								7.9	1.29	1.28	82
	269-272	59.4	0.0	41.5	58.5					8.3	1.30	1.25	82
	280-283	59.4	0.3	60.3	39.4					7.6	1.31	1.36	81
	290-293	58.8	1.0	68.3	30.7					12.8	1.29		82
	301-304	40.7	0.2	32.1	67.7					7.4	1.52		69
	340-343	37.9	1.7	45.7	52.6					6.5	1.57	1.58	66
	360-363	40.5	Tr	42.0	58.0					6.7	1.53		68
	426-429	39.9	Tr	28.3	71.7					6.6	1.53		68
	440-443	43.1	39.9	24.5	35.6					6.5	1.49		70
	460-463	42.9	0.6	38.3	61.1					6.6	1.49		70
	480-483	39.9								7.0	1.53	1.58	68
	500-503	50.2	Tr	36.4	63.6					6.5	1.41		75
	520-523	55.9	0.4	25.4	74.2					6.8	1.35	1.42	78
	540-543	52.0	Tr	32.0	68.0					6.1	1.39		76
	560-563	52.6	Tr	35.7	64.3					6.5	1.38		77
	580-583	50.1	0.3	39.4	60.3					6.4	1.41		75
	599-602	49.0	Tr	38.2	61.8					5.7	1.58	1.51	74
	606-609	32.1	Tr	36.6	63.4					5.9	1.70		58
	702-705	61.6	Tr	37.5	62.5					5.9	1.28		82
	720-723	44.7	0.0	50.0	50.0					6.2	1.47		71

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % MgCO$_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-2	170-175											
	175-180											
	180-185	22.7	4.5	15.4	14.4	11.7	16.1	14.8	41.0	40.0	30.0	30.0
	185-190											
	192-195											
	197-200											
	207-210											
	217-220	26.5	4.6	13.9			14.5	13.6	38.6	41.6	0.0	58.3
	227-230											
	235-238											
	250-253	26.3	4.7	13.7			18.2	14.3	36.9	28.5	57.1	14.2
	260-263	29.7	4.3	12.9	10.1	11.3	19.2	12.9	33.6			
	269-272	23.6	7.5	12.0			15.7	12.8	40.0	20.0	58.0	18.0
	280-283					9.8						
	290-293	25.1	10.3	14.9			12.2	8.3	47.9	16.0	48.0	36.0
	301-304	22.8	3.9	24.3			14.6	14.8	34.7	36.2	22.7	40.9
	340-343	23.3	4.0	19.8	13.8	3.5	17.0	13.0	36.0	47.0	27.4	25.6
	360-363											
	426-429									44.9	27.5	27.5
	440-443	25.8	4.6	23.0			11.3	11.8	34.6	46.6	30.0	23.3
	460-463	25.4	4.5	23.0			13.6	12.2	35.0	61.0	18.6	20.3
	480-483	29.0	8.0	26.0			10.0	12.0	25.0	20.4	45.4	34.0
	500-503	27.9	4.5	11.0			9.4	8.7	47.0	59.5	21.4	19.0
	520-523	28.4	5.2	13.0			10.0	8.0	43.4	55.4	24.3	20.2
	540-543	33.2	7.5	9.9	8.7	3.5	10.4	9.3	38.8	37.5	31.2	31.2
	560-563	27.6	8.0	13.5			11.2	9.4	39.5	47.0	27.9	25.0
	580-583	29.3	4.4	13.2	11.1	5.5	16.1	11.7	36.7	5.4	43.2	51.3
	599-602	26.7	5.0	14.3	13.4	5.0	15.9	12.6	37.9	31.1	36.3	32.4
	606-609	26.4	5.6	10.3	8.3	5.5	19.7	11.5	37.7	48.9	24.4	26.5
	702-705	30.0	5.2	13.0			21.0	11.4	20.0	33.6	32.7	33.6
	720-723	29.3	7.5	13.8			21.3	11.7	27.7			

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-2	170-175	7.8	-140								
	175-180	7.8	-160								
	180-185	7.8	-150								
	185-190	7.7	-120				1.42	0.52	10.72	2.81	2.93
	192-195	7.7	-180								
	197-200	7.9	-170	6.8	4.1	2.7					
	207-210	7.8	-210								
	217-220	7.8	-210				1.46	0.56	9.91	2.82	2.93
	227-230	7.9	-170	6.3	4.2	2.1					
	235-238	8.1	-200				1.39	0.56	11.19	2.84	2.69
	250-253	8.6	-250								
	260-263	8.3	-210								
	269-272	8.4	-210				1.51	0.64	9.25	3.05	3.78
	280-283	8.2	-180				1.44	0.58	10.29	3.71	2.95
	290-293	8.2	-200				1.31	0.42	6.20	2.07	2.72
	301-304	8.6	-170				1.51	0.54	8.62	2.48	3.32
	340-343	7.9	-160								
	360-363	7.9	-120								
	426-429	7.9	-130	4.8	3.7	1.1	1.49	0.48	8.71	2.11	2.95
	440-443	7.6	-160				1.52	0.50	9.03	2.30	3.18
	460-463	7.5	-200								
	480-483	7.6	-260				1.60	0.52	6.34	2.13	3.06
	500-503	8.0	-280								
	520-523	8.0	-280								
	540-543	8.2	-220				1.68	0.60	6.84	2.40	3.38
	560-563	7.9	-220								
	580-583	8.1	-190				1.31	0.47	6.95	2.41	2.40
	599-602	8.1	-160				1.67	0.60	7.03	3.13	3.19
	606-609	8.0	-160				0.95	0.33	4.84	1.63	1.65
	702-705	8.1	-180								
	720-723	8.1	-160								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-2	170-175											
	175-180											
	180-185											
	185-190											
	192-195	0.068	0.083	74		33				0.98	<0.005	12.4
	197-200											
	207-210											
	217-220									0.95	<0.005	14.0
	227-230	0.068	0.078	65		29						
	235-238											
	250-253	0.074	0.079	72		31				1.03	<0.005	14.1
	260-263											
	269-272											
	280-283	0.064	0.065	73		29	<20					17.5
	290-293	0.073	0.074	77		31						
	301-304	0.093	0.074	1181		24				1.00	<0.005	14.0
	340-343	0.085	0.070	85		30				1.09	<0.005	19.8
	360-363									1.13	<0.005	
	426-429											
	440-443	0.085	0.074	89		33				1.00	<0.005	19.8
	460-463	0.085	0.065	86		29	<20			1.05	<0.005	22.8
	480-483											
	500-503	0.062	0.065	85		29						9.9
	520-523											
	540-543									0.91	<0.005	
	560-563	0.076	0.065	92		38						11.1
	580-583									1.11	<0.005	
	599-602	0.064	0.065	68		26				0.98	<0.005	12.0
	606-609	0.077	0.070	301		30	< 20			0.99	<0.005	12.1
	702-705	0.044	0.037	49		20				0.97	<0.005	8.4
	720-723											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
D-2	740-743	46.9	1.2	50.9	47.9					6.5	1.44		73
	756-759	44.4	1.5	53.9	44.6					6.9			
	761-764	29.5	0.2	39.4	60.4					5.4			
	860-863	28.6	1.7	42.3	56.0					5.7			
	880-883	29.5	4.8	33.1	62.1					6.3			
	900-903	21.6	Tr	96.9	3.1					4.8	1.87		
	911-913	24.2	Tr	46.0	54.0					5.8			
	1006-1009	24.6								4.8			
	1020-1023	25.3	Tr	24.1	75.9					5.1			
	1040-1043	20.6	Tr	10.4	89.6					3.6			
	1060-1063	31.0	Tr	4.6	95.4					6.5			
D-3	6-8	80.1	0.4	72.3	27.3	7.4	2.7	+0.75	1.89	15.5			
	8-10	80.2								15.1	1.12	1.09	
	10-12	80.1								15.1			
	12-14	80.2	0.4	70.1	29.5					15.7			
	14-16	80.7								15.3	1.12	1.15	
	16-18	79.2								15.6			
	18-20	79.5								15.8	1.12		
	20-23	79.5								14.8			
	23-26	80.1								16.1	1.20	1.18	
	26-30	80.1								15.9			
	30-33	79.5	0.5	65.9	33.6					13.7	1.14	1.26	
	33-36	78.8								14.0			
	36-40	78.3								12.5	1.15		
	40-43	78.5								14.8			
	43-46	78.4								14.8	1.16	1.18	
	46-50	78.6								14.8			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-2	740-743	30.7	8.9	8.4	5.8	6.0	17.8	10.4	33.9	52.5	20.0	27.5
	756-759	35.8	5.8	7.0	0.0	2.3	24.9	11.9	26.3	40.2	31.3	28.3
	761-764	33.5	7.5	9.0			28.0	13.5	24.0	0.0	67.3	32.6
	860-863	22.6	9.6	11.0			24.2	13.0	32.3	5.3	66.6	28.0
	880-883	24.8	6.6	13.2			24.1	12.2	30.9			
	900-903	27.9	7.2	0.9			44.5	15.4	19.2			
	911-913	30.9	8.1	1.8			46.8	13.5	12.1	42.3	23.7	33.8
	1006-1009	27.9	6.4	6.8			28.7	15.0	29.9			
	1020-1023	25.9	8.1	2.6			30.7	11.4	32.4	41.9	30.6	27.4
	1040-1043	35.1	10.9	0.2			42.4	18.7	11.2	15.0	46.2	38.8
	1060-1063	39.5	9.6	0.0			10.0	4.5	41.2	35.7	33.6	30.5
D-3	6-8	22.5	3.9	31.0			15.7	17.1	26.6	20.0	40.0	40.0
	8-10											
	10-12											
	12-14											
	14-16	25.6	8.1	30.4			19.3	16.7	16.2	20.0	40.0	40.0
	16-18											
	18-20											
	20-23											
	23-26											
	26-30	25.2	3.4	14.6			17.8	15.9	38.6	20.0	40.0	40.0
	30-33											
	33-36											
	36-40	19.1	9.1	36.4			16.0	19.2	19.1			
	40-43											
	43-46											
	46-50											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-2	740-743	7.9	-180				1.73	0.72	6.55	3.42	3.29
	756-759	8.1	-200				1.97	0.65	8.17	3.62	3.32
	761-764	7.9	-185				1.95	0.82	7.93	3.69	3.69
	860-863	7.9	-180								
	880-883	7.9	- 80								
	900-903	8.4	- 20	5.2	4.7	0.5	1.70	0.73	7.69	4.54	3.07
	911-913	8.2	- 10								
	1006-1009	8.0	+ 10				2.00	0.82	6.17	4.07	3.63
	1020-1023	8.2	- 80				1.14	0.65	11.29	6.33	1.63
	1040-1043										
	1060-1063										
D-3	6-8	7.8	-120				1.25	0.48	12.64	2.56	2.12
	8-10	7.8	-140				1.04	0.53	10.48	2.29	1.80
	10-12	7.9	-150				1.14	0.51	12.86	2.79	2.00
	12-14	8.0	-140								
	14-16	8.0	-130				1.10	0.53	11.94	3.17	1.99
	16-18	8.0	-150								
	18-20	8.0	-180								
	20-23	7.8	-220								
	23-26	8.3	-230				1.00	0.47	7.61	2.50	1.81
	26-30	8.1	-280								
	30-33	8.2	-180								
	33-36	8.1	-180								
	36-40	8.0	-190				1.15	0.47	12.84	2.67	2.14
	40-43	7.9	-190								
	43-46	7.9	-200				1.00	0.47	8.54	2.40	1.91
	46-50	7.8	-180								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-2	740-743									1.35	<0.005	7.2
	756-759	0.059	0.065	128		35				0.97	<0.005	7.9
	761-764	0.051	0.083	3016		32				1.41	<0.005	8.0
	860-863	0.052	0.092	114		33				0.46	<0.005	11.2
	880-883											3.2
	900-903											
	911-913	0.051	0.070	2309		29						
	1006-1009									0.98	<0.005	4.4
	1020-1023	0.046	0.065	81		32						
	1040-1043	0.039	0.057	38		20						
	1060-1063											
D-3	6-8	0.057	0.092	64		29	<20					
	8-10											
	10-12	0.046	0.087	52		22						
	12-14	0.052	0.150	57		20	<20					
	14-16											
	16-18	0.053	0.092									
	18-20					25						
	20-23											
	23-26											
	26-30	0.049	0.092	48		19	<20					
	30-33											
	33-36											
	36-40											
	40-43	0.059	0.070	35		19						
	43-46											
	46-50	0.054	0.070	49		18	<20					

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
D-3	50-53	77.8	0.7	70.5	28.8					14.3			
	53-56	77.2								14.7			
	56-60	77.1								14.3	1.19	1.28	
	60-63	77.2	1.0	70.1	28.9					15.3			
	63-66	76.8								14.4	1.24	1.18	
	66-70	77.1								13.2			
	70-73	77.5								13.1	1.20	1.23	
	73-76	75.6								11.9			
	76-80	75.3	0.9	61.9	37.2					7.6			
	80-83	75.2								11.5	1.22	1.31	
	83-86	75.0								17.7			
	86-90	72.7								10.4			
	90-93	71.4	0.9	59.8	39.3					9.4	1.26	1.20	
	100-105	72.6	0.5	69.1	30.4					11.0			
	105-110	68.9								9.7			
	110-115	68.3								10.5			
	115-120	67.9	0.5	65.2	34.3					10.0			
	120-125	65.6								9.4			
	125-130	67.0								9.9			
	130-135	58.6								9.8			
	135-140	66.4								9.5			
	140-145	64.9	0.8	60.8	38.4					8.7			
	145-150	65.5								9.6			
	150-155	63.9								9.4			
	155-160	68.1								11.1			
	160-165	68.1	1.2	64.8	34.0					12.4			
	165-170	67.5								10.9			
	170-175	67.8								11.1			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-3	50-53	19.2	5.0	31.4	28.2	6.6	18.7	16.9	25.4	0.0	100	0.0
	53-56											
	56-60											
	60-63	24.7	3.8	29.8			16.0	15.1	25.5	25.0	60.0	15.0
	63-66											
	66-70											
	70-73											
	73-76											
	76-80	19.7	4.5	31.3			18.2	17.7	26.1	20.0	80.0	0.0
	80-83											
	83-86											
	86-90	24.6	2.6	25.4			16.5	17.5	30.6			
	90-93											
	100-105	25.6	4.4	22.4	19.0	7.5	18.3	16.5	18.6	6.6	46.6	46.6
	105-110											
	110-115											
	115-120											
	120-125											
	125-130	20.5	7.4	20.1			19.5	16.3	32.2	20.0	40.0	40.0
	130-135											
	135-140											
	140-145											
	145-150											
	150-155	29.1	8.8	11.3	9.6	10.0	16.8	15.6	33.7	66.6	16.6	16.6
	155-160											
	160-165											
	165-170											
	170-175											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-3	50-53	7.9	-190								
	53-56	7.9	-170								
	56-60	7.9	-195				1.15	0.53	13.41	2.55	2.13
	60-63	7.9	-200								
	63-66	7.9	-240								
	66-70	7.9	-210				1.22	0.49	13.83	2.68	2.18
	70-73	8.0	-200								
	73-76	8.0	-190								
	76-80	8.0	-160				1.22	0.47	12.79	2.62	2.23
	80-83	8.1	-160								
	83-86	8.2	-170								
	86-90	8.1	-160				1.18	0.50	12.38	2.94	2.19
	90-93	8.1	-170				1.22	0.50	11.46	2.76	2.34
	100-105	8.2	- 70				1.21	0.50	11.91	2.86	2.24
	105-110	7.9	-170								
	110-115	7.8	-150								
	115-120	7.8	-200								
	120-125	7.9	-220				1.21	0.50	12.71	2.90	2.16
	125-130	7.7	-220								
	130-135	8.0	-220								
	135-140	8.0	-180								
	140-145	7.9	-210								
	145-150	7.9	-230								
	150-155	7.9	-270				1.32	0.50	11.08	2.65	2.44
	155-160	8.0	-270								
	160-165	8.0	-270								
	165-170	8.0	-270								
	170-175	8.0	-270								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-3	50-53											
	53-56											
	56-60	0.060	0.065	55		29						
	60-63											
	63-66											
	66-70	0.060	0.096	54		31						
	70-73											
	73-76											
	76-80	0.057	0.100	56		25						
	80-83											
	83-86											
	86-90	0.056	0.083	57		24						
	90-93	0.059	0.100	62		25						
	100-105	0.059	0.100	61		24						
	105-110											
	110-115											
	115-120											
	120-125	0.058	0.096	56		23						
	125-130											
	130-135											
	135-140											
	140-145											
	145-150											
	150-155	0.067	0.079	73		28						
	155-160											
	160-165											
	165-170											
	170-175											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
D-3	175-180	65.8								10.0			
	180-185	62.3	0.9	51.0	48.1					7.8			
	185-190	63.6								7.3			
	190-195	64.6								8.7			
	195-197	65.3								8.1			
	200-205	63.9	0.5	47.9	51.6					7.8			
	210-215	62.6								7.5			
	220-225	62.6								8.8			
	230-235	49.5	17.2	41.0	41.8					5.0			
	240-245	41.2	20.5	43.6	35.9					3.9			
	245-250	42.4	3.9	40.7	55.4					5.4			
	250-255	38.7	0.9	35.0	64.1					5.5			
	260-265	36.2	1.9	66.5	31.6					5.4			
	288-290	30.1	2.1	57.6	40.3					4.5			
	300-303	40.1	Tr	36.4	63.6					6.2			
	320-323	38.4	Tr	47.4	52.6					6.4			
	342-345	37.1	0.2	40.4	59.4					5.4			
	360-363	41.8	0.4	36.8	62.8					6.0			
	380-383	42.8	Tr	51.6	48.4					5.3			
	413-416	40.0	0.2	49.5	50.3					5.2			
	423-426	40.1	Tr	52.1	47.9					8.7			
	447-450	41.6	0.2	52.6	47.2					5.1			
	460-463	39.1	0.5	60.0	39.5					4.9			
	480-483	43.6	0.8	36.4	62.8					10.6			
	500-503	42.9	2.3	33.6	64.1					5.6			
	530-533	42.2	0.2	52.8	47.0					5.2			
	553-556	40.0	Tr	43.4	56.6					5.3			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-3	175-180	22.9	6.7	21.9			18.6	15.8	29.5	20.0	40.0	40.0
	180-185											
	185-190											
	190-195											
	195-197											
	200-205	31.0	5.4	12.4	9.9	8.4	13.9	14.9	37.0	0.0	62.5	37.5
	210-215											
	220-225											
	230-235	38.1	14.4	13.6	9.5	14.5	25.6	12.5	13.6	0.0	64.5	35.5
	240-245	42.3	7.9	6.2			12.2	11.4	31.0	54.3	26.3	19.4
	245-250	44.6	8.5	4.7			8.8	7.4	33.0	55.4	20.5	24.1
	250-255	61.3	5.0	8.4			8.7	6.9	16.8			
	260-265	51.3	8.3	6.3			10.0	6.8	23.8	67.6	14.7	17.6
	288-290	46.3	18.0	3.0	0.0	2.5	7.3	9.3	20.0	36.4	31.8	31.8
	300-303											
	320-323	43.2	6.7	7.1			11.3	6.0	31.4	34.4	31.0	34.6
	342-345	37.7	5.4	8.5			11.5	7.8	36.6	44.4	27.7	27.7
	360-363											
	380-383	31.4	8.3	12.3			8.7	10.9	39.1	23.8	33.4	42.8
	413-416	30.7	7.0	8.4			11.1	8.2	42.3	10.0	40.0	50.0
	423-426											
	447-450	33.8	9.7	11.8			12.1	9.9	32.4	21.9	36.5	41.4
	460-463											
	480-483	44.1	8.4	14.9			13.6	8.8	18.7	48.2	25.9	25.9
	500-503	40.2	11.0	9.5			13.1	11.9	25.8	34.5	32.1	33.4
	530-533	33.1	3.3	15.1			12.6	11.9	35.6	38.4	30.7	30.7
	553-556											

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-3	175-180	8.0	-250				1.34	0.49	12.42	2.90	2.48
	180-185	7.9	-270								
	185-190	8.0	-270								
	190-195	7.9	-240								
	195-197	7.8	-200								
	200-205	8.0	-100				1.45	0.53	8.98	2.59	2.48
	210-215	8.1	-200								
	220-225	8.2	-150								
	230-235	8.3	-150				1.26	0.65	6.69	2.24	2.04
	240-245	8.2	-160								
	245-250	8.2	-100								
	250-255	8.2	-100				1.59	0.71	5.42	2.24	2.83
	260-265	8.2	-200								
	288-290	8.0	-200				1.37	0.78	5.38	2.14	2.28
	300-303										
	320-323	7.8	-200								
	342-345	7.8	-200				1.76	0.62	5.75	2.16	3.21
	360-363	7.7	-280								
	380-383	7.7	-200				1.61	0.59	6.88	2.14	3.03
	413-416	7.8	-220								
	423-426	7.7	-200				1.67	0.62	6.69	2.18	3.18
	447-450	7.7	-200								
	460-463	7.7	-200								
	480-483	7.6	-260				1.67	0.59	7.53	2.22	3.36
	500-503	7.5	-150				1.53	0.61	7.72	2.56	2.66
	530-533	7.6	-190								
	553-556	7.6	-240								

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-3	175-180	0.067	0.100	108		24						
	180-185											
	185-190											
	190-195											
	195-197											
	200-205	0.074	0.061	64		24						
	210-215											
	220-225											
	230-235	0.056	0.061	45		20						
	240-245											
	245-250											
	250-255	0.077	0.057	63		23						
	260-265											
	288-290	0.069	0.057	52		22						
	300-303											
	320-323											
	342-345	0.110	0.061	81		26						
	360-363											
	380-383	0.085	0.057	74		24						
	413-416											
	423-426	0.072	0.065	79		26						
	447-450											
	460-463											
	480-483	0.074	0.070	87		25						
	500-503	0.077	0.061	72		27						
	530-533											
	553-556											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY ($g\ cm^{-3}$) CALCULATED	BULK DENSITY ($g\ cm^{-3}$) EXPERIMENTAL	POROSITY (%)
D-3	565-568	41.8	Tr	29.7	70.3					6.0			
	593-596	38.2	Tr	32.3	67.3					4.9			
	617-620	38.2	0.5	52.4	47.1					5.0			
	637-640	39.0	0.2	43.7	56.1					5.9			
	660-663	34.2	Tr	57.8	42.2					5.0			
	678-681	32.5	1.4	47.6	51.0					4.9			
	693-696	33.6	5.1	54.8	40.1					5.3			
	720-723	22.3	20.0	45.1	34.9					6.4			
	738-741	26.7	7.8	54.2	38.0					6.7			
	748-751	22.1	26.3	68.4	5.3					3.4			
	758-761	20.0	3.1	53.2	43.7	6.5	1.20	-0.18	0.67	2.3			
	780-783	19.0	3.7	90.8	5.5					2.0			
	800-803	24.7	1.5	83.9	14.6	6.8	1.40	-0.02	1.17	3.3			
	833-836	20.8								2.5			
	840-843	24.5	0.2	72.5	27.3					3.5			
	860-863	23.8								1.5			
	880-883	31.0								4.8			
	897-900	29.4	0.2	69.2	30.6					3.3			
	910-913	30.4								6.0			
	919-922	20.3	4.8	54.1	41.1					3.5			
	927-930	19.3	11.3	36.7	52.0					3.6			
	939-942	22.0	8.0	28.0	64.0								
D-4	571-573		42.4	27.9	29.7								
W-1	10-12	28.8	3.0	29.0	68.0					6.7			
	12-14	27.5								6.3			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
D-3	565-568	35.2	4.6	10.5			9.2	8.4	40.3	43.2	24.4	32.4
	593-596	33.7	4.1	11.1			13.6	9.9	37.1	33.7	38.9	27.4
	617-620	36.0	6.5	13.5			12.8	12.2	30.5	40.8	26.5	32.6
	637-640											
	660-663	35.6	6.7	7.6			11.9	10.9	38.0	58.3	20.9	20.8
	678-681	25.2	6.4	5.3			20.2	14.3	42.7	54.2	20.8	25.0
	693-696	33.1	7.0	8.6			19.7	13.6	31.2	56.1	19.2	24.7
	720-723	37.0	9.1	4.0			29.2	11.8	20.3	51.6	25.8	22.4
	738-741	30.0	6.0	5.0			25.0	11.8	35.0	53.2	25.9	20.9
	748-751											
	758-761	26.2	14.0	5.1			37.5	23.1	17.0	31.0	34.5	34.5
	780-783											
	800-803											
	833-836	25.4	9.8	4.7			46.7	22.1	13.2	36.3	31.8	31.8
	840-843											
	860-863	34.9	18.0	7.5			33.6	19.1	34.5	29.6	41.1	35.9
	880-883											
	897-900	36.0	5.4	2.4	0.0	0.0	44.1	19.8	12.0	16.6	42.9	40.5
	910-913											
	919-922	36.1	5.9	1.5			28.3	14.9	27.8	47.6	23.8	28.6
	927-930											
	939-942	24.0	9.0	5.5			22.6		38.6	64.5	18.8	16.5
D-4	571-573											
W-1	10-12							4.3				
	12-14							5.6				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
D-3	565-568	7.6	-210				1.72	0.53	6.45	2.18	3.67
	593-596	7.6	-210				1.73	0.59	6.00	2.41	3.17
	617-620	7.5	-220								
	637-640	7.7	-220								
	660-663	8.0	-200				1.68	0.62	8.08	2.79	2.93
	678-681	7.5	-210				1.49	0.61	8.50	3.50	2.76
	693-696	7.6	-180								
	720-723	8.0	- 80				1.44	0.74	7.39	3.98	2.24
	738-741										
	748-751	8.1	+ 20								
	758-761										
	780-783	7.9	+ 20				0.80	0.62	9.55	5.46	0.95
	800-803	7.8	- 10								
	833-836										
	840-843	8.2	+ 50				1.26	0.65	11.41	5.70	2.08
	860-863										
	880-883	8.3	+ 20								
	897-900	8.2	-100				1.30	0.65	8.88	5.29	2.16
	910-913	8.0	-270								
	919-922	8.1	-150								
	927-930						1.66	1.11	7.63	3.70	2.89
	939-942										
D-4	571-573										
W-1	10-12										
	12-14										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
D-3	565-568	0.077	0.061	89		31						
	593-596	0.077	0.048	81		28						
	617-620											
	637-640											
	660-663	0.067	0.065	74		29						
	678-681	0.085	0.057	63		28						
	693-696											
	720-723	0.050	0.070	56		21						
	738-741											
	748-751											
	758-761											
	780-783	0.034	0.044	26		12						
	800-803											
	833-836											
	840-843	0.059	0.061	49		34						
	860-863											
	880-883											
	897-900	0.067	0.057	61		39						
	910-913											
	919-922											
	927-930	0.053	0.061	66		28	< 20					
	939-942											
D-4	571-573											
W-1	10-12											
	12-14											

CORE	CORE DEPTH (cm)	MOISTURE CONTENT (%)	SAND (%)	SILT (%)	CLAY (%)	MEAN GRAIN SIZE (PHI)	STANDARD DEVIATION (PHI)	SKEWNESS	KURTOSIS	ORGANIC MATTER (%)	BULK DENSITY (g cm^{-3}) CALCULATED	BULK DENSITY (g cm^{-3}) EXPERIMENTAL	POROSITY (%)
W-1	14-16	24.6								8.8			
	16-18	24.7								17.6			
	18-20	22.9								13.6			
	23-25	19.8	4.0	21.0	75.0					12.8			
	27-29	28.3								12.8			
	32-35	23.6	7.0	31.0	62.0					6.2			
	869-873	25.7								5.4			
	875-879	18.5								3.7			
	1173-1177	6.9								1.5			
	1177-1179	7.3								2.9			
W-2	10-11	25.0	1.0	21.0	78.0					5.7			
	11-12	27.1								6.1			
	12-14	25.7								6.8			
	14-15	26.6								5.7			
	15-17	26.9								4.9			
	17-19	22.6	4.0	21.0	75.0					6.2			
	19-20	27.3								5.6			
	20-22	24.8								6.0			
	22-24	26.5								5.1			
	24-26	26.1								4.5			
	26-28	26.4								6.2			
	28-31	21.6								6.4			
	31-33	22.4	0.5	24.5	75.0					5.8			

CORE	CORE DEPTH (cm)	QUARTZ (%)	FELDSPAR (%)	TOTAL CALCITE (%)	Mg-CALCITE (%)	MOLE % $MgCO_3$ in CALCITE	DOLOMITE (%)	TOTAL CARBONATE (%) (L.O.C.)	TOTAL CLAY MINERALS (%)	EXPANDABLE CLAY MINERALS (%)	ILLITE (%)	KAOLINITE + CHLORITE (%)
W-1	14-16							4.7				
	16-18							3.8				
	18-20							3.0				
	23-25							3.6				
	27-29							3.3				
	32-35							1.1				
	869-873							18.6				
	875-879							17.8				
	1173-1177							22.9				
	1177-1179							37.7				
W-2	10-11							4.8				
	11-12							4.6				
	12-14							4.6				
	14-15							3.6				
	15-17							6.4				
	17-19							6.5				
	19-20							29.4				
	20-22							8.7				
	22-24							3.8				
	24-26							5.6				
	26-28							6.0				
	28-31							6.3				
	31-33							7.4				

CORE	CORE DEPTH	pH	Eh (mv.)	TOTAL CARBON (%)	CARBONATE CARBON (%)	ORGANIC CARBON (%)	POTASSIUM (%)	SODIUM (%)	CALCIUM (%)	MAGNESIUM (%)	IRON (%)
W-1	14-16										
	16-18										
	18-20										
	23-25										
	27-29										
	32-35										
	869-873										
	875-879										
	1173-1177										
	1177-1179										
W-2	10-11										
	11-12										
	12-14										
	14-15										
	15-17										
	17-19										
	19-20										
	20-22										
	22-24										
	24-26										
	26-28										
	28-31										
	31-33										

CORE	CORE DEPTH	MANGANESE (%)	PHOSPHOROUS (%)	ZINC (ppm)	CADMIUM (ppm)	COPPER (ppm)	LEAD (ppm)	MERCURY (ppb)	CHLORIDE (ppm)	TOTAL SULFUR (%)	SULFATE SULFUR (%)	SOLUBLE SALT (%)
W-1	14-16											
	16-18											
	18-20											
	23-25											
	27-29											
	32-35											
	869-873											
	875-879											
	1173-1177											
	1177-1179											
W-2	10-11											
	11-12											
	12-14											
	14-15											
	15-17											
	17-19											
	19-20											
	20-22											
	22-24											
	24-26											
	26-28											
	28-31											
	31-33											

APPENDIX F

Sedimentological Data Collected from the South Basin of Lake Manitoba by the Manitoba Department of Mines, Resources and Environmental Management (J. Crowe, personal communication, 1978). Station numbers refer to the grid line intersects shown on Figure F-1.

