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SEDIMENTOLOGY AND STRATIGRAPHY OF GLACIAL LAKE SOURIS, NORTH DAKOTA: EFFECTS OF A GLACIAL-LAKE OUTBURST

by

Mark L. Lord

Bachelor of Science, State University of
New York College at Cortland, 1981

Master of Science
University of North Dakota, 1984

A Dissertation
Submitted to the Graduate Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

Grand Forks, North Dakota
August
1988

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This Dissertation submitted by Mark L. Lord in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

Alan E. Kehew
(Chairperson)

John R. Reid

Richard D. LeFever

Kenneth A. Harris

L. Elliot Shubert

This Dissertation meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

639500

Permission

Title Sedimentology and Stratigraphy of Glacial Lake Souris, North Dakota: Effects of a Glacial-Lake Outburst

Department Geology and Geological Engineering

Degree Doctor of Philosophy

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Signature Mark L. Lord

Date May 20, 1988

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My family, including my parents and especially my wife, Patty, have been very supportive of my education; it has been much appreciated. I apologize to my wife and child, Joshua, for the valuable time I have missed with them during the completion of this degree; the time missed has not been for lack of caring.

ABSTRACT

Glacial-lake outbursts commonly occurred along the southern margin of the Laurentide Ice Sheet as ice-marginal lakes suddenly drained. These outbursts released huge volumes of water with tremendous erosive potential, forming large trench-shape channels. Although glacial-lake spillways have been studied in detail, the effects of outbursts on downstream lakes have not. The purpose of this study was to demonstrate the effects of the Glacial Lake Regina outburst on the lake that received the flows, Glacial Lake Souris.

Glacial Lake Souris, located in what is now North Dakota, was inundated by about 74 km^3 of water carrying 25 km^3 of sediment from the outburst of Lake Regina (Saskatchewan). Prior to the outburst, the bottom of Lake Souris was irregular with two shallow depressions and comprised of diamicton overlain by silt and clay rhythmites. Quiet-water lake sedimentation was abruptly halted by coarse-grained outburst sedimentation.

Based on surficial mapping, subsurface sample collection, and textural analyses, the outburst sediments have been grouped into three lithofacies: 1) matrix-rich gravel, commonly with lignite, that generally occurs at the base of the outburst sediments; 2) matrix-deficient gravel, generally without lignite, that occurs near the ground surface adjacent to the Souris spillway; and 3) sand, the most widespread lithofacies, that tends to overlie other lithofacies. Lignite particles are abundant in much of the sand; at depth, outsize lignite clasts are common.

Three major depositional processes probably are responsible for deposition of the outburst sediments: braided rivers, low-density turbidity currents (the dominant process), and high-density turbidity currents or modified grain flows. Most high-density flows resulted directly from the influx of the outburst or from continuous avalanching due to rapid sedimentation. Low-density turbidity currents occurred for the entire duration of the outburst and were caused by the continuous influx of sediment-laden flows and by residual currents from high-density flows.

The emptying of Lake Souris was triggered by inundation of the lake by outburst waters before silt- and clay-size sediment had time to settle out. Incision of the lake bottom by outburst flows occurred concurrently with falling lake level.

INTRODUCTION

General Background

This study is concerned with the effects of a glacial-lake outburst on the lake that received the outburst discharges, Glacial Lake Souris. During the late Wisconsinan, proglacial lakes formed along the southern margin of the Laurentide Ice Sheet as meltwater ponded in topographic lows, isostatic depressions, and basins bounded by ice-marginal deposits. Whereas the existence of such lakes has long been recognized (Upham, 1896), much new insight has been gained over the last decade on the development, stability, chronology, and drainage of glacial lakes in the mid-continent region (Teller and Clayton, 1983; Karrow and Calkin, 1985; Kehew and Lord, 1986, 1987). Part of the increased understanding has resulted from the recognition that many of the ice and/or debris dams of such proglacial lakes failed suddenly and released huge water volumes (Kehew and Lord, 1987).

Several aspects related to such glacial-lake outbursts have been studied in detail. For example, the geomorphology of glacial-lake spillways, the paleohydrology of the outburst flows, the sedimentology of gravel deposits within spillways, and the effects on downstream, glacial-lake water levels have been discussed by numerous workers for events within and outside the mid-continent region (Bretz, 1929; Malde, 1968; Baker, 1973; Kehew, 1982; Clayton, 1983; Kehew and Clayton, 1983; Teller, 1985; Kehew and Lord, 1986; Lord and Kehew, 1987). Whereas the general effects of outburst on downstream, glacial lakes have been studied, detailed investigations of outburst-deposited sediment in a lake environment are lacking (Kehew and Clayton, 1983). This study was undertaken in an attempt to narrow this gap in knowledge and to add to the understanding about the character and importance of outbursts as a glacial meltwater process, at least along segments of the margin of the Laurentide Ice Sheet.

Objectives

The foremost objective of this study is to explain the origin and pattern of deposition of the coarse-grained sediments that cover much of the Glacial Lake Souris basin floor. Such an explanation must interrelate aspects of, and be consistent with, the lithology, stratigraphy, sedimentology, and geomorphology of the lake plain, as well as being consistent with the regional geologic framework.

Specific objectives of this study are 1) to describe the lithofacies present in the Lake Souris basin and their stratigraphic relationships, 2) to reconstruct the conditions of Lake Souris prior to the hypothesized inundation of the basin by glacial-lake outburst flows, 3) to demonstrate the sedimentologic and geomorphic effects of such an outburst on Lake Souris, and 4) to present a depositional model for outburst flows into ponded water and discuss the implications of such a model for analogous areas.

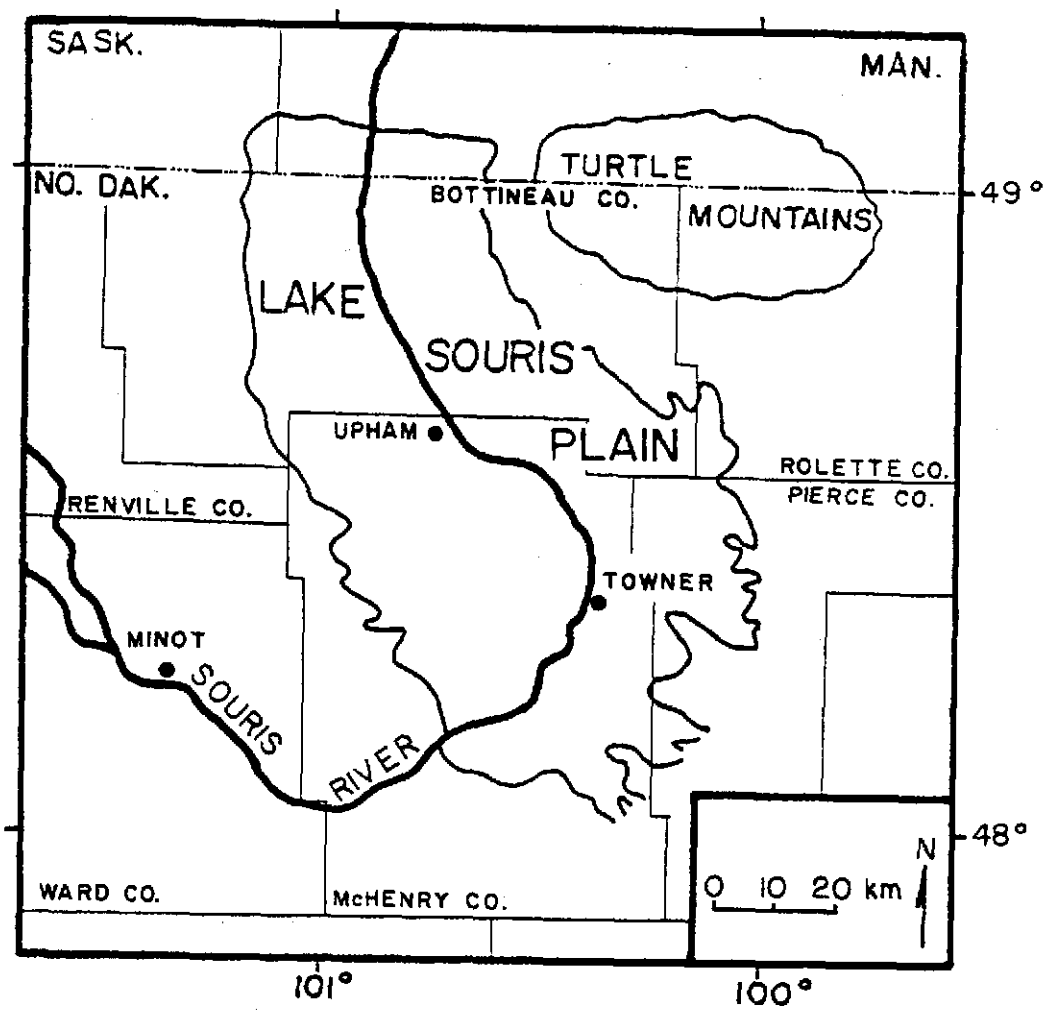
In this study, the regional geologic setting and information directly pertinent to Glacial Lake Souris are presented first. After a discussion of methodology used for this study, the lithofacies and stratigraphy of sediments of the Lake Souris basin are then described and interpreted. It is in this section that the outburst-deposited sediments are identified and the foundation for documenting the effects of outburst flows on Lake Souris is established. Detailed textural information on the glacial-lake outburst sediment deposited in Lake Souris is given. These data are used to interpret the effects of the outburst on sedimentation and serve as a basis for developing a model of deposition for the outburst flows. The conclusions presented in this study will be used to interpret analogous regions and to assess the role of outbursts as a glacial-meltwater process.

Geologic Setting

Area of Study

The Glacial Lake Souris plain is located in north-central North Dakota and, to a small extent, along the international border in southwest Manitoba (Fig. 1). This study is concerned primarily with the coarse-grained sediments of Lake Souris; they occur within an area bounded by the 48 degree and 48 degree 45 minute parallels, and the 100 degree and 101 degree meridians. The Souris River flows north through the region of study, bisecting the Lake Souris plain. To the northeast of the Lake Souris plain are the Turtle Mountains, an isolated upland region which diverted glacial flow and meltwater paths during the Pleistocene Epoch.

Figure 1. Location of the Lake Souris plain and regional physiographic features.

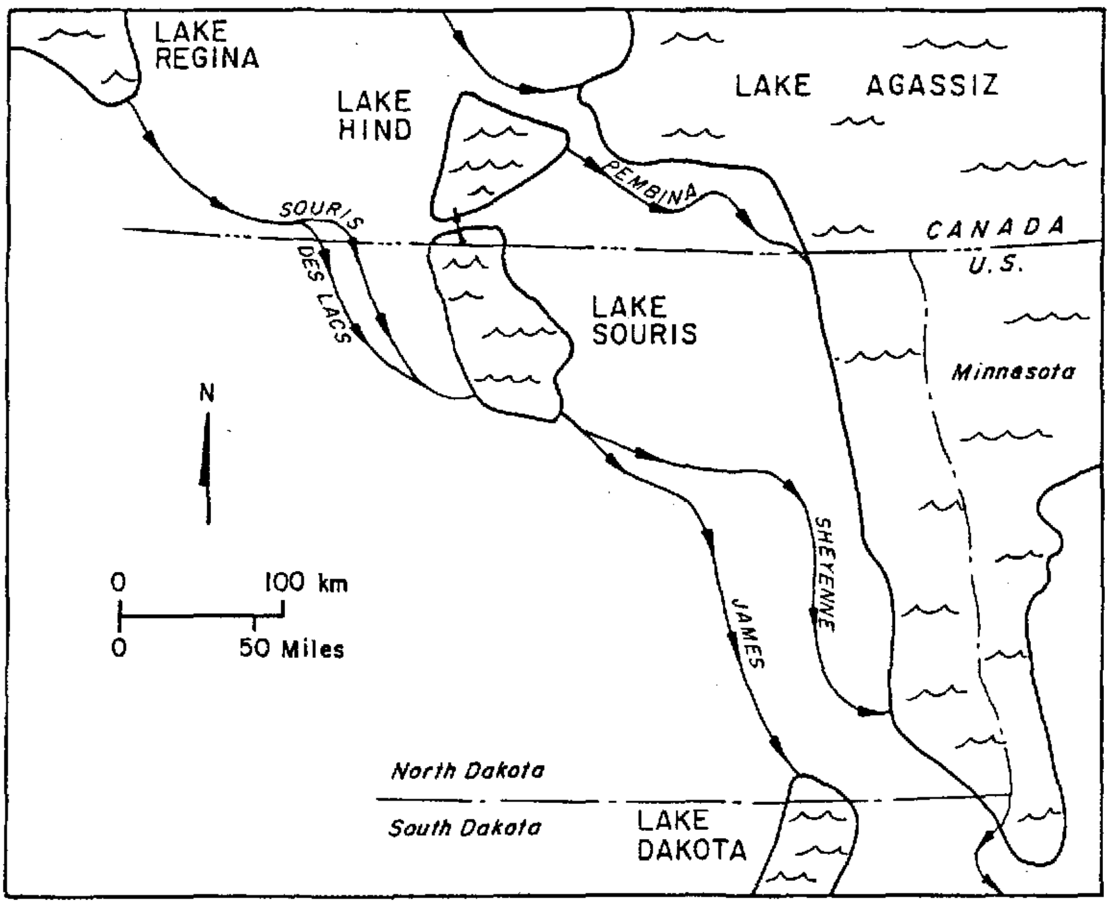

SASK.
MAN.
TURTLE
MOUNTAINS
NO. DAK.
BOTTINEAU CO.
LAKE
SOURIS
PLAIN
UPHAM
ROLETTE CO.
PIERCE CO.
RENVILLE CO.
TOWNER
MINOT
SOURIS
RIVER
49°
48°
WARD CO.
McHENRY CO.
0 10 20 km
N
101°
100°

Regional Geology

Glacial Lake Souris was one of several proglacial lakes that formed along the southwestern margin of the Laurentide Ice Sheet during the Wisconsinan glaciation. The ages of these lakes, and the positions of associated ice margins and spillways are discussed by Clayton and Moran (1982). Pertinent to this study are the lakes and spillways that were connected to Lake Souris. Glacial Lake Regina (Fig. 2) drained through the Souris and Des Lacs spillways (Christiansen, 1956); this spillway system terminates at Lake Souris. Glacial Lake Arcola, which existed about 75 km north-northwest of where the Souris spillway crosses the international border, also drained to the south through the Souris spillway. Lake Souris had outlets to the south and to the north. It first drained to the south through the Sheyenne and James spillways into Glacial Lake Dakota; subsequently, it drained entirely through the Sheyenne spillway into Glacial Lake Agassiz (Kehew and Clayton, 1983). The final drainage of Lake Souris occurred to the north through the Souris-Hind spillway into Glacial Lake Hind. Lake Hind drained through the Pembina spillway into Lake Agassiz. All of the spillway segments shown on Figure 2 are attributed to erosion by discharges from glacial-lake outbursts (Kehew, 1982; Kehew and Clayton, 1983). More detailed discussions of the chronologic development and origin of these spillways and glacial lakes are given in Kehew and Clayton (1983) and Kehew and Lord (1986, 1987).

The textural characteristics and lithology of sediments deposited in Lake Souris were strongly influenced by the regional geology. Low-

Figure 2. Regional glacial lakes and glacial-lake spillways related to Glacial Lake Souris.


LAKE REGINA
LAKE HIND
LAKE AGASSIZ
PEMBINA
SOURIS
DES LACS
CANADA
U.S.
LAKE SOURIS
Minnesota
N
0
100 km
0
50 Miles
SHEYENNE
JAMES
North Dakota
South Dakota
LAKE DAKOTA

relief, hummocky, glacial collapse topography predominates over most of the region shown in Figure 2 (Christiansen, 1956; Clayton, 1980). Glacial-drift thicknesses range from a few metres to about 60 m. High-relief, glacial collapse topography occurs in the Moose Mountains, located just north of the Lake Arcola plain, and in the Turtle Mountains to the northeast of the Lake Souris plain (Fig. 1). Drift thicknesses in these regions reach up to 200 m (Clayton and others, 1980). Directly beneath the glacial drift are poorly indurated, fine-grained Paleocene and Cretaceous bedrock formations. Limited outcrops of bedrock occur along spillway sides and in ice-thrust masses (Lord, 1988).

Glacial Lake Souris

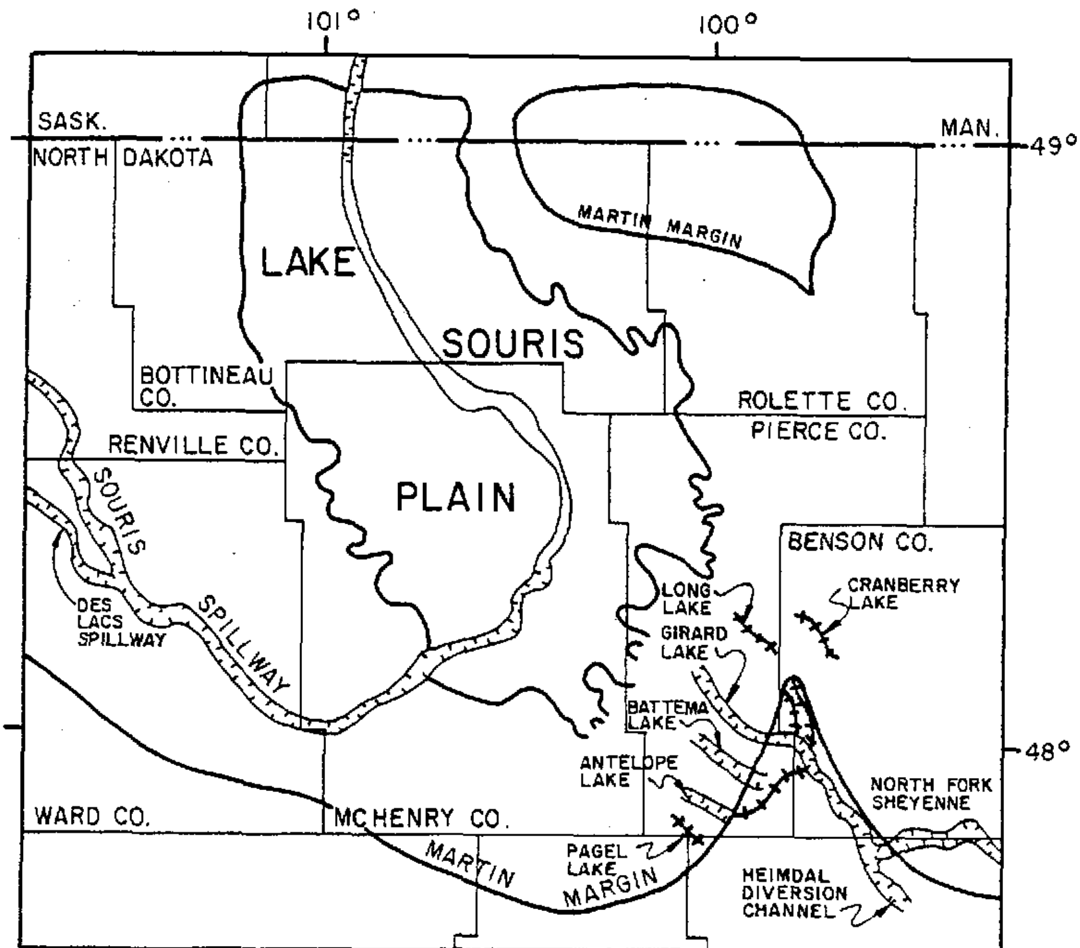
Introduction: It is not the purpose of this study to examine the entire history of Lake Souris; nonetheless, any interpretations put forth in this study should consider what has been discussed by previous workers. The objective of this section, then, is to review briefly the development and drainage history of Lake Souris to construct a framework into which later interpretations can be incorporated.