STATION	ORGANIC MATTER (%)	SILT + CLAY (%)	MEAN GRAIN SIZE (PHI)	SORTING COEFFICIENT
K - 20	27.68	96.76	6.2	1.3
J - 21	11.11	89.08	5.7	1.8
K - 15	7.11	53.96	3.7	2.3
L - 16	5.10	33.41	4.5	2.5
K - 16	16.06	83.58	6.1	0.8
J - 16	11.08	69.70	5.5	1.4
K - 17	14.57	96.36	6.5	1.0
H - 16	13.54	92.15	6.7	1.1
L - 17	14.34	90.67	6.0	1.8
L - 19	16.57	93.73	-	-
N - 19	13.57	97.78	6.8	1.1
N - 20	14.90	99.04	6.1	1.5
L - 20	18.51	97.62	5.9	1.0
M - 17	12.95	97.62	6.5	1.2
L - 18	30.41	96.40	7.5	0.4
K - 18	16.78	91.50	-	-
J - 19	17.60	96.53	6.8	1.1
K - 19	13.63	95.50	-	-
M - 19	26.30	97.09	6.3	1.7
M - 20	16.08	98.23	6.3	1.4

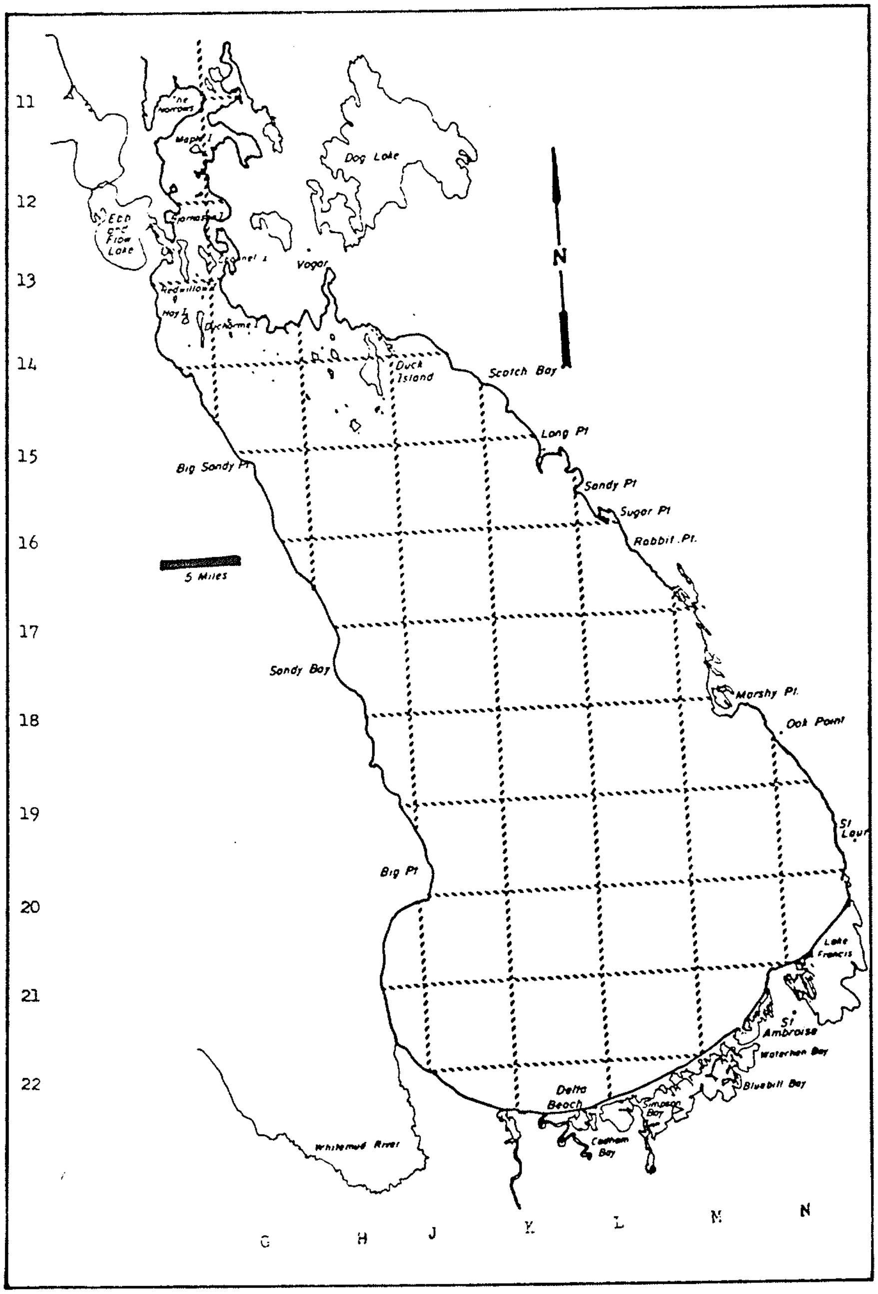


Figure F-1. Sampling grid location map for sediment samples collected by the Manitoba Department of Mines, Resources and Environmental Management.

APPENDIX G

STATISTICAL ANALYSIS OF MODERN-SEDIMENT PARAMETER INTERRELATIONSHIPS

G.1 INTRODUCTION

Various statistical analyses were made on the surface sediment data collected in this study. The goals of these analyses were to (a) quantitatively describe the various attributes of the sediment (such as, parameter mean, standard deviation, etc.) and (b) investigate and analyse interrelationships among the sediment parameters. The results of (a) were included in the descriptive section (Chapter 4, Tables 4-1 to 4-3). The purpose of this Appendix is to present and discuss the results of (b).

In order to help simplify and interpret the rather complex correlation coefficient matrix (discussed below), R-mode factor analysis (investigation of association among sample variables) was undertaken. Factor analysis has been used with some success in numerous lake sediment studies (e. g., Callender, 1968; Dean and Gorham, 1976a, b; Mackin and Owen, 1979; Thomas et al, 1973) to help determine or confirm the basic processes that have controlled lacustrine sedimentation. However, it must be emphasized that the interpretation of both the simple correlation matrix, as well as the factor loading matrix extracted from it, is rather subjective and often not very definitive. Although multivariate statistical techniques such as factor analyses are important and powerful tools because of the ability to simplify an original large and varied data matrix into a much smaller number of hypothetical variables or factors, interpretation must always be done with real or probable geologic processes and relationships in mind. In addition, the constraints imposed by such things as "closed" data sets (Chayes, 1971) and questionable levels of significant factor loading (Jones and Bowser, 1978) often make interpretation difficult.

G.2 DATA SET

An initial correlation coefficient matrix was generated from a data set consisting of analytical values for twenty-seven variables from thirty-two locations in the South Basin (Table G-1). However, by including sample data from the two strikingly anomalous areas of the basin, the resulting correlations portrayed a rather distorted and confused pattern. It is believed that a more realistic picture is established by partitioning this "mixed population" and analyzing the covariation pattern among the variables of the more homogeneous clay and silt-rich sediment of the basin. A similar, essentially textural, separation was necessary in sediment analyses in Placentia Bay, Newfoundland (Willey, 1976) and Loch Leven, Scotland (Maitland, 1979).

A new correlation coefficient matrix was derived for the twenty-seven variables from twenty-seven locations. All surface sediment data from the relict sand areas as defined by the 20% sand contour line on Figure D-5 was excluded from further computations. Likewise, the variables, mercury, cadmium, lead, aragonite, detailed carbonate mineralogy parameters, bulk density, porosity, and water chemistry, were not included in the statistical analyses because of incomplete records. Color and fossil content were excluded because of their qualitative nature. Finally, in an effort to reduce the skewed nature of the various parameter sample distributions, a logarithmic transformation was applied to the data (Alder and Roessler, 1977, p. 346).

Table G-1. Linear correlation coefficient matrix of 27 physical, chemical and mineralogical surface sediment variables from 32 locations in the South Basin of Lake Manitoba (relict sand areas included).

	Moisture content	Water depth	Organic matter	Total carbonates	pH	Eh	Total clay minerals	Quartz	Calcite	Dolomite
Moisture content	1.000									
Water depth	.378	1.000								
Organic matter	.728	.594	1.000							
Total carbonates	.689	.261	.190	1.000						
pH	.326	.427	.269	.447	1.000					
Eh	-.257	-.220	-.305	-.019	-.095	1.000				
Total clay minerals	.664	.542	.809	.236	.278	-.342	1.000			
Quartz	-.867	-.532	-.801	-.590	-.377	.189	-.816	1.000		
Calcite	.650	.472	.785	.333	.104	-.232	.594	-.803	1.000	
Dolomite	.270	.100	-.085	.610	.536	.092	-.004	-.293	-.062	1.000
Feldspar	-.368	-.500	-.666	-.086	-.231	.401	-.711	.568	-.631	-.117
Clay (size)	.409	.517	.649	.057	.292	.113	.588	-.424	.465	.055
Mean grain size	.807	.576	.829	.141	.394	-.157	.687	-.712	.687	.232
Potassium	-.005	-.344	.039	-.368	-.029	.070	-.091	.097	.071	.084

	Moisture content	Water depth	Organic matter	Total carbonates	pH	Eh	Total clay minerals	Quartz	Calcite	Dolomite
Sodium	-.576	-.633	-.830	-.144	-.447	.401	-.788	.730	-.677	-.187
Calcium	.750	.641	.622	.663	.479	-.222	.666	-.899	.697	.482
Magnesium	.447	-.062	-.081	.799	.332	.089	.034	-.389	.010	.871
Iron	.723	.321	.687	.300	.461	-.175	.546	-.691	.592	.242
Manganese	.848	.445	.816	.380	.382	-.307	.707	-.815	.718	.188
Phosphorous	.554	.514	.726	.148	.271	-.318	.590	-.622	.741	-.082
Silt	.585	.319	.547	.344	.368	-.414	.712	-.777	.528	.418
Copper	.585	.365	.603	.151	.355	-.127	.493	-.518	.450	.121
Zinc	.637	.542	.808	.175	.505	-.319	.731	-.604	.444	.077
Expandable clays	.188	.333	.330	.064	.402	.042	.222	-.189	.026	.430
Illite	.650	.319	.321	.153	.135	-.410	.627	-.660	.733	-.099
Kaolinite + chlorite	.612	.463	.629	.265	.146	-.340	.318	-.647	.597	.188
Sand	-.707	-.543	-.804	-.315	-.470	.285	-.799	.838	-.688	-.375

	Feldspar	Clay (size)	Mean grain size	Potassium	Sodium	Calcium	Magnesium	Iron	Manganese
Feldspar	1.000								
Clay (size)	-.467	1.000							
Mean grain size	-.819	.826	1.000						
Potassium	-.072	.232	.200	1.000					
Sodium	.876	-.542	-.870	.004	1.000				
Calcium	-.573	.371	.651	-.239	-.677	1.000			
Magnesium	.050	-.065	.087	-.175	-.025	.502	1.000		
Iron	-.460	.611	.734	-.529	-.637	.514	.197	1.000	
Manganese	-.589	.562	.786	.232	-.762	.666	.206	.916	1.000
Phosphorous	-.588	.468	.639	.156	-.659	.600	-.100	.592	.722
Silt	-.700	.025	.551	-.050	-.781	.692	.370	.500	.648
Copper	-.479	.666	.680	.424	-.598	.365	.053	.781	.791
Zinc	-.596	.593	.741	.122	.777	.499	-.036	.708	.774
Expandable clays	-.401	.605	.602	.153	-.403	.262	.196	.369	.333
Illite	-.555	.322	.578	.188	-.665	.505	-.030	.619	.725
Kaolinite + chlorite	-.638	.319	.610	.006	-.674	.596	.184	.510	.627
Sand	.832	-.560	-.902	-.083	.939	-.772	-.270	-.745	.841

	Phosphorous	Silt	Copper	Zinc	Expandable clays	Illite	Kaolinite + chlorite	Sand
Phosphorous	1.000							
Silt	.473	1.000						
Copper	.464	.441	1.000					
Zinc	.622	.530	.763	1.000				
Expandable clays	.187	.125	.302	.424	1.000			
Illite	.683	.614	.544	.596	-.105	1.000		
Kaolinite + chlorite	.528	.695	.503	.555	.122	.774	1.000	
Sand	-.646	-.842	-.671	-.759	-.432	-.686	-.752	1.000

G.3 CORRELATION MATRIX

The relationship between the twenty-seven variables is shown in Table G-2. This matrix of simple linear correlation coefficients exhibits numerous complex interrelationships. Approximately 20% of the variable pairs show strong correlations. With twenty-seven samples used in the analysis, a correlation coefficient of greater than $|0.49|$ is significant at the 0.01 alpha confidence level; greater than $|0.60|$ is significant at the 0.001 alpha confidence level. To facilitate a brief preliminary discussion of some of the more noteworthy features of this matrix, separate tables showing significant variable pair correlations within the physical parameter grouping, within the mineralogical parameter grouping, and within the chemical parameter grouping are presented (Tables G-3 to G-5).

Among the physical parameters (Table G-3), organic matter, clay, moisture content, and mean grain size are all positively correlated with each other, whereas sand and silt are strongly inversely proportional to mean grain size, clay and organic matter. Part of these strong relationships, particularly with respect to the clay versus sand and silt parameters, is, of course, essentially a function of the closure of the data set. That is, since the percent sand plus percent silt plus percent clay must equal 100%, there would be, even in the absence of any relation between the variables, a tendency toward negative correlation (Chave and MacKenzie, 1961; Miesch, 1976; Butler, 1978, 1979).

Other relationships suggested by the physical parameter associations are fairly straightforward. It is expected that the organic content would show a good positive correlation with the percent clay and

Table G-2. Correlation coefficient matrix of 27 physical, chemical, and mineralogical surface sediment variables from 27 locations in the South Basin of Lake Manitoba (relict sand areas excluded).

	Moisture content	Depth	Organic matter	Total carbonate	pH	Eh	Total clay minerals	Quartz	Calcite	Dolomite	Feldspar	Clay (size)	Mean grain size
Moisture content	1.000												
Depth	.164	1.000											
Organic matter	.755	.404	1.000										
Total carbonates	-.217	.253	-.324	1.000									
pH	-.447	.216	-.184	.076	1.000								
Eh	-.282	-.128	-.257	.069	.169	1.000							
Total clay minerals	.511	.263	.516	.027	-.221	-.299	1.000						
Quartz	-.520	-.255	-.569	-.049	.349	.054	-.634	1.000					
Calcite	.593	.244	.551	.048	-.383	-.127	.227	-.749	1.000				
Dolomite	-.698	-.173	-.731	.311	.325	.309	-.629	.506	-.536	1.000			
Feldspar	-.579	-.308	-.249	.032	.192	.391	-.655	.607	-.496	.507	1.000		
Clay (size)	.563	.477	.716	-.413	-.083	-.047	.189	-.206	.533	-.507	-.256	1.000	
Mean grain size	.491	.351	.622	-.406	-.016	.067	.035	-.195	.521	-.247	-.542	.848	1.000
Potassium	.164	-.425	.088	-.623	-.045	.155	-.199	.030	.109	-.075	.136	.299	.296
Sodium	-.331	-.589	-.576	.030	-.219	.421	-.266	.079	-.190	.408	.239	-.399	-.253
Calcium	.158	.515	.075	.608	-.001	-.104	.277	-.554	.671	.036	-.369	-.040	-.012
Magnesium	-.519	-.543	-.753	.388	-.041	.193	-.497	.302	-.361	.831	.134	-.572	-.401
Iron	.388	-.025	.494	-.699	.020	.005	.024	-.158	.311	-.368	.046	.649	.512
Manganese	.644	.103	.639	-.593	-.197	-.243	.205	-.262	.445	-.628	-.105	.635	.473
Phosphorous	.563	.311	.620	-.149	-.070	-.193	.238	-.353	.541	-.578	-.252	.508	.394
Silt	-.007	-.302	-.340	.314	-.117	-.264	.129	-.006	-.084	.096	.178	-.666	-.842
Copper	.345	.140	.352	-.058	.001	.110	-.011	.026	.125	-.374	.017	.557	.515

Table G-2 (cont.)

	Moisture content	Depth	Organic matter	Total carbonate	pH	Eh	Total clay minerals	Quartz	Calcite	Dolomite	Feldspar	Clay (size)	Mean grain size
Zinc	.460	.349	.660	-.501	.191	-.128	.292	-.039	.020	-.502	-.084	.673	.497
Expandable clays	.223	.241	.260	-.194	-.078	-.022	-.118	.141	-.104	.096	-.102	.438	.544
Illite	.562	.195	.565	-.273	-.245	-.177	.121	-.120	.278	-.364	-.244	.623	.419
Kaolinite + chlorite	.494	.215	.496	-.216	-.245	-.159	.075	-.069	.206	-.266	-.244	.593	.403
Sand	-.437	-.212	-.528	.112	.054	.067	-.501	.565	-.514	.219	.589	-.547	-.510

Table G-2 (cont.)

	Potassium	Sodium	Calcium	Magnesium	Iron	Manganese	Phosphorous	Silt	Copper	Zinc	Expandable clays	Illite
Potassium	1.000											
Sodium	.361	1.000										
Calcium	-.399	-.084	1.000									
Magnesium	-.065	.645	.104	1.000								
Iron	.820	-.098	-.328	-.494	1.000							
Manganese	.645	-.260	-.185	-.626	.840	1.000						
Phosphorous	.222	-.549	.492	-.611	.530	.645	1.000					
Silt	-.146	.139	.168	.283	-.369	-.206	-.179	1.000				
Copper	.476	-.089	-.389	-.443	.631	.627	.191	-.287	1.000			
Zinc	.181	-.523	-.221	-.724	.536	.592	.506	-.302	.652	1.000		
Expandable clays	.146	-.149	-.062	-.079	.108	.499	.210	-.371	.074	.257	1.000	
Illite	.520	-.212	-.031	-.368	.370	.491	.538	-.161	.241	.441	.563	1.000
Kaolinite+ Chlorite	.223	-.154	-.022	-.027	.297	.401	.463	-.164	.206	.392	.601	.983
Sand	-.155	-.015	-.224	.166	-.309	-.236	-.352	.333	-.146	-.309	-.069	-.345

Table G-2 (cont.)

	Kaolinite+ Chlorite	Sand
Kaolinite+ Chlorite	1.000	
Sand	-.351	1.000

Table G-3. Significant inter-correlations among the surface sediment physical variables. ++ or -- indicates significant positive or negative correlation at .001∝ level; + or - indicates significant positive or negative correlation at .01∝ level. Data from relict sand areas not included.

	Depth	Moisture content	Organic matter	Mean grain size	Sand	Silt	Clay
Depth							
Moisture content							
Organic matter		++					
Mean grain size		+	++				
Sand			-	-			
Silt				--			
Clay		+	++	++	-	--	

the mean grain size because of the affiliation of organic matter for the finer grain sizes of the sediment. This is due, in part, to the greater adsorption capacity of the smaller particles (Tissot and Welte, 1978, p. 56) and, in part, to the lower density of the organic matter (Slatt, 1974). Likewise, the moisture content-clay relationship reflects the high porosity of the finer-grained sediment.

Among the mineralogical parameters (Table G-4), dolomite, quartz and feldspar all show significant positive correlation with each other and inverse relationships with calcite and clay minerals. Several of the mineralogical parameters show significant correlations with the physical variables. Dolomite and quartz show strong negative correlation with moisture content, clay and organic matter, whereas calcite tends to vary positively with these physical parameters. Quartz and feldspar are correlated with sand, and clay minerals with moisture content, mean grain size, and organic matter.

These physical-mineralogical variable interrelationships suggest some degree of size segregation of the various mineral components. It is generally accepted that quartz and feldspars tend to be relatively enriched in the coarser fraction of sediment (Thomas et al, 1972a; Thomas, 1969a; Sly and Thomas, 1974; Jones and Bowser, 1978), whereas clay minerals and organic matter are concentrated in the finer fractions (Frin, 1969; Thomas, 1969b; Thomas et al, 1972b; 1976). Similarly, the negative correlation between calcite and dolomite and the positive association of the clay-calcite pair seemingly can be adequately explained by invoking terminal grain size concepts. The terminal grain size of calcite, or the

Table G-4. Significant inter-correlations among the surface sediment mineralogical variables. ++ or -- indicates significant positive or negative correlation at .001α level; + or - indicates significant positive or negative correlation at .01α level. Data from relict sand areas not included.

	Total Carbonates	Calcite	Dolomite	Quartz	Feldspar	Total clay minerals	Expandable clays	Illite	Kaolinite+ Chlorite
Total Carbonates									
Calcite									
Dolomite		-							
Quartz		--	+						
Feldspar		-	+	++					
Total clay minerals			--	--	--				
Expandable clays									
Illite							+		
Kaolinite+ Chlorite							+	++	

smallest size to which calcite can be reduced by physical abrasion, is, according to Dreimanis and Vagners (1971) and further confirmed by Kennedy and Smith (1977), considerably less than that of dolomite. Consequently, according to this hypothesis, detrital calcite would respond differently to a given set of hydrodynamic conditions than dolomite. This point is discussed in greater detail in Section 6.

Few of the chemical parameters analyzed in this study show striking correlation with one another (Table G-5). Iron, manganese, copper, zinc, and phosphorous all show moderate to high positive correlation with each other and negative association with magnesium. Sodium is inversely related to phosphorous and zinc, while iron and manganese vary positively with potassium.

These intra-chemical associations offer little new insight into any possible processes or features controlling the sediment picture in the South Basin. The strong association between iron and manganese is expected because of the two metals' essentially similar chemical reactivity in freshwater systems as pointed out by numerous investigations (Wetzel, 1975, p. 251; Stumm and Morgan, 1970, page 525; Morgan and Stumm, 1965; Delfino and Lee, 1968). However, the lack of any correlation between these two elements and redox and pH changes in the sediment is puzzling since the mobility (solubility) of the various Fe and Mn compounds is believed to be, to a large degree, controlled by pH-Eh conditions (Krauskopf, 1957, chapter 10; Garrels and Christ, 1965, chapter 7; Sly and Thomas, 1974; Burns and Nriagu, 1976).

Table G-5. Significant inter-correlations among the surface sediment chemical variables. ++ or -- indicates significant positive or negative correlation at .001α level; + or - indicates significant positive or negative correlation at .01α level. Data from relict sand areas not included.

	pH	Eh	Potassium	Sodium	Calcium	Magnesium	Iron	Manganese	Phosphorous	Copper	Zinc
pH											
Eh											
Potassium											
Sodium											
Calcium											
Magnesium				++							
Iron			++			-					
Manganese			++			--	++				
Phosphorous				-	+	--	+	++			
Copper							++	++			
Zinc						--	++	+	+	++	

The phosphorous-iron and phosphorous-calcium correlations have been noted in many lake sediment investigations (e.g., Kemp et al, 1976; Williams et al, 1971a, b; Bortleson and Lee, 1972; Bortleson, 1970; Wentz and Lee, 1969; Otsuki and Wetzel, 1972) and are related to the sorption of phosphorous by Fe and Mn hydrous oxides, clay minerals and calcium carbonate.

Several of the chemical parameters show high correlation coefficients with numerous mineralogical variables. Predictably, iron and potassium both show high positive correlation with illite but inverse relationships with total carbonate, dolomite, and quartz parameters. Also, as would be expected, calcium varies positively with total carbonate and calcite but inversely with quartz. Magnesium is positively related to dolomite. The trace metals also show strong inverse relationships with carbonate.

The Fe-Mn-P-Zn group of elements show strong positive association with the physical parameters of mean grain size, organic matter, clay, and moisture content, whereas sodium and magnesium exhibit a significant inverse relationship with these physical variables.

In summary, examination of the linear correlation coefficients among twenty-seven surface sediment parameters reveals several primary and indirect interrelationships which are of potential value in helping understand the present depositional processes and sedimentary environment of the South Basin of Lake Manitoba. These associations seem to be relatively straightforward and have been demonstrated in other geolimnological or sedimentological studies. The minerals, in general, show sympathetic trends with various grain-size parameters suggesting that quartz, dolomite, and feldspar are segregated in the coarser fraction of the sediment and clay minerals and organic matter in the finer grain sizes. Elemental associations probably reflect (a) the mineralogical composition of the sediment, with, for example, sodium associated with the coarser fraction in response to a higher plagioclase feldspar component in this grain size group, and (b) the greater sorption capacity of the fine-grained clay particles for elements (and compounds containing the elements) of the Fe-Mn-P-Cu-Zn group.

G.4 FACTOR ANALYSIS

G.4.1 General Comments

The previous discussion outlined some of the more obvious interrelationships among twenty-seven physical, chemical and mineralogical attributes evaluated on the modern bottom sediments of the South Basin. The purpose of R-mode factor analysis is to simplify, summarize and possibly clarify these multivariate relationships. This is done essentially by creating a minimum number of new, hypothetical variables which are linear combinations of the original ones and contain nearly (but never exactly) the same amount of information (Jöreskog et al, 1976). Thus, each original variable can be redefined in terms of these appropriately "weighted" new variables or factors such as: $Z_j = a_{1j}F_1 + a_{2j}F_2 + \ldots + a_{mj}F_m + a_jE_j$ (Klovan, 1975); where Z_j is an original variable, and $a_{1j}F_1$, $a_{2j}F_2$ . . . are the new variables or factors. Since $a_{1j}F_1$, $a_{2j}F_2$ etc. will be common to several variables, they are termed common factors, whereas a_jE_j is a factor unique to Z_j. The "weights," a_{1j}, a_{2j}, etc. are factor loadings and the F_1, F_2, etc. are factor scores. The total statistical variance of an original variable will then be the sum of the squared loadings which is termed, in factor analysis jargon, the communality. Likewise, the total amount of variance accounted for by each new variable can be computed.

In a matrix display of the factor loadings of these m new variables (factors), the columns of the matrix can be thought of as a list of coefficients of a linear equation relating the original variables to the particular factor, while the rows will show how the variance of the particular original variable is distributed among the factors (Klovan, 1975, page 41). Thus, the values in the columns of the factor loading matrix can be used to give some kind of physical meaning or causal influence to the factor while the rows can show how the original variables interrelate with or contribute to the various factors.

Since the new variables can be thought of as linear combinations of the original variables, they are, in general terms, averages of the originals. Thus, the loading matrix, which represents simply a list of vectoral projections of the original variables onto a set of factor axes in m-dimension space, is often difficult to interpret. It is, therefore, useful to move the positions of the factor axes such that (a) each factor will have only a few variables with high loadings; (b) each original variable will have high loadings on only a few factors; and (c) for any pair of factors, few of the variables will have high loadings on both, many variables will have small loadings on both, and some variables will have high loadings on one factor but not on the other (Klovan, 1975).

This repositioning of the factor axes (rotation) will basically result in producing factor loadings which more closely approach either +1, -1 or 0 thereby facilitating a meaningful interpretation of the factors. Thus, in the rotated factor matrix, high positive loadings are indicative of a variable (or group of variables) closely related to the positive end of the factor axis, loadings near zero suggest that the variables are essentially independent of the factor, and high negative loadings indicate that the variable is strongly unrelated to the positive end of the factor axis. Each factor can then (theoretically),by the association of the particular group of original variables, be interpreted in terms of the natural processes controlling this association.

From the geological perspective, this last interpretive step is the most important in the analytical procedure. Although the extraction and solution of the derived factors can be accomplished successfully from a mathematical standpoint, if they cannot be confidently interpreted with respect to underlying causal processes or environmental significance, they are of little geologic use.

G.4.2 Results and Factor Interpretation

The results of the R-mode factor analysis of the Lake Manitoba samples is shown in Figure G-1 and Table G-6. Ten factors account for over 95% of the sample variance. However, only the factors that explain at least 5% of the variance will be considered here (after Jöreskog et al, 1976; Fogarasi and Mokievsky-Zubok, 1978). Similarly, since there is little agreement as to what constitutes a significant factor loading (Jöreskog et al, 1976) only rotated loadings of greater than $|0.5|$ will be considered in the interpretation of the factors.

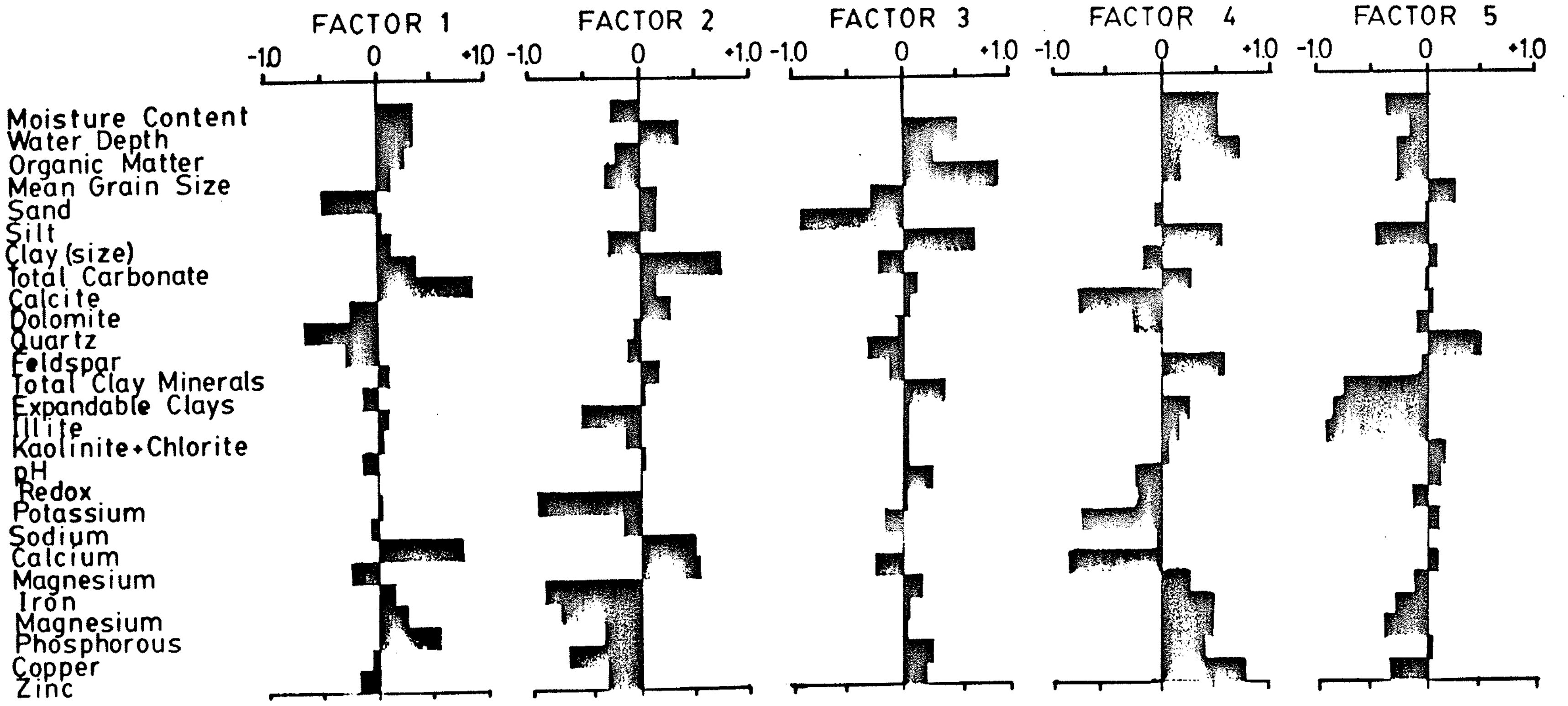


Figure G-1. Factor loadings of the first five factors extracted by R-mode analysis of the modern surface sediment of the South Basin of Lake Manitoba (data from relict sands excluded).

Table G-6. Loadings for 10 rotated factors of R-mode factor analysis of the South Basin surface sediment data (excluding relict sands).

Variables	Factors										
	1	2	3	4	5	6	7	8	9	10	Communality
Moisture content	.332	-.236	-.007	.496	-.379	-.381	-.127	.299	.022	.092	.965
Depth	.344	.378	.504	.481	-.174	.375	-.091	.017	.139	.104	.943
Organic matter	.254	-.202	.271	.688	-.309	-.150	-.096	.337	.076	.051	.934
Total carbonates	.359	.750	-.224	-.185	.055	.152	.128	-.041	-.033	.011	.970
pH	-.138	.012	.048	.037	.183	.899	.101	-.025	-.046	.039	.967
Eh	.025	-.003	.283	-.261	.109	.023	.827	-.156	-.083	-.046	.995
Total clay minerals	.100	.171	-.141	.567	.078	-.263	-.144	.589	.021	-.038	.966
Quartz	-.647	-.036	-.031	-.267	-.106	.346	-.088	-.504	-.004	-.062	.986
Calcite	.845	-.168	.114	.216	-.023	-.317	-.116	.068	.036	.254	.967
Dolomite	-.250	.257	.039	-.775	.023	.383	.095	-.157	.105	-.004	.980
Feldspar	-.271	-.101	-.323	-.038	.485	.137	.749	-.057	-.164	-.115	.967
Clay(size)	.125	-.349	.604	.505	-.496	.046	-.040	.219	.083	-.063	.965
Mean grain size	.129	-.291	.837	.177	-.292	-.004	-.078	.157	.142	.031	.986
Potassium	.035	-.919	.015	-.231	-.144	-.029	.103	.041	.025	.163	.970
Sodium	-.053	-.171	-.137	-.767	.108	-.256	.317	.175	.031	-.002	.926
Calcium	.750	.495	-.002	-.006	-.007	.151	-.157	.214	.015	.212	.968
Magnesium	-.123	.592	-.145	-.893	.082	-.014	.021	-.020	.023	-.065	.979
Iron	.129	-.890	.183	.226	-.120	.079	.042	.103	.141	.048	.935
Manganese	.245	-.752	.068	.447	-.253	-.099	-.108	.002	.131	.149	.952
Phosphorous	.547	-.300	.016	.425	-.392	.099	-.101	.054	.114	.661	.981
Silt	.028	.144	-.925	-.071	.066	-.061	-.075	-.033	.219	.111	.980
Copper	-.082	-.618	.266	.377	-.046	.019	.175	-.031	.037	-.054	.980
Zinc	-.171	-.362	.205	.700	-.273	.254	-.006	.188	.144	.125	.952
Expandable clays	-.140	.029	.387	-.010	-.755	-.109	-.022	-.131	-.055	.057	.964
Kaolinite+ chlorite	.059	-.142	.077	.135	-.919	-.092	-.079	.125	.708	.058	.972
Illite	.106	-.514	.054	.214	-.887	-.109	-.084	.114	.477	.131	.935
Sand	-.495	.155	-.287	-.015	.212	-.078	.059	-.816	-.231	-.059	.986
Percent of variability accounted for by factors:	34.6	15.2	9.7	8.4	6.9	4.2	4.0	3.4	3.1	3.0	

Factor 1, accounting for approximately 35% of the total sample variance is dominated by high positive loading on calcite, Ca, and P, and inverse negative loading on quartz and sand. This factor is interpreted as a calcite precipitation factor. Physicochemically precipitated calcite grains in lacustrine environments are typically smaller than sand size (Kelts and Hsü, 1978; Brunskill, 1969; Müller and Wagner, 1978), thus accounting for the mutual exclusion of the sand-quartz and calcite-Ca variables. Furthermore, *in situ* precipitated $CaCO_3$ has been shown to co-precipitate phosphate both by adsorption and by intercrystalline incorporation into the calcite lattice (Otsuki and Wetzel, 1972; Bortleson and Lee, 1972) thus explaining the Ca-calcite-P association.

Factor 2 explains 15% of the total variance and relates the illite-Fe-K-Cu variables at the negative end of the axis. Positive loading is shown on the total carbonate, Ca, and Mg variables. This factor is interpreted as a clay mineral factor. The Fe-K association reflects the composition of the most dominant clay mineral in the lake - illite - and the Cu variable shows the effects of this trace metal sorption onto the fine-grained clay mineral particles. The high negative loading of the Mn variable on this factor is probably a result of indirect association via the high Fe-Mn variable pair correlation.

Similarly, Factor 5 (7% of the sample variance) also seems to be reflecting the clay mineralogy variation within the basin. In this factor, high loadings are shown on the clay sized material and on the three individual clay mineral groups.

The last two factors can be interpreted as essentially energy related factors. Factor 3 (10% of the variance) is basically a grain-size factor with mean grain size and clay showing high positive loading and silt exhibiting high negative loading. Factor 4, accounting for about 8% of the sample variance, is indicative of the secondary or indirect relationship imposed by the general segregation of mineral species in particular grain size fractions. It shows high positive loading on organic matter, clay minerals, clay-sized material, moisture content, water depth,and Zn, with negative loading on dolomite, Mg, feldspar, and Na.

In summary, factor analysis of twenty-seven physical, chemical, and mineralogical variables from the South Basin surface sediments has emphasized several significant interrelationships among the variables and given some insight into the dominant factors controlling the variability of the modern bottom sediments. A factor interpreted to be indicative of calcium carbonate precipitation accounts for much of the variance in the data and is the dominant factor extracted from the correlation coefficient matrix. Further supporting evidence for this mechanism in the lake will be discussed in Section 6.3. The remaining significant factors can be related to the clay mineralogy and to the energy regime of the lake. However, in contrast to many other lacustrine depositional environment studies (e.g., Sly, 1978, 1977, 1973; Thomas et al, 1973; Mackin and Owen, 1979; Moore, 1961), bathymetry evidently does not play a dominant role in controlling the nature and pattern of sedimentation. While this may be an artifact of sampling (all sampling stations were "offshore" sites in water depths greater than 3.5 m), the extreme shallowness of the South Basin probably dictates that bathymetry is, in fact, not a major factor in controlling wave induced energy dissipation. Other energy regime factors, such as wind setup and seiches, shoreline and offshore currents, stream and groundwater influx, position in basin relative to maximum or effective wind fetch, or a combination of these factors with a 6 to 7 month ice cover, also may be more significant than bathymetry in controlling sedimentation patterns. Unfortunately, these additional factors are very difficult to quantify or predict.

APPENDIX H

Lake Manitoba water chemistry data collected at two sites in the South Basin by the Manitoba Government Water Quality Division, 1973-1977. The Delta site is located about 1 kilometre offshore (north) from the town of Delta, Manitoba; the Sandy Bay site is located about 1 kilometre offshore from a point about 7 kilometres east of the town of Amaranth, Manitoba.

DELTA SITE

Date	Temperature (°C)	Specific Cond. (micromhos/sec)	Total Dissolved Solids(mg/l)	pH	$CaCO_3$ (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	OH (mg/l)	As (mg/l)	Cd (mg/l)	Cu (mg/l)	Pb (mg/l)
8/73	22	1900	1265	8.7	203	208	19	0	0	0.02	0.01	0.02
2/74	0	2500	1600	8.2	270	329	0	0	0	nd	0.01	0.01
6/74	19	1410	770	8.3	135	150	7	0	0	0.01	0.01	0.02
3/75	0	2410	nd	8.0	286	349	0	0	0	0.00	0.00	0.01
6/75	14	1480	870	8.5	212	220	19	0	0.04	0.00	0.00	0.01
9/75	nd	1830	1060	8.7	208	205	24	0	0.04	0.00	0.00	0.01
1/76	0	2220	1260	8.2	272	322	0	0	0.04	0.00	0.00	0.01
6/76	17	1166	717	8.6	185	209	8	0	0.04	0.00	0.00	0.01
8/76	19	1628	966	8.9	194	203	11	0	0.04	0.00	0.00	0.01
10/76	7	1650	894	8.5	215	243	10	0	0.04	0.00	0.00	0.01
2/77	0	2140	1270	8.1	284	346	0	0	0.04	0.00	0.00	0.01
5/77	20	1650	984	8.6	210	232	12	0	0.00	0.00	0.01	0.01

Date	Ni (mg/l)	Zn (mg/l)	Ca (mg/l)	Mg (mg/l)	Total Hardness (mg/l)	Mn (mg/l)	Fe (mg/l)	K (mg/l)	Na (mg/l)	Total Organic Carbon (mg/l)	Total Inorganic Carbon (mg/l)
8/73	0.03	0.07	nd	68	385	0.25	0.05	nd	280	nd	nd
2/74	nd	0.01	nd	93	430	nd	nd	nd	375	21	nd
6/74	0.01	0.02	48	51	330	0.05	0.03	16	170	19	42
3/75	nd	0.00	50	80	453	0.08	0.06	26	350	17	58
6/75	nd	nd	5	60	253	0.05	0.82	18	190	14	47
9/75	nd	nd	40	56	330	0.02	0.17	18	150	17	54
1/76	nd	nd	45	76	426	0.02	0.05	24	310	16	57
6/76	nd	nd	45	42	286	0.04	0.41	15	160	16	38
8/76	nd	nd	38	56	324	0.02	0.09	19	220	17	44
10/76	nd	0.02	45	57	347	0.02	0.29	19	230	23	50
2/77	nd	nd	55	79	462	0.02	0.02	23	280	19	69
5/77	nd	nd	43	57	340	0.02	0.10	18	220	18	47

Date	Turbidity (NTU)	F (mg/l)	NH_3 (mg/l)	NO_3+NO_2 (mg/l)	Total P (mg/l)	Ortho-P (mg/l)	Cl (mg/l)	SO_4 (mg/l)	O_2 saturation (%)
8/73	16	0.40	0.10	0.20	0.02	nd	460	176	87
2/74	6	nd	nd	0.05	0.02	nd	570	260	nd
6/74	6	nd	0.02	0.03	0.04	0.03	215	110	93
3/75	3	nd	0.08	0.06	0.05	0.03	540	230	nd
6/75	20	nd	0.04	0.33	0.12	0.05	260	165	nd
9/75	6	nd	0.02	0.07	0.05	0.02	360	148	nd
1/76	2	nd	0.06	0.03	0.02	0.02	500	195	99
6/76	16	nd	0.02	0.02	0.04	0.02	200	120	92
8/76	9	nd	0.04	0.01	0.03	0.02	330	145	97
10/76	28	nd	0.18	0.83	0.08	0.02	330	155	81
2/77	1	nd	0.20	0.15	0.02	0.02	410	210	nd
5/77	3	nd	0.05	0.01	0.06	0.02	310	150	92

SANDY BAY SITE

Date	Temperature (°C)	Specific Cond. (micromhos/sec)	Total Dissolved Solids (mg/l)	pH	$CaCO_3$ (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	OH (mg/l)	As (mg/l)	Cd (mg/l)	Cu (mg/l)	Pb (mg/l)
8/73	22	1920	1260	8.7	208	225	0	0	nd	nd	0.01	0.02
3/75	0	2470	nd	8.3	286	349	0	0	nd	nd	nd	nd
6/75	15	1970	1100	8.6	226	217	29	0	nd	nd	nd	nd
9/75	nd	2020	1160	8.8	216	220	22	0	nd	nd	nd	nd
1/76	0	2150	1270	8.4	248	269	19	0	nd	nd	nd	nd
6/76	19	1377	807	8.6	200	227	0	0	nd	nd	nd	nd
8/76	18	1465	838	8.8	200	223	11	0	nd	nd	nd	nd
10/76	8	1796	1046	8.7	222	246	12	0	nd	nd	nd	nd
2/77	0	2066	1256	8.2	266	325	0	0	nd	nd	nd	nd
5/77	20	1620	958	8.6	210	227	14	0	nd	nd	nd	nd
9/77	12	1690	960	8.6	210	232	12	0	nd	nd	nd	nd

Date	Ni (mg/l)	Zn (mg/l)	Ca (mg/l)	Mg (mg/l)	Total Hardness (mg/l)	Mn (mg/l)	Fe (mg/l)	K (mg/l)	Na (mg/l)	Total Organic Carbon (mg/l)	Total Inorganic Carbon (mg/l)
8/73	nd	nd	nd	69	385	0.25	0.07	nd	280	nd	60
3/75	nd	0.16	50	80	453	nd	nd	26	340	16	51
6/75	nd	nd	35	74	392	nd	nd	21	260	15	58
9/75	nd	nd	40	61	350	nd	nd	19	280	19	54
1/76	nd	nd	45	78	433	nd	nd	29	310	17	42
6/76	nd	nd	40	48	297	nd	nd	17	190	19	45
8/76	nd	nd	60	58	388	nd	nd	18	190	25	50
10/76	nd	nd	43	58	344	nd	nd	20	220	23	51
2/77	nd	nd	50	75	433	nd	nd	22	280	21	45
5/77	nd	nd	40	57	334	nd	nd	18	210	22	47
9/77	nd	nd	50	65	391	nd	nd	18	235	26	47

Date	Turbidity (NTU)	F (mg/l)	NH_3 (mg/l)	NO_3+NO_2 (mg/l)	Total P (mg/l)	Ortho-P (mg/l)	Cl (mg/l)	SO4 (mg/l)	O_2 saturation (%)
8/73	14	0.44	0.07	0.22	0.02	0.03	470	180	95
3/75	1	nd	0.06	0.04	0.08	0.02	530	228	nd
6/75	4	nd	0.07	0.08	0.03	0.02	400	170	93
9/75	9	nd	0.02	0.74	0.04	0.03	400	155	nd
1/76	1	nd	0.05	0.03	0.03	0.02	510	190	94
6/76	1	nd	0.35	0.11	0.04	0.02	250	190	95
8/76	6	nd	0.40	0.01	0.16	0.02	280	145	93
10/76	15	nd	0.02	0.07	0.06	0.02	370	160	84
2/77	2	nd	0.17	0.09	0.20	0.02	410	200	nd
5/77	5	nd	0.03	0.01	0.12	0.02	310	150	95
9/77	60	nd	0.04	0.14	0.02	0.02	325	164	89

APPENDIX I

Core Descriptions

The following appendix provides a description of the sediment recovered from each coring site and lists other miscellaneous field and location data for each site. The initials JTT, CTS, and WML refer to Dr. J. T. Teller, Dr. C. T. Shay, and the author respectively. The descriptions are based on visual examination of the sediment and therefore the textural aspect of the descriptions may not always precisely correspond to the results of the laboratory grain size analyses listed in Appendix E. The locations of sample sites are given in kilometres distance along a particular bearing from either the towns of Delta or Oak Point, Manitoba. Refer to Figure 2-1 for location of cores.

CORE NUMBER:	1	Field Location:	9.65 km from Delta at 294°
Date Acquired:	2/4/78	Water Depth: (corrected relative to long-term mean)	3.65 m
Date Extruded and Described:	2/4/78	Ice Thickness:	94 cm
Date Frozen:		Photographs:	4
Date Thawed:		Subsamples:	21
Date Subsampled:	2/16/78	Subsample ID #:	133 - 153
Acquired by:	JTT, CTS, WML	Described by:	JTT, WML

Field Comments: Drive 85 cm, recovered 52 cm

Depth (cm from top of core)	Description
0 - 52	Sand, fine to medium, v. dk. gray (2.5 Y 3/0); Top has a black rind probably the result of coring; mollusk shell fragments throughout.

CORE NUMBER:	2	Field Location:	13.27 km from Delta at 325°
Date Acquired:	2/4/78	Water Depth: (corrected relative to long-term mean)	4.77 m
Date Extruded and Described:	2/4/78	Ice Thickness:	94 cm
Date Frozen:	-	Photographs:	-
Date Thawed:		Subsamples:	10
Date Subsampled:	5/5/78	Subsample ID #:	715 - 724
Acquired by:	JTT, CTS, WML	Described by:	WML, JTT

Field Comments: Drive 13 cm, hard bottom, difficult coring, bent square rod.

Depth (cm from top of core)	Description
0 - 20	Sand, medium to fine, black (5Y 2.5/2) to dk. grayish brouwn (2.5Y 4/2); shell fragments thoroughout, organic-rich in lower 5 cm.

CORE NUMBER: 3

Field Location: 19.71 km from Delta at 325°

Date Acquired: 2/5/78

Water Depth: 4.84 m (corrected relative to long-term mean)

Date Extruded and Described: 2/5/78

Ice Thickness: 92 cm

Date Frozen:

Photographs: -

Date Thawed:

Subsamples: 23

Date Subsampled: 5/5/78

Subsample ID #: 725 - 747

Acquired by: JTT, CTS, WML

Described by: WML, JTT

Field Comments: Drive 71 cm, recovered 63 cm, sight Langruth at 299°.

Depth (cm from top of core)	Description
0 - 11	Silt, sandy; dark greenish gray (5GY 4/1); highly fossil.., gradational lower contact.
11 - 57	Sand, silty, fine to medium at 20 - 25 cm, becomming finer or more silty with depth; dark gray (5Y 4/1); fossils to 18 cm, none observed below; sharp lower contact.
53 - 63	Silt, clayey to clay, silty; dark greenish gray (5GY 4/1); sticky, slightly blocky at upper contact; numerous root fibers at contact and at 60-61 cm.

CORE NUMBER:	4	Field Location:	20.93 km from Delta at 343°
Date Acquired:	2/5/78	Water Depth:	5.89 m (corrected relative to long-term mean)
Date Extruded and Described:	2/5/78	Ice Thickness:	96 cm
Date Frozen:		Photographs:	-
Date Thawed:		Subsamples:	27
Date Subsampled:	5/5/78	Subsample ID #:	1181 - 1207
Acquired by:	JTT, CTS, WML	Described by:	WML , JTT

Field Comments: Drive 96 cm, recovered 80 cm

Depth (cm from top of core)	Description
0 - 80	Clay, silty; dark gray (5Y 4/1); fossils throughout; shell concentration at 20-21, 72-74; 3.5 cm limestone grain at 13-15, several limestone grains (1-2 cm) at 15-16 cm.

CORE NUMBER: 5

Date Acquired: 2/5/78

Date Extruded and Described: 2/5/78

Date Frozen:

Date Thawed:

Date Subsampled: 5/5/78

Acquired by: JTT, CTS, WML

Field Location: 19.30 km from Delta at 2°

Water Depth: 5.47 m (corrected relative to long-term mean)

Ice Thickness: 98 cm

Photographs: -

Subsamples: 32

Subsample ID #: 1124a - 1155

Described by: WML, JTT

Field Comments: Drive 100 cm, recovered 92 cm.

Depth (cm from top of core)	Description
0 - 92	Clay, silty; gray (5Y 4.5/1), scattered fossils to 60 cm.

CORE NUMBER: 6	Field Location: 15.28 km from Delat at 13°
Date Acquired: 2/5/78	Water Depth: 5.20 m (corrected relative to long-term mean)
Date Extruded and Described: 2/5/78	Ice Thickness: 98 cm
Date Frozen: 2/5/78	Photographs: -
Date Thawed: 4/26/78	Subsamples: 4
Date Subsampled: 6/18/78	Subsample ID #: 1297 - 1301
Acquired by: JTT, CTS, WML	Described by: WML

Field Comments: Drive 100 cm, stong smell of H_2S, sight Delta 199°, Diversion 209°.

Depth (cm from top of core)	Description
0 - 96 cm	Clay, silty; gray (5Y 4.5/1) uniform throughout, several concentations of shells..

CORE NUMBER: 7

Field Location: 11.26 km from Delta at 16°

Date Acquired: 2/5/78

Water Depth: 4,6m
(corrected relative
to long-term mean)

Date Extruded
and Described: 2/5/78

Ice Thickness: 99cm

Date Frozen: 2/5/78

Photographs: -

Date Thawed: 2/27/78

Subsamples: 30

Date Subsampled: 2/27/78

Subsample ID #: 1 - 30

Acquired by: JTT, CTS, WML

Described by: WML

Field Comments: full drive, site diversion and tower.

Depth (cm from top of core)	Description
0 - 86	Clay, silty; very soft, dark gray (5Y 4/1), shell fragments abundant throughout.

CORE NUMBER: 8

Field Location: 6.84 km from Delta at 314°

Date Acquired: 2/6/78

Water Depth: 4.5 m (corrected relative to long-term mean)

Date Extruded and Described: 2/6/78

Ice Thickness: 92 cm

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 4/22/78

Subsamples: 27

Date Subsampled: 4/22/78

Subsample ID #: 1156 - 1180

Acquired by: JTT , WML

Described by: JTT, WML

Field Comments: full drive but lost about 10 cm ? off bottom, also questionable top because of possible disturbance.

69 cm recovered.

Depth (cm from top of core)	Description
0 - 69	clay, silty; dark gray (5Y 4/1); occasional mollusks.

CORE NUMBER: 9

Field Location: 8.0 km from Delta at 342°

Date Acquired: 2/6/78

Water Depth: 5.1 m (corrected relative to long-term mean)

Date Extruded and Described: 2/6/78

Ice Thickness: 97 cm

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 4/22/78

Subsamples: 14

Date Subsampled: 4/22/78

Subsample ID #: 1268 - 1281

Acquired by: JTT, WML

Described by: WML

Field Comments: Drive 90 cm, recovered 83 cm ; difficult driving in lower 10cm.

Depth (cm from top of core)	Description
0 - 83	clay, silty; gray (5Y 4.5/1), upper 3 cm very high moisture content, several shell concentrations, lower 2 cm is silty to fine sand, dark greenish gray (5GY 4/1).

CORE NUMBER: 10

Field Location: 28.16 km from Delta at 11°

Date Acquired: 2/6/78

Water Depth: 5.8 m (corrected relative to long-term mean)

Date Extruded and Described: 2/6/78

Ice Thickness: 98 cm

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 4/22/78

Subsamples: 17

Date Subsampled: 4/22/78

Subsample ID #: 1222 - 1238

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: full drive, recovered 90 cm

Depth (cm from top of core)	Description
0 - 90	Clay, silty; dark gray (5Y 4/1) firmer in lower half of core, fewer fossils from 65 1- 85 cm, many shells from 85 - 90.

CORE NUMBER: 11	Field Location: 24.14 km from Delta at 29°
Date Acquired: 2/6/78	Water Depth: 5.1 m (corrected relative to long-term mean)
Date Extruded and Described: 2.6.78	Ice Thickness: 99 cm
Date Frozen: 2/6/78	Photographs: -
Date Thawed: 4/22/78	Subsamples: 5
Date Subsampled: 4/22/78	Subsample ID #: 1292-1296
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: full drive, full recovery

Depth (cm from top of core)	Description
0 - 100	Clay, silty; gray (5Y5/1) lower half of core is firm, lower 10 cm has very few shells, upper 20 cm very soft.

CORE NUMBER: 12	Field Location: 20.11 km from Delta at 21°
Date Acquired: 2/6/78	Water Depth: 4.8 km (corrected relative to long-term mean)
Date Extruded and Described: 2/6/78	Ice Thickness: 99 cm
Date Frozen: 2.6.78	Photographs: -
Date Thawed: 5/12/78	Subsamples: 34
Date Subsampled: 5/12/78	Subsample ID #: 99 - 132
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: Full drive, recovered 98 cm.

Depth (cm from top of core)	Description
0 - 98	Clay, silty; darkegray (5Y 4/1) firmer in lower 50 cm.

CORE NUMBER: 13

Date Acquired: 2/6/78

Date Extruded and Described: 2/6/78

Date Frozen: 2/6/78

Date Thawed: 4/11/78

Date Subsampled: 64/11/78

Acquired by: JTT, WML

Field Location: 16.89 km from Delta at 36°

Water Depth: 4.7 m (corrected relative to long-term mean)

Ice Thickness: 1.02 m

Photographs: -

Subsamples: 35

Subsample ID #: 64 - 98

Described by: JTT, WML

Field Comments: full drive, full recovery

Depth (cm from top of core)	Description
0 - 100	Clay, silty; dark gray (5Y 4/1) several distinct shell zones at 27.0 - 27.5 cm, 69.0 - 70.5, cm, 79.0 - 80.0 cm, and 84.5 - 85.0 cm; thin clay laminae at 96.0 - 96.3 cm, moderately firm throughout.