The first geologic map of the Lake Souris plain was produced by Upham (1896) in conjunction with his well-known study of Lake Agassiz. Although he did produce a preliminary map of Lake Souris, his main interest in Lake Souris was its relationship to Lake Agassiz. Numerous workers have studied aspects of Lake Souris, but, as with Upham, the majority has been more interested in its relation to some other topic, especially Lake Agassiz (Elson, 1955; Clayton and others, 1980; Brophy and Bluemle, 1983; Fenton and others, 1983). As a consequence, there is no complete synthesis of all information relating to Lake Souris and there are basic inconsistencies between different studies. Studies that are thorough and relevant to this study will be incorporated in the summary given below.

Origin and Drainage History: There is no conclusive evidence for a Glacial Lake Souris prior to the late Wisconsinan; the formation of such a proglacial lake would have become more likely with each successive advance because of the topographic changes accompanying glaciation (Bluemle, 1985). In the early stages of development, Lake Souris existed as a series of isolated supraglacial and ice-walled lakes (Moran and Deal, 1970; Deal, 1971). During the late Wisconsinan, Lake Souris existed at least at two times, separated by a readvance of ice; informally these lakes have been termed Glacial Lake Souris I and II (Schnacke, 1982). Lake Souris is first known to have formed as the Souris Lobe retreated from the Martin ice margin (Fig. 3) (Clayton and others, 1980). It is not known how far to the north the Souris Lobe receded nor the extent to which Lake Souris spread. Bluemle (1985) has suggested that Lake Souris I, bounded by ice to the north, covered portions of Pierce, McHenry, and possibly Bottineau Counties (Fig. 3). In central Pierce County, Lake Souris I sediment consists of clayey silt (Schnacke, 1982).

Lake Souris I drained to the southeast through numerous outlets; these include valleys now occupied by Cranberry Lake, Long Lake, Girard Lake, Battema Lake, Antelope Lake, and Pagel Lake (Fig. 3)

Figure 3. Location of the Martin ice margin and outlets of Glacial Lake Souris (modified from Clayton and others, 1980 and Clayton and Moran, 1982).



ABANDONED CHANNELS

MAJOR MINOR

(Schnacke, 1982; Bluemle, 1985; Lord, 1988). Each of these outlets was used for a short period of time, and, except for the Girard Lake spillway, range in elevation from 466 to 472 m (Clayton and others, 1980). The Girard Lake spillway (elevation about 457 m) is hypothesized to have been formed by one or more outbursts from Lake Souris (Schnacke, 1982; Kehew and Clayton, 1983). Flow from these events continued through the Sheyenne spillway and possibly the Heimdal diversion channel, which connects to the James spillway (Fig. 3). Kehew and Clayton (1983) have suggested that two outbursts may have occurred through the Girard Lake spillway: one that flowed down the Heimdal diversion into the James spillway (leading to Lake Dakota), and a later flood that flowed down the Sheyenne spillway (leading to Lake Agassiz) which is lower in elevation.

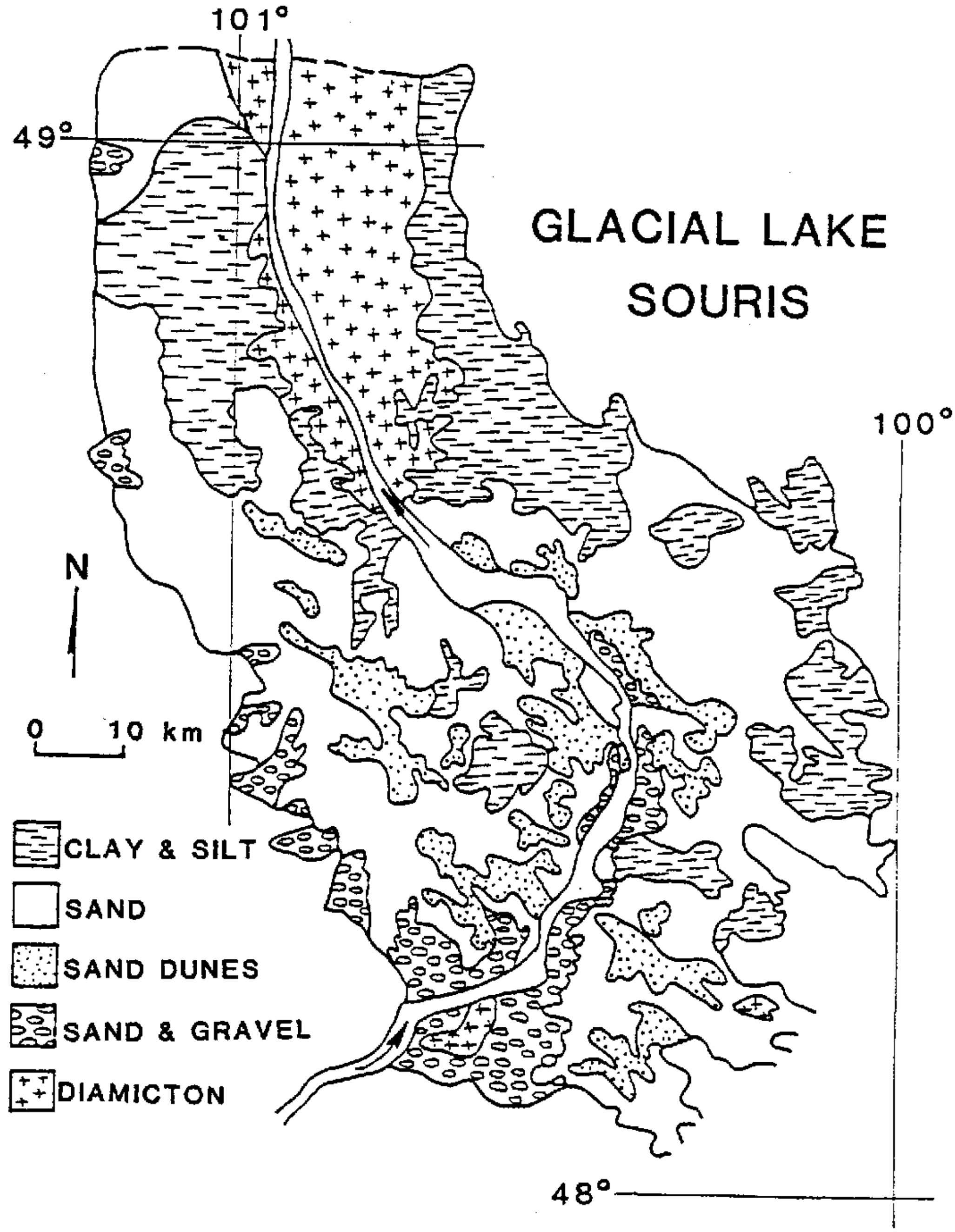
A short-lived readvance of the Souris Lobe to the Martin ice margin overrode Lake Souris I and all of its former southeastern outlets (Clayton and others, 1980; Kehew and Clayton, 1983; Bluemle, 1985). As the Souris Lobe again retreated, Lake Souris II formed along the margins of the glacier and used the lowest outlet, Girard Lake, as its spillway (Kehew and Clayton, 1983). Unless specified otherwise, any subsequent reference to Lake Souris refers to Lake Souris II. At sometime after the Souris Lobe had retreated north of the international border, flows from the outburst of Lake Regina (Fig. 2) debouched into Lake Souris (Kehew, 1982; Kehew and Clayton, 1983). The influx of water from the outburst probably triggered a complete and rapid drainage of Lake Souris through the Souris-Hind spillway (elevation: 455 m) into Lake Hind (Fig. 2) (Kehew and Clayton, 1983;

Kehew and Lord, 1987). During the outburst some water may have flowed out of Lake Souris through the Girard spillway before the northern outlet developed, but it was probably minor because the morphology of the outlet, which was previously overridden by ice, was only slightly modified (Kehew and Clayton, 1983).

Alternative, more complex histories of Lake Souris, which involve more glacial advances and retreats, have been proposed by some workers (Brophy and Bluemle, 1983; Fenton and others, 1983). The focus of those studies, however, was not directly on Lake Souris and, consequently, involved some assumptions not justified by the geology of the Lake Souris area. It also should be noted that Lake Souris has been mapped as connected to Lake Hind along a narrow strip in the vicinity of the international border (Elson, 1955; Aggregate Resources Section, 1980). Kehew and Clayton (1983) stated that such a connection probably was not in existence at the time when Lake Souris received the outburst flows from Lake Regina.

Sediments: Sediments of the Lake Souris basin are dominantly sand with lesser amounts of silt and gravel, and very little clay (Lemke, 1951, 1960). Much of the sediment in the Lake Souris basin was deposited by flows of the Lake Regina outburst (Kehew and Clayton, 1983; Kehew and Lord, 1987). A fan-shape deposit of gravel occurs at the mouth of the Souris spillway; sand and some silt are present basinward of the fan (Fig. 4) (Clayton, 1980; Bluemle, 1982; Lord, 1988). Lake sediment reaches thicknesses of 30 m in the southern portion of the basin and thins to a few metres in the northern portion (Bluemle, 1982).

Figure 4. General geologic map of Glacial Lake Souris (modified from Lord, 1988; Appendix D).


101°
49°
GLACIAL LAKE
SOURIS
100°
N
0 10 km
CLAY & SILT
SAND
SAND DUNES
SAND & GRAVEL
DIAMICTON
48°

Adjacent to the Souris River in Bottineau County, till is present at the surface, where it is cut by lineations trending roughly parallel to the river (Fig. 4; Appendix D). Lemke (1960) suggested that a stagnant block of ice in this area may have prohibited the accumulation of lake sediments. Alternatively, lake sediments in this area may have been eroded when Lake Souris drained rapidly to the north (Bluemle, 1985).

Geomorphology: There are several morphologic features of Lake Souris that are important in assessing its drainage history: these include shoreline features, sand dunes, and abandoned channels. Beach ridges and other shoreline features of Lake Souris are indistinct and disconnected; thus, correlation is not possible (Lemke, 1951; Moran and Deal, 1970; Bluemle, 1982, 1985). Most shoreline features occur along the northeast margin of Lake Souris (Bluemle, 1985; Lord, 1988). Though correlation of shoreline features has not been possible, several lake levels have been suggested based on the abundance of shoreline features at several elevations. The three most prominent probable strandlines occur at 472 m, 457 m, and 450 m (Lemke, 1960; Moran and Deal, 1970; Bluemle, 1982). Other possible strandline levels identified occur at 447, 460, 465, 469, 479, and 484 metres (Moran and Deal, 1970). The studies of lake levels have not addressed the possible effects of differential rebound nor the complex history of the lake in relation to these levels. In spite of these complications, the prominent strandline elevations may be used as rough guidelines in the interpretation of drainage history.

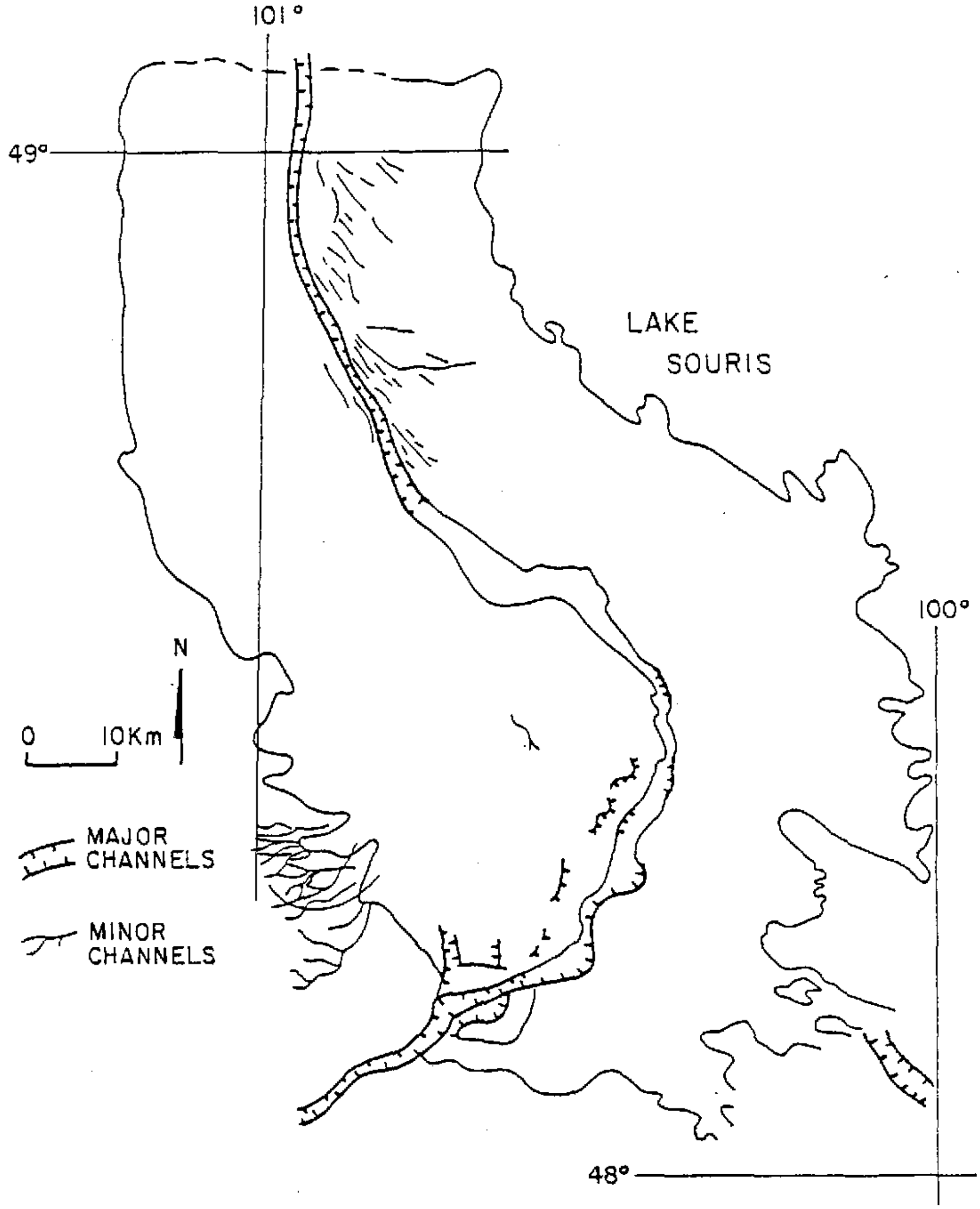
Sand dunes cover much of the southern half of the Lake Souris plain (Appendix D) (Lemke, 1960; Bluemle, 1982). In areas where the dunes have high relief, up to 20 metres, they are longitudinal or irregular dunes (Lord, 1988). The dunes are thought be developed in reworked well-sorted, outburst-deposited sediment (Kehew and Clayton, 1983).

Many abandoned channels and channel scars occur within and adjacent to Lake Souris. All of these channels probably formed during the late Wisconsinan and are therefore related to the history of Lake Souris (Clayton, 1980; Bluemle, 1985; Lord, 1988). A map of these abandoned channels was made from the channels mapped by Lord (1988) (Fig. 5). The most prominent channel is the Souris spillway which has a well-defined trench shape at the inlet to Lake Souris and in the northern third of the lake basin. The network of anastomosing minor channels, about 20 km northwest of Verendrye (Fig. 1), probably carried overflow from the Souris spillway near Minot during the outburst of glacial Lake Regina (Kehew, 1982). The channel scars trending parallel to the Souris spillway in the northern third of the lake plain may have formed as Lake Souris drained rapidly to the north through the Souris-Hind spillway (Bluemle, 1985).

The Lake Regina outburst: implications for Lake Souris

The characteristics of the outburst from Glacial Lake Regina are critical to understanding the potential effects of such flows upon arrival at Lake Souris. Conversely, information gained from studying the sediments of Lake Souris may be used to evaluate the validity of hypotheses concerning the characteristics of the outburst flows.

Figure 5. Abandoned Pleistocene channels related to Lake Souris (modified from Lord, 1988; Appendix D).


101°
49°
LAKE
SOURIS
100°
N
0
10Km
MAJOR
CHANNELS
MINOR
CHANNELS
48°

Because an objective of this study is to demonstrate the effects of the Regina outburst on Lake Souris, the characteristics of the outburst will be reviewed.

Discharges from the catastrophic drainage of Lake Regina flowed down the Souris and Des Lacs spillways (Fig. 2) (Kehew, 1982). An estimated 7.4 x 10^{10} m^3 of water was released within a few weeks from that lake (Kehew and Clayton, 1983). The outburst flows had tremendous erosive power; they carved out the entire Souris spillway upstream from its confluence with the Moose Mountain spillway. The Souris spillway, downstream from the confluence, and the Des Lacs spillway existed prior to the outburst, but were markedly enlarged by the flows (Kehew, 1982; Lord and Kehew, 1987).

Paleohydraulic calculations for the Regina outburst, based on channel morphology and maximum particle sizes, indicate that discharges of 5.8 x 10^4 to 8.2 x 10^5 m^3s^{-1} and velocities of 2.9 to 11.7 ms^{-1} were achieved (Lord and Kehew, 1987). Because the sediments into which the spillways are eroded are generally poorly consolidated and fine-grained, and because of the erosive power of the outburst flows, sediment-water concentrations were high. The outburst flows probably were hyperconcentrated (flow transitional between clear water and debris flow), averaging about 20 percent sediment by weight and possibly reaching 40 percent in some areas (Lord and Kehew, 1987).

Volumetric comparisons between the sediment eroded by the Regina outburst and that redeposited within the spillways show that only a small percentage of the material was redeposited within the spillways (Table 1). These data have important implications for Lake Souris

Table 1. Comparison of textures and volumes of material eroded versus redeposited, within the Souris and Des Lacs spillways, by the Glacial Lake Regina outburst (Kehew and Lord, 1987).

	Sediment eroded from spillways		Outburst Sediment deposited within spillways		Percent material redeposited in spillway
	Percent	Volume (km^3)	Percent	Volume (km^3)	
Clay & Silt	67	17.4	2	0.01	0.1
Sand	28	7.3	17	0.13	1.8
Gravel	5	1.3	81	0.61	46.1
Total	100	26.0	100	0.75	2.9

because it received the sediment-charged water; an estimated 25 km^3 of sediment was delivered to Lake Souris by the outburst (Lord, 1987). In addition, by taking into account the textural characteristics of the sediment eroded versus redeposited (Table 1), estimates of the sediment volume can be made of different size fractions potentially delivered to Lake Souris.