CORE NUMBER: 14

Field Location: 10.48 km from Delta at 30°

Date Acquired: 2/6/78

Water Depth: 4.5 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 2/6/78

Ice Thickness: 1 m

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 5/12/78

Subsamples: 5

Date Subsampled: 5/12/78

Subsample ID #: 1287 - 1291

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: full drive, full recovery.

Depth (cm from top of core)	Description
0 - 100	clay, silty; very dark gray (5Y 3/1) upper 12 cm verly soft, scattered mollusk shell throughout, lower 90 cm is slightly darker (5Y 4/1).

CORE NUMBER: 15

Field Location: 5.63 km from Delta at 15°

Date Acquired: 2/6/78

Water Depth: 4.5 m (corrected relative to long-term mean)

Date Extruded and Described: 2/6/78

Ice Thickness: 97 cm

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 5/12/78

Subsamples: 5

Date Subsampled: 5/12/78

Subsample ID #: 1302 - 1306

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive, recovered 84 cm.

Depth (cm from top of core)	Description
0 - 84	Clay, silty dark gray (5Y4/1) occasional mollusks.

CORE NUMBER: 16

Field Location: 3.06 km from Delta at 14°

Date Acquired: 2/6/78

Water Depth: 4.3 m (corrected relative to long-term mean)

Date Extruded and Described: 2/6/78

Ice Thickness: 97 cm

Date Frozen: 2/6/78

Photographs: -

Date Thawed: 4/15/78

Subsamples: 14

Date Subsampled: 4/15/78

Subsample ID #: 1208 - 1221

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive, recovered 73 cm; lost measuring tape end.

Depth (cm from top of core)	Description
0 - 73	Clay, slightly silty, dark gray (5Y 4/1) upper 10 cm very soft, scattered shells throughout..

CORE NUMBER:	17	Field Location:	12.06 km from Oak Point at 180^c
Date Acquired:	2/7/78	Water Depth: (corrected relative to long-term mean)	5.2 m
Date Extruded and Described:	2/8/78	Ice Thickness:	109 cm
Date Frozen:	2/8/78	Photographs:	-
Date Thawed:	4/23/78	Subsamples:	30
Date Subsampled:	4/23/78	Subsample ID #:	1094 - 1124
Acquired by:	JTT, WML1;	Described by:	JTT, WML

Field Comments: Full drive, recocvered 96 cm, three attempts because the piston was tkoo loose.

Depth (cm from top of core)	Description
0 - 96	Clay, silty; dark gray (5Y 4/1), abundant scattered mollusk shells, concentation at 28.0 - 30.0., roots and fibers at 80 cm.

CORE NUMBER:	18	Field Location:	8.04 km from Oak Point at 214°
Date Acquired:	2/7/78	Water Depth: (corrected relative to long-term mean)	5.8 m
Date Extruded and Described:	2/8/78	Ice Thickness:	109 cm
Date Frozen:	2/8/78	Photographs:	-
Date Thawed:	5/16/78	Subsamples:	32
Date Subsampled:	5/16/78	Subsample ID #:	1062 - 1093
Acquired by:	JTT, WML	Described by:	JTT, WML

Field Comments: full drive, recovered 94 cm

Depth (cm from top of core)	Description
0 - 94	Clay, silty, dark gray (5Y 4/1), shells throughout, live worm-like organism (Nematode ?) at 5 cm depth.

CORE NUMBER: 19

Field Location: 11.28 km from Oak Point at 265°

Date Acquired: 2/7/78

Water Depth: 5.6 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 2/8/78

Ice Thickness: 1 m

Date Frozen: 2/8/78

Photographs: -

Date Thawed: 2/14/ 78

Subsamples: 32

Date Subsampled: 2/14/78

Subsample ID #: 31 - 63

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive, recovered 98 cm, water temperatures: bottom:- 4.5°, 5.5 m:- 4.5°, 5.0 m: 4.0°, 4.5 m: 3.0°, 4.0 m: 2.6°, 3.5 m: 2.2°, 3.0 m: 2.4°, 2.5 m: 1.9°, 2.0 m: 2.0°, 1.5 m: 1.5°, 1.0 m: 0.5°

Depth (cm from top of core)	Description
0 - 98	Clay, silty, gray (5Y 4.5/1), scattered mollusk shells, shell concentration zone at 73.0 - 76.0 cm

CORE NUMBER: 20

Field Location: 8.05 km from Oak Point at 266°

Date Acquired: 2/7/78

Water Depth: 4.1 m (corrected relative to long-term mean)

Date Extruded and Described: 2/8/78

Ice Thickness: 96 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 3

Date Subsampled: 2/8/78

Subsample ID #: 912 - 914

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: drive 22 cm, did not pound, recovered about 6 cm; water temperatures: 3.5 m: 4.0°, 3.0 m: 2.6°, 2.5m, 2.0 m 1.5 m : 1.6°, 1.0 m: 0.5°

Depth (cm from top of core)	Description
0 - about 6 cm	Gravel, sandy, and clay, sandy and silty; dark gray (5Y 4/1), pebbles to 3 cm diameter, carbonate and mafic igneous grains, entire core is disturbed, not certain of stratigraphic relationships.

CORE NUMBER: 21

Field Location: 3.22 km from Oak Point at 272°

Date Acquired: 2/7/78

Water Depth: 3.0 m (corrected relative to long-term mean)

Date Extruded and Described: 2/8/78

Ice Thickness: 97 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 11

Date Subsampled: 2/8/78

Subsample ID #: 850 - 860

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: f drive 27 cm recovered 27 cm; water temperatures: 2.0 m: 3.0°, 1.0 m: 1.1°

Depth (cm from top of core)	Description
0 - 8	Gravel, sandy, high carbonate content of grains, sharp lower contact, fibers and rootlets at contact.
8 - 26 cm	Clay, silty, occasional sand grains, very firm, sticky, drier feel, dark greenish gray (5GY 4/1), abundant root fibers (interpreted as root fibers by Nambudiri) several carbonate grains up to 1 cm in diameter.
26 - 27	clay, gravelly, sandy, 5 Y 2.5/1.

CORE NUMBER: 22

Field Location: 19.33 km from Oak Point at 270°

Date Acquired: 2/21/78

Water Depth: 5.7 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 2/22/78

Ice Thickness: 94 cm

Date Frozen: 2.22.78

Photographs: -

Date Thawed: 3/14/78

Subsamples: 5

Date Subsampled: 3/14/78

Subsample ID #: 1282-1286

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: full drive to 1 m, full recovery; full drive to 2 m, recovered 97 cm, water temperatures: bottom: 3.2°, 5.5 m, 5.0m, 4.5 m, 4.0 m, 3.5 m, 3.0 m, 2.5 m, 2.0 m:1.1°, 1.5 m: 0.2°

Depth (cm from top of core)	Description
0 - 100	Clay, silty, dark gray (5Y 4/1), firm at base, scattered mollusk shells.
100 - 197	clay, as above, fewer shells.

CORE NUMBER: 23

Field Location: 20.94 km from Oak Point at 288°

Date Acquired: 2/21/78

Water Depth: 5.9 m (corrected relative to long-term mean)

Date Extruded and Described: 2/21/78

Ice Thickness: 89 cm

Date Frozen: -

Photographs: 5

Date Thawed: -

Subsamples: 51

Date Subsampled: 2/22/78

Subsample ID #: 484 - 536

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive to 1 m, recovered 1 m; full drive to 2 m, recovered 1 m; drive 200 - 265 cm, recovered 65 cm; Water temperatures: bottom: 4.0°, 5.5 m: 3.6°, 5.0 m: 2.5°, 4.5,m, 4.0, 3.5 m, 3.0 m, 2.5m and 2.0 m: 0.3°, 1.5 m, and 1.0 m: 0.4°. Core from 0-100 cm given to D. Slater for pollen before subsampling and pH and Eh measurements taken.

Depth (cm from top of core)	Description
0 - 100	Clay, silty; dark gray (5Y 4/1), no visible laminae lupper 10 cm soupy grading to firm at base of core, scattered shells throughout with a zone of high concentration at 10 - 23 cm.
100 - 200	Clay as above except fewer shellswith no observed shells below 150 cm.
200 - 257.5	AClay, as above except grading to gray (5Y 4.5/1) below 216 cm; no shells.
257.5 - 265	Composed of clay spherules and pellets nearly spherical and very well rounded, maximum size of the pellets is 9 mm, minimum size is 1 mm, pellets do not have any laminae or nuclei, and are in a clay matrix, dark greenish gray (5GY 4/1), sediment is friable and breaks apart easily, dry, sticky feel.

CORE NUMBER: 24	Field Location: 22.55 km from Oak Point at 305°
Date Acquired: 2/21/78	Water Depth: 5.9 m (corrected relative to long-term mean)
Date Extruded and Described: 2/21/78	Ice Thickness: 87 cm
Date Frozen: -	Photographs: -
Date Thawed: -	Subsamples: 29
Date Subsampled: 2/23/78	Subsample ID #: 1239 - 1267
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: Full drive to 1 m, full recovery; full drive to 2 m, full recovery; Water temperatures: bottom: 4.3°, 5.0 m: 2.5°, 4.5 m, 4.0m, 3.5 m, 3.0 m, 2.5 m: 0.7°, 2.0 m, 1.5 m, and 1.0 m: 0.2°.

Depth (cm from top of core)	Description
0 - 100	Clay, silty, dark gray (5Y 4/1) scattered shells throughout with greatest abundance in upper 50 cm.
100 - 200	Clay as above except fewer shells, very weakly laminated in lower25 cm, slightly lighter color below 150 cm but not different than5Y 4/1.

CORE NUMBER: 25

Field Location: 16.91 km from Oak Point at 296°

Date Acquired: 2/21/78

Water Depth: 5.6 m (corrected relative to long-term mean)

Date Extruded and Described: 2/21/78

Ice Thickness: 98 cm

Date Frozen: 2/21/78

Photographs: -

Date Thawed: 3/22/78

Subsamples: 38

Date Subsampled: 3/22/78

Subsample ID #: 1024 - 1061

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive to 1 m, recovered 94 cm; drive 100 - 126 cm recovered 26 cm; Water temperatures: bottom: 4.9°, 5.0 m, 4.5 m, 4.0 m, and 3.5 m: 3.5°, 3.5 m, 3.0 m, 2.5 m, and 2.0 m: 1.3°, 1.5 m and 1.0 m: 0.4°.

Depth (cm from top of core)	Description
0 - 94	Clay, silty, gray (5Y 4.5/1) upper 12 cm very fluid, abundant mollusk shells with zones of concentration at 62.0 - 63.0 and 28.0 - 31.0., firmer at base,
94 - 100	missing
100 - 125	Silt, slightly sandy and clayey, dark gray (5Y 4/1), mollusk shells scattered throughout, occasional coarser grains near base, sharp lower contact.
125 - 126	silt, pebbly, sandy, clayey, dark gray (5Y 4/1), carbonate pebbles up to 15 mm in diameter.

CORE NUMBER: 26

Field Location: 16.91 km from Oak Point at 264°

Date Acquired: 2/22/78

Water Depth: 5.9 m (corrected relative to long-term mean)

Date Extruded and Described: 2/23/78

Ice Thickness: 89 cm

Date Frozen: 2/23/78

Photographs: -

Date Thawed: 3/22/78

Subsamples: 58

Date Subsampled: 3/22/78

Subsample ID #: 915 - 972

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive to 1 m, recovered 98 cm; full drive to 2 m, recovered 92 cm, full drive to 3 cm, recovered 99 cm drive to 325, recovered 25 cm; Water temperatures: bottom: 5.1°, 5.5 m, 5.0 m, 4.5 m: 4.0°, 4.0 m, 3.5 m: 3.1°, 3.0m: 1.3°, 2.5m, 2.0 m, 1.5 m, and 1.0 m: 1.2°.

Depth (cm from top of core)	Description
o - 98	Clay, silty, dark gray (5Y 4/1), scattered shell fragments, possible burrow at 52 - 57 cm.
98 - 100	missing
100 - 192	Clay as above
192 - 200	missing
200 - 298	Clay as aboveaexcept few shells, very weak color banding in lower 58 cm with "carbonaceous" lenses at 286 cm, 271 - 273 cm and 273.5 - 274 cm; also below 267 is generally slightly darker color.
298 - 300	missing
300 - 312	clay as above except no shells.
312 -325	Clay, silty, very dark gray (5Y 3/1) to dark greenish gray (5GY 4/1), much lower water content, sticky, several shell fragments, very distinctive structure, angular, blocky, "fitted together", easily disaggragated but below 320 cm does not fall apart easily, root fibers at 313.

CORE NUMBER: 27

Field Location: 14.50 km from Oak Point at 240°

Date Acquired: 2/22/78

Water Depth: 5.5 m (corrected relative to long-term mean)

Date Extruded and Described: 2/23/78

Ice Thickness: 90 cm

Date Frozen: 2/24/78

Photographs: -

Date Thawed: 3/12/78

Subsamples: 48

Date Subsampled: 3/12/78

Subsample ID #: 802 - 849

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Full drive to 1 m, recovered 91 cm; full drive to 2 m, recovered 89 cm, drive to 257 cm, recovered 57 cm; Water temperatures: bottom: 5.2°, 5.0 m: 3.9°, 4.5 m: 3.0°, 4.0 m, 3.5 m, 3.0 m, 2.5m, and 2.0 m: 1.3°, 1.5 m and 1.0 m: 1.2°.

Depth (cm from top of core)	Description
0 - 91	Clay, silty, dark gray (5Y 4/1), abundant shells.
91 - 100	missing
100 - 189	Clay as above except fewer shells.
189 - 200	missing
200 - 240	Clay, as above.
240 - 257	Clay, silty, dark greenish gray (5GY 4/1) to dark gray (5Y 4/1), dry, blocky structure with some small pellets, gradational upper contact from 240 to 244.

CORE NUMBER: 28	Field Location: 28.19 km from Oak Point at 282°
Date Acquired: 2/23/78	Water Depth: 6.1 m (corrected relative to long-term mean)
Date Extruded and Described: 2/24/78	Ice Thickness: 90 cm
Date Frozen: 2/24/78	Photographs: -
Date Thawed: 3/12/78	Subsamples: 52
Date Subsampled: 3/12/78	Subsample ID #: 537 - 588
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: Full drive to 1 m, full recovery; full drive to 2 m, recovered 96 cm, full drive to 3 m, recovered 96 cm; Water temperatures: bottom: 5.1°, 5.5 m, and 5.0 m: 4.8°, 4.5 m: 1.5°, 4.0 m, 3.5 m, 3.0 m, 2.5 m, 2.0 m and 1.5 m: 1.4°, 1.0 m: 1.5°

Depth (cm from top of core)	Description
0 - 100	Clay, silty, dark gray (5Y 4/1), soupy in upper 10 cm, occasional shells throughout but more abundant from 10 - 35 cm, shell concentation at 26.0 - 34.0 cm, a 1 mm lighter gray laminae at 66 cm.
100 - 196	Clay as above, no mollusk shells observed below 173 cm.
196 - 200	missing
200 - 290	Clay as above.
290 - 296	Clay, silty, dark greenish gray (5GY 4/1), drier, finer, darker than above, angular blocky strucuture is well developed in upper becoming less well developed in lower, shells present.

CORE NUMBER: 29 (see D-1)

Field Location: (same as D-1)

Date Acquired:

Water Depth:
(corrected relative
to long-term mean)

Date Extruded
and Described:

Ice Thickness:

Date Frozen:

Photographs:

Date Thawed:

Subsamples:

Date Subsampled:

Subsample ID #:

Acquired by:

Described by:

Field Comments:

Depth (cm from top of core)	Description	Unit Interpretation

CORE NUMBER:	30	Field Location:	8.05 km from Delta at 325°
Date Acquired:	3/10/ 78	Water Depth:	3.9 m (corrected relative to long-term mean)
Date Extruded and Described:	3/10/ 78	Ice Thickness:	104 cm
Date Frozen:	-	Photographs:	-
Date Thawed:	-	Subsamples:	1
Date Subsampled:	3/12/78	Subsample ID #:	641
Acquired by:	WML	Described by:	WML

Field Comments: Drive 20 cm, recovered 5 cm, core fell out of core barrel onto ice, uncertain stratigraphic relationships.

Depth (cm from top of core)	Description
0 - 5	Sand, fine grained, high "carbonaceous" content.

CORE NUMBER: 31

Field Location: 8.86 km from Delta at 330°

Date Acquired: 3/10/78

Water Depth: 4.5 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 3/10/78

Ice Thickness: 144 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 18

Date Subsampled: 3/12/78

Subsample ID #: 894 - 911

Acquired by: WML

Described by: WML

Field Comments: Drive 75 cm, recovered 49 cm, bottom 8 cm fell out of core barrel onto ice.

Depth (cm from top of core)	Description
0 - 48	Clay, silty, dark gray (5Y 4/1), scattered shells throughout, upper 13 cm soupy.
48 - 49	clay, sandy, silty, dark gray (5Y 4/1), no shells.

CORE NUMBER: 32

Field Location: 17.72 km from Delta at 339°

Date Acquired: 3/10/78

Water Depth: 5.3 m (corrected relative to long-term mean)

Date Extruded and Described: 3/10/78

Ice Thickness: 104 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 26

Date Subsampled: 3/12/78

Subsample ID #: 654 - 679

Acquired by: WML

Described by: WML

Field Comments: Full drive, recovered 90 cm; Water temperatures: bottom and 5.0 m: 5.2°, 4.5 m, 4.0 m, 3.5m and 3.0 m: 2.8°, 2.5 m: 2.0°, 2.0 m: 1.2°, 1.5 m and 1.0 m: 1.0°.

Depth (cm from top of core)	Description
0 - 49	Clay, slightly silty, dark gray (5Y 4/1), scattered mollusk shells throughout, greater abundance at 38 - 49 cm, concentation at 45.5 cm, sharp lower contact.
49 - 64	sand, medium to fine grained, 5Y 3.5/1, becoming slightly finer at base.
64 - 72	silt, sandy and silty sand, dark gray (5Y 4/1).

CORE NUMBER: 33

Field Location: 18.52 km from Delta at 310^0

Date Acquired: 3/10/78

Water Depth: 4.5 m (corrected relative to long-term mean)

Date Extruded and Described: 3/10/78

Ice Thickness: 112 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 12

Date Subsampled: 3/12/78/

Subsample ID #: 642 - 653

Acquired by: WML

Described by: WML

Field Comments: drive 37 cm, recovered 25 cm

Depth (cm from top of core)	Description
0 - 22	Clay, silty, dark gray (5Y 5/1), upper 8 cm soupy, soft throughout, abundant shells, mainly shell fragments below 10 cm, several large gastropod shells near base.
22 - 25	Clay, pebbly, sandy, 5Y 5/1, sharp upper contact, pebbles to 1 cm in diameter, mainly carbonate grains, very poorly sorted, shelly.

CORE NUMBER: 34

Field Location: 5.64 km from Delta at 280°

Date Acquired: 3/10/78

Water Depth: 3.9 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 3/10/78

Ice Thickness: 125 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 33

Date Subsampled: 3/12/78

Subsample ID #: 861 - 893

Acquired by: WML

Described by: WML

Field Comments: Full drive to 1 m, recovered 94 cm; drive to 110 cm, recovered 5 cm.

Depth (cm from top of core)	Description
0 - 26	silt, clayey dark gray (5Y 4/1), scattered shells and shell fragments throughout, upper 5 cm soupy, becaming less clayey at base.
26 - 32	sand, silty, fine to very fine grained, slightly darker than above, scattered shell fragments, abundannt black specks.
32 - 42	Silt, sandy and clayey, finer than above, an 8 mm diameter carbonate pebble at 34 cm, less sand content, slightly lighter.
42 - 91	Sand, slightly silty, sharp upper contact is both textural and color, 2 cm silt-rich laminae at 72.5 - 74.5 cm, slight color change from 5Y 3/2 to 5Y 4/1 below 75 cm.
91 - 94	Clay, silty and silty, clayey, dark gray (5Y 4/1)
94 - 100	missing
100 - 105	sand, silty, dark gray (5Y 4/1), fossil fragments.

CORE NUMBER: 35

Field Location: 2.42 km from Delta at 129°

Date Acquired: 3/10/78

Water Depth: 1.9 m
(corrected relative
to long-term mean)

Date Extruded
and Described: 3/10/78

Ice Thickness: 94 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 20

Date Subsampled: 3/12/78

Subsample ID #: 748 - 767

Acquired by: WML

Described by: WML

Field Comments: Site in Cadham Bay of Delta Marsh, drive 53 cm, full recovery.

Depth (cm from top of core)	Description
0 - 18	Clay, silty and sand y, 5Y 3/1 , few shell fragments, abundant root fibers throughout.
18 - 37	Clay slightly silty, sharp upper contact, color change, 5Y 6/1, abundant black streaks, abundant fibers, firm, sticky, low moisture content, dry, gradational lower contact.
37 - 53	Clay, silty, mainly a color contrast, "oxidized" color: 2.5Y 5/2 to 2.5Y 5/4 and 5Y 4/1, abundant roots at 37 - 40 cm.

CORE NUMBER: 36	Field Location: 3.22 km from Delta at 285°
Date Acquired: 3/10/78	Water Depth: 4.2 m (corrected relative to long-term mean)
Date Extruded and Described: 3/10/78	Ice Thickness: 110 cm
Date Frozen: -	Photographs: -
Date Thawed: -	Subsamples: 5
Date Subsampled: 3/12/78	Subsample ID #: 1307 - 1311
Acquired by: WML	Described by: WML

Field Comments: Full drive to 1 m, recovered 89 cm, very difficult driving in last 10 cm.

Depth (cm from top of core)	Description
0 - 89	Clay, very silty, dark gray (5Y 4/1), black streaks in upper 10 to 15 cm, considerably more clay rich at base, scattered mollusk shells.

CORE NUMBER: 37	Field Location: 13.69 km from Delta at 36°
Date Acquired: 3/11/78	Water Depth: 4.6 m (corrected relative to long-term mean)
Date Extruded and Described: 3/11/78	Ice Thickness: 123 cm
Date Frozen: -	Photographs: -
Date Thawed: -	Subsamples: 51
Date Subsampled: 3/12/78	Subsample ID #: 973 - 1023
Acquired by: WML	Described by: WML

Field Comments: Full drive to 1 m, recovered 84 cm,; full drive to 2 m, recovered 97 cm; drive to 297, recovered 91 cm.

Depth (cm from top of core)	Description
0 - 84	Clay, silty, dark gray (5Y 4/1), scattered shells, upper 2 cm soupy, black bone or shell 4cm long at 82 cm.
84 - 100	missing
100 - 197	Clay,as above, shell concentzation at 104 - 105 cm, below 150 becomes slightly more silt-rich, sandy shell-rich laminae at 166 cm, subtle textural change at 170 cm becoming less silty below, large (3 cm) shell at 165, scattered to abundant shells throughout.
197 - 200	missing
200 - 276	Silt, slightly sandy and clayey, dark gray (5Y 4/1) no shells observed below 215 cm.
276 - 289	Silt, clayey, 5Y 3/1, very weakly laminated.
289 - 291	Silt, clayey, dark greenish gray (5GY 4/1), blocky structure, dry, some pellets, sticky, crumbly.

CORE NUMBER: 38

Field Location: 24.16 km from Delta at 36°

Date Acquired: 3/11/78

Water Depth: 5.0 m (corrected relative to long-term mean)

Date Extruded and Described: 3/11/78

Ice Thickness: 115 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 60

Date Subsampled: 3/13/78

Subsample ID #: 589 -640

Acquired by: WML

Described by: WML

Field Comments: Full drive to 1 m; recovered 93 cm; full drive to 2 m, recovered 98 cm; drive to 285, full recovery; Water temperatures: bottom: 5.9°, 4.5 m: 2.8°, 4.0, 3.5 m, 3.0 m, and 2.5 m: 1.2°, 2.0 m: 1.0°, 1.5 m and 1.0 m: 0.9°.

Depth (cm from top of core)	Description
0 -93	Clay, silty, dark gray, (5Y 4/1) soupy in upper 10 cm, scattered shells throughout, shells seem mostly fragmented, a live red worm (?) at 7 cm.
93 - 100	missing
100 - 198	Clay as above, except fewer shells.
198 - 200	missing
200 - 282	Clay as above.
282 - 285	Clay, silty, dark greenish gray (5GY 4/1) dry, crumbly, blocky structure which grades into a pelletal structure in the upper cm.

CORE NUMBER: 39

Field Location: 5.23 km from Delta at 330°

Date Acquired: 3/11/78

Water Depth: 4.8 m (corrected relative to long-term mean)

Date Extruded and Described: 3/11/78

Ice Thickness: 113 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 43

Date Subsampled: 3/14/78

Subsample ID #: 299 - 341

Acquired by: WML, CTS

Described by: WML

Field Comments: Full drive to 1m, recovered 89 cm; drive 100 - 171, recovered 60 cm.

Depth (cm from top of core)	Description
0 - 69	Clay, silty, becoming more silty with depth, dark gray (5Y 4/1), upper 10 cm soupy with dark, finely disseminated organics, shells common throughout with concentration at 19-19.5 cm and 32.5-33 cm, lower contact is gradational over 4 cm.
69 - 89	Sand, fine grained, silty, clayey, dark gray (5Y 4/1), abundant shell fragments.
89 - 100	missing
100 - 146	Sand as above, fibers present throughout, wood in lower 10 cm, shell concentration at 132 - 134.cm.
146 - 149	Silt, sandy, clayey, dark gray (5Y 4/1), upper contact is gradational over 3 cm, abundant shells, large (4 cm) wood fragment at 147.5, weak blocky structure, fibers throughout, crumbly at base.
149 - 160	Silty, sandy, good blocky structure, friable into large angular blocks, dry, dark greenish gray (5GY 4/1

CORE NUMBER: 40

Field Location: 4.83 km from Delta at 281°

Date Acquired: 3/10/78

Water Depth: 3.7 m (corrected relative to long-term mean)

Date Extruded and Described: 3/13/78

Ice Thickness: 113 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 34

Date Subsampled: 3/13/78

Subsample ID #: 681 - 714

Acquired by: WML

Described by: WML

Field Comments: Full drive to 1 m, recovered 86 cm; drive 100 - 127, full recovery; Water temperatures: bottom: 3.7°, 3.0 mL: 2.7°, 2.5 m, 2.0 m, and 1.5 m: 1.4°, 1.0 m: 1.0°.

Depth (cm from top of core)	Description
0 - 86	Clay, silty, dark gray (5Y 4/1), becoming slightly lighter at 35 - 45 cm, upper 3 cm soupy, large 3 cm charcoal fragment at 11 cm, scattered shells throughout, roots and fibers abundant at base, much firmer below 50 cm.
86 - 100	missing
100 - 121	Clay, as above but becoming more silty around 110 - 112 cm
121 - 127	Clay, silty, dark gray to dark greenish gray (5Y 4/1 to 5GY 4/1), more compact than above, slightly crumbly with good blocky structure, very abundant fibers in upper 2 cm.

CORE NUMBER: 41

Field Location: 8.86 km from Delta at 296°

Date Acquired: 2/10/78

Water Depth: 4.6 m (corrected relative to long-term mean)

Date Extruded and Described: 2/11/78

Ice Thickness: 98 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 1

Date Subsampled: 3/23/78

Subsample ID #: 1428

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: drove 10 cm, stopped by flexing rods, extruded core on ice, recovered 4 cm sand, did not retain; attempted coring again at same spot, drove 40 cm, retained this core, recovered 36 cm; Used soil auger and sampler to penetrate deeper than corer: 0 - 1.1 m: probably alternating sand and silt; 1.1 m - 2.1 m: clay and silty clay.

Depth (cm from top of core)	Description
0 - 36	Sand, fine to very fine grained, slightly clayey, fibers present, abundant shells, a 1 cm thick laminae of clay at 12 - 13 cm, slightly finer grained and more clayey at base.

CORE NUMBER: 42	Field Location: 22.55 km from Delta at 335°
Date Acquired: 2/11/78	Water Depth: 5.6 m (corrected relative to long-term mean)
Date Extruded and Described: 2/12/78	Ice Thickness: 99 cm
Date Frozen: -	Photographs: -
Date Thawed: -	Subsamples: 19
Date Subsampled: 2/12/78	Subsample ID #: 1312 - 1330
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: Drive to 1 m, recovered 80 cm; drive from 1 - 2m, recovered 80 cm. Used soil probe to recover sediment from deeper than end of core: 200 - 219 cm: clay, silty, dark gray, soft, scattered shells, sharp lower contact; 219 - 235 cm: clay, sticky, dry breaks and crumbles, indistinct pellets, shells, fibers (?).

Depth (cm from top of core)	Description
0 - 80	Clay, silty, and clayey silt, dark gray (5Y 4/1), scattered to abundant mollusk shells, soft.
80 - 100	missing
100 - 180	clay and silt as above, concentration of mollusk shells at 112 - 113 cm, and 154 - 156 cm, no shells observed below 156.

CORE NUMBER: 43

Field Location: 17.72 km from Delta at 324°

Date Acquired: 2/11/78

Water Depth: 4.8 m (corrected relative to long-term mean)

Date Extruded and Described: 2/12/78

Ice Thickness: 97 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 8

Date Subsampled: 3/19/78

Subsample ID #: 1331 - 1338

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Drive 75 cm, full recovery; very difficult coring and extruding; attempted to use soil probe, penetrated to 175 cm depth, recovered loose sand, fg, quartz-rich.

Depth (cm from top of core)	Description
0 - 55	Sand, dark gray (5Y 4/0.5), medium to fine grained, scattered shells and shell fragments, salt and pepper appearance.
55 - 75	Sand, slightly silty, clayey, slightly softer than above, otherwise as above.

CORE NUMBER: 44

Field Location: 15.30 km from Delta at 306°

Date Acquired: 2/11/78

Water Depth: 4.5 m (corrected relative to long-term mean)

Date Extruded and Described: 2/12/78

Ice Thickness: 95 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 6

Date Subsampled: 3/19/78

Subsample ID #: 1331a - 1336a

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Drive 75 cm, rrecovered 59 cm.

Depth (cm from top of core)	Description
0 - 40	Clay, silty, gray (5Y 5/1), soft throughout, very fluid in upper 4 cm, very sharp lower contact.
40 - 59	Clay, silty, dark greenish gray (5GY 4/1), dry, sticky, weak angular platy structure to very fine blocky structure in upper 5 cm grading to crumbly and finer blocky structure in lower 10 cm, pin point size holes are present in upper 5 cm, holes are empty and not associated with any type of plant remains.

CORE NUMBER: 45

Field Location: 12.08 km from Delta at 302°

Date Acquired: 2/11/78

Water Depth: 4.4 m (corrected relative to long-term mean)

Date Extruded and Described: 2/12/78

Ice Thickness: 39 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 5

Date Subsampled: 3/19/78

Subsample ID #: 1337a - 1341

Acquired by: JTT, WML

Described by: JTT, WML

Field Comments: Drive 36 cm, recovered 36 cm.

Depth (cm from top of core)	Description
0 - 4	Clay, silty, gray (5Y 5/1), soft, shell concentration at base, sharp lower contact.
4 - 10	Clay, silty, and clayey silt, dark greenish gray (5GY 4/1), firm, drier than above, no shells, gradational lower contact.
10 - 18	Clay as above but becoming increasingly darker colored until below 14 cm color is black (7.5 YR 2.5/0), good angular platey structure.
18 - 20	Clay as above but slightly lighter (5Y 3/1) and less well developed structure.
20 - 27	Clay as above, upper 4 cm is very dry and consists of rounded pellets in a clay matrix, good blocky structure overall, becoming very silty near base, dryness and degree of structural development both decrease downward, lower contact is indistinct, color grades to 5GY 4/1 at about 25 cm.
27 - 36	Silt, clayey, sandy, becoming sandy silt by 30 cm, dark gray (5Y 4/1).

CORE NUMBER:	46	Field Location:	11.89 km from Delta at 312°
Date Acquired:	2/11/78	Water Depth:	5.1 m (corrected relative to long-term mean)
Date Extruded and Described:	-	Ice Thickness:	98 cm
Date Frozen:	-	Photographs:	0-
Date Thawed:	-	Subsamples:	_
Date Subsampled:	-	Subsample ID #:	-
Acquired by:	JTT, WML	Described by:	JTT, WML

Field Comments: No core taken, could not drive sampler; used soil probe to determine sediment: 0 - 46 cm: sand, fine to very fine grained, slightly silty, dark gray, abundant shells;
46 - 57 cm: silt, clayey, fiber throughout, dark gray
57 - 70 cm: sand, fine grained, abundant shells.

Depth (cm from top of core)	Description

CORE NUMBER: 47	Field Location: 20.98 km from Delta at 311°
Date Acquired: 2/11/78	Water Depth: 5.1 m (corrected relative to long-term mean)
Date Extruded and Described: 2/12/78	Ice Thickness: 96 cm
Date Frozen: -	Photographs: -
Date Thawed: -	Subsamples: 8
Date Subsampled: 3/19/78	Subsample ID #: 1342 - 1349
Acquired by: JTT, WML	Described by: JTT, WML

Field Comments: Drive 60 cm, recovered 54 cm.

Depth (cm from top of core)	Description
0 - 20	Silt, sandy, clayey, dark gray (5Y 4/1), abundant shells with a 5 cm pelecypod shell fragment at base, very abundant root fibers throughout.
20 - 30	Sand, clayey, silty, dark gray (5Y 4/1), firm, fibers still common to abundant, grading into lower unit.
30 - 33	Silt, clayey, color as above, dry, with abundant fibers throughout.
33 - 54	Clay, silty, dark greenish gray (5GY 4/1), dry good blocky structure grading to fine and crumbly structure with depth, fiber not as common as above.

CORE NUMBER: 48

Field Location: 7.60 km from Delta at 304°

Date Acquired: 3/11/78

Water Depth: 4/4.9 m (corrected relative to long-term mean)

Date Extruded and Described: -

Ice Thickness: 105 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: -

Date Subsampled: -

Subsample ID #: -

Acquired by: WML

Described by: WML

Field Comments: Drive 10 cm, stopped by rod flex, no recovery although fine grained sand was coating the core barrel.

Depth (cm from top of core)	Description

CORE NUMBER: D - 1

Date Acquired: 2/23/78 to 2/25/78

Date Extruded and Described: 2/28/78 to 3/8/78

Date Frozen: -

Date Thawed: -

Date Subsampled: 2/28/78 to 3/8/78

Acquired by: JTT, WML

Field Location: 19.33 km from Oak Point at 255°

Water Depth: 5.7 m (corrected relative to long-term mean)

Ice Thickness: 102 cm

Photographs: 14

Subsamples: 105

Subsample ID #: 342 - 415, 454 - 484

Described by: JTT, WML

Field Comments: Used Livingstone corer to sample 0 - 1 m (cores 29 a, b, c), took three duplicate cores; Water temperatures: bottom: 4.9°, 5.0 m: 3.0°, 4.5 m: 2.5°, 4.0 m: 1.5°, 3.5 m, 3.0 m: 2.5 m, 2.0 m, and 1.5 m: 1.1°.

Depth (cm from top of core)	Description
0 - 119	Clay, silty, dark gray (5Y 4/1), upper 7 cm soupy, shells common with concentration at 22 - 24 cm, fibers present at 60 - 65 cm, becoming stiffer with depth.
119 - 121	missing
121 - 132	Clay as above.
132 - 159	Clay, silty, slightly coarser than above, slightly darker (5Y 4/1), faintly color laminated, shells are common but fewer than above.
159 - 196	missing
196 - 243	Clay as above, shells becoming rare, a 1 mm thick clay laminae at 240 cm.
243 - 259	missing
259 - 319	Clay as above, becoming mottled 5Y 5/1 and 5Y 4/1 in lower 30 cm, fish scale at 317.
319 - 320	missing
320 - 330	Clay as above, sharp lower contact

D - 1 continued

330 - 349	Clay, silty, 5GY 4/1, much firmer, drier than above, not visibly laminated, no shells, weak angular blocky structure, scattered rounded pellets, slight color change to 5Y 4/1 at 344 - 348 cm.
349 - 381	missing
381 - 385	interpreted as out of place.
385 - 410	Clay as above except no structural development and slightly moister than above, scattered mollusc shells, very poorly laminated.
410 - 441	missing
441 - 473	Clay, silty, "lumpy", very soft, somewhat soupy, consists of lumps of dry clay in a matrix of very soft, moist clay, lumps are 5GY 4/1 to 5Y 4/1 and commonly 2 - 5 mm in diameter, gradational lower contact, questionable as to whether this unit is in place, possibly out of place or at least highly disturbed.
473 - 499	Clay, silty, 5Y 4/1, scattered shells, moist as above, silty laminae at 498.
499 - 502	missing
502 - 563	Clay as above, occassional black particles.
563 - 606	Clay, silty, 5Y 5/1, mottled 5Y 4/1 in upper 30 cm, possible contorted bedding, concentration of black organic matter at 579 - 581 cm, no observed shells.
606 - 624	Clay as above, but faint to distinctly laminated, laminae are mainly color changes, silty at 612 - 614.
624 - 670	Clay, silty, 5Y 5/1 to 5Y 4/1, disturbed in upper 10 cm, possibly faintly laminated from 635 - 660 cm, soft, does not easily break, becoming firmer with depth, zone of dark gray to black (2.5 Y 3/1) organic matter disseminated through 663 - 665 cm, laminae are more distinct from 660 - 670 cm, sharp lower contact, 2 mm thick silt laminae at 663 and 670 cm, no observed shells.
670 - 685	Clay, slightly silty, 5Y 4/1 sharp color and textural contact with upper unit, occasional shells.
685 - 737	Clay, slightly silty, becoming more silty with depth, 5Y 4/1, soft, several 2 mm thick silty laminae at 735 - 737 cm, no observed laminae in upper 40 cm, contorted laminae at 725 - 737, rare shells, upper 5 cm highly disturbed and possibly out of place.
737 - 746	Clay, silty, 5GY 4/1, sharp upper contact, much stiffer and drier than above, more silt content than above, weakly developed small blocky structure at 745 - 746 cm, occasional shell fragments, some black organic matter.

D-1 continued

746 - 784	Clay as above but becoming clayey silt with depth, several distinct laminae of silt at 770 - 772 cm, broken shells common, several whole mollusk shells, overall color is 5GY 4/1 but becoming 5Y 4/1 below 780 cm, numerous organic specks, upper 6 cm consists of 'lumpy' clay and pelleted clay and is probably highly disturbed.
784 - 807	missing
807 - 839	Silt, clayey to silt, 5GY 4/1 to 5Y 6/2, firm, dry, weakly developed small blocky structure in upper 10 cm grading to very poorly developed blocky structure with depth, becoming more silty with depth, poorly laminated near base.
839 - 867	missing
867 - 887	Clay, silty, pelleted and lumpy, very soft, 5Y 4/1, to N5, grading to lower, probably disturbed, possibly out of place.
887 - 905	Clay, slightly silty, N5, soft, no shells, no bedding sharp lower contact.
905 - 929	Silt and clayey silt, 5GY 4/1 to 5Y 6/2, similar in appearance to 807 - 839 cm, silty laminae increasing in abundance with depth.
929 - 964	Silt, clayey, color as above, several pockets of silt and sand scattered throughout, large blocky structure well developed in upper 20 cm, gradational lower contact over 3 cm, silty sand pockets are laminated.
964 - 975	Silt, sandy, clayey, 5Y 5/3 to 5Y 5/4, well laminated with several distinct laminae of very fine grained sand at 970, sharp contacts.
975 - 983	Silt, clayey, and silty clay, 5Y 4/1, weak, small blocky structure, massive in lower 10 cm.
983 - 990	missing
990 - 1030	Clay, silty, 5Y 3/2 to 5Y 4/1, massive but softer than above or below, probably disturbed.
1030 - 1054	Clay, slightly silty, 5Y 3/1 to 5Y 4/1, carbonate pebbles common (diameter to 8 mm), some mottling from 1040 - 1050 cm, several silty and sandy clasts or blebs at base.
1054 - 1112	Clay as above but with fewer pebbles and more silty and sandy clasts or blebs (concentrations at 1077 - 1080 cm, 1090 - 1092 cm, and 1103 - 1106 cm, very indistinctly laminated overall.

D-1 continued

1112 - 1141	Clay as above but softer, higher moisture content, upper 4 cm probably disturbed, becoming 5Y 4/1 below 1125 cm, 3.5 cm carbonate pebble at 1122 cm.
1141 - 1152	Clay as above but many more silt clasts.
1152 - 1170	Clay as above but fewer silt clasts.
1170 - 1177	Clay as above but 5Y 3/1.
1177 - 1234	missing
1234 - 1356	Clay, slightly silty grading to clay at base, scattered carbonate pebbles up to 3 cm diameter throughout, 5Y 3/2 but color is rather variable ranging from 5Y4/1 to 5Y 3.5/1, abundant silty clasts, silt clasts are 1 - 6 mm in size and range in color from 5Y 5/1 to 5YR 6/3 , upper 30 cm exhibits weakly developed large blocky structure on broken surface, sediment is difficult to break, sticky, very plastic, silt clasts increase in abundance from 1280 to 1310.

CORE NUMBER:	D - 2	Field Location:	20.14 km from Oak Point at 228°
Date Acquired:	2/25/78 to 2/26/78	Water Depth:	5.7 m (corrected relative to long-term mean)
Date Extruded and Described:	3/4/78 to 3/10/78	Ice Thickness:	101 cm
Date Frozen:	-	Photographs:	15
Date Thawed:	-	Subsamples:	87
Date Subsampled:	3/4/78 to 3/10/78	Subsample ID #:	250 - 298 and 416 - 453
Acquired by:	WML	Described by:	JTT, WML

Field Comments: Used Livingstone corer to sample 0 - 2 m: Full drive to 1 m, recovered 92 cm; full drive to 2 m, recovered 89 cm; Used antifreeze to thaw auger on morning of 2/26/78, possible sample confusion at 10 - 12 feet depth and 18 - 20 feet depth: drove Shelby but no recovery, redrove and recovered sediment, last 30 feet very difficult augering, skip samples at depths of 20 - 23 feet, and 25 - 28 feet.

Depth (cm from top of core)	Description
0 - 300	Clay, silty, dark gray (5Y 4/1) very poorly laminated throughout with better developed laminae near base, laminae are mainly color differences (i.e., more olive gray, 5Y 5/2) and differences in shell material, shells are scattered to abundant throughout with concentrations at 80 - 83 cm, and 113 - 114 cm, shells are less common to rare below 240 cm, an ostracod (?) zone is present at 268 - 272 giving the sediment a silty and sandy feel, slightly darker color at basal 30 cm.
300 - 304	Clay, silty to clayey silt, 5GY 4/1 to 5Y 4/1, dry and blocky in upper 2 cm grading to less well developed structure in lower 2 cm, very sharp upper contact, upper 2 cm break into rounded pellets and discrete units having smooth rounded curved surfaces, gradational lower contact.
304 - 333	Clay, silty, probably out of place.

D - 2 continued

333 - 365	Clay, silty, 5Y 4/1 to 5GY 4/1, firm, dry, weak angular blocky structure, poorly laminated to not visibly laminated, slightly higher moisture content below 354 cm, rare shells, weakly developed yellow (5Y6/6) band or stain at 350 cm.
365 - 426	Clay, silty, 5Y4/1, very soft with pellets, probably disturbed and possibly out of place.
426 - 487	Clay, silty, 5Y 4/1, poorly laminate throughout, best lamination in upper 10 cm, good structural development (pelletal to blocky structure) from 426 to 456 cm, grading to little visible structure to base.
487 - 490	Clay, silty, 5Y 4/1, rare shells.
490 - 548	Clay, silty, overall color is 5Y 4/1 but several lighter and darker bands are developed throughout, firm but lacks any structure, no shells, not dry.
548 - 603	Clay, silty, 5Y 4/1 to 5GY 4/1, 548 to 580 does not break easily, very plastic, structureless, possibly disturbed, specks of black material throughout moderately soft, rare shells, sharp lower contact.
603 - 611	Clay, silty, 5GY 4/1 to 5Y 4/1, very good angular blocky structure best developed in upper 5 cm, decreasing with depth, slightly drier than above or below but not as dry as 300 to 304 interval.
611 - 701	missing
701 - 760	Clay, silty, 5Y 4/1 becoming 5Y3/2 in lower several cm, 716 to 760 is more plastic than above, becomes clayey silt at 752.
760 - 765	Clay, silty, 5GY 4/1, slightly angular, blocky structure on broken edge, drier than above, shell fragments.
765 - 853	missing
853 - 857	possibly out of place.
857 - 887	Clay, silty, and clayey silt, 5Y 4/1 to 5GY 4/1, well laminated, rare shells, gradational lower boundary.
887 - 915	Silt, clayey, 2.5Y 6/2 to 2.5Y 4/2, well laminated dark yellow brown (2.5Y 4/2) stain 910 - 915, laminations are composed of thin silt beds (0.2 mm) and thicker clay beds (1.3 mm), laminae less distinct below 910.

D - 2 continued

915 - 1005	missing
1005 - 1015	Clay, silty, firm, 5GY 4/1 to 2.5Y 4/1, distinct color banding below 1012 cm, shells common to rare..
1015 - 1029	Clay, silty, 5Y 3/2, with occasional silt laminae, well laminated overall.
1029 - 1058	Silt, clayey and silt, laminated, occasional sandy beds, lower 7 cm is more clayey, carbonate pebbles present throughout, basal 15 cm are highly charged with silt and sand clasts and blebs and have a wide range of particle sizes (pebbly, sandy silty clay), overall color is 10 YR 5/3 but great variation in colors due to the clasts.
1058 - 1068	Clay, silty, firm, 1065 to 1068 contain abundant silty and sandy clasts, granules and pebbles of a wide variety of colors including 10YR 5/3, 5Y 5/2, 10YR 7/2, 2.5Y 3/2 and 2.5Y 4/2.

CORE NUMBER: D - 3

Field Location: 13.29 km from Delta at 358°

Date Acquired: 2/27/78 to 3/28/78

Water Depth: 4.8 m (corrected relative to long-term mean)

Date Extruded and Described: 3/6/78 to 3/10/78

Ice Thickness: 121 cm

Date Frozen: -

Photographs: -

Date Thawed: -

Subsamples: 106

Date Subsampled: 3/7/78 to 3/10/78

Subsample ID #: 154 - 249

Acquired by: WML

Described by: WML, JTT

Field Comments: Used Livingstone corer to sample 0 - 3 m: Full drive to 1 m, recovered 93 cm; full drive to 2 m, recovered 97 cm, drive 200 - 278, recovered 69 cm; difficult augering at 25' and after 31'; lost upper 7 cm of core (0 - 7 cm).

Depth (cm from top of core)	Description
0 - 7	missing
7 - 93	Clay, silty, 5Y 4/1 to 5Y 5/2, indistinct color banding, scattered mollusk shells throughout, soft to firm at base,
93 - 100	missing
100 - 197	Clay as above, carbonate pebble at 111 cm, plant fragments at 133 cm.
197 - 200	missing
200 - 245	Silt, very clayey in upper, grading to less clayey more sandy from 230 to 245, 5Y 4/1, sharp lower contact, occasional shells, weak color lamination in lower 15 cm.
245 - 269	Clay, silty to silt, very clayey, 5GY 4/1, firmer than above, lower amount of sand and silt, occasional shell and shell fragments, good blocky structure, grading to crumbly.
269 - 274	missing
274 - 353	Clay, silty and silt, clayey, well laminated with laminae generally less than 1 cm thick and 1 to 4 cm apart, colors range from 5Y 4/1 to 2.5Y 2.5/0, rare shells. Upper 16 cm and lower 19 cm distorted,

D - 3 continued

353 - 394	Clay, silty as above but becoming increasingly darker colored with depth to N3 and N2.5 at base, Silt laminae are increasing with depth, lower 20 cm are mottled with a lighter tan oxidized color possibly due to storage in core tube, rare shells,
394 - 396	missing
396 - 423	Clay, silty as above, upper 16 cm are disturbed.
423 - 428	Silt, clayey, N2.5, greasy feel, a large mollusc shell at 425.
428 - 449	Silty, clayey, N3 to N2.5, rare mollusk shells, poorly laminated.
449 - 455	Clay, silty, and silt, clayey, N3 to N2.5, similar to above.
455 - 457	missing
457 - 498	Silt, clayey, N2.5, occasional shell, gradational lower contact, upper 16 cm is disturbed.
498 - 515	Silt, clayey, 2.5Y 3/1, more silty than above, distinct color change, occasional shell fragments.
515 - 518	missing
518 - 577	Silt, clayey as above, upper 12 cm is disturbed, below 536 laminations are better developed with increasing silty laminae more common, shells common throughout, colors range from 2.5Y 3/1 to 5GY 4/1.
577 - 597	missing
579 - 592	Silt, clayey as above, disturbed.
592 - 643	Silt, clayey, and clay, silty, 5GY 4/1, abrupt increase in silt laminae below 617, well laminated throughout.
643 - 676	Clay, silty, upper 14 cm disturbed, carbonate pebble at 647 cm, beginning at about 670 and continuing to the base the sediment exhibits good blocky structure on a broken surface, sharp lower contact.
676 - 690	Clay, silty and silt, clayey, 5GY 4/1 to 5Y 3.5/1, fine angular blocky structure on broken surface.
690 - 699	Clay, and silt as above, 5Y 2.5/1, fibers and wood fragments at 695 cm, carbonate pebble at 695.
699 - 701	missing
701 - 717	interpreted as out of place.
717 - 754	Silt, clayey as above, but exhibits a finer and more poorly developed blocky structure, pebbles throughout, becoming more silty and sandy in lower 7 cm.

D - 3 continued

754 - 764	Silt, 5Y 5/1 to 5Y 4/1, well laminated.
764 - 774	interpreted as out of place.
774 - 811	Silt as above
881 - 822	missing
822 - 831	Silt as above, disturbed.
831 - 883	Silt and sandy silt with clayey silt, grading downward to silty clay, well laminated, colors range from 5GY 4/1 to 5Y 3/1 and 5Y 5/2, carbonate pebble at 836 cm.
883 - 905	Silt, clayey, 5Y 4/1 to 5GY 4/1, weakly laminated, soft in lower 10 cm.
905 - 915	Silt, clayey becoming silty clay, 5Y 3/1, scattered silt blebs, becoming more clayey with depth.
915 - 957	Clay, pebbly, sandy, silty, 5Y 4/1 to 5Y 3/1 to 5Y3/2, occasional laminae of silty clay and silt in upper 14 cm, below 929 is very faint bedding, otherwise mainly nonbedded, pebbles are mainly carbonates, olive brown staining is present on pebbles and structural surfaces.

CORE NUMBER: D - 4

Date Acquired: 3/1/78

Date Extruded and Described: 4/15/78 to 7/ 15/78

Date Frozen: -

Date Thawed: -

Date Subsampled: 4/15/78 to 7/15/78

Acquired by: WML

Field Location: on land lsd 4, section 22, township 13, range 7 EPM

Water Depth: - (corrected relative to long-term mean)

Ice Thickness: -

Photographs: -

Subsamples: 2

Subsample ID #: 2 680 and 1499

Described by: 680, 1499 WML

Field Comments: Severe corrosion on inside of shelby tubes, several shelby tubes damaged while coring, others had to be cut to extrude sediment, very difficult augering.

Depth (cm from top of core)	Description	Unit Interpretation
0 - 152	missing	
152 - 185	Sand, medium to fine grained, slightly coarser at base, 10YR 5/3.	
185 - 305	missing	
305 - 350	Clay, silty and sandy with abundant silt clasts, 2.5Y5/2 overall but clasts are variable colored, firm, dense, slightly sticky, several pebbles,	
350 - 365	missing	
365 - 399	Clay, 10YR 4/1, dense, firm, blocky structure throughout on broken surface (may be an artifact of extrusion) slightly silty, abundant clasts of silt and till (?), several pebbles.	
399 - 426	missing	
426 - 460	Clay as above.	
460 - 487	missing	
487 - 518	Clay as above.	
518 - 548	missing	
548 - 588	Clay, very silty, sandy with abundant pebbles, 10YR 6/3 very stiff, firm, dry, no observed bedding.	

D - 4 continued

588 - 609	missing
609 - 649	Clay;pebbly, sandy, silty, 2.5Y 4/2, firm, stiff, dry.

W - 1 (drilled and described by Manitoba Hydro, 3/16/77)
located 1 km offshore from Section 35, township 14, range 9, EPM at 107°

0 - 125 cm: Grey clay, medium to soft.

125 - 440 cm: Brown, mottled medium to low plastic silty clay, trace fine sand, stiffness increasing with depth.

440 - 610 cm: Dense, dark grey medium plastic silty clay, some silt pockets, some gravel, some fine to coarse sand.

610 - 910 cm: DBrown and grey mottled medium plastic silty clay with numerous silt pockets throughout, some mine to medium sand, trace of gravel.

910 - 960 cm: Grey, stiff low plastic silt, with medium to fine sand, trace of gravel.

W - 2 (drilled and described by Manitoba Hydro, 3/16/78)
located 1.5 km offshore from Section 35, township 14, range 9, EPM at 107°

0 -260 cm: Mottled grey, brown clay, soft, moist.

260 - 570 cm: Brown, medium to low plastic silty clay, some very fine silt seams

570 - 612 cm: Brown and grey dense mottled slity, clay with numerous silt pockets, some fine sand, trace of gravel.

612 - 910 cm: Brown, moist, dense silty clay of slight plasticity, with medium to fine sand, trace gravel.

APPENDIX J

Variation with depth of various sediment characteristics in cores D-1, D-2, and D-3.

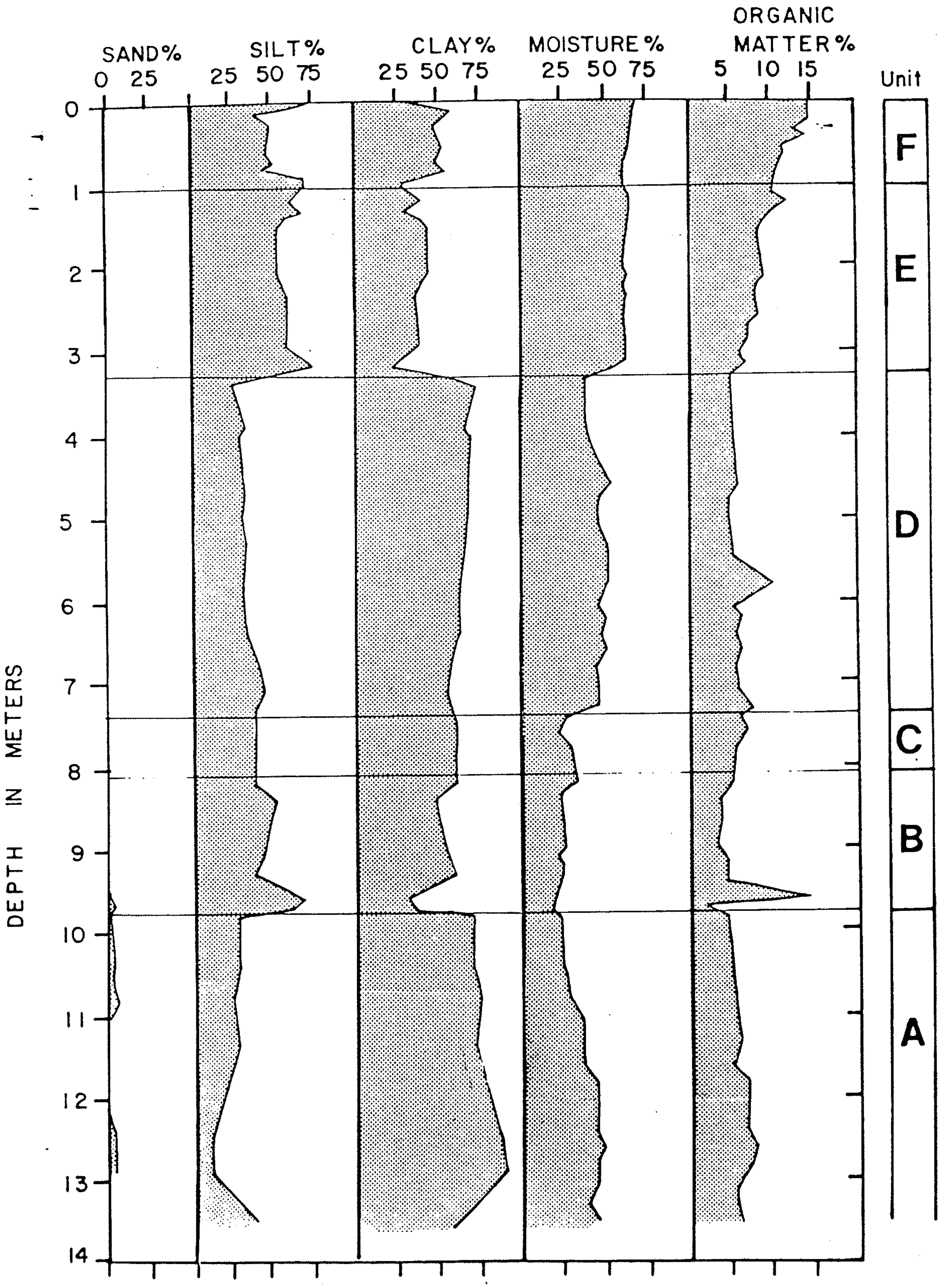


Figure J-1. Variation of physical parameters with depth in core D-1.