The Lake Regina outburst flow characteristics described above can be used to help interpret the Lake Souris sediments. For example, the well-sorted sands in Lake Souris have been classified as underflow deposits partly because this origin is consistent with the characteristics of the outburst flows (Kehew and Clayton, 1983).

METHODS OF STUDY

Sediment Collection and Analysis

Preliminary Work

All but a few of the samples collected for this study were obtained using the North Dakota Geological Survey's truck-mounted hollow-stem auger. Preliminary work consisted mainly of the selection of drilling locations. The primary purpose of the drilling was to obtain a vertical and horizontal sampling of the coarse-grained sediments of Lake Souris. Several factors were important in deciding upon drilling locations. Geologic maps of McHenry County by Bluemle (1982) and Pierce County by Carlson and Freers (1975) were studied to determine approximate locations of sandy lake sediment in the Lake Souris plain. Topographic maps of the bedrock surface in these same two reports show the locations of pre-glacial channels; these locations were avoided when drilling. A preliminary contour map of depth to till in the study area was constructed, using data from Randich (1971, 1981), so that approximate sand thicknesses would be known. In addition to the geologic information, road maps were used to determine which areas were accessible to the drilling rig. Based on the above described data, about 70 drilling sites were chosen so that locations would be approximately evenly spaced over the study area.

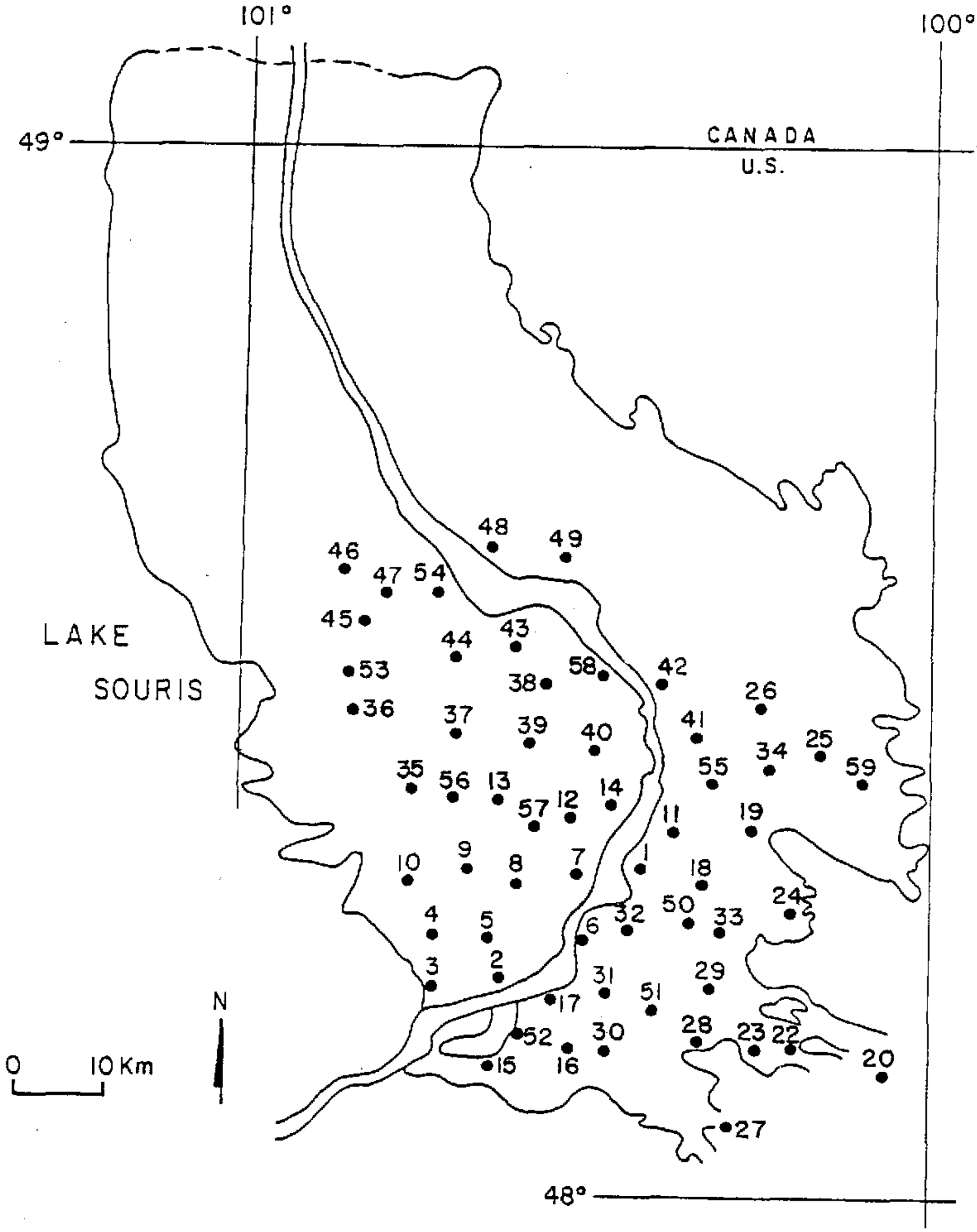
Drilling

Drilling for this study was conducted during parts of the summers of 1985 and 1986. The method of drilling used was to auger downward at a slow rate of rotation to the desired depth and then pull the auger directly out of the hole with no rotation. Initially, holes were drilled to a depth of about 3 m at which time the auger was pulled out and sampled. The hole was then drilled an additional 3 m when the auger was pulled out and sampled again. This process was repeated until the desired drilling depth was reached. This method tends to minimize potential sample contamination and errors in assigning depths to samples. The disadvantage to this method is that it markedly increases the amount of time to drill a hole.

Two exceptions occurred to the method just described. Generally, after hole depths exceeded about 12 m, holes were drilled in additional increments of 4.5 m, instead of 3 m, to save time. The second exception was when drilling became difficult due to hard and/or rocky sediment. In these situations, the auger commonly had to be rotated backward some before it could be pulled out of the hole, thereby permitting some sample movement on the auger flights.

Drilling was continued until either clay or till was reached, except in locations where drilling became too difficult. The depth of the sample holes ranged from about 2 m to 28 m and averaged about 10 m. Sixty-one holes were drilled for this study (Fig. 6; Appendix A); the cumulative length of sediment sampled by augering was about 620 m. Sediment samples were collected directly from auger flights at about 0.75 m intervals and at noticeable lithologic changes; about 800

Figure 6. Location of sample holes drilled for this study; detailed locations are given in Appendix A.


101°
100°
49°
CANADA
U.S.
LAKE
SOURIS
48°
0
10 Km
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16
27

samples were collected. General lithologic descriptions were made forall holes in the field. Information on sample depths, textural characteristics, and sedimentary structures was recorded.

Laboratory Work

The laboratory work required for this study consisted primarily of describing all of the samples collected and then completing a textural analysis on selected samples. All samples collected, except diamictons, were described for grain size, sorting, dry and wet color (using the Munsell Soil Color Chart), sedimentary structures, abundance of lignite, and any other distinguishing characteristics. As the sediments were being described, samples were chosen for textural analyses. Samples from hole sites located in the coarse-grained fan were analyzed for texture; this includes all holes on the west side of the Souris River (Fig. 6) and the majority of those on the east side. Samples from individual holes were chosen for textural analyses at about 1.5 m intervals or at noticeable textural changes, whichever was less. Only samples composed of silt or coarser sediment were analyzed. Of the samples collected, 169 were analyzed for texture; specific information on the samples analyzed may be found in Appendix B.

Textural characteristics of the sediments were determined using a settling tube for samples consisting of sand and/or silt. Samples containing sand and gravel were analyzed by determining the texture of the sand fraction using the settling tube and of the gravel fraction using sieves. Sample preparation for the settling tube included several steps. Bulk samples collected from the auger flights, which had average masses of about 600 g each, were split with a sample splitter until the mass of the sample was between 15 g and 30 g. To disaggregate clumps in the sediment, the reduced sample was put into a beaker, mixed with water, stirred, set several hours, and then dried in an oven at low temperatures. Each sample was then split several times until the sample mass was between 0.2 and 0.4 g. The textures of the sample were then determined using standard settling tube techniques (Gibbs, 1974). The settling tube used for this procedure has a drop distance up to about 105 cm and has an inside diameter of 19 cm.

For sand and gravel sediments, the sample was sieved using a -1 phi screen to split sand from gravel. The texture of the gravel was determined using standard sieve techniques (Folk, 1980) with screens at quarter-phi intervals. The texture of the sand was determined using the settling tube. The results of the textural analyses of the coarse and fine fractions of the samples were normalized and combined to obtain complete sediment-size distribution data. Using moment measures, the textural statistics for all samples were calculated by a computer program written by LeFever (1986a).

Mapping The Lake Souris Plain Area

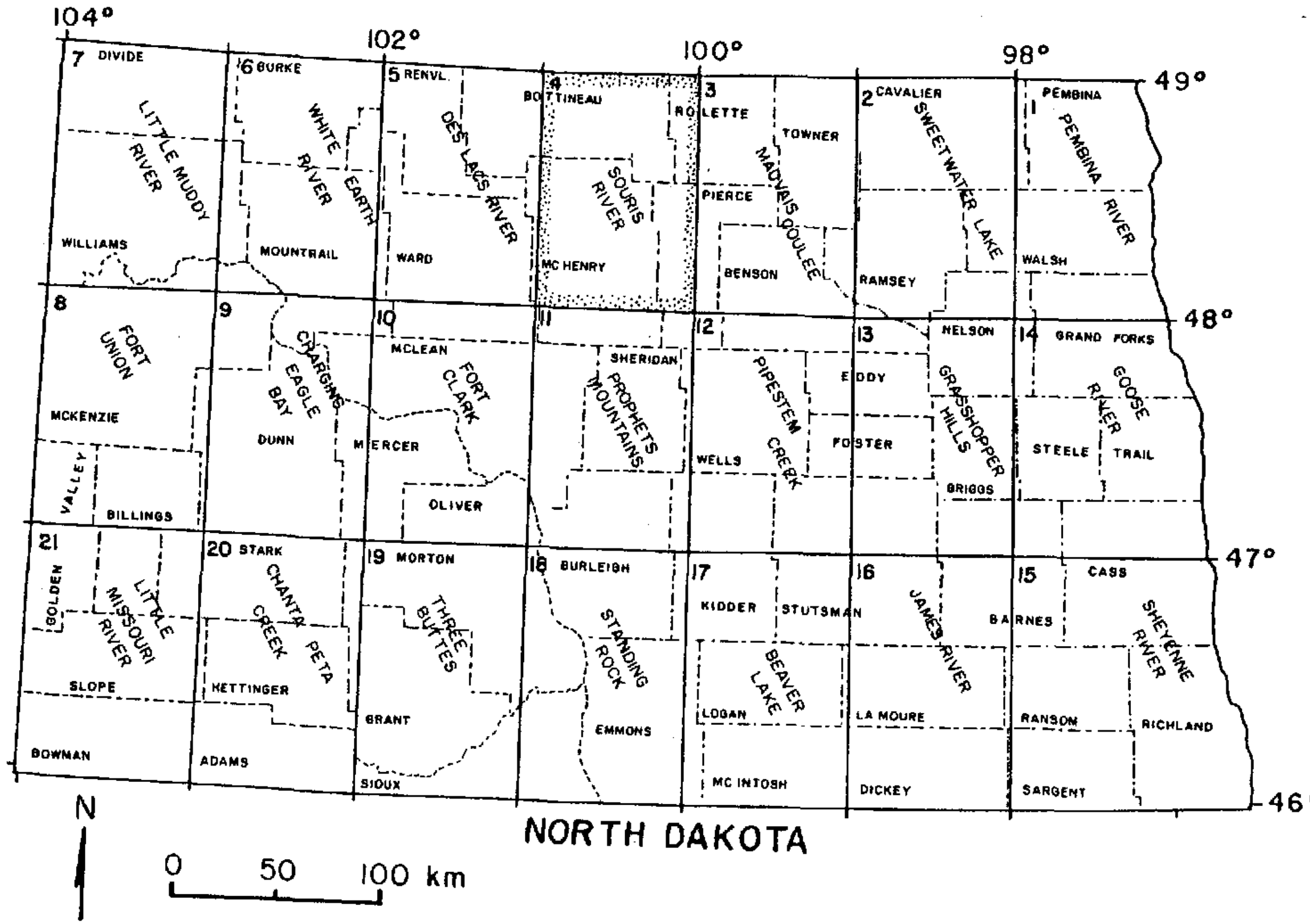
An objective of this study was to construct a map of the coarse-grained sediments of Lake Souris. Such an area, the Souris River Map Area, was mapped (Lord, 1988) in conjunction with a project for the North Dakota Geological Survey. The size and boundaries of the map were chosen to comply with that established for the North Dakota Geological Survey's Atlas Series (Fig. 7). A one degree by one degree surficial geologic map was produced (Appendix D) that includes the coarse-grained sediments as well as the southeastern outlets to Lake Souris. Because of the importance of this map to this study, the pertinent methodology for its construction is briefly summarized below.

A preliminary map of the Souris River Map Area was made based on interpretations of aerial photographs and a compilation of existing drilling data. The preliminary map was constructed on county road maps (scale: 1:31,680) and then compiled onto a base map (scale: 1:250,000). Approximately four weeks were spent checking the map in the field during the 1987 summer. During this time, approximately 200 holes were bored with a hand auger to a depth of about 1.5 m and most of the map area was visually inspected. Based on the field data collected and the rechecking of most aerial photographs, a final draft of the map area was constructed.

Analytical Methods

Standard analytical methods were used to help interpret the data. Primarily these consisted of cross sections and contour maps. Geologic cross sections were based mostly on data collected for this study; however, where more detail was required, these data were augmented by data collected by the United States Bureau of Reclamation. The Bureau of Reclamation drilled approximately 13,000 holes, all with detailed lithologic logs, in the Lake Souris plain in

Figure 7. Location of Souris River Map Area (outline stippled) and other North Dakota Geological Survey Atlas Series map areas.



NORTH DAKOTA

conjunction with the Garrison Diversion irrigation project.

Various contour maps were constructed, including elevation, structure, isopach, and textural variation maps. Preliminary contour maps were made using a computer program (LeFever, 1986b); these maps were modified slightly to conform better to the geologic setting. Trend-surface analysis was applied to several surfaces, also using a computer program (LeFever, 1986c), to test for statistical significance.

In addition to the above described analytical methods, the depositional processes, fan development, and paleoflow conditions of the coarse-grained sediments in the Lake Souris basin were considered in conjunction with existing models.

LITHOFACIES AND STRATIGRAPHY

Description of Lithofacies

Introduction

The lithofacies descriptions that follow are based largely on samples that were collected by from sample holes drilled for this project. In the few places within the study area that exposed sections of sediment do occur, the information from them is incorporated into the descriptions. The samples collected from the auger flights tended to be deformed during drilling; thus, there are limitations on the types of information that can be obtained from these samples. For example, descriptions of sedimentary structures are limited to the presence or absence of laminations and their thicknesses. In addition, little information about the character of contacts between lithofacies can be derived from the data collected.

Five major lithofacies have been identified in the sediments studied: diamicton, laminated silt and clay, matrix-rich gravel, matrix-deficient gravel, and sand. Relative abundances of different facies could be calculated; however, because sampling was biased towards certain sediment types to meet the objectives of this study, these values would have little meaning. Instead, the approximate number of samples collected from each facies is given to help establish the basis of the descriptions. Detailed sediment sample descriptions are given in Appendix A.

Diamicton Lithofacies (D)

The diamicton lithofacies consists of unsorted, matrix-supported gravelly sand, silt, and clay. About 65 percent of the 110 diamicton samples (from 37 holes) are massive, whereas the remainder exhibit 1 to 3 cm thick indistinct layering (Fig. 8). The average textural composition of the samples composing the diamicton facies is 3.7 percent gravel, 34.5 percent sand, 38.8 percent silt, and 23.0 percent clay (Remple, 1987). Maximum clast size in the samples averages about 1.5 cm. The average lithology of the very coarse sand fraction of the samples is 3.1 percent shale, 68.4 percent crystalline, 23.0 percent carbonate, 3.6 percent sandstone and siltstone, and 1.9 percent lignite (Remple, 1987). The thickness of this facies is not known because drilling was seldom continued to its lower contact.

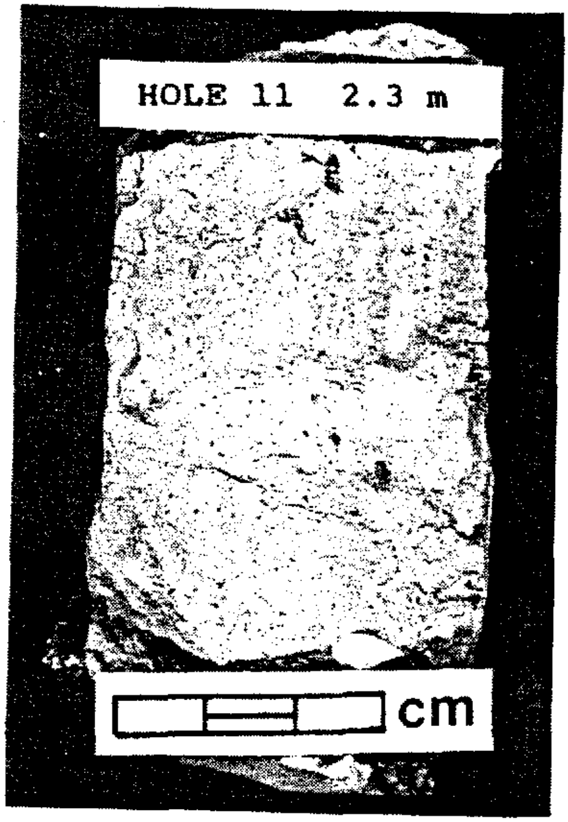
Laminated Silt and Clay Lithofacies (SCl)

The laminated silt and clay lithofacies consists of thinly laminated silt and clay; very fine sand laminations do occur within this facies, but are scarce (Fig. 9). About 150 samples from 37 holes are included in the laminated silt and clay lithofacies. Laminations are typically about 1 mm thick and range from 0.3 to 10 mm thick. The majority of the laminations are rhythmically laminated, consisting of alternating layers of silty, lighter sediment with clayey, darker sediment. In some places, the rhythmites are texturally homogeneous

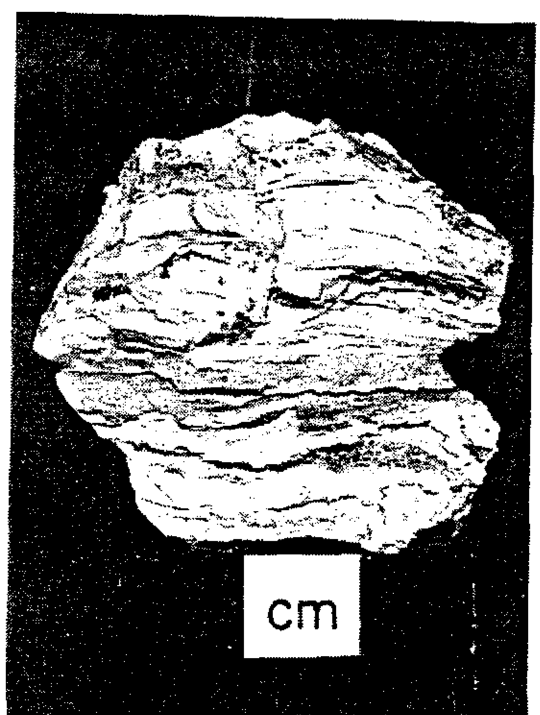
Figure 8. Sediment sample of diamicton lithofacies. Sample is from hole 11 at a depth of 2.3 m.