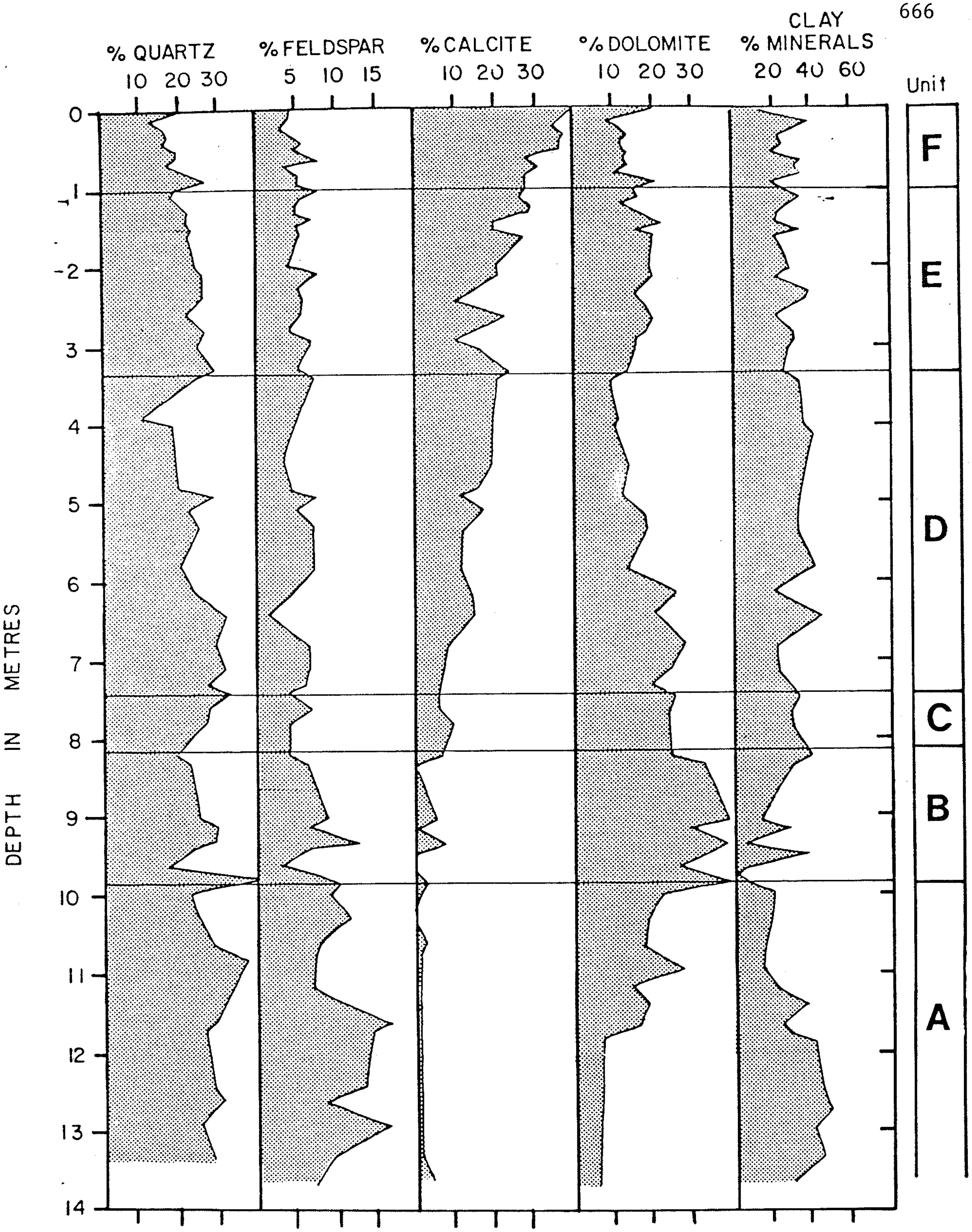


Figure J-2. Variation of mineralogy with depth in core D-1.

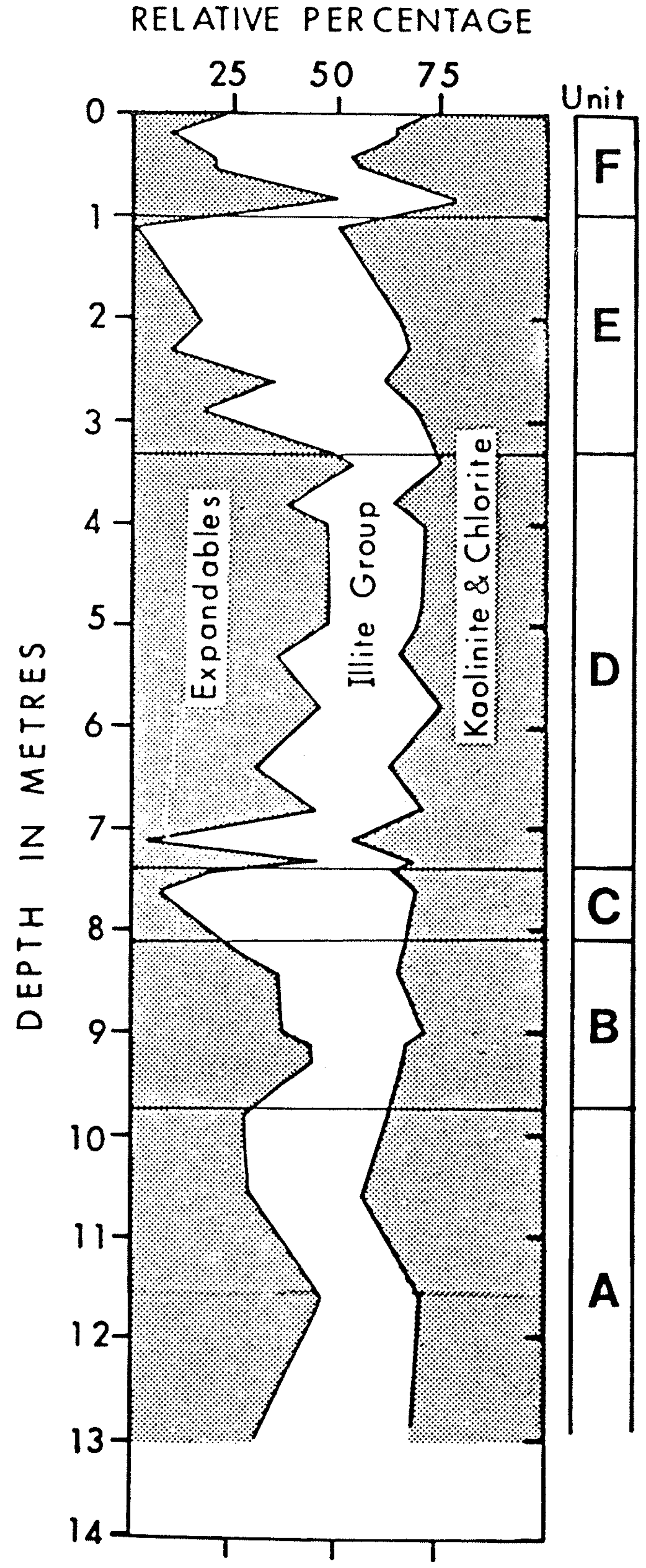


Figure J-3. Variation in relative percentage of clay minerals with depth in core D-1.

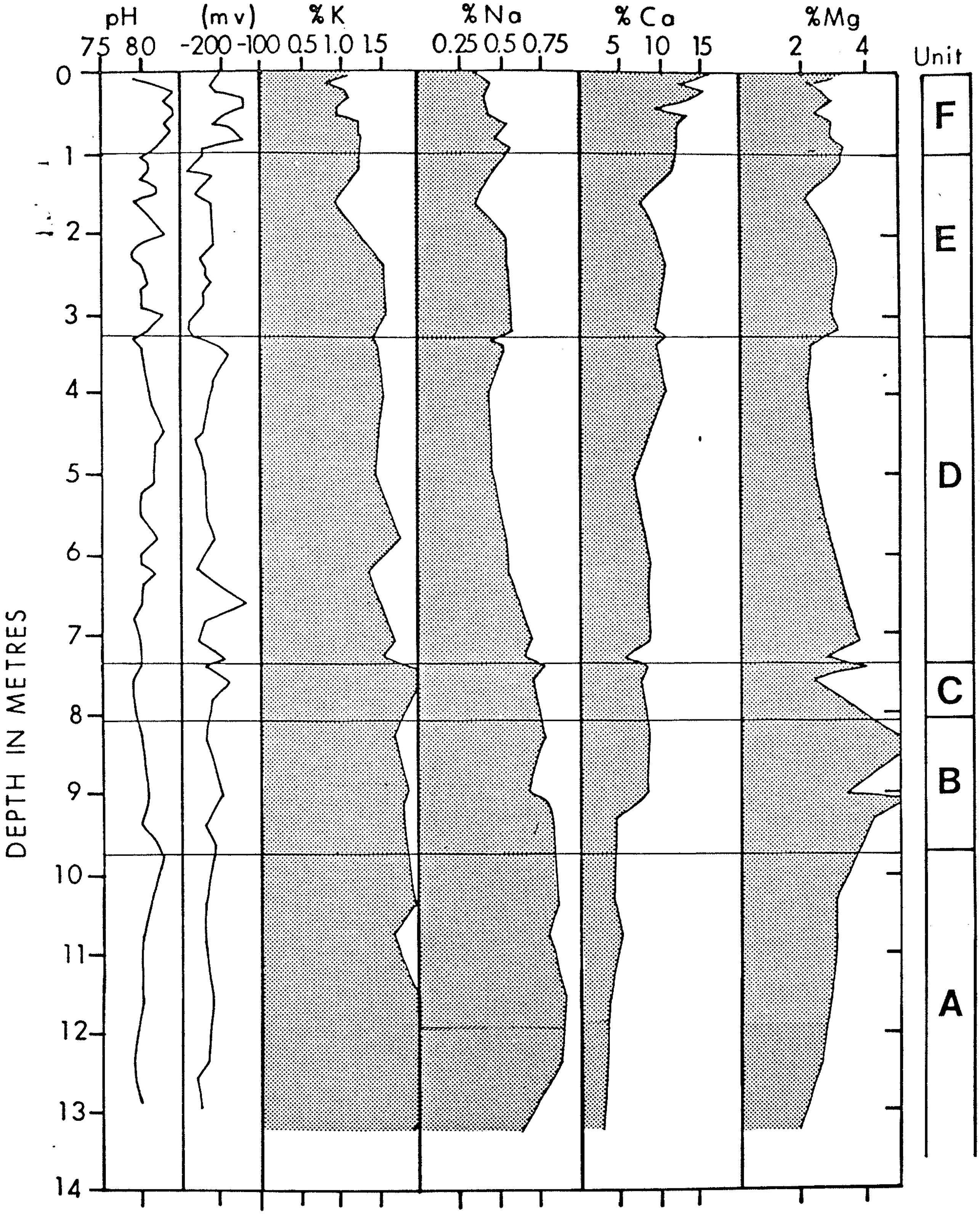


Figure J-4. Variation of pH, Eh, and elemental concentrations with depth in core D-1.

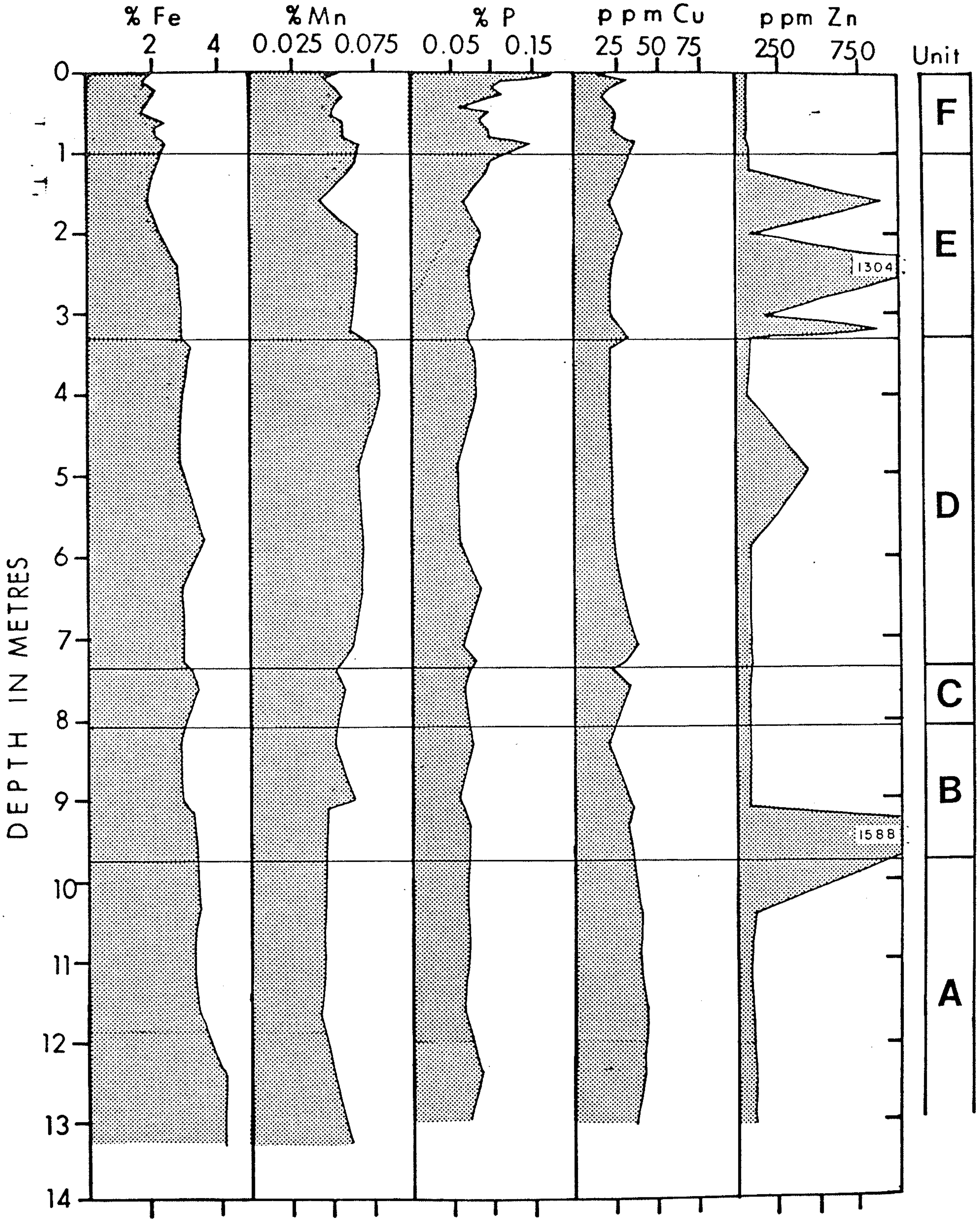


Figure J-5. Variation of elemental concentration with depth in core D-1.

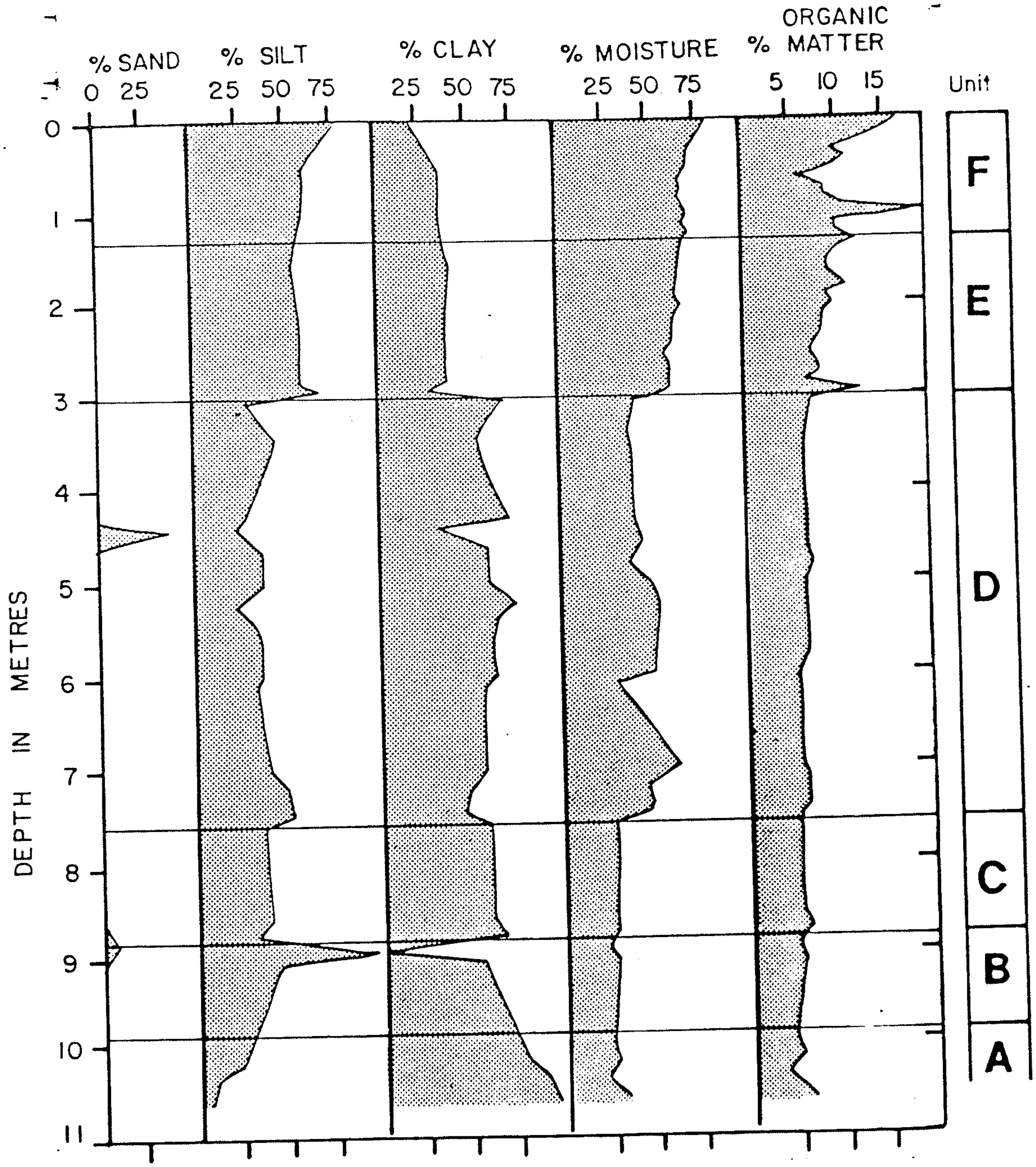


Figure J-6. Variation of physical parameters with depth in core D-2.

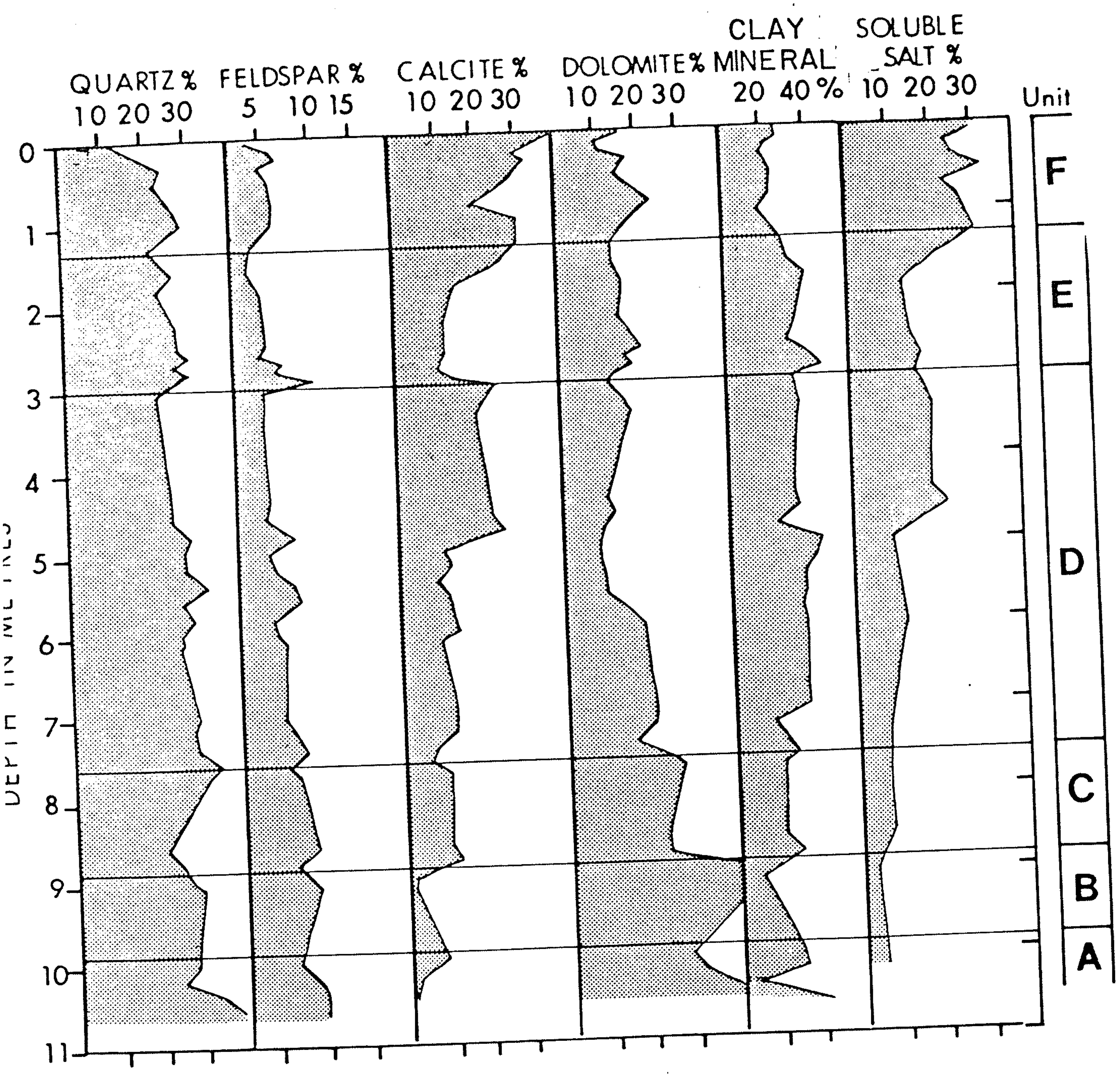


Figure J-7. Variation of mineralogy with depth in core D-2.

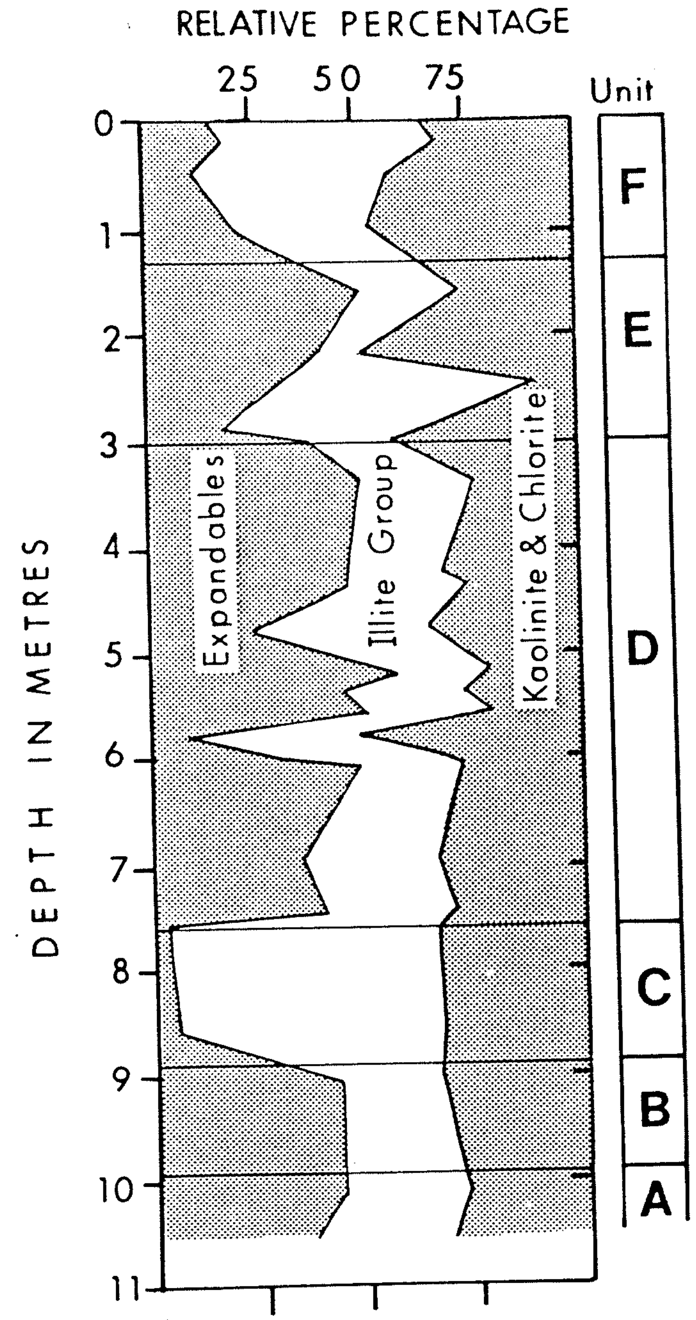


Figure J-8. Variation in relative percentage of clay minerals with depth in core D-2.

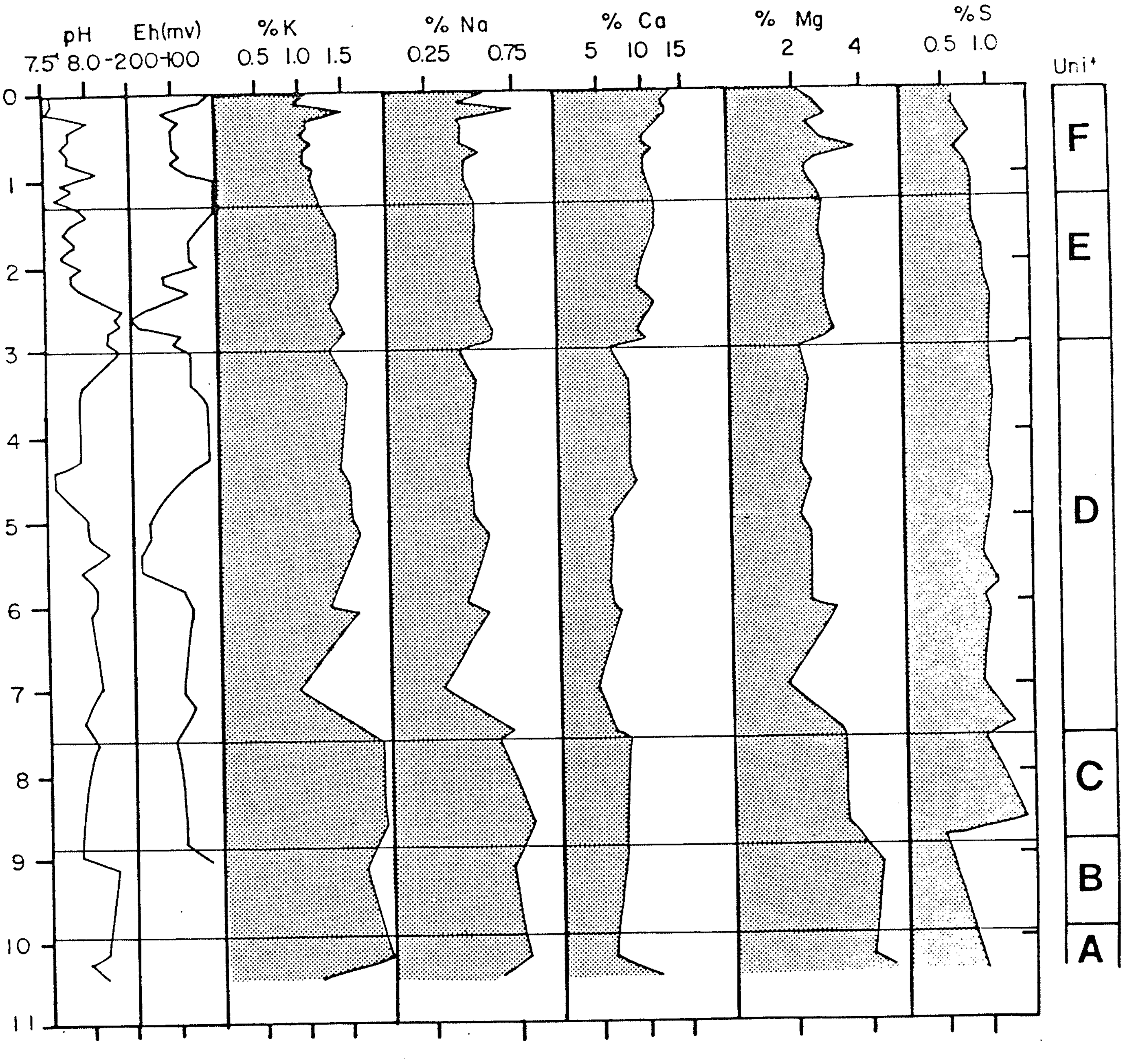


Figure J-9. Variation of pH, Eh, and elemental concentrations with depth in core D-2.