Figure 9. Sediment sample of laminated silt and clay lithofacies. Sample is from hole 5 at a depth of 14.6 m.

8.



9.



and laminations are discerned on the basis of lithologic differences. Lighter laminations consist almost entirely of quartz whereas darker laminations contain some dark particles, commonly lignite. Small sections of apparently massive clay and silt do occur, but are rare.

The occurrence of outsize particles, such as very coarse sand, within the sediment is not uncommon. The thickness of the laminated silt and clay facies varies from less than 1 m up to about 5.5 m.

Matrix-rich Gravel Lithofacies (Gmr)

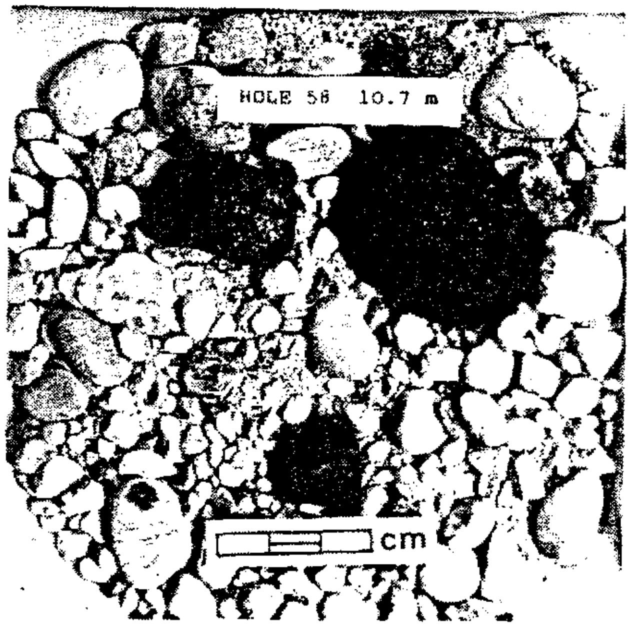
The matrix-rich gravel lithofacies is distinguished from the matrix-deficient gravel lithofacies (next section) in that they contain an abundance of fine-grained matrix material and commonly contain lignite clasts (Fig. 10). Most sediments of both gravel lithofacies contain more sand than gravel, but all of the sediments are gravelly. The term gravel is used in the lithofacies names because gravel is readily observed in the sediments of the two gravel lithofacies.

The sediments of the matrix-rich gravel lithofacies are poorly sorted and generally contain particles as small as very fine sand and silt; clasts up to 10 cm in diameter were obtained during augering. About 50 samples from 13 holes are included in this facies. Lignite clasts are common throughout sediments of this facies; they account for about 90 percent of the gravel-size particles in some samples. Lignite is also abundant in the matrix material. Clasts of other highly erodable lithologies, such as laminated clay and diamicton, occur within these sediments, but are rare.

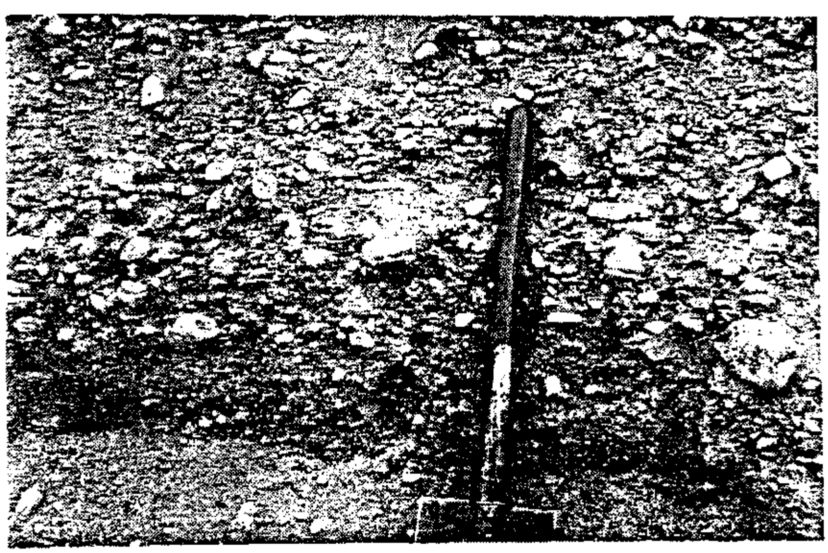
Figure 10. Sediment sample of matrix-rich gravel lithofacies; note presence of lignite clasts (black particles). Sample is from hole 58 at a depth of 10.7 m. Note: the sediment is a grab sample off of the auger flight that has been dumped into a dish, thus, its appearance probably is not representative.

Figure 11. Exposure of matrix-deficient gravel lithofacies exhibiting indistinct tabular cross-bedding (dipping to northwest--left). Shovel handle is about 50 cm in length. Location of exposure is SE 1/4, sec. 35, T. 155 N., R. 77 W.

10.



11.



The percentage of matrix material commonly decreases upward, as does the amount of lignite. Thickness of this facies ranges from about 0.5 m to 4 m. Sedimentary structures in this facies, if any, were destroyed by augering or masked by the coarseness.

Matrix-deficient Gravel Facies (Gmd)

Sediments of the matrix-deficient gravel facies generally are poorly sorted, although they tend to be better sorted than those of the matrix-rich gravel facies. Most matrix material consists of coarse and very coarse sand; lignite clasts are rare to absent. Well-sorted coarse and very coarse sands, with no lignite, are included in this facies because they appear similar to the gravels and are commonly gradational with them. Exposed sections of this facies occur along terraces adjacent to the Souris spillway near its inlet to Glacial Lake Souris. Fresh, undisturbed exposures of these sediments are limited to a few square metres in area, but do show tabular cross-bedding with coset thicknesses of about 0.5 to 1 m (Fig. 11). Particle diameters at the exposed sections are up to about 25 cm.

About 20 samples from 5 holes were collected by augering sediments of the matrix-deficient gravel facies. Sections of this facies are up to 3 m thick.

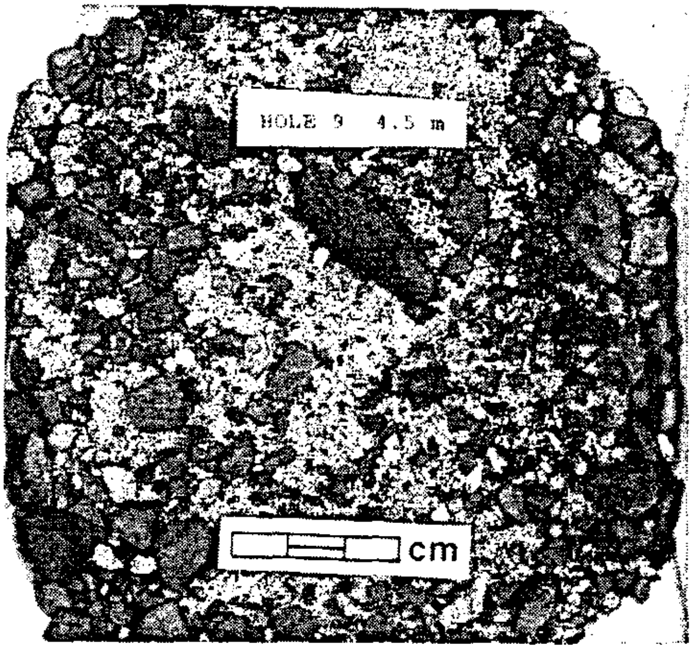
Sand Lithofacies (S)

The sand facies comprises well-sorted to very well-sorted, lignite-bearing sands (Fig. 12); coarse and very coarse silts with similar characteristics are included in this facies, but are much less

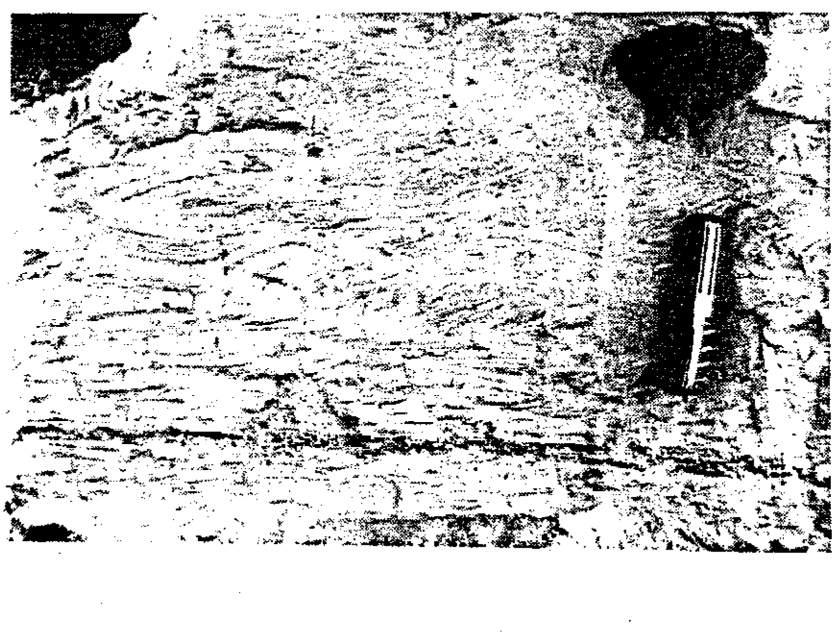
Figure 12. Sediment sample of sand lithofacies with abundant outsize lignite clasts. Sample is from hole 9 at a depth of 4.5 m.

Figure 13. Exposure of sand lithofacies exhibiting climbing ripple cross-laminations; flow was to the north (left). Pocket knife is about 8 cm long. Location of exposure is SE 1/4, sec. 23, T. 157 N., R. 78 W.

12.



13.



common. Sediments from this facies are the most abundant, accounting for over half of the samples collected (about 500 samples from 56 holes). The concentration of lignite typically varies between 2 and 10 percent. Exceptions occur in some near-surface sands, usually in the upper metre, where lignite is rare or absent. Outsize lignite clasts, up to 3 cm, commonly occur in otherwise well-sorted sands. Sections of sand with outsize lignite clasts were present in 17 of the holes sampled in the Lake Souris basin; these sections ranged from 1 to 7 m thick.

Most samples appear massive, but some exhibit indistinct layering from 2 to 30 mm thick. The boundaries of the layers are marked by higher concentrations of lignite. One exposure of the sand facies does occur in the southwestern portion of the Lake Souris plain (SE 1/4, sec. 23, T. 157 N., R. 78 W.); the sediment consists of fine and very fine sand, and exhibits climbing ripple cross-laminations and about 1 cm thick planar bedding (Fig. 13).

The thickness of the sand facies ranges from about 1 m to 25 m; thick, homogeneous vertical sections are common. Sediments of this facies are in some places gradational with those of the matrix-rich gravel facies; the sand most commonly occurs above the gravel.

Description of Stratigraphy

Purpose

The purpose of this section is to describe the locations in which the five lithofacies occur within the Lake Souris basin, to demonstrate the vertical and lateral relationships between facies, and to show the geometry of some of the lithofacies surfaces. Following the description of stratigraphy, the lithofacies are interpreted, based on information presented in the descriptions of the lithofacies and information presented in this section.

Occurrence

The most widespread lithofacies is sand which occurs throughout the entire lake basin. The diamicton facies is also widespread and was encountered in most places, except for a group of holes bored on the north edge of the detailed study area (Fig. 14). Where this lithofacies was sampled, it occurred almost exclusively beneath the other lithofacies; it is likely, therefore, that the absence of diamicton in some holes simply means that holes were not bored deeply enough to reach it.

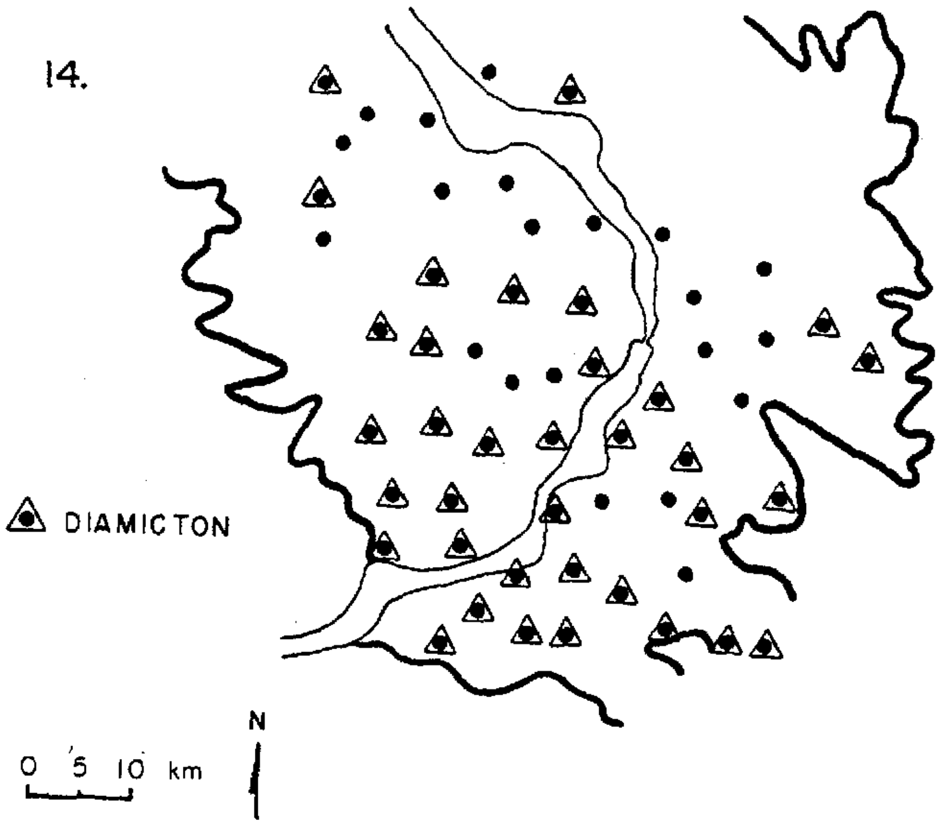
The remaining three lithofacies are less widespread (Fig. 15). The laminated silt and clay lithofacies is not present in the vicinity of the inlet to Lake Souris. Conversely, the two gravel facies are present in the inlet area and immediately adjacent to the Souris spillway. The distribution pattern for the silt and clays versus the gravels are almost opposite (Fig. 15).

The surface distribution of the different lithofacies is shown on the geologic map of Lake Souris (Fig. 4, Appendix D) (Lord, 1988). In Figure 4, the diamicton lithofacies is equivalent to till (map units 6 to 13; Appendix D), the laminated silt and clay facies to clay and silt (map unit 16; Appendix D), the two gravel facies to sand and gravel (map unit 14; Appendix D), and the sand facies to sand (map

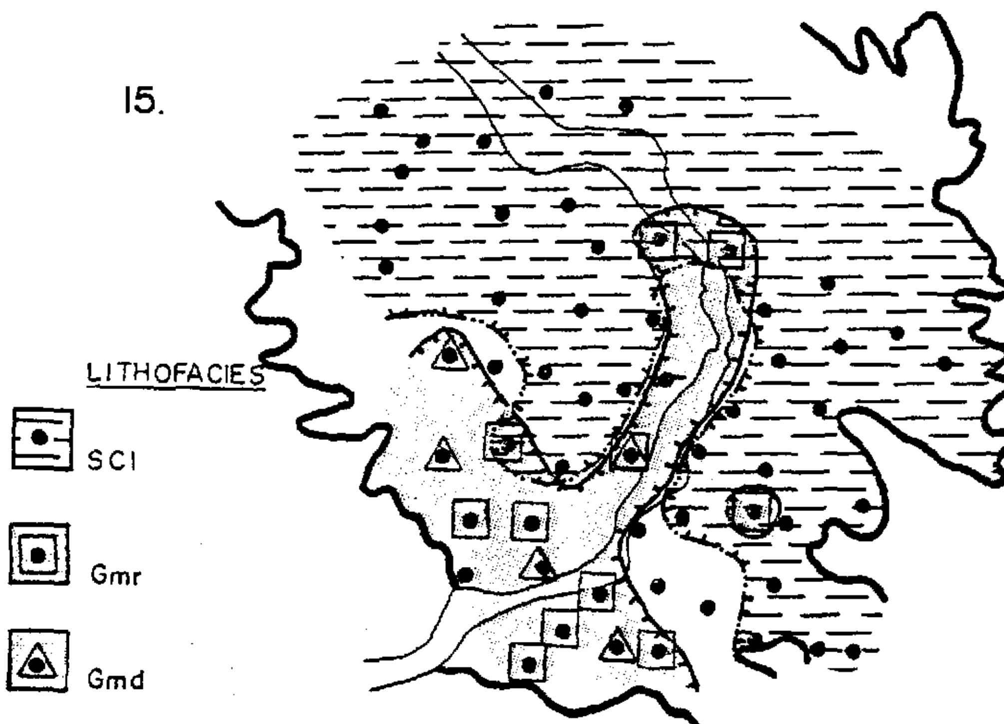
Figure 14. Location of holes where diamicton lithofacies is present. Dots indicate hole locations. The outline of the southern half of Lake Souris and the Souris spillway are marked for reference. The same outline will be used throughout the text.

Figure 15. Location of holes where laminated silt and clay (SCl), matrix-rich gravel (Gmr), and matrix-deficient gravel (Gmd) lithofacies are present.

14.



15.



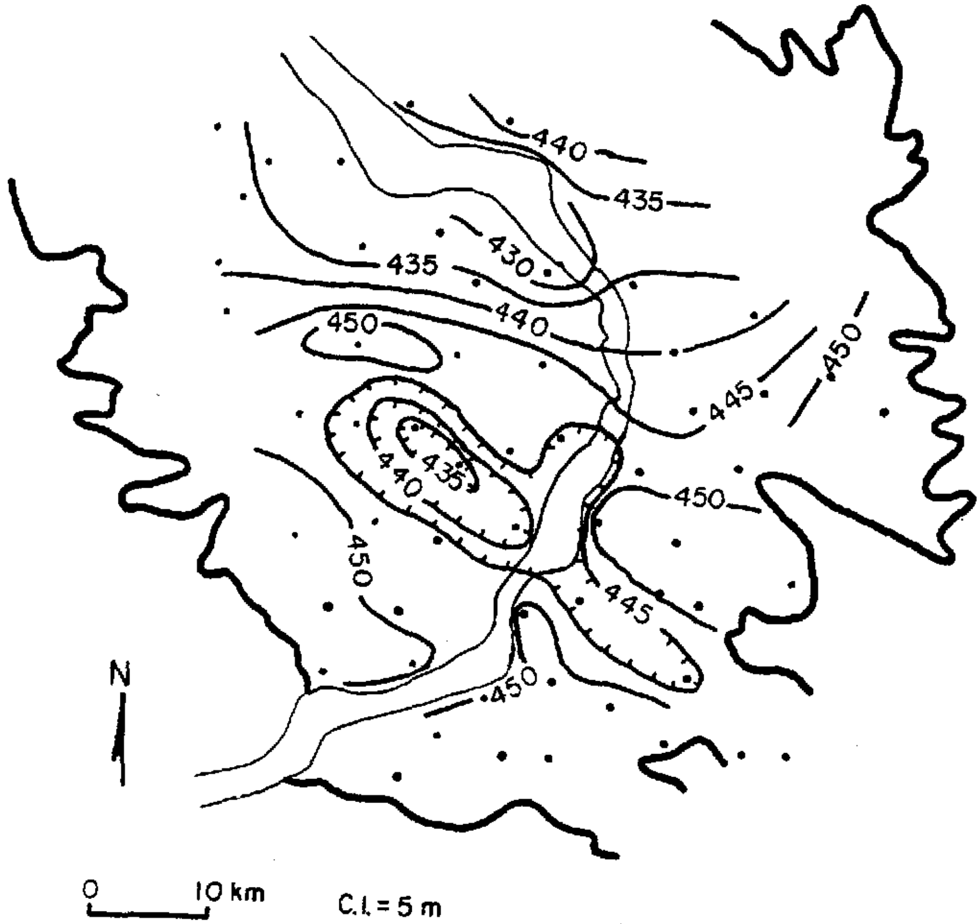
units 3, 4, 5, and 17; Appendix D). The geologic maps reinforce prior observations, namely, the abundance of sand throughout the study area and the restriction of gravel to the inlet and spillway areas. Braided channel scars are present on the gravel surface a few kilometres northeast of Verendrye (Appendix D). In addition, the maps do demonstrate that at the surface silt and clay become more extensive in the northern part of Lake Souris, beyond the area of detailed study.

Vertical and Lateral Lithofacies Relations

Typically, the sequences of lithofacies within Lake Souris are simple; most lithofacies occur in only one position in the holes bored--they generally are not repeated. A structure contour map of the diamicton lithofacies, which underlies the other lithofacies, shows two shallow depressions in the study area, one in the southern portion of the study area and a second to the north (Fig. 16). The two topographic lows are separated by a linear high that trends northwest-southeast with about 20 m of relief (subsurface).

The laminated silt and clay, sand, and gravel lithofacies all commonly overlie the diamicton lithofacies. The frequency of vertical transitions between lithofacies is shown in Table 2. Sand, the uppermost lithofacies in 52 holes, most commonly overlies the two gravel facies and the laminated silt and clay. Representative geologic cross-sections, parallel and perpendicular to the Souris spillway across Lake Souris, exhibit the major vertical and lateral sequences of the different lithofacies in the lake basin (Figs. 17 and

Figure 16. Structure contour map of the diamicton lithofacies. Sea level is datum.



440
435
430
435
440
450
445
450
435
440
450
450
445
450
N
0
10 km
C.I. = 5 m

Table 2. Frequency of vertical transitions between lithofacies. Only holes located within detailed studied area are included. Lithofacies key: D=diamicton, SCl=laminated silt and clay, S=sand, Gmr=matrix-rich gravel, Gmd=matrix-deficient gravel.

		OVERLYING				
	FACIES	D	SCl	S	Gmr&Gmd	TOTAL
UNDERLYING	D	---	12	10	8	30
	SCl	0	---	21	3	24
	S	1	1	---	4	6
	Gmr & Gmd	1	0	12	---	13
	TOTAL	2	13	43	15	73

Figure 17. Geologic cross section of the Lake Souris basin sediments oriented parallel to the Souris River.

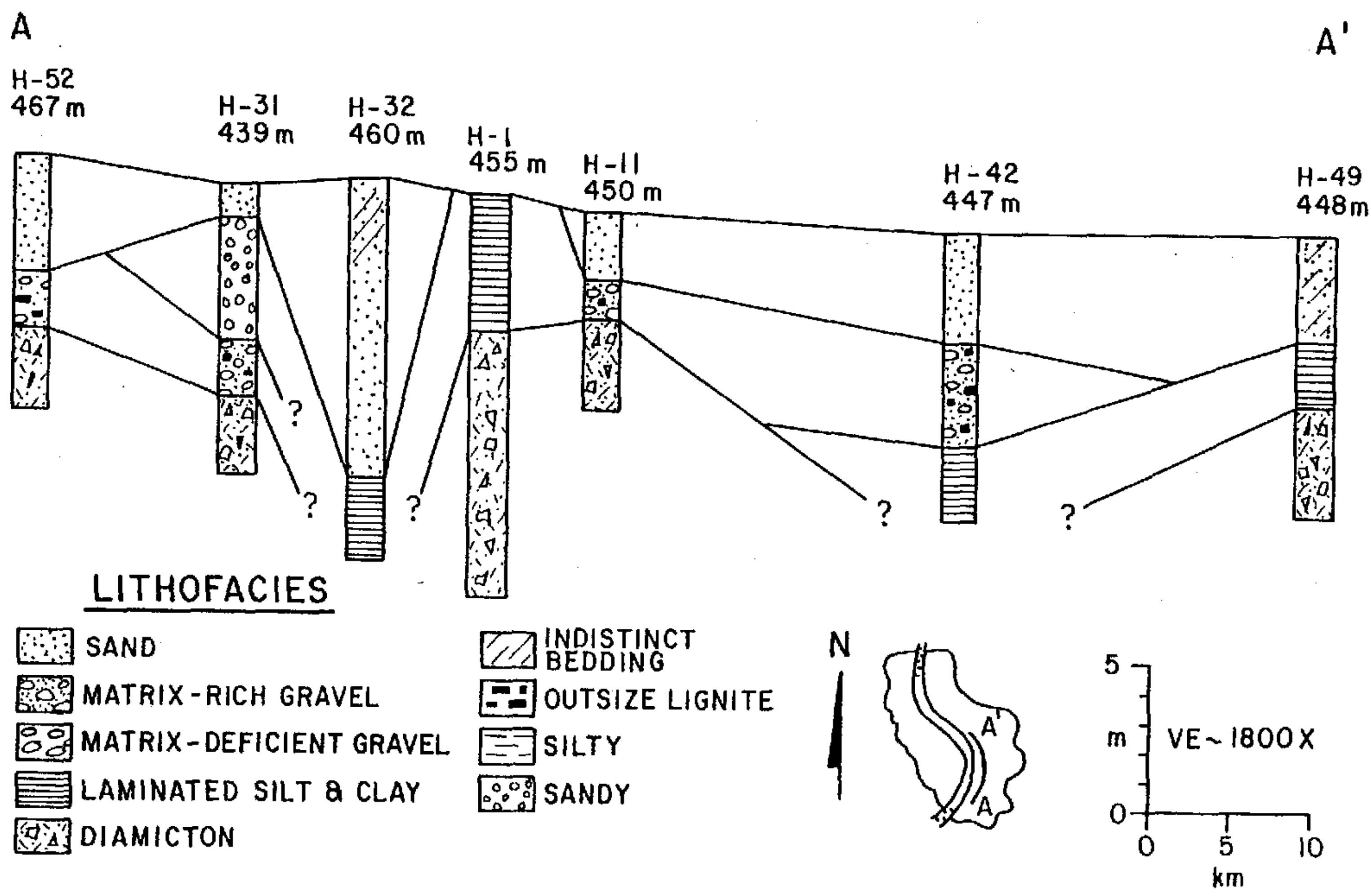
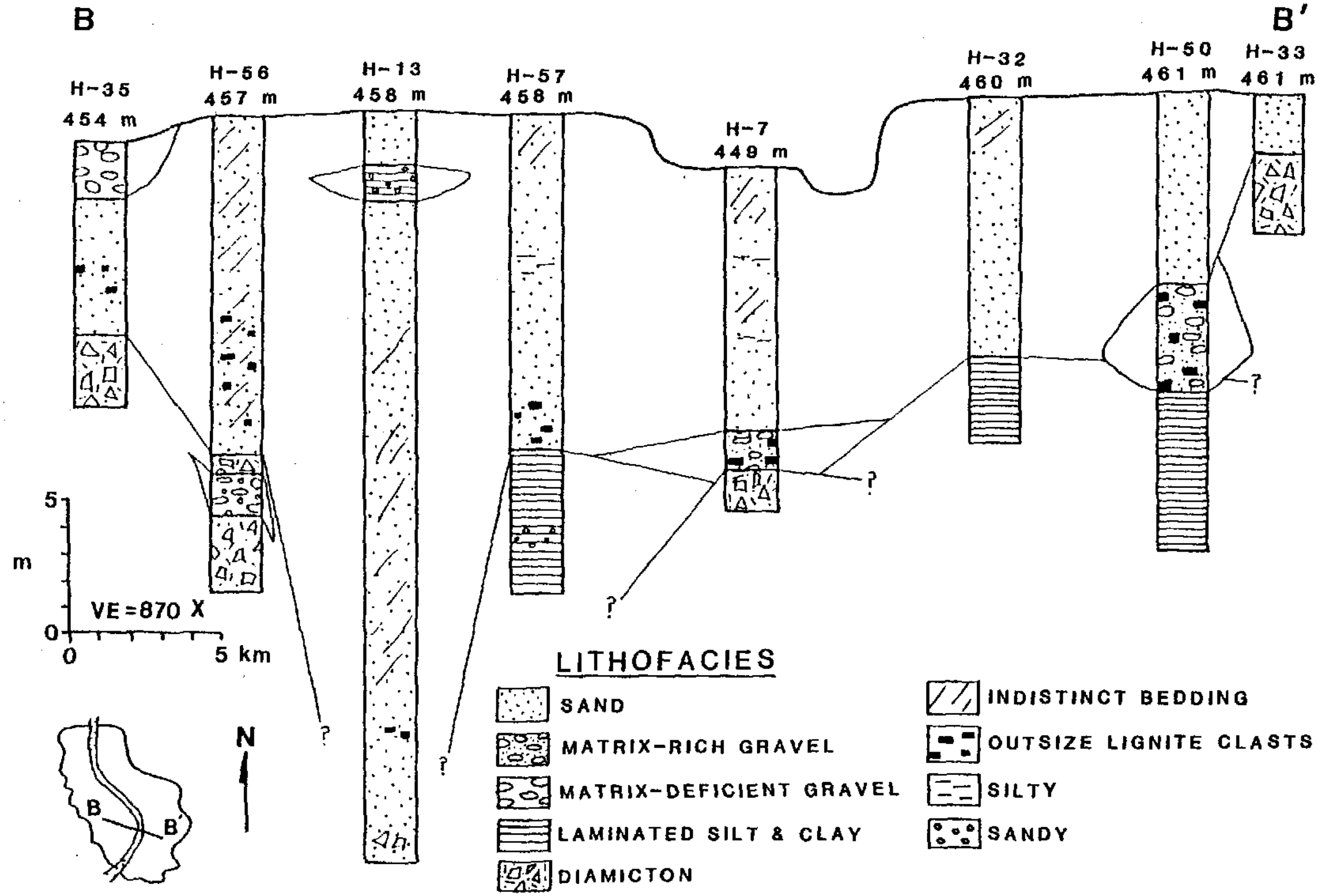

A
A'
H-52
467 m
H-31
439 m
H-32
460 m
H-1
455 m
H-11
450 m
H-42
447 m
H-49
448m
?
LITHOFACIES
SAND
MATRIX-RICH GRAVEL
MATRIX-DEFICIENT GRAVEL
LAMINATED SILT & CLAY
DIAMICTON
INDISTINCT BEDDING
OUTSIZE LIGNITE
SILTY
SANDY
N
5
m
0
VE~1800X
0
5
10
km

Figure 18. Geologic cross section of the Lake Souris basin sediments oriented perpendicular to the Souris River.


B
B'
H-35
454 m
H-56
457 m
H-13
458 m
H-57
458 m
H-7
449 m
H-32
460 m
H-50
461 m
H-33
461 m
5
m
0
VE=870 X
0
5 km
N
B
B'
LITHOFACIES
SAND
MATRIX-RICH GRAVEL
MATRIX-DEFICIENT GRAVEL
LAMINATED SILT & CLAY
DIAMICTON
INDISTINCT BEDDING
OUTSIZE LIGNITE CLASTS
SILTY
SANDY

18). Common lithofacies sequences, also implied by the frequency transition matrix, can be seen in the cross-sections, for example, diamicton to gravel to sand (holes 7, 11, 31, and 52), diamicton to silt and clay to sand (hole 49), and laminated silt and clay to sand (holes 32 and 57) (Figs. 17 and 18).

The influence on sedimentation of the two shallow basins on the diamicton facies surface is demonstrated in Figure 17; the overlying facies are thicker in the basins. In addition, the presence of gravel is shown near the inlet and again downstream from the topographic high on the diamicton surface. Laminated silt and clay are present at the surface in hole 1; this is coincident with the northwest-southeast band of silt and clay shown on the geologic map of Lake Souris (Fig. 4).

Interpretation

Introduction

The presence of an irregular contact between the diamicton and the laminated silt and clay, the variable thickness of the silt and clay, and the almost exclusive occurrence of gravel or sand capping the sequence indicates a diverse sedimentation history. A complex glacial origin for Lake Souris was followed by quiet-water sedimentation of silt and clay that was abruptly halted by high-energy deposition of sand and some gravel.

Interpretations presented in this section are brief and, for some lithofacies, preliminary. More detailed characteristics and interpretations of outburst-related sediments will be presented later in the text.

Diamicton Lithofacies (D)

Most sediments comprising this lithofacies are interpreted to have been directly deposited by glaciers; this is consistent with the lithology, pattern of occurrence, and glacial history of the area. Also, the patterns of sedimentation are consistent with prior interpretations of deposition of till from stagnant ice (Moran and Deal, 1970; Clayton, 1980; Bluemle, 1982). Some of the layered, gravelly diamictons may represent mudflow deposits off the ice, and thus, technically are not tills (Lawson, 1982).

The origin of the linear topographic high separating the two shallow basins on the diamicton surface is uncertain, but it may represent a minor ice-margin position (Remple, 1987). A possible ice-margin in this area also is suggested by the presence of ice-thrust depression-hill forms that indicate local glacier movement from the northeast (Bluemle, 1988). The linear high on the diamicton surface will subsequently be referred to informally as the till high.

Laminated Silt and Clay Lithofacies (SCl)

The laminated silts and clays are interpreted to be low-energy glacial-lake deposits. It is unlikely the rhythmites are varves representing annual layers of sediment accumulation, because thinness of the rhythmites (about 1 mm) coupled with the thickness of the laminated silt and clay sections (up to 5.5 m) would imply thousands of years of sediment accumulation. This length is well out of the realm of the presumed life of the lake of just several hundred years (Clayton and Moran, 1982). Alternatively, the origin of the majority of the laminations may be due to diurnal fluctuations in meltwater input, intraseasonal meltwater fluctuations, or slump-generated turbidites (Smith, 1978; Smith and Ashley, 1985; Liverman, 1987).

The absence of thick laminations, the lack of coarse-grained sediment, and variable thickness in the laminated silt and clay lithofacies suggests a low-energy environment. This is consistent with earlier interpretations suggesting that Lake Souris originated as isolated supraglacial lakes on stagnant ice (Moran and Deal, 1970; Deal, 1971); glacier-meltwater input would have been small and sediment-accumulation thicknesses would have been variable.

Matrix-rich Gravel Lithofacies (Gmr)

Poorly sorted, lignite-bearing, matrix-rich gravels are interpreted to have been deposited rapidly from inertia-driven and gravity-driven density flows into Lake Souris. This interpretation is supported by several kinds of evidence. (1) This facies, Gmr, is present at large depths (over 10 m at holes 30 and 58, Figure 6) within the basin, at long distances from any inlet into Lake Souris. Density currents can transport sediment tens of kilometres from an inlet source (Houbolt and Jonker, 1968). (2) Lithofacies Gmr is not present at the surface. Sediments deposited by underflows, such as flow from a density current, are restricted to topographically low areas and do not occur on highs (Smith and Ashley, 1985). (3) These poorly sorted sediments contain fragile clasts whose sources were at least tens of kilometres away; transport by normal bedload processes, as in a braided river, probably would have destroyed such clasts.

Transport by a fluid of relatively high viscosity, where turbulence is dampened and larger clasts are more likely to be transported in suspension, is consistent with this facies interpretation (Hein, 1982; Eyles, 1987; Lord and Kehew, 1987). (4) Almost all sediments of this facies grade upward into sand (the single exception, hole 31, grades to matrix-deficient gravel); sediments typical of a prograding delta coarsen upward (Leckie and McCann, 1980).

Matrix-deficient Gravel Lithofacies (Gmd)

The matrix-deficient gravels are interpreted to have been deposited by braided rivers. Evidence for this includes the occurrence of facies Gmd near and at the surface in the vicinity of the Souris spillway, the poor sorting, the tabular cross-bedding in exposures, and the channel scars on the surface of the sediment. Sediments of this facies tend to be better sorted than those of the matrix-rich gravel facies, and contain much fewer fragile clasts, such as lignite. These characteristics, in addition to those just described, conform to gravel deposits of braided rivers as opposed to deposits of high-density flows (Hein, 1984).

Sand Lithofacies (S)

Dunes are developed in a large portion of the sand lithofacies surface; therefore, much of the near-surface sediment of the sand facies has an eolian origin. Moreover, the thick sections of well-sorted sand in the subsurface must represent a depositional environment in which the deposits can be easily reworked to form dunes. The distinction between sands of eolian origin and those of other origin is of little importance to the objectives of this study. The eolian sands have similar characteristics to the other sands, except that lignite is usually absent in the upper metre of the sediments, probably because of reworking by wind.

The sands of this lithofacies share several characteristics with the matrix-rich gravels: lignite is abundant throughout most of the sediments (except for the upper metre), outsize lignite clasts are relatively common, and the facies occurs almost exclusively above the laminated silt and clay facies and the diamicton facies. Furthermore, the sand facies commonly is vertically and laterally gradational with the matrix-rich gravel facies. For these reasons, a similar origin is suggested for most of the sand facies, as for facies Gmr, namely, deposition from density flows. The term density flow is used here with a broad definition, referring to any flow with a sediment-water concentration high enough such that it would move as an underflow upon entering a standing body of water; the flow may or may not have had characteristics of clear-water flow (Newtonian).

Sections of well-sorted sand as thick as those measured in the Lake Souris basin are uncommon in glacial-lake environments. Relatively thick sections of sand that do occur in sediments of glacial lakes or fans associated with submarine channels are most commonly interpreted as deposits of turbidity currents, glacial-lake outburst flows, or some type of sediment-gravity flow (Gilbert, 1975; Rust, 1977; Shaw and others, 1978; Cheel and Rust, 1980; Postma and others, 1983; Teller and Thorleifson, 1983; Eyles, 1987; Eyles and others, 1987).

Development of Lithofacies Sequences

Determining the order in which the lithofacies were deposited is straightforward because the vertical sequences are uncomplicated. Deposition of the diamicton facies occurred first, followed by the laminated silt and clay facies, followed by the sand and gravel facies. Where the sand and gravel facies occurs in the same vertical section, the sand overlies the gravel in almost all places.