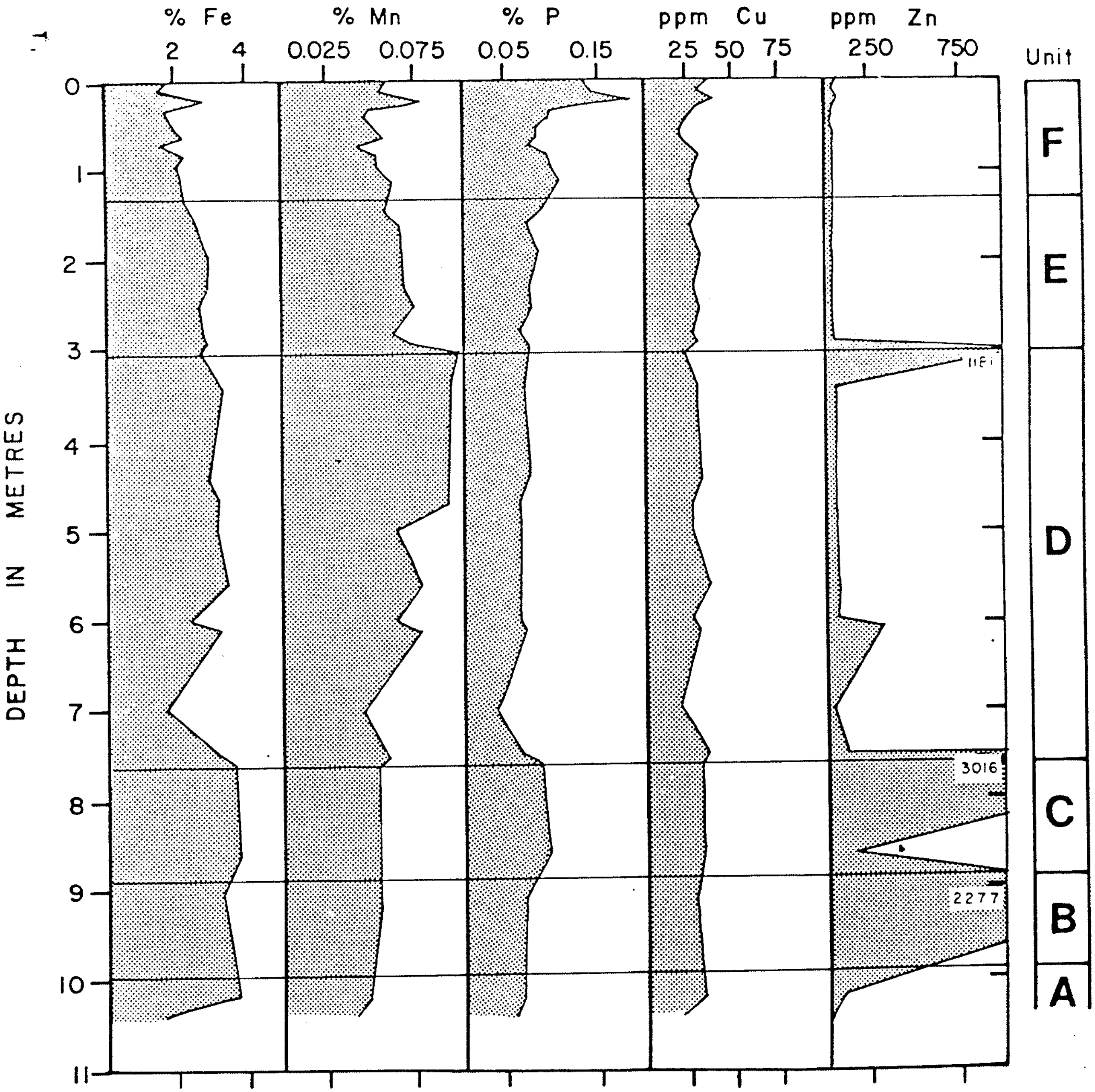


Figure J-10. Variation of elemental concentration with depth in core D-2.

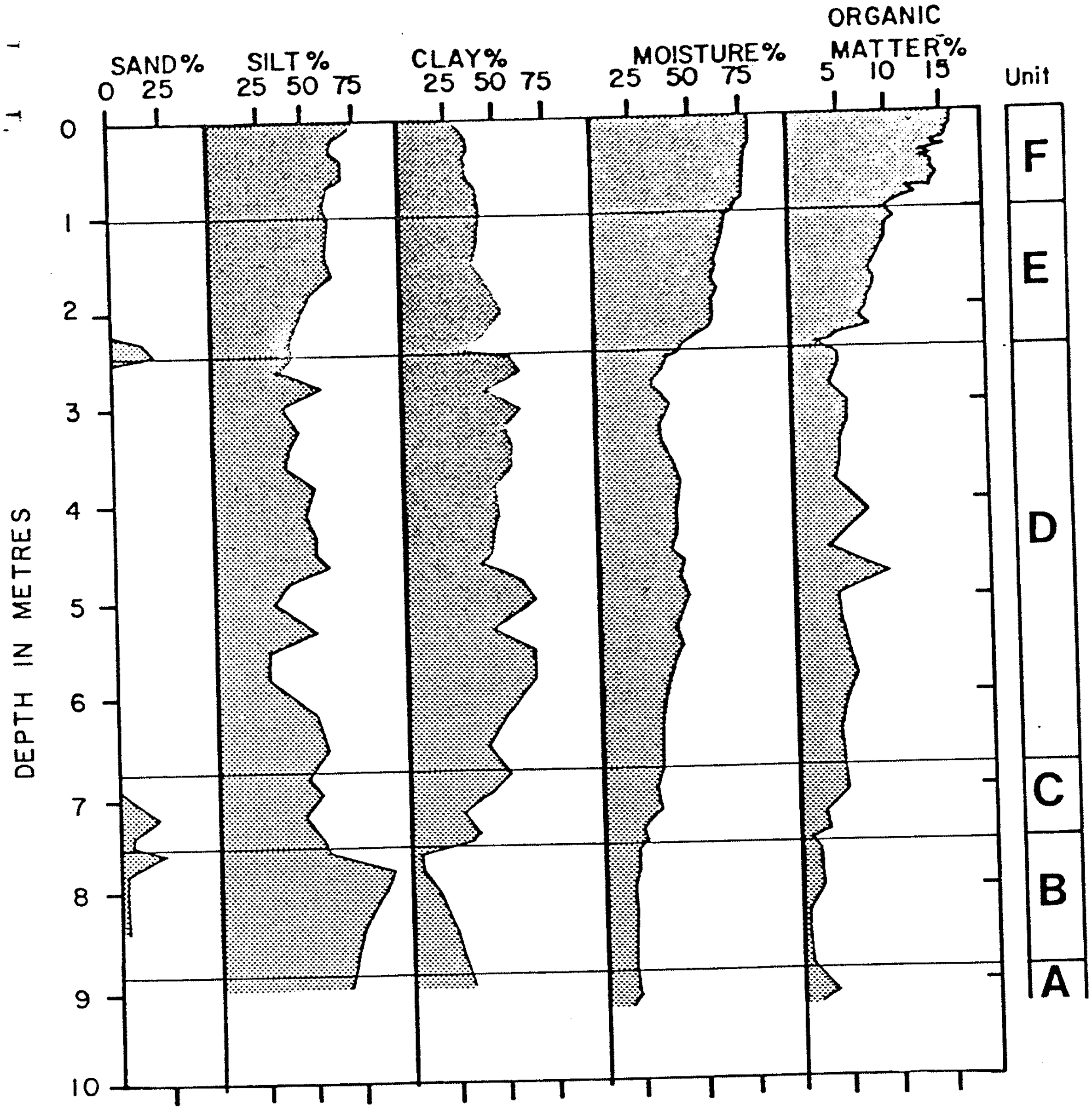


Figure J-11. Variation of physical parameters with depth in core D-3.

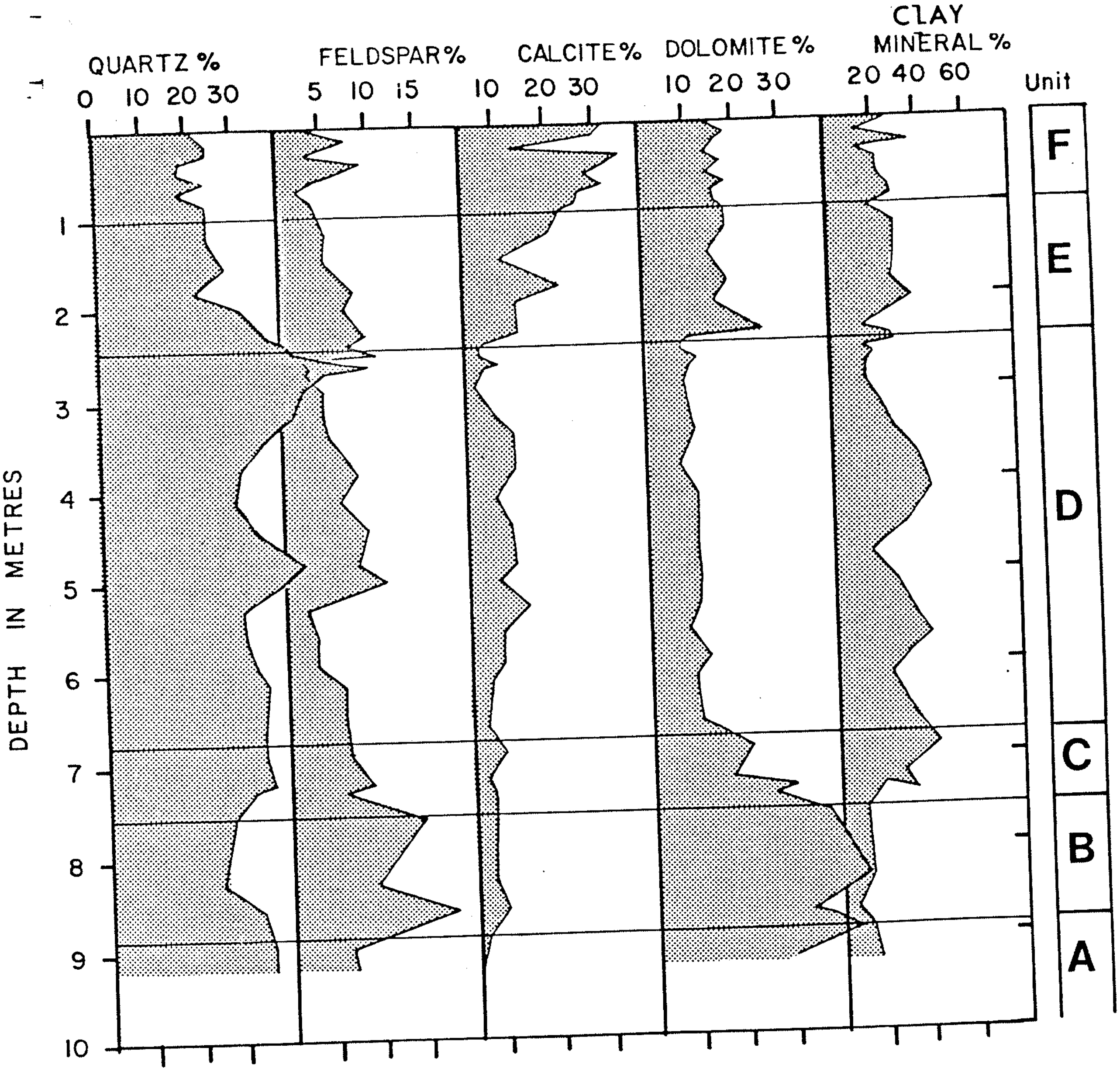


Figure J-12. Variation of mineralogy with depth in core D-3.

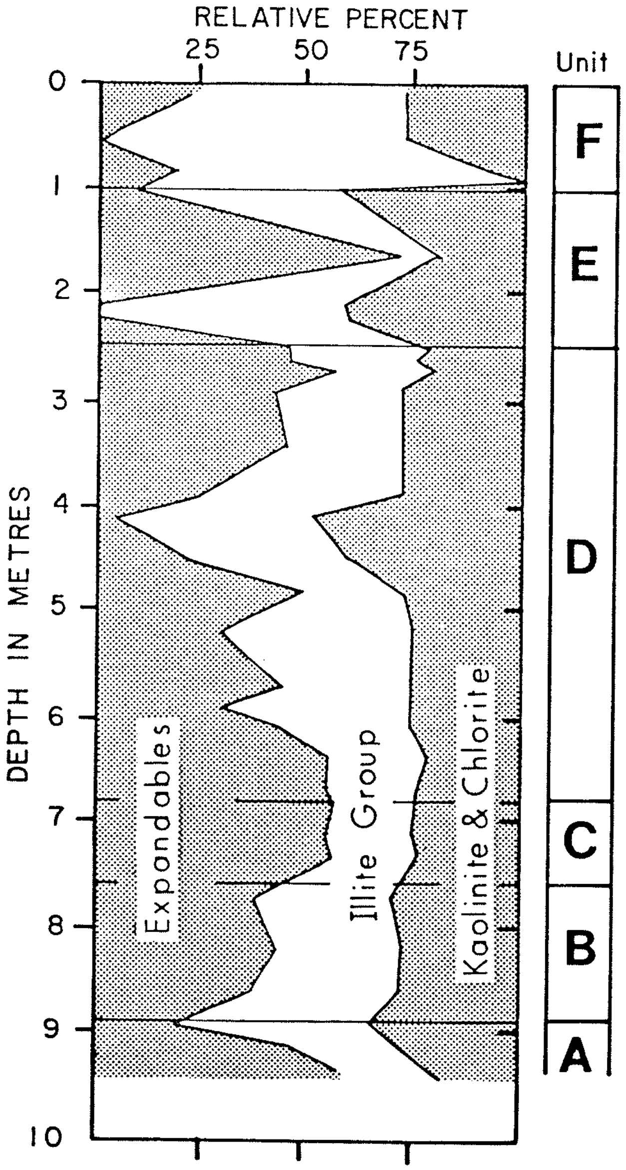


Figure J-13. Variation in relative percentage of clay minerals with depth in core D-3.

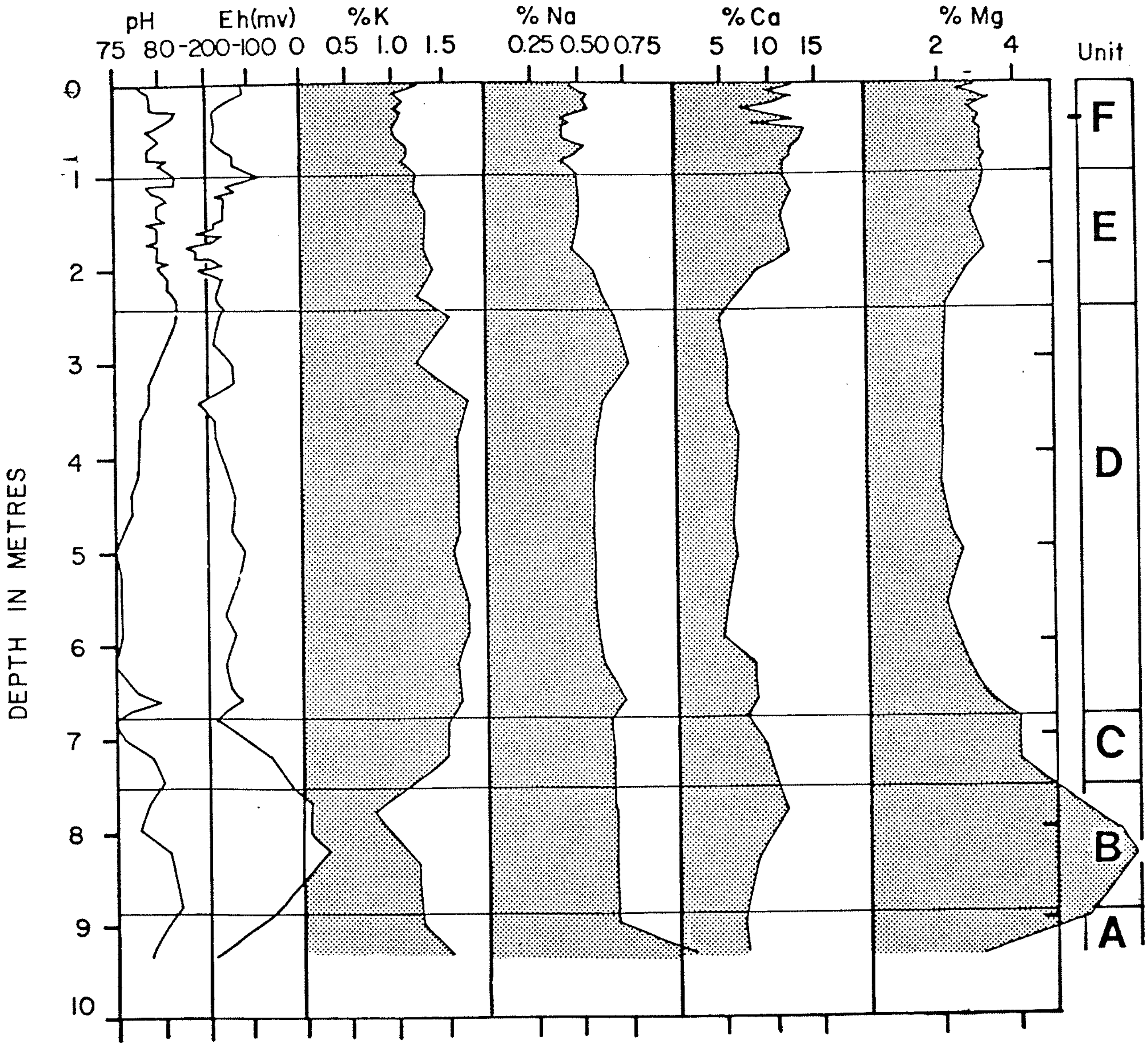


Figure J-14. Variation of pH, Eh, and elemental concentrations with depth in core D-3.

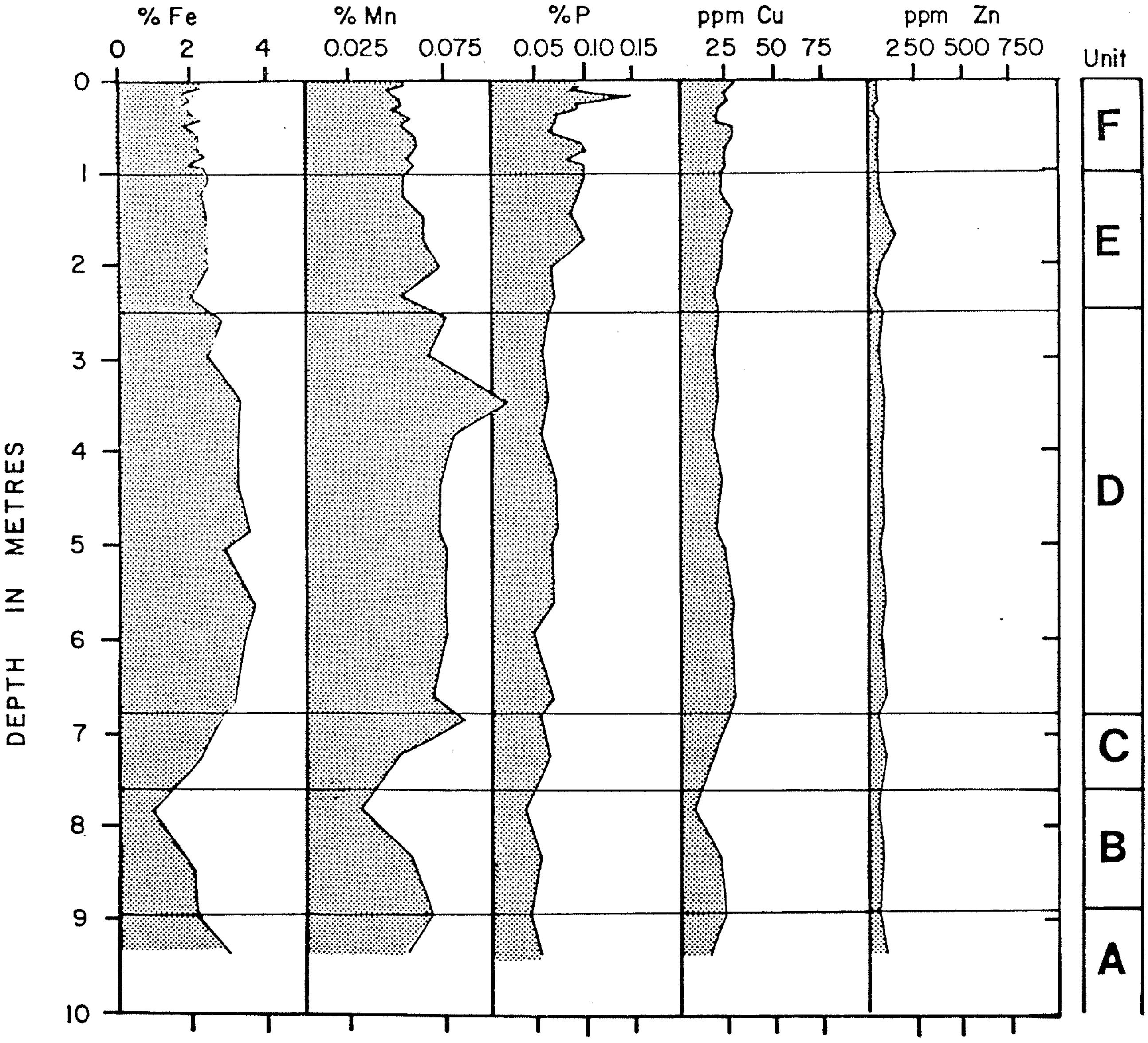


Figure J-15. Variation of elemental concentration with depth in core D-3.

APPENDIX K

Summary of subsurface water chemistry data from the Lake Manitoba-Lake Winnipegosis area.

The following tables and figure are taken from van Everdingen (1971). Figure K-1 identifies the sample location points.

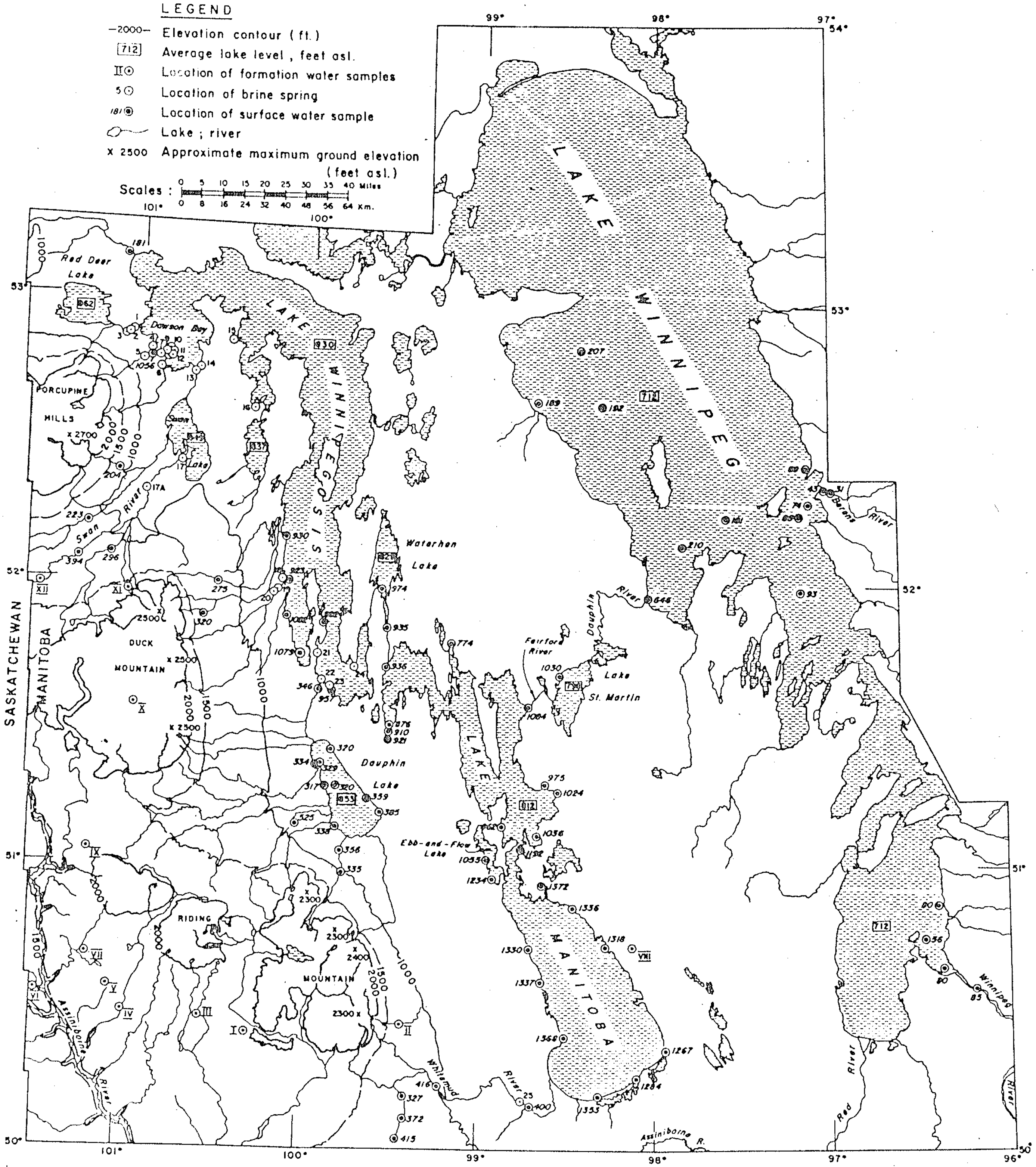


Figure K-1. Surface drainage and major topographic features in southern Manitoba. Locations of brine springs and sampling points for formation waters and surface waters. Sum of dissolved constituents is indicated for surface water samples (from van Everdingen, 1971).

Table K-1. Chemical analyses for Paleozoic formation waters in southern Manitoba. Location numbers refer to Figure K-1 (from van Everdingen, 1971).

			Constituents in mg/liter							Ion ratios			
Location, elevation	Sample elevation in feet	Formation	Sum	Ca^{++}	Mg^{++}	$Na^+ + K^+$	Cl^-	$SO_4^=$	HCO_3^-	$\frac{Na^+ + K^+}{Cl^-}$	$\frac{Ca^{++} + Mg^{++}}{Na^+ + K^+}$	$\frac{Ca^{++}}{Mg^{++}}$	$\frac{SO_4^=}{Cl^-}$
I 8-34-16-21-W1	- 527	Dawson Bay	212,850	2546	1042	76,908	122,750	4588	75	0.966	0.064	1.48	0.028
1981	- 715	Winnipegosis	198,350	3331	1079	70,663	115,250	3643	185	0.965	0.083	1.87	0.023
	-1569	Red River	106,590	2484	904	35,947	58,750	4854	260	0.943	0.127	1.67	0.061
	-1839	Winnipeg	242,810	4344	946	87,326	143,000	2847	85	0.942	0.078	2.79	0.015
II 16-11-17-15-W1	+ 315	Souris River	71,907	2190	425	24,918	41,300	2850	224	0.930	0.133	3.13	0.051
1206													
III 6-23-17-23-W1	- 546	Souris River	120,500	2132	527	35,718	56,500	5126	215	0.975	0.076	2.45	0.067
1852	- 656	Dawson Bay	212,240	2318	1155	75,770	121,000	4492	60	0.966	0.064	1.22	0.027
	- 853	Winnipegosis	232,820	2567	1293	84,303	136,500	3464	120	0.952	0.064	1.20	0.019
IV 1-27-17-26-W1	- 969	Souris River	201,323	2594	1022	74,309	118,894	4303	201	0.964	0.066	1.54	0.027
1780	-1091	Souris River	98,661	2094	782	34,699	55,201	5516	378	0.969	0.112	1.62	0.074
	-1311	Prairie Evap.	158,480	2523	745	57,895	92,203	4839	275	0.968	0.074	2.05	0.037
	-1766	Red River	260,473	2823	832	97,688	155,290	3675	165	0.970	0.049	2.06	0.018
	-2350	Winnipeg	292,393	2873	845	110,458	175,309	2806	104	0.971	0.044	2.06	0.012
V 4-30-18-26-W1	- 908	Souris River	50,000	1677	472	16,570	26,296	4510	476	0.972	0.170	2.16	0.127
1798	-1007	Dawson Bay	256,932	2510	847	96,615	153,106	3732	122	0.973	0.046	1.80	0.018
VI 16-18-18-29-W1	- 911	Souris River	211,456	6002	1404	74,141	126,779	3038	92	0.902	0.129	2.59	0.018
1585	- 968	Souris River	170,374	5433	1721	58,131	102,151	2806	134	0.877	0.163	1.92	0.020
	-1059	Souris River	130,529	2690	586	49,996	72,185	4706	366	1.068	0.084	2.78	0.048
	-1890	Interlake	307,884	2236	983	116,779	184,406	3285	195	0.976	0.038	1.38	0.013
	-2700	Winnipeg	255,691	4282	817	94,355	153,470	2657	110	0.948	0.069	3.18	0.013
VII 16-32-19-27-W1	-1422	Interlake	267,103	3777	866	99,321	160,385	2669	85	0.955	0.060	2.65	0.012
1811	-1822	Red River	82,518	2041	188	29,496	32,284	4101	42	1.404	0.092	6.59	0.094
	-2244	Winnipeg	59,010	1461	328	20,694	46,466	4253	61	0.687	0.111	2.70	0.068
VIII 14-17-20-5-W1	+ 305	Red River	1,196	29	25	322	213	390	207	2.329	0.251	0.70	1.351
835	- 197	Winnipeg	27,501	942	185	9,107	13,527	3484	256	1.038	0.157	3.09	0.190
IX 13-4-24-27-W1	- 178	Souris River	37,222	1308	568	11,781	18,410	4685	470	0.987	0.219	1.40	0.188
1870													
X 16-18-30-25-W1	+ 44	Winnipegosis	13,657	351	149	4,591	6,976	1389	231	1.015	0.149	1.43	0.147
2336													
XI 16-35-34-26-W1	+ 655	Souris River	4,400	39	3	1,586	1,745	623	545	1.401	0.032	7.80	0.264
1824	+ 225	Dawson Bay	10,021	74	57	3,601	4,792	907	669	1.159	0.054	0.79	0.140
	+ 117	Winnipegosis	8,992	170	44	3,211	4,550	829	380	1.088	0.087	2.34	0.135
XII 11-1-35 29-W1	+ 110	Winnipegosis	11,567	212	88	4,078	5,719	1212	525	1.099	0.101	1.46	0.156
1359	- 236	Interlake	56,009	1529	500	19,194	30,566	4048	350	0.968	0.141	1.86	0.078
	- 583	Stony Mountain	106,900	1850	513	36,778	61,000	4603	300	0.930	0.084	2.20	0.056
	- 995	Winnipeg	195,049	2444	900	72,203	114,724	4729	100	0.970	0.062	1.65	0.030

Table K-2. Chemical analyses for brine springs in the Lakes Winnipegosis-Manitoba area. Location numbers refer to Figure K-1 (from van Everdingen, 1971).