The inundation of Lake Souris by outburst flows from Lake Regina caused the complete drainage of Lake Souris (Kehew and Clayton, 1983); hence, the outburst-deposited materials should be the uppermost sediments (sands and gravels) in the lake basin. Of interest to this study is the identification of sediments deposited by the outburst flows. First, is the deposition of the silt and clay due to the same event (process) as that responsible for the sand and gravel facies? Second, is all of the sand and gravel related to the outburst or is it polygenetic?

The laminated silt and clay sediments generally are not considered to be related to the outburst flows. They occur throughout the lake basin and do not appear to be gradational, vertically or laterally, with the overlying sand and gravel sediments. Furthermore, if the laminated silts and clays are related to inflows from the Souris inlet, the laminations should thicken and coarsen toward the inlet (Ashley, 1975; Gustavson and others, 1975); they do not. Their origin is most consistent with a quiet-water lake environment, possibly multibasinal in its early stages (Moran and Deal, 1970; Deal, 1971), and not related to deposition from outburst flows. Possible exceptions may occur in portions of the lake basin distal to the Souris inlet.

The sand and gravel lithofacies are vertically and laterally continuous throughout the lake basin, with the exception of the northwest-southeast trending deposit of silts and clays (Fig. 4) directly overlying the till high (Figs. 16 and 17). These coarse sediments represent a sudden change in the energy of the lake and are interpreted as deposits from the outburst flows from Lake Regina. It is reasonable to ask, however, whether the occurrence of sand and gravel on either side of the till high is related to the same event or to two periods of deposition at different levels of Lake Souris. The primary evidence for two periods of deposition is the presence of two separate gravel deposits: a fan-shape one at the Souris inlet and a more elongate one near Towner, just upstream of the northwest-southeast trending deposit from silt and clay (Fig. 4).

Evidence for only one event includes the homogeneity and continuity of the sand and gravel sediments; there is no disruption in the sediment sequences. For example, if the northern fan was formed in an earlier, smaller Lake Souris, then fine-grained sediments from the later, larger Lake Souris should be expected to overlie the sand and gravel (Liverman, 1987). Furthermore, the morphology of the Souris Valley does not suggest two periods of deposition. If the topographically higher southern fan formed first, the fan sediments should be expected to exhibit regular incision from the Souris inlet to the northern fan. Although the eastern side of the Souris River valley is bounded by a relatively well-defined scarp, the western side is not. To the contrary, former channel scarps demostrate that substantial flow was at times directed away from the Souris River to the north and north-northwest (Fig. 5; Appendix D). Moreover, all of the overflow channels west of Lake Souris terminate at the mapped limit of the lake (Fig. 5; Appendix D). If Lake Souris was smaller and confined to the northern portion of the basin at the time of the outburst, the overflow channels should extend well into the lake basin.

In addition to the sedimentary and morphologic evidence against two periods of fan deposition, the occurrence of two fans can adequately be explained by one period. It can reasonably be assumed that the water volume of Lake Souris increased significantly upon arrival of the outburst flows and that lake currents increased markedly, especially once drainage of Lake Souris began. The till high may have acted as a barrier to lake currents causing water to be funneled through the gap at the present location of the Souris River. Flow competence through the constriction probably would have been higher, thereby accounting for the coarse-grained sediment fan at that location.

To summarize, Lake Souris originated as a low-energy glacial lake that had little meltwater input, as indicated by the scarcity of coarse-grained material. Fine-grained sedimentation was curtailed by the arrival of flows from the outburst of Lake Regina. The outburst flows deposited vast amounts of coarse-grained sediment, especially sand. In the sections that follow, the sediments deposited by the outburst flows will be described and interpreted in more detail. In addition, the interrelationships of the different types of deposits and the development of the coarse-grained fan will be considered.

SEDIMENTOLOGY AND DEVELOPMENT OF OUTBURST SEDIMENTS

Introduction

Descriptions are given in this section of, first, the textural characteristics of the sediments deposited by the Lake Regina outburst and, second, the pre-outburst and post-outburst setting of Lake Souris. Following the descriptions, the flow conditions and depositional processes active in the development of the coarse-grained fan will be interpreted. The term "fan" is a non-genetic term used to describe to the outburst-deposited coarse-grained sediments in Lake Souris. Also, the accumulations of the coarse-grained sediment on either side of the till high will be referred to as the southern fan and the northern fan.

Textural Description

The outburst-deposited sediments are well represented among those analyzed for texture, except for gravel (lithofacies Gmd) that occurs at the surface near the Souris inlet. In the inlet area, because drilling was expected to be difficult and because numerous exposures already exist there, few gravels were analyzed. Given that the textural data are not fully representative of all the coarse-grained outburst sediment, the textural characteristics are described below.

About 50 holes drilled for this study are within the detailed study region; textural analyses were conducted for samples from 38 of these holes.

The bulk characteristics of the sediment are represented in Figure 19 a to d. The outburst sediments are composed mostly of fine to medium sand (Fig. 19a) and generally are well sorted to moderately well sorted (Fig. 19c). The coarsest one percent of most samples ranges from fine sand to coarse sand (0 to 3 phi), but is gravel in numerous samples. The modal tendency of skewness is not as narrow as the other textural parameters; the average value is 0.03, which is essentially symmetrical. The values of textural parameters for individual samples are listed in Appendix B; individual percentages for quarter-phi intervals of all samples are listed in Appendix C.

Plots of sorting versus mean and of coarsest one percent versus median (Fig. 20 a and b) both show two groups of samples; the largest group contains sediment as coarse as about 1 phi (medium sand). Sediments comprised of medium and finer sands are very well sorted to moderately well sorted (sorting between 0.3 and 0.9) (Fig. 20a). Conversely, sediments coarser than medium sand show a general trend of becoming more poorly sorted with increasing grain size.

Grain-size distributions of samples analyzed for texture vary considerably between different lithofacies. The sands most commonly are well sorted with unimodal size distributions (Fig. 21a). Typically, both gravel facies are poorly sorted, but the matrix-rich gravels generally exhibit polymodal distributions with no strong modal group (Fig. 21b), whereas the matrix-deficient gravels are more

Figure 19. Histograms of 5 textural parameters for all samples (n=169); a) mean and median, b) coarsest one percent, c) sorting, d) skewness.

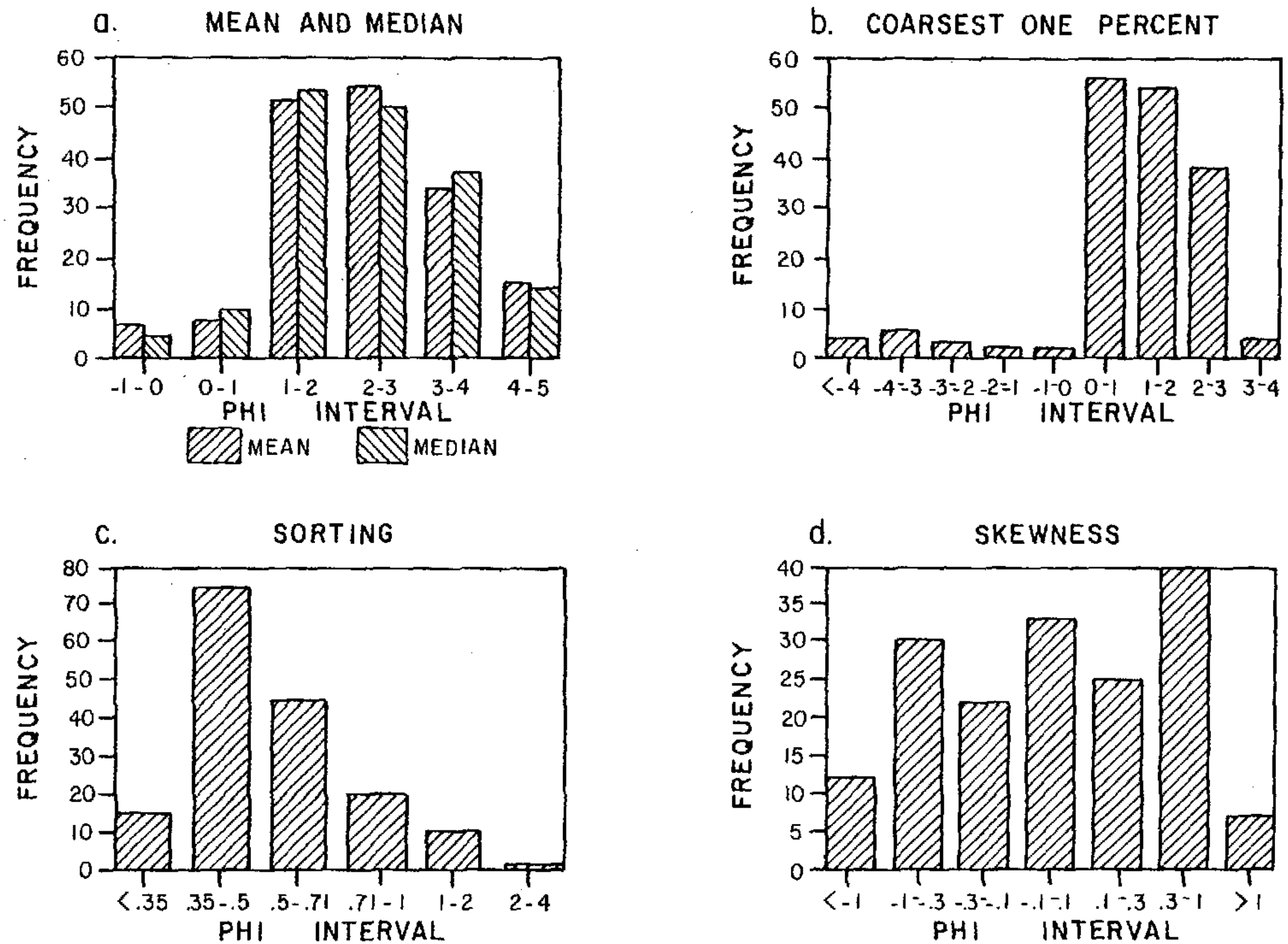
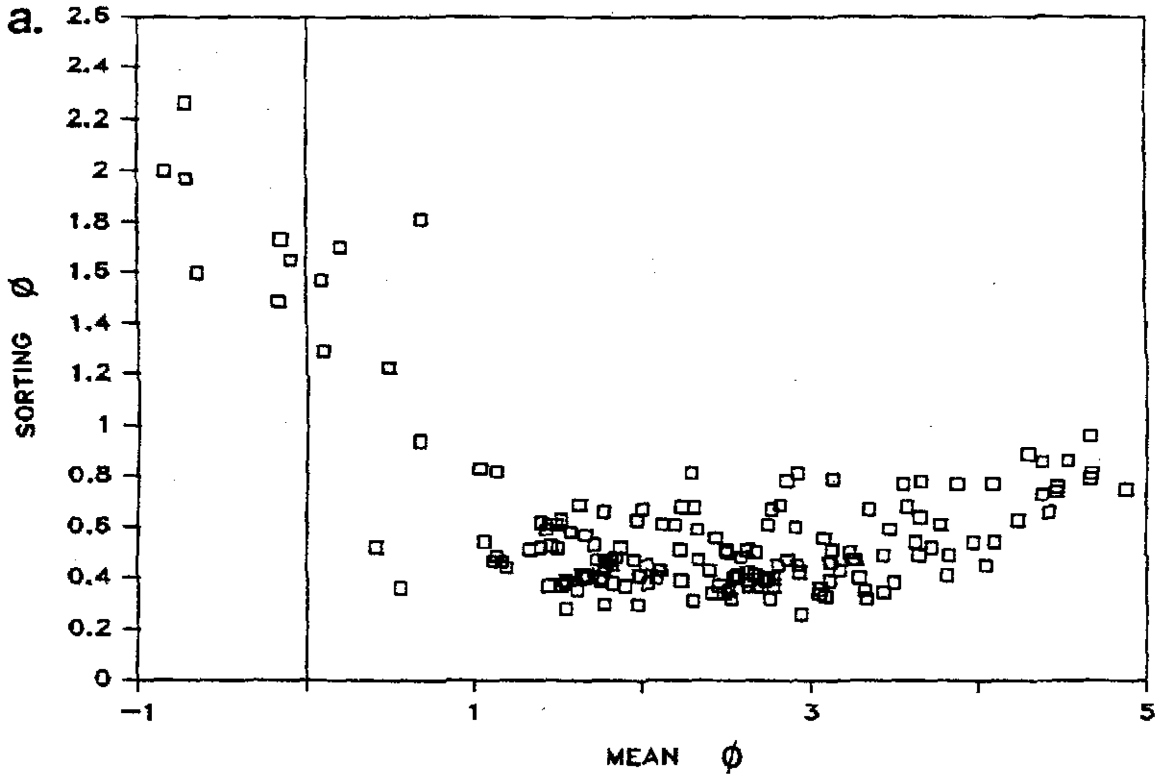

a. MEAN AND MEDIAN
FREQUENCY
60 50 40 30 20 10 0
-1-0 0-1 1-2 2-3 3-4 4-5
PHI INTERVAL
MEAN
MEDIAN
b. COARSEST ONE PERCENT
FREQUENCY
60 50 40 30 20 10 0
<-4 -4-3 -3-2 -2-1 -1-0 0-1 1-2 2-3 3-4
PHI INTERVAL
c. SORTING
FREQUENCY
80 70 60 50 40 30 20 10 0
<.35 .35-.5 .5-.71 .71-1 1-2 2-4
PHI INTERVAL
d. SKEWNESS
FREQUENCY
40 35 30 25 20 15 10 5 0
<-1 -1-.3 -.3-.1 -.1-.1 .1-.3 .3-1 >1
PHI INTERVAL

Figure 20. Cross-plots of a) sorting versus mean, and b) coarsest one percent versus median; n=169. Lines on plots are zero lines for reference.


a.
SORTING ø
MEAN ø
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−1
1
3
5

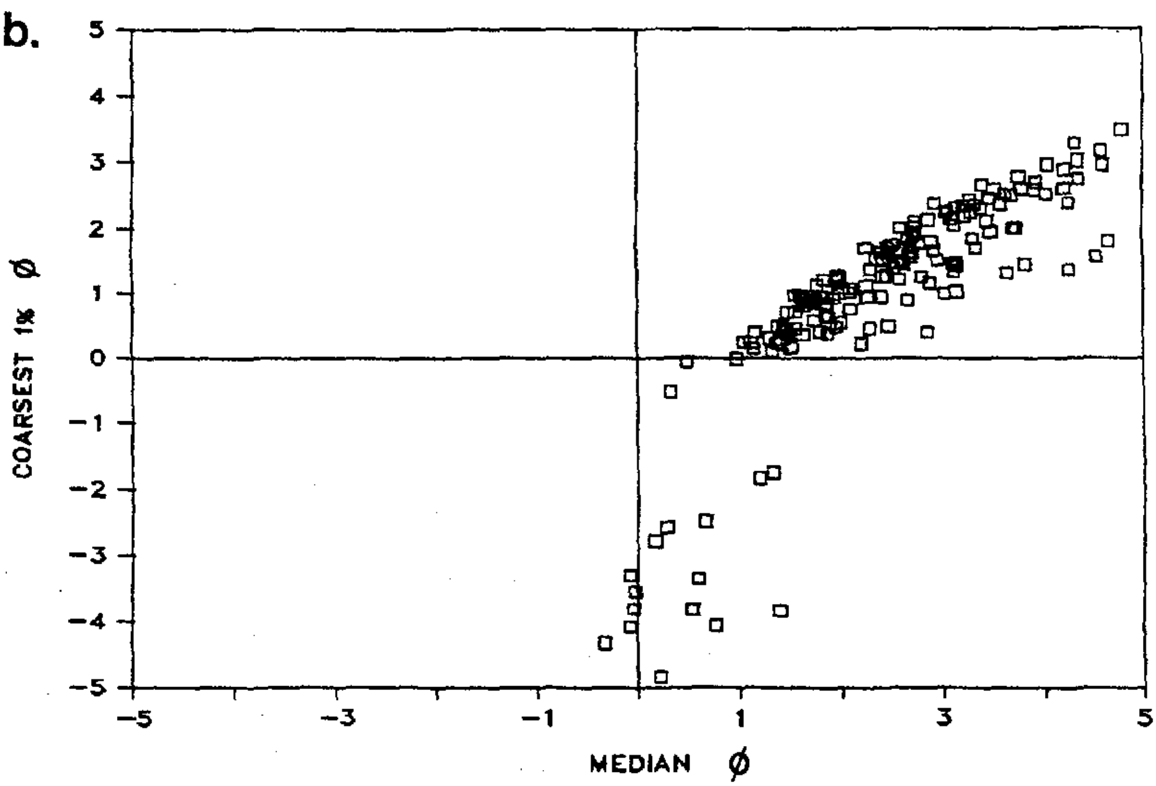
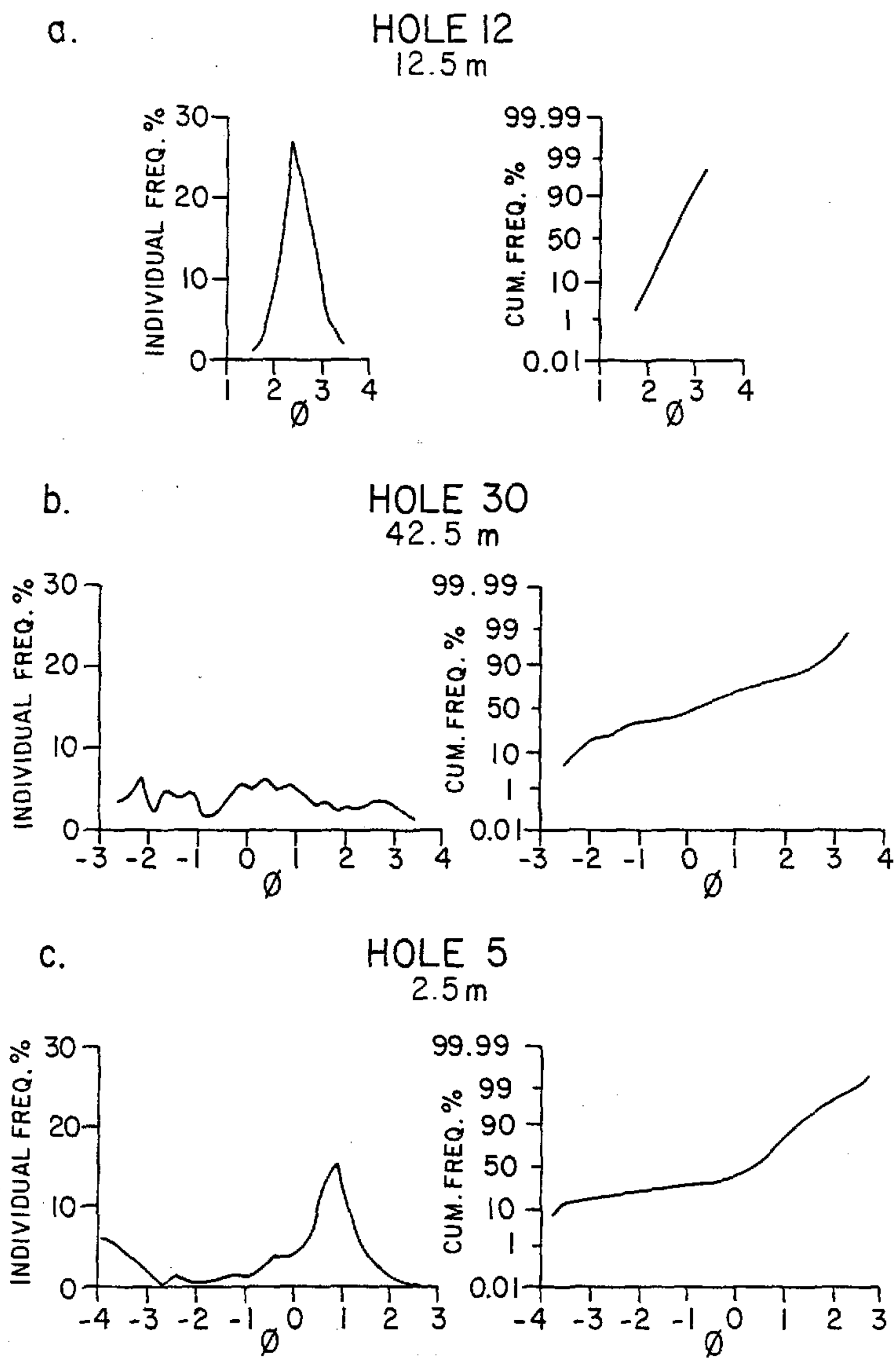

b.
COARSEST 1% ø
MEDIAN ø
5
4
3
2
1
0
−1
−2
−3
−4
−5
−5
−3
−1
1
3
5

Figure 21. Individual and cumulative frequency grain size curves for representative samples of a) sand lithofacies, b) matrix-rich gravel lithofacies, and c) matrix-deficient lithofacies.


a.
HOLE 12
12.5 m
INDIVIDUAL FREQ. %
CUM. FREQ. %
Ø
b.
HOLE 30
42.5 m
INDIVIDUAL FREQ. %
CUM. FREQ. %
Ø
c.
HOLE 5
2.5 m
INDIVIDUAL FREQ. %
CUM. FREQ. %
Ø

commonly bimodal (Fig. 21c).