			Constituents, in mg/l								Ion ratios					
Location #	T, °C	Q, gpm	Sum of Constituents	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$	Br^{-}	$\frac{Na^+}{K^+}$	$\frac{Na^+ + K^+}{Cl^-}$	$\frac{Ca^{++} + Mg^{++}}{Na^+ + K^+}$	$\frac{Ca^{++}}{Mg^{++}}$	$\frac{SO_4^{=}}{Cl^-}$	$\frac{Cl^-}{Br^-}$
1*	-	2.0	46,584	1128.	365.	15593.	858.	26284	2365.	-	30.9	0.944	0.123	1.88	0.066	-
2	11.1	3.5	51,899	1134.	343.	18716.	11.	29080.	2600.	15.	3014.	0.993	0.104	2.01	0.066	4316.
3	5.6	7.25	53,333	1185.	329.	19413.	6.	29600	2678	22.	6029.	1.011	0.102	2.18	0.067	2981.
4*	-	4	57,140	1284.	371.	19110.	1568.	31842.	3002.	-	20.7	0.970	0.106	2.06	0.073	-
5	15.6	15.25	29,013	600.	195.	10223.	9.	16340.	1646.	tr.	1933.	0.965	0.102	1.84	0.074	-
6	11.1	17.25	57,888	1325.	316.	20710.	95.	34240.	3085.	108.	372.	0.935	0.101	2.64	0.067	721.
7*	-	-	61,057	1281.	328.	20876.	1349.	34074.	3149.	-	26.3	0.981	0.096	2.37	0.068	-
8*	-	20.0	60,074	1302.	341.	20632.	1087.	33684.	3028.	-	32.3	0.974	0.101	2.32	0.066	-
9	6.7	45.5	59,297	1200.	304.	20406.	113.	34240.	2993.	41.	308.	0.922	0.095	2.40	0.065	1931.
10*	-	-	63,064	1146.	341.	21819.	1033.	35432.	3293.	-	35.9	0.976	0.088	2.03	0.069	-
11	16.7	7.5	63,344	1424.	351.	22191.	352.	35620.	3299.	107.	107.	0.970	0.103	2.46	0.069	750.
12	6.7	-	62,251	1443.	345.	21629.	231.	35280.	3243.	80.	159.	0.951	0.106	2.54	0.068	995.
16*	-	-	61,250	1296.	325.	20876.	1347.	34171.	3235.	tr.	26.3	0.976	0.097	2.42	0.070	-
17*	-	-	53,478	1238.	282.	18160.	1039.	29916.	2843.	-	29.7	0.967	0.104	2.67	0.070	-
18*	-	-	33,304	944.	288.	10525.	1124.	18350.	2073.	-	15.9	0.940	0.146	1.99	0.083	-
19	5.6	14.5	26,383	718.	240.	8863.	3.	14800.	1732.	27.	4817.	0.923	0.144	1.82	0.086	1228.
20	5.6	14.5	33,626	855.	212.	12107.	71.	18240.	2123.	18.	289.	1.027	0.114	2.45	0.086	2236.
21	7.2	-	40,066	976.	504.	15181.	45.	20650.	2695.	15.	579.	1.135	0.136	1.17	0.096	3065.
25	-	36.25	9,771	400.	239.	3063	tr.	5330.	725.	tr.	>3000.	0.887	0.297	1.02	0.086	-

* After Tyrrell, 1889; others from Cole, 1915

Table K-3. Comparison of ion ratios for subsurface and surface waters in southern Manitoba (from van Everdingen, 1971).

	$\frac{Ca^{++} + Mg^{++}}{Na^{+} + K^{+}}$	$\frac{SO_4^{=}}{Cl^{-}}$	$\frac{Na^{+}}{K^{+}}$	Sum of constituents
Paleozoic formation waters*	0.038-0.219	0.012-0.190	--	10,000-307,000
Brine springs*	0.088-0.146	0.065-0.096	15.9-6,029	10,000- 63,344
Surface waters affected by brine discharge**	0.4 -0.8	0.08 -0.25	25.1-49.0	646- 1,368
Surface waters outside brine discharge area***	1.4 -18.3	0.3 -5.8	1.3-17.1	43- 525

* 1 spring sample and 3 formation water samples with less than 10,000 mg/liter dissolved solids were omitted.

** Lake Winnipegosis, Lake Manitoba, Ebb-and-Flow Lake, Fairford River, Lake St. Martin, Sturgeon Bay at mouth of Dauphin River.

*** Dauphin Lake, 9 rivers draining Manitoba Escarpment, Lake Winnipeg, Berens River and Winnipeg River.

APPENDIX L

Cores with sediment showing marker zone characteristics.

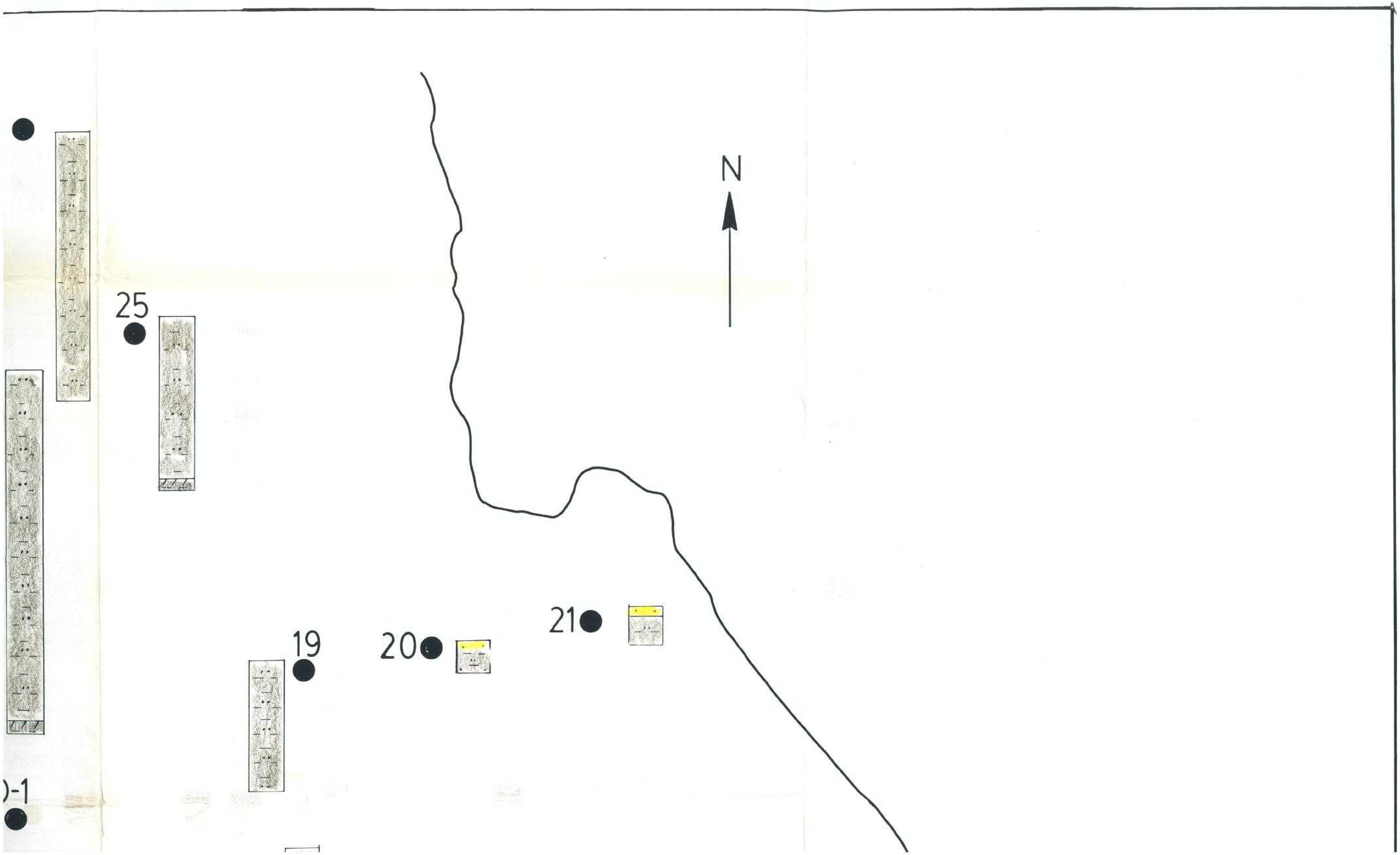
The following table lists all cores from Lake Manitoba in which modern zones are identified, indicates the appropriate core depth, thickness of the zone and summarizes which characteristics are present in each zone.

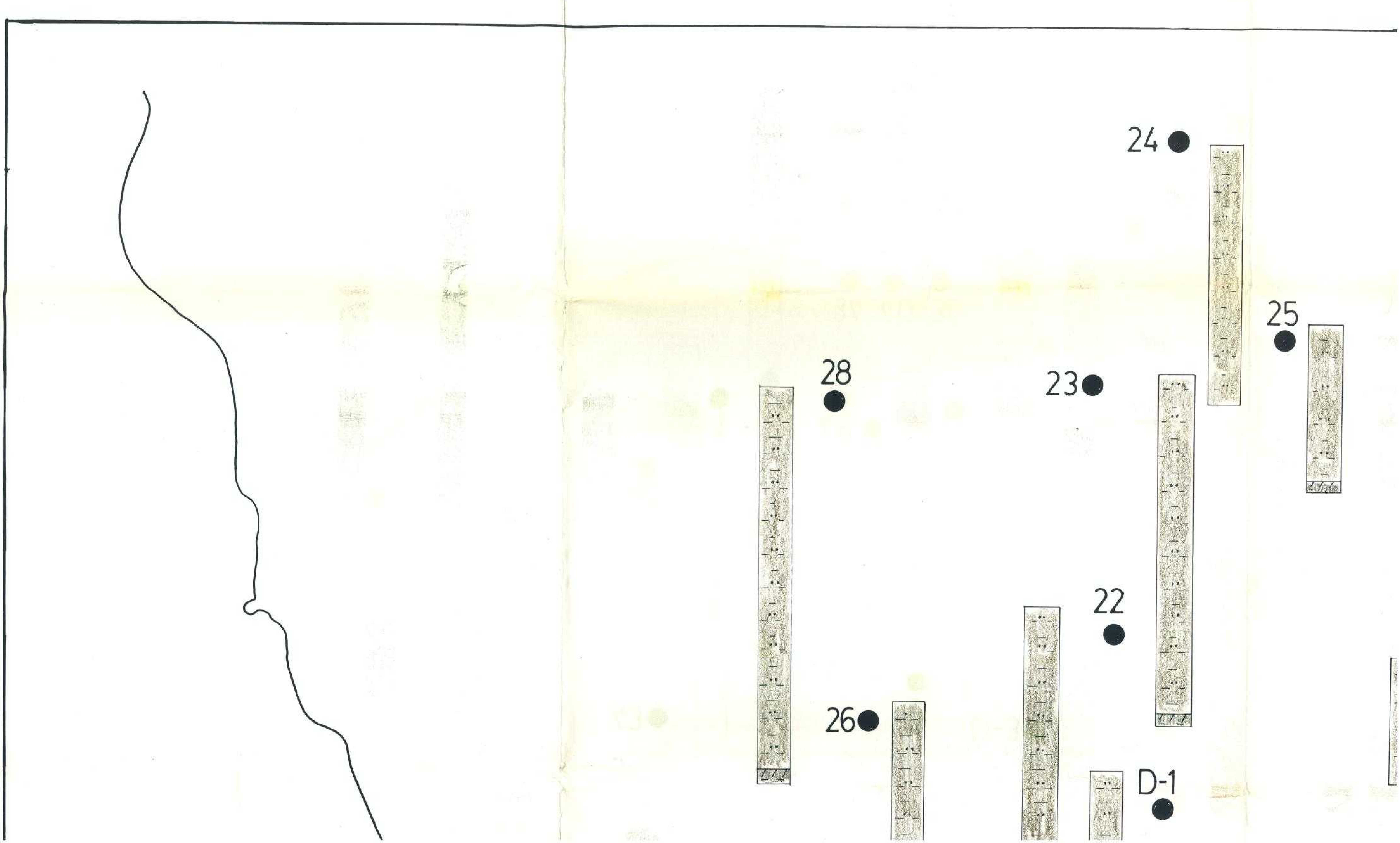
Core	3(?)	21(?)	23	25(?)	26	27	28	32(?)	37	38	39	40	41(?)*	42*
Depth (cm)	53-63	8-26	257-265	125-126	312-325	240-257	290-296	64-72	289-292	282-285	146-160	121-127	110-113	219-235
Thickness of marker horizon (cm)	10+	18	8+	1+	13+	17+	6+	8+	2+	3+	14+	6+	3+	16+
5GY 4/1 Color	X	X	X		X	X	X		X	X	X	X		
Moisture content decrease (relative to overlying sediment)	X	X	X		X	X	X		X	X	X			X
Structure														
angular blocky	X				X	X	X		X	X	X	X		
pelletal			X			X			X	X				X
granular/crumbly									X	X	X	X		
prismatic/columnar														
Root fibers	X	X									X	X		X
Textural change (relative to overlying sediment)	X	X	X	X	X	X	X	X	X	X	X	X	X	

X indicates marker horizon in the core exhibits this particular characteristic.
+ indicates thickness could not be determined precisely because of missing core, out-of-place core or insufficient penetration.
(?) questionable marker horizon
* soil tube and hand augering only; no core sample.

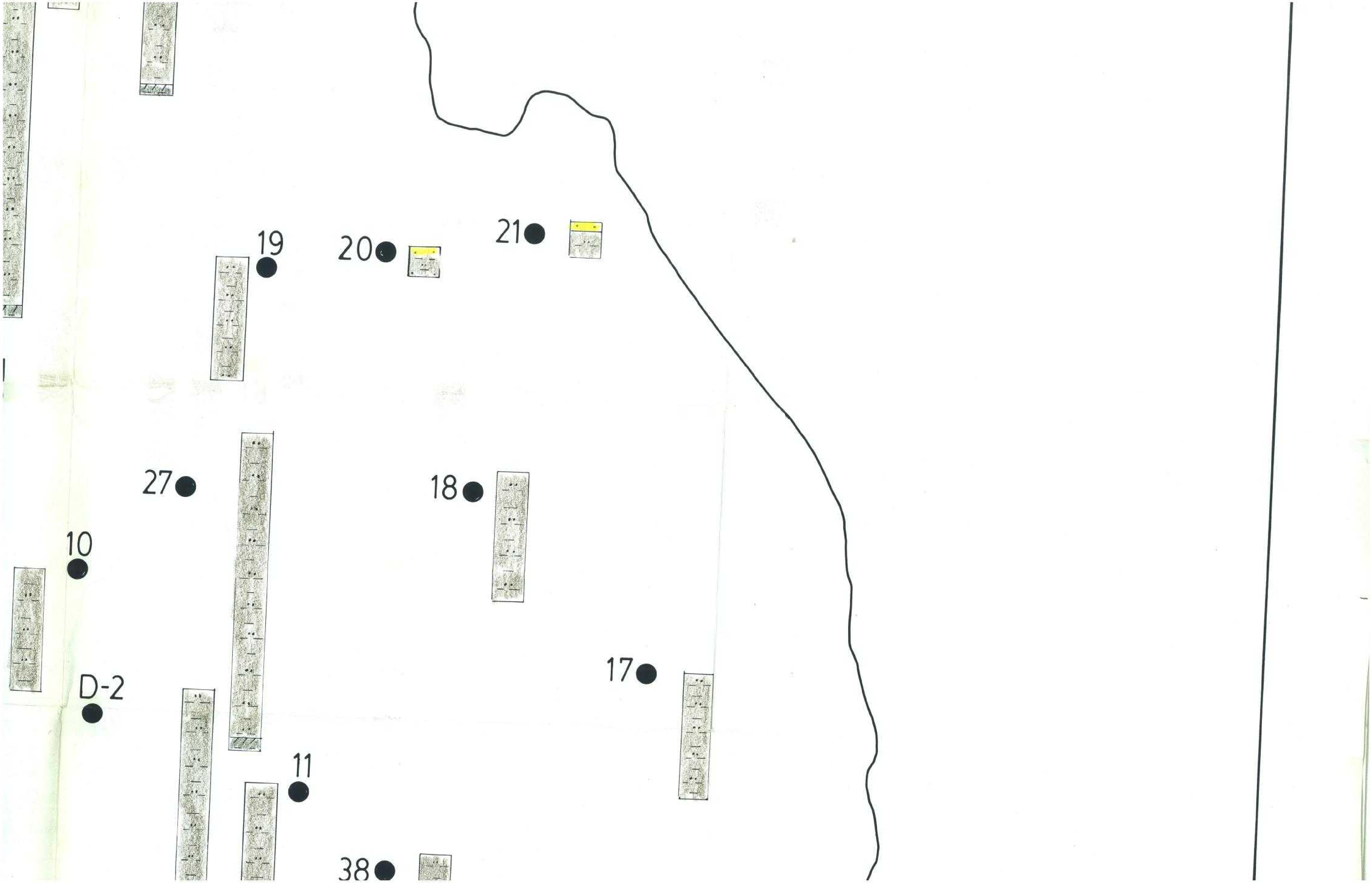
Core	45	46(?)*	47	D-1	D-1(?)	D-1	D-1	D-1	D-2	D-2	D-2	D-2	D-3	D-3	D-3
Depth (cm)	20-27	46-57	33-52	330-349	441-473	737-746	807-839	975-983	300-304	333-487	603-611	760-765	245-269	676-679	717-754
Thickness of marker horizon (cm)	7	11	19	19+	32+	9+	32+	8+	4+	154+	8+	5+	24+	21+	37+
5GY 4/1 Color	X		X	X	X	X	X		X	X	X	X	X	X	
Moisture content decrease (relative to overlying sediment)	X			X	X	X	X	X	X	X	X	X	X		X
Structure															
angular blocky			X	X		X	X	X	X	X	X	X	X	X	X
pelletal	X			X	X				X	X					
granular/crumbly			X										X		
prismatic/columnar										X					
Root fibers		X												X	
Textural change (relative to overlying sediment)		X	X	X			X	X	X	X		X	X		X

X indicates marker horizon in the core exhibits this particular characteristic.
+ indicates thickness could not be determined precisely because of missing core, out-of-place core or insufficient penetration.
(?) questionable marker horizon.
* soil tube and hand augering only; no core sample.


N
25
19
20
21
-1


24
25
28
23
22
26
D-1


22
26
D-1
2'
10
D-2
42
4
5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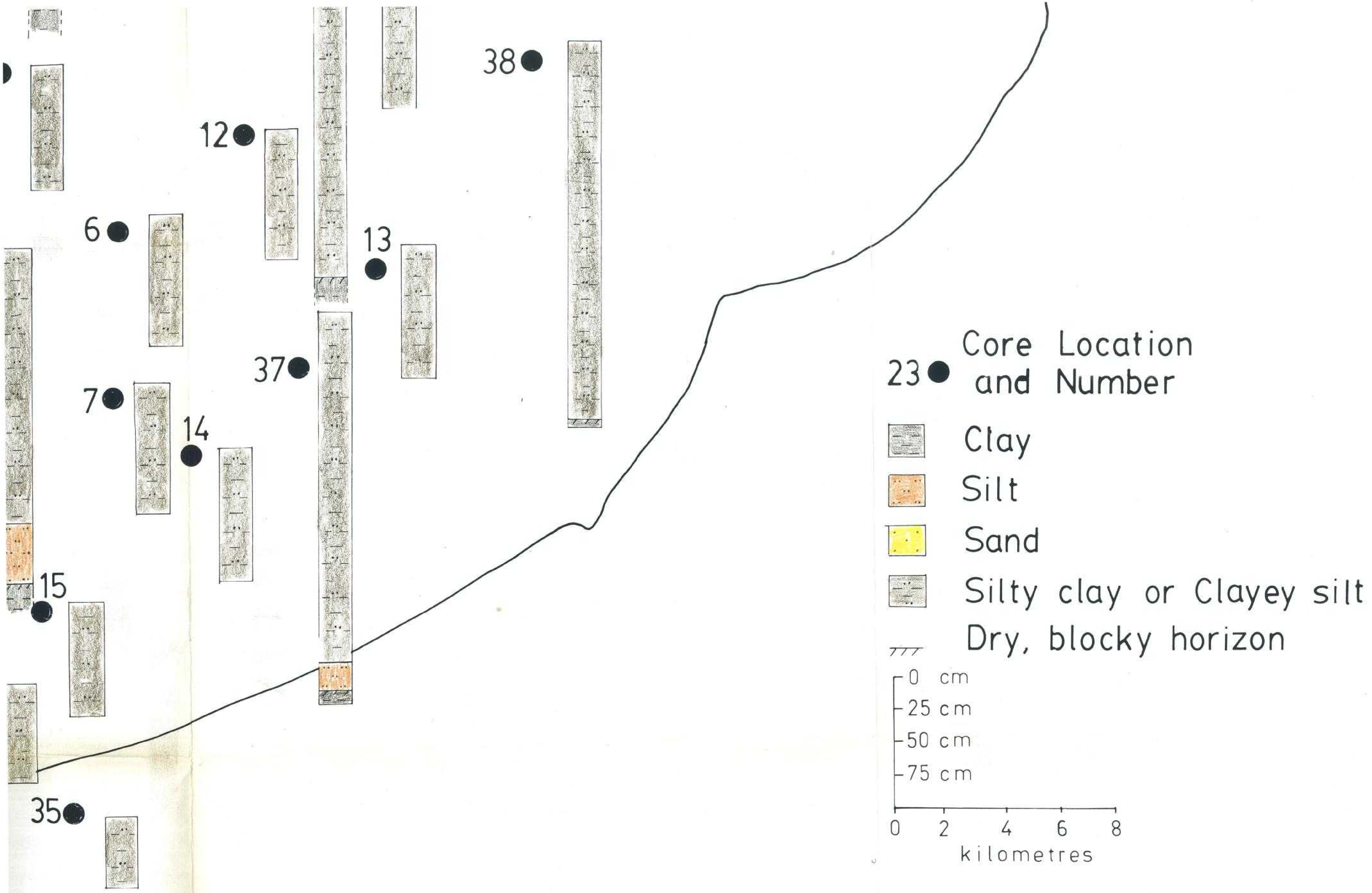
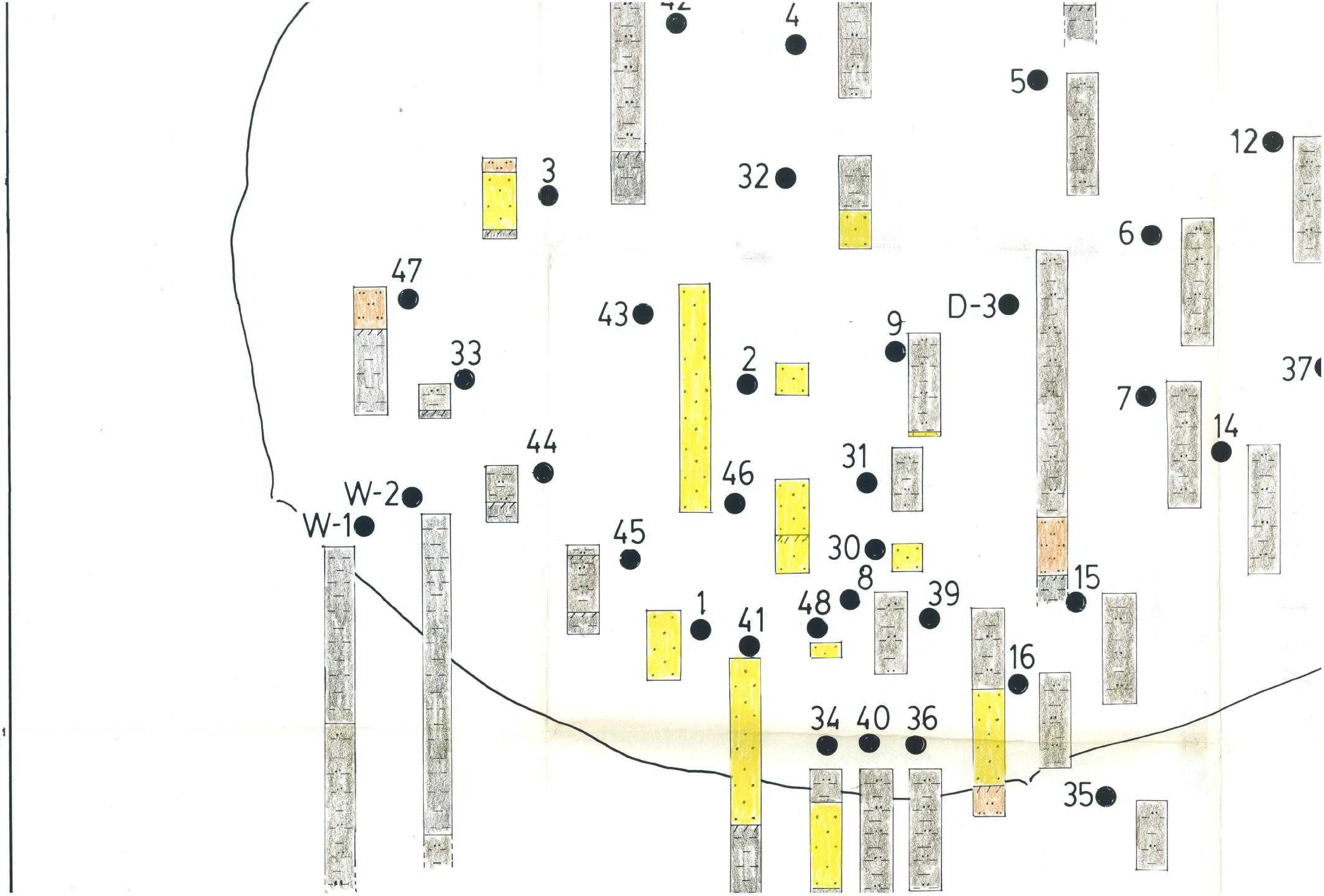
20
21
27
18
10
D-2
17
11
38


38
12
6
13
37
7
14
15
35
23
Core Location and Number
Clay
Silt
Sand
Silty clay or Clayey silt
Dry, blocky horizon
0 cm
25 cm
50 cm
75 cm
0
2
4
6
8
kilometres


42
4
5
12
3
32
6
47
43
D-3
9
2
33
37
7
14
44
31
46
W-2
W-1
45
30
8
15
39
1
41
48
16
34
40
36
35