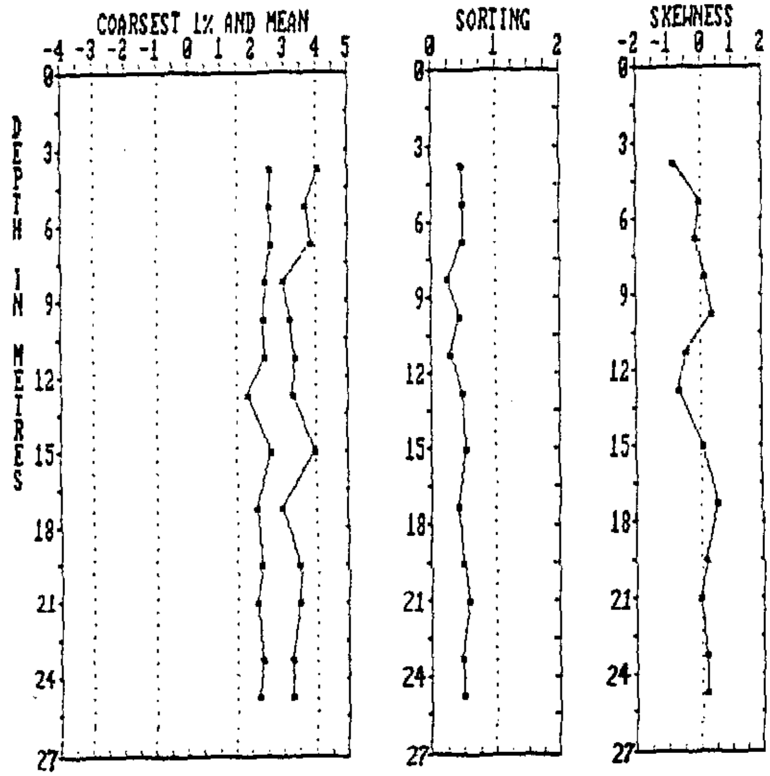
Vertical textural variations of sediments were examined by plotting textural parameters versus depth. As with grain-size distributions, there are considerable variations in trends throughout the Lake Souris basin. About half of the holes exhibit little textural variation with depth; that is, the mean grain size varies less than about 1.5 phi over the depth of the hole. In most cases, these holes show a gradual coarsening upward. Sediments from some holes, such as 13, are remarkably homogeneous over their entire depth (Fig. 22a). About 20 percent of the holes show a coarse sediment spike at the bottom of the outburst sediment and then fine upward into homogeneous sections (Fig. 22b). Two holes, one near the Souris spillway and the other near the western edge of Lake Souris, have coarsening upward trends (Fig. 23a). The remaining holes have irregular trends with more complex patterns (Fig. 23b).

Hole depth versus mean sediment size data may be used to construct cross sections to show lateral variations. Vertical trends within holes show little correspondence to other holes, although the amount of textural variation between holes is generally small--most are sand (Fig. 24).

Contour maps of sediment textural parameter values were constructed to show areal variations over the Lake Souris basin. Textural data presented in this manner permit large-scale trends to be observed and include all the data. Textural parameters (mean, coarsest one percent, sorting, and skewness) were averaged for each hole and then contoured. Because the majority of holes exhibit little

Figure 22. Selected plots of depth versus textural parameter values for a) a homogeneous section, b) a section with a coarse-grained spike at the bottom of the outburst sediments.

a. HOLE 13



b. HOLE 58

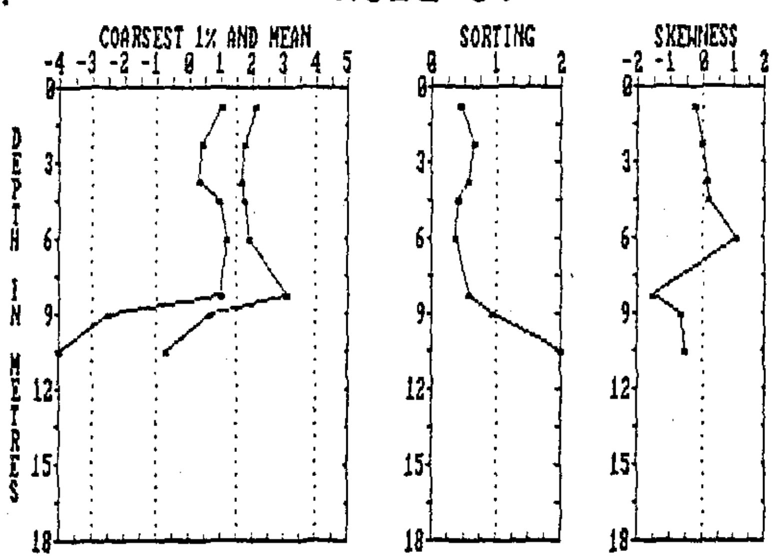
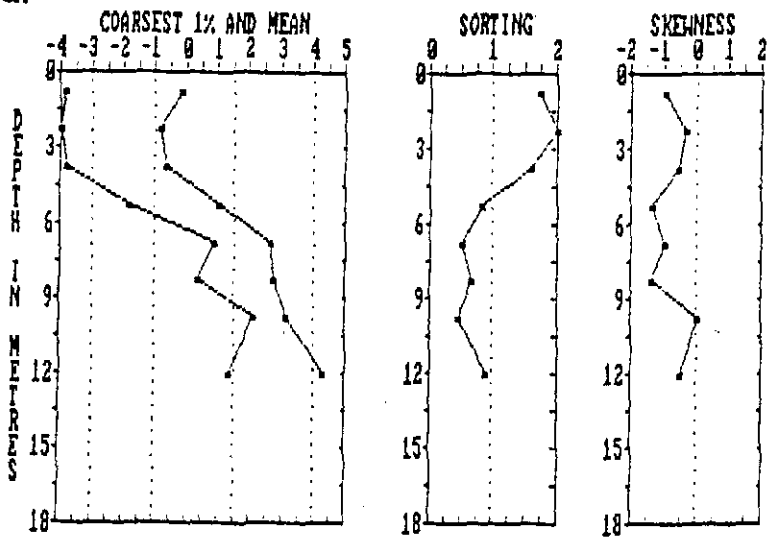


Figure 23. Selected plots of depth versus textural parameter values for a) a coarsening upward section, and b) an irregular section.

a. HOLE 5



b. HOLE 42

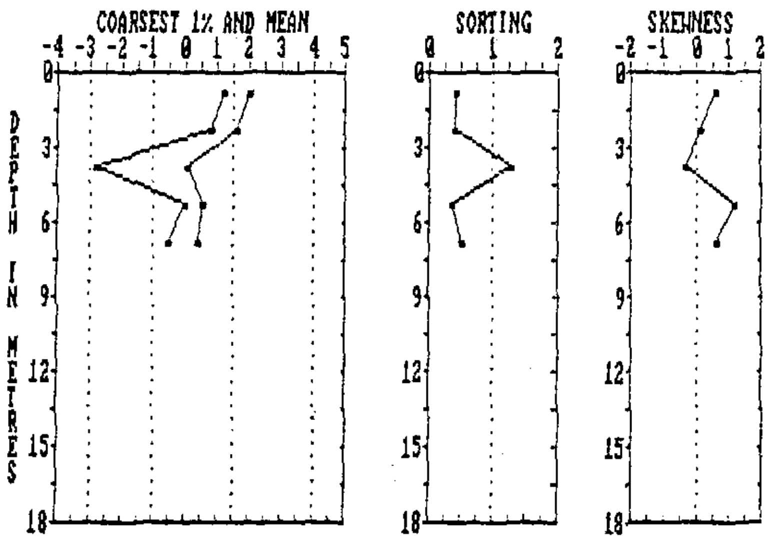
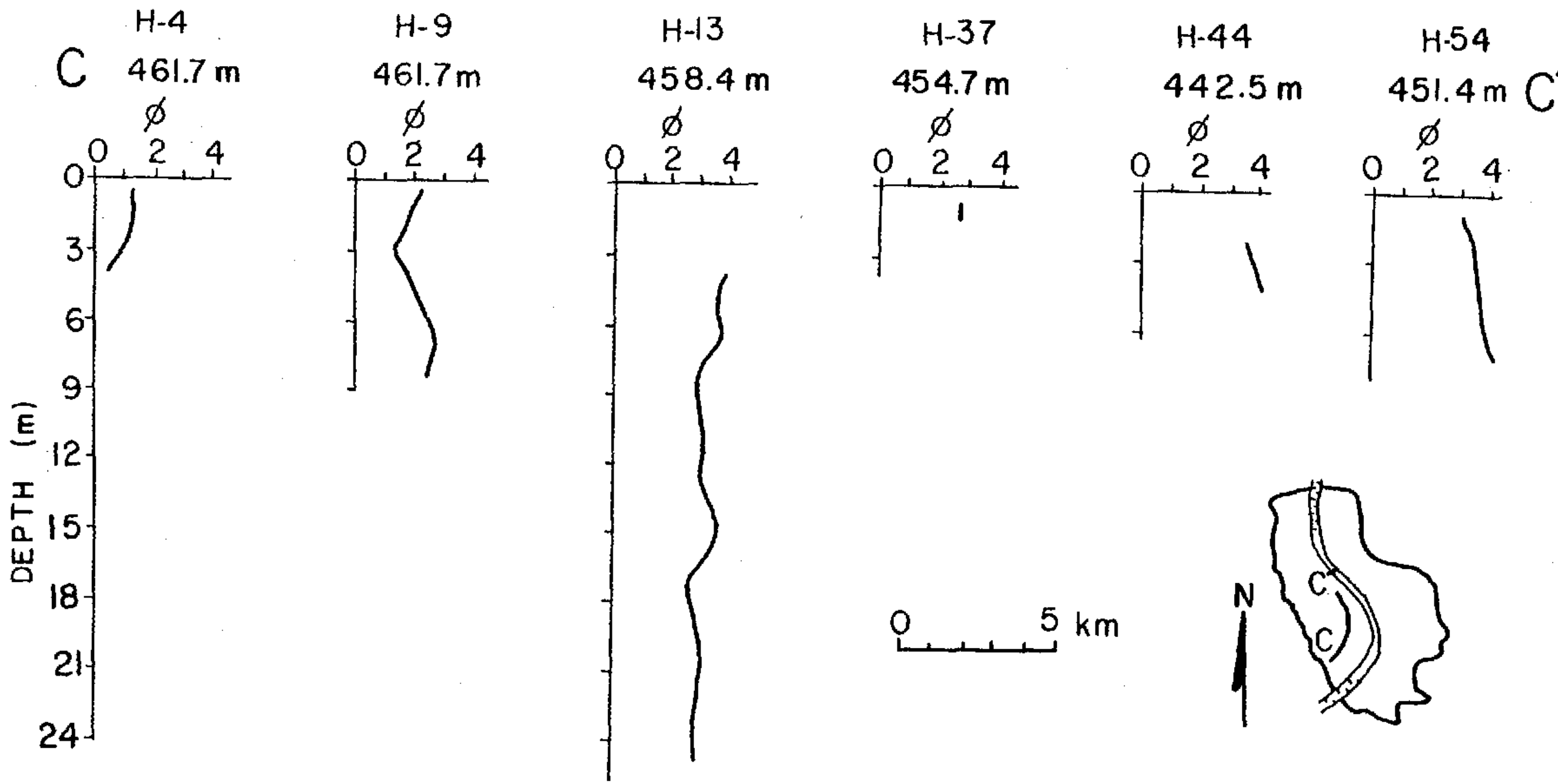


Figure 24. Cross section, oriented parallel to the Souris River, showing mean grain size of outburst-deposited sediments.



C
C'
H-4
461.7 m
H-9
461.7 m
H-13
458.4 m
H-37
454.7 m
H-44
442.5 m
H-54
451.4 m
ø
0 2 4
DEPTH (m)
0
3
6
9
12
15
18
21
24
0 5 km
N

vertical textural variation, this should be a valid technique. To make the average values more representative of the vertical section, textural values of the coarse-grained spikes at the bottom of some outburst sediments were removed from the data set. This did not cause changes in any of the contour patterns, but did smooth some of the data; the resulting maps are shown in Figure 25.

The averaged mean and coarsest one percent exhibit similar trends; they show sediment sizes becoming finer towards the northwest and patterns that are symmetrical about the Souris spillway (Fig. 25 a and b). Trend-surface analysis of these two data sets produced significant first- and third-order surfaces for the mean and first order for the coarsest one percent (Fig. 26 a and b). The trend surface of the mean shows two coarse-grained areas which are coincident with the northern and southern fan locations; sediment gradually becomes finer away from the fans. The residuals of the third-order trend surface of the averaged mean were contoured, but the pattern was very irregular and not significant.

The averaged sorting and skewness have more irregular trends than the averaged mean (Fig. 25 c and d); neither data set has a significant trend. In general, however, sediments in the northern half of the study area are more positively skewed than those in the southern half.

To help evaluate vertical changes in sedimentation patterns, some averaged textural parameters were compared to textural values for bottom samples. A contour map of the averaged mean minus the mean of the bottom samples shows a fining upward trend near the Souris River

Figure 25. Contour maps of textural parameter values averaged for each hole. Values of the coarse-grained spikes at the bottom of holes are not included in the averaged values; a) averaged mean, b) averaged coarsest one percent, c) averaged sorting, and d) averaged skewness.

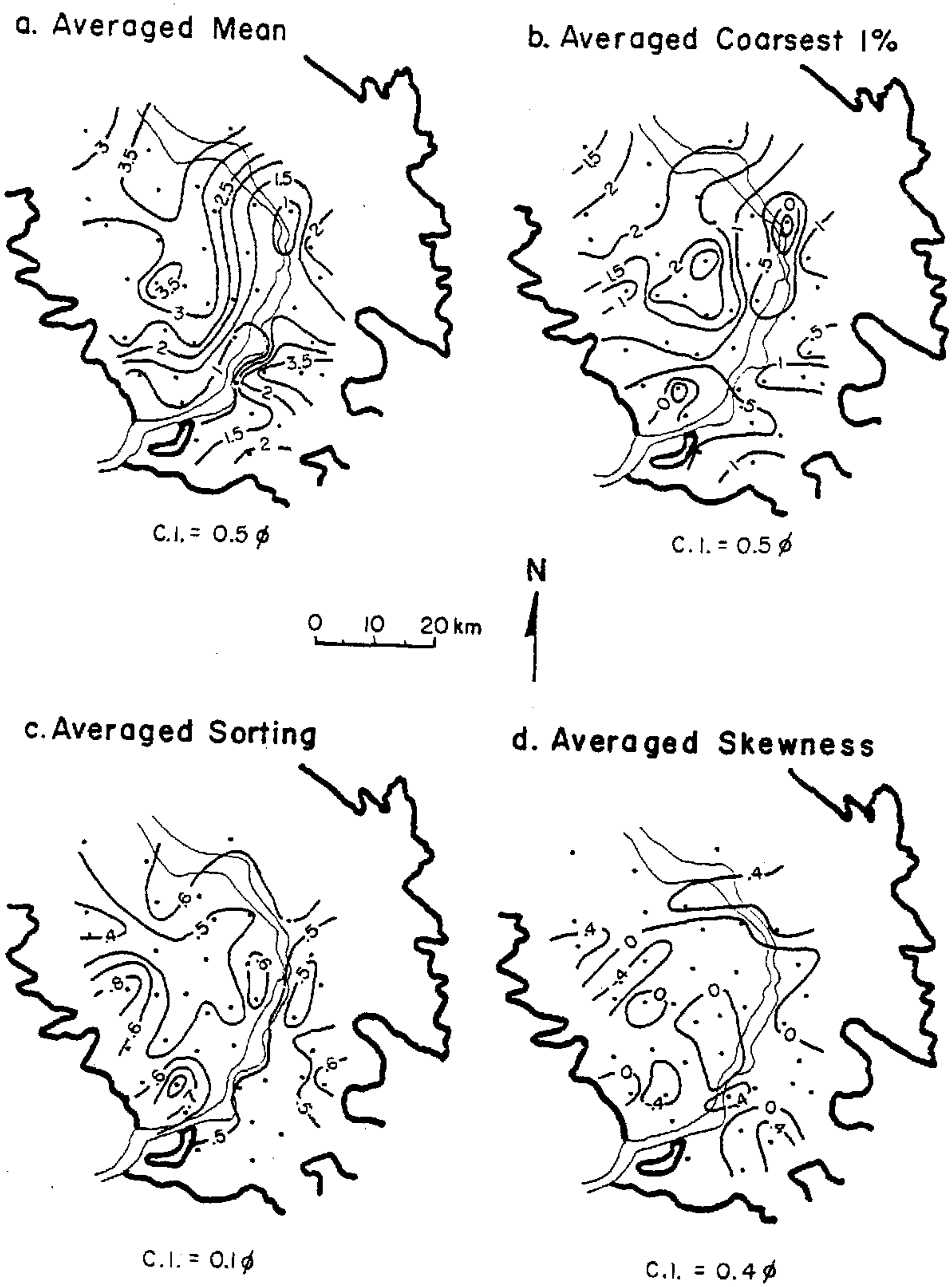
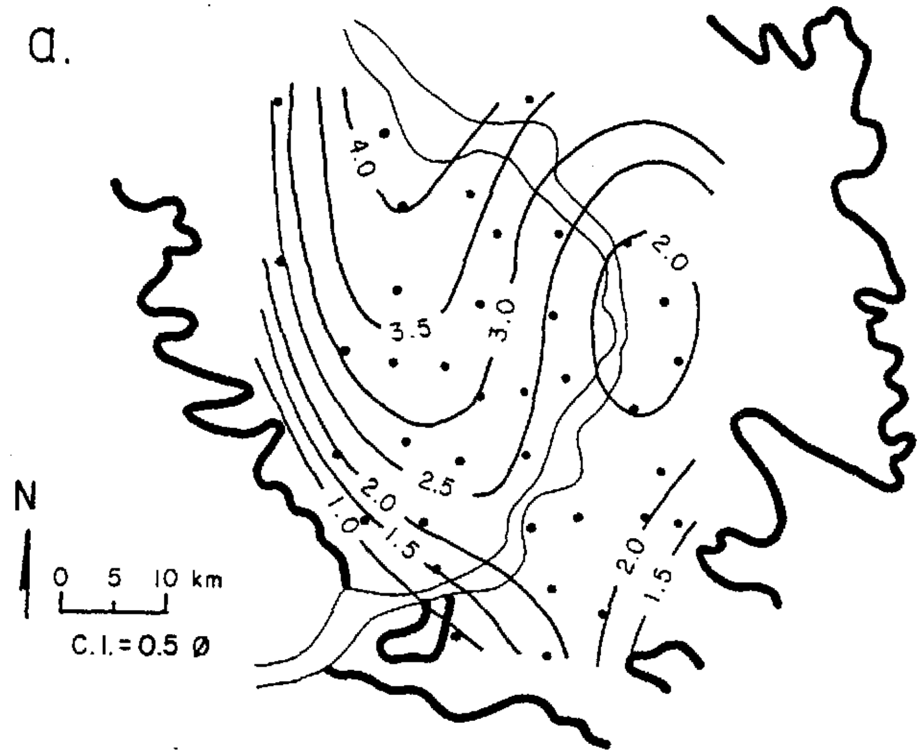
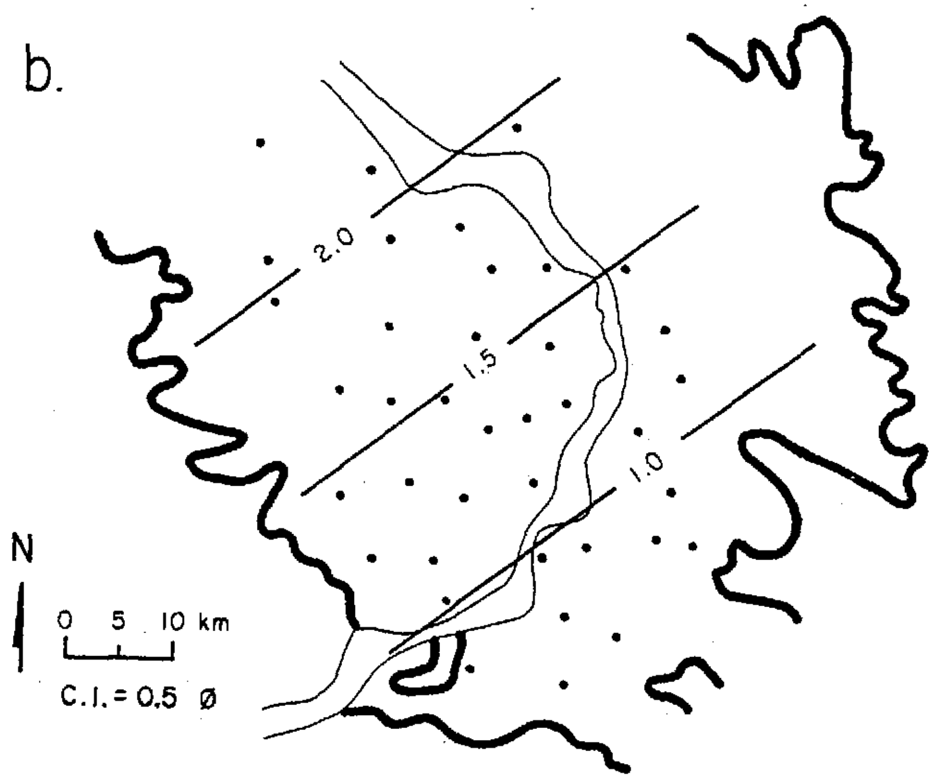

a. Averaged Mean
C.I. = 0.5 ø
b. Averaged Coarsest 1%
C.I. = 0.5 ø
0 10 20 km
N
c. Averaged Sorting
C.I. = 0.1ø
d. Averaged Skewness
C.I. = 0.4 ø

Figure 26. Trend surfaces significant to the 97.5 percent level. a) Third-order surface of averaged mean grain size; explained variation = 67 percent (see Fig. 25a). b) First-order surface of averaged coarsest one percent; explained variation = 23 percent (see Fig. 25b).


a.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1.0
2.0
2.0
1.5
N
0 5 10 km
C.I.=0.5 Ø


b.
2.0
1.5
1.0
N
0 5 10 km
C.I.=0.5 Ø

and coarsening upward trend elsewhere (Fig. 27a); averaged sorting minus sorting of the bottom samples has a similar trend (Fig. 27b).

Pre-outburst and Post-outburst Setting of Lake Souris

In order to establish a complete framework for understanding the effects of the outburst on Lake Souris, the conditions of Lake Souris before and after the outburst should be examined. Important to understanding the depositional processes of the outburst are 1) the slope and depth of water in the Souris spillway just upstream from the inlet to the Lake Souris basin, and 2) the water level of Lake Souris at the time of the outburst. Unfortunately, there is little direct information on either. The slope of the Souris spillway is taken to be the slope of an erosional terrace that flanks the inner channel, 0.0019 (Christiansen, 1956; Lord and Kehew, 1987). Maximum water depth estimates within the Souris spillway range from about 20 to 70 m, but about 45 m is considered most realistic (Lord and Kehew, 1987; Komar, in press, a).

The elevation of the water in the Souris spillway at the time it discharged into Lake Souris is unclear, but a probable range of levels may be estimated. Estimated water levels of Glacial Lakes Regina, Souris, Hind, and Agassiz are plotted, in addition to high-water-mark data from the Souris spillway (Fig. 28). These data indicate the water level in the Souris spillway just upstream from Lake Souris was between 466 and 470 m. The elevation of Lake Souris at the time of the outburst has been estimated to be about 448 m by Bluemle (1985) and about 457 m by Kehew and Clayton (1983). Therefore, a head

Figure 27. Contour map of textural parameter values. a) Averaged mean grain size minus mean grain size of bottom outburst sample; positive values indicate fining upward. b) Averaged sorting minus sorting of bottom outburst sample; positive values indicate sediments become more poorly sorted upward.

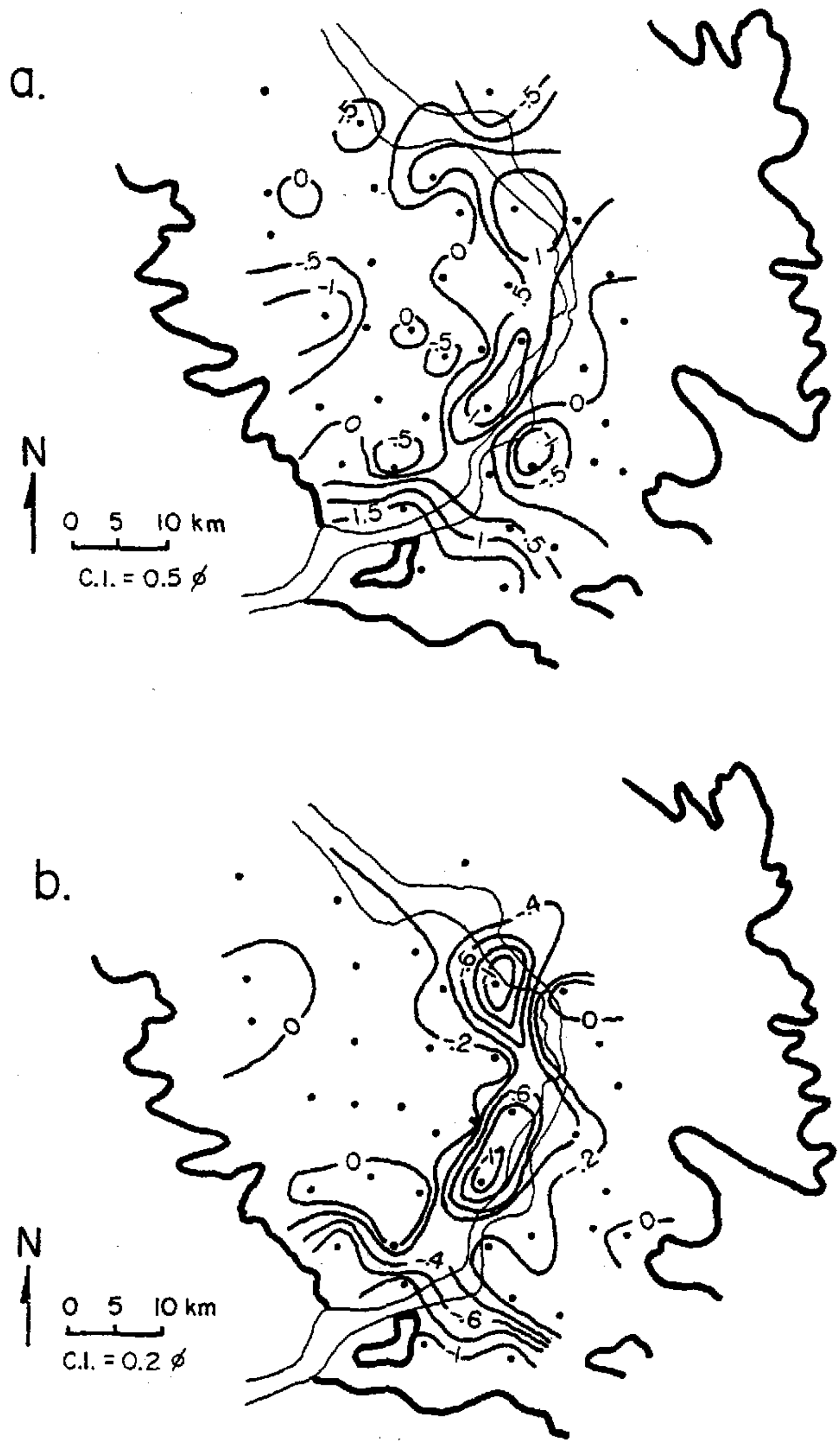
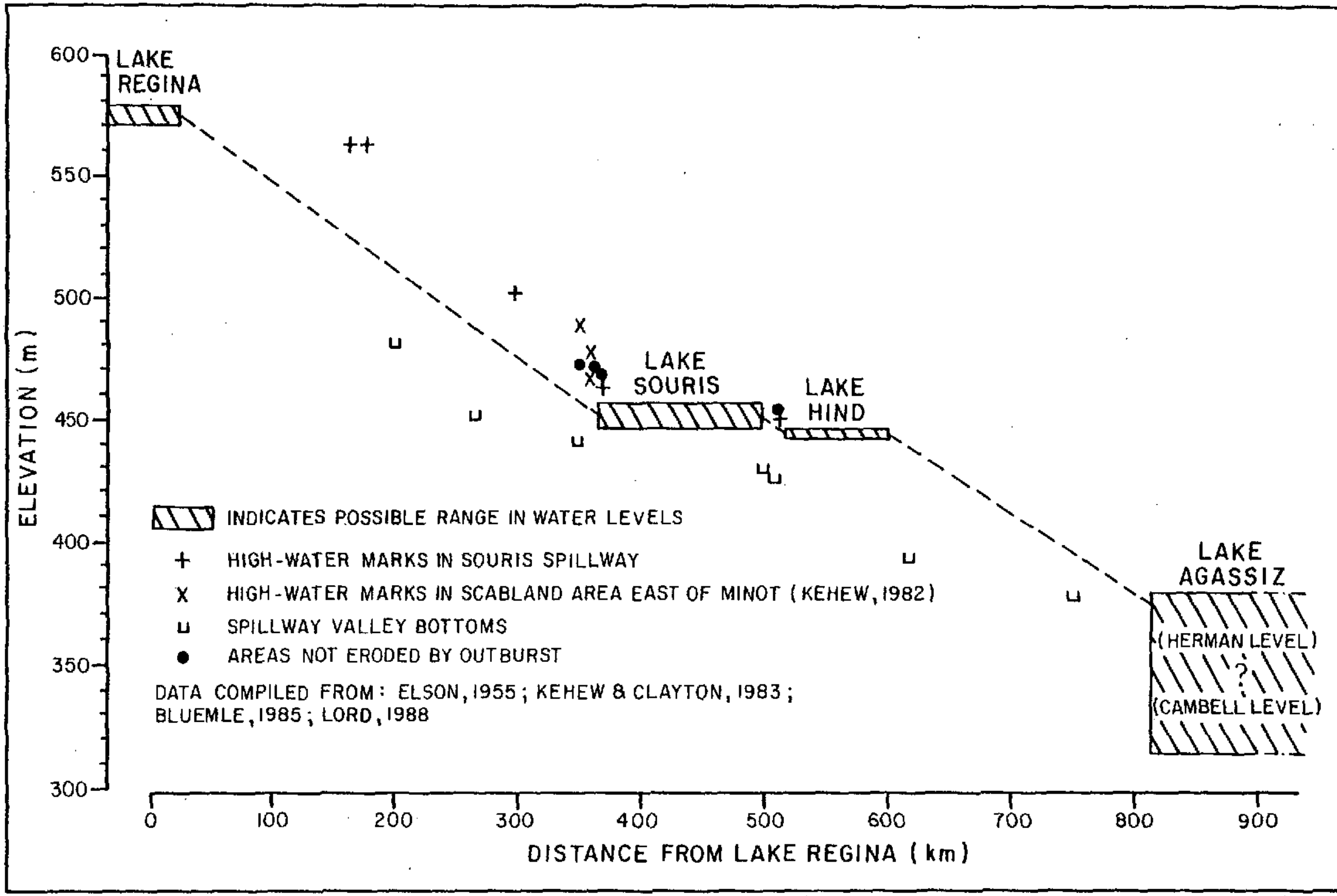

a.
N
0 5 10 km
C.I. = 0.5 ø
b.
N
0 5 10 km
C.I. = 0.2 ø

Figure 28. Regional topographic profile showing glacial lakes, spillway valley bottoms, and high-water marks of the Lake Regina outburst flows; ranges of possible lake levels also are shown.


LAKE REGINA
LAKE SOURIS
LAKE HIND
LAKE AGASSIZ
(HERMAN LEVEL)
?
(CAMBELL LEVEL)
ELEVATION (m)
600
550
500
450
400
350
300
0
100
200
300
400
500
600
700
800
900
DISTANCE FROM LAKE REGINA (km)
INDICATES POSSIBLE RANGE IN WATER LEVELS
+ HIGH-WATER MARKS IN SOURIS SPILLWAY
X HIGH-WATER MARKS IN SCABLAND AREA EAST OF MINOT (KEHEW, 1982)
ᴗ SPILLWAY VALLEY BOTTOMS
● AREAS NOT ERODED BY OUTBURST
DATA COMPILED FROM: ELSON, 1955; KEHEW & CLAYTON, 1983;
BLUEMLE, 1985; LORD, 1988

difference of 9 to 22 m is implied between the water level in the lake and the spillway.

Probable water depths throughout Lake Souris have been estimated by assuming a lake level of 457 m and subtracting the elevations at the base of the outburst sediments (Fig. 29). No corrections for differential isostatic uplift have been made because it is not known what, if any, they should be. Lake Souris was shallowest over the region of the till high, and deepest in the northern basin.

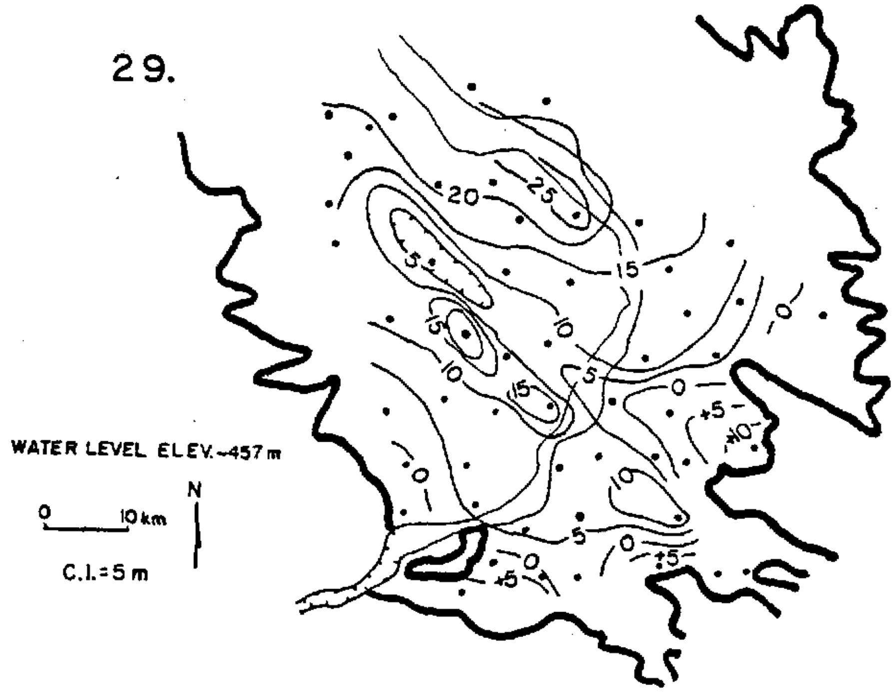
The lake-basin configuration is reflected by the outburst sediment patterns. Outburst-deposited sediment is thickest in the southern basin and thinnest over the till high (Fig. 30). A detailed cross section of the southern fan, which incorporates data from the U.S. Bureau of Reclamation, shows an irregular pre-outburst lake bottom and complex sediment patterns (Fig. 31). In general, the sediments are coarsest near the fan apex and finer at the center of the southern basin.

The morphology of the Souris spillway is reflective of the discharges that formed it; because of this, numerous spillway cross sections were made between the inlet area and the Souris-Hind spillway (Fig. 32). Upstream from the Lake Souris inlet, the Souris spillway has a well-defined trench shape with a scarp relief of about 25 m. The relief of the valley diminishes to a few metres near the center of the lake basin and then increases to about 25 m again near the international border (Fig. 32 and 33).

Figure 29. Contour map of the probable water depths in Glacial Lake Souris prior to inundation by the outburst flows.

Figure 30. Isopach map of the outburst-deposited sediments in the Lake Souris basin.

29.


WATER LEVEL ELEV.~457 m
0 10 km
N
C.I.=5 m
20
25
15
5
15
10
10
5
15
0
0
+5
+10
10
5
0
0
+5
+5

30.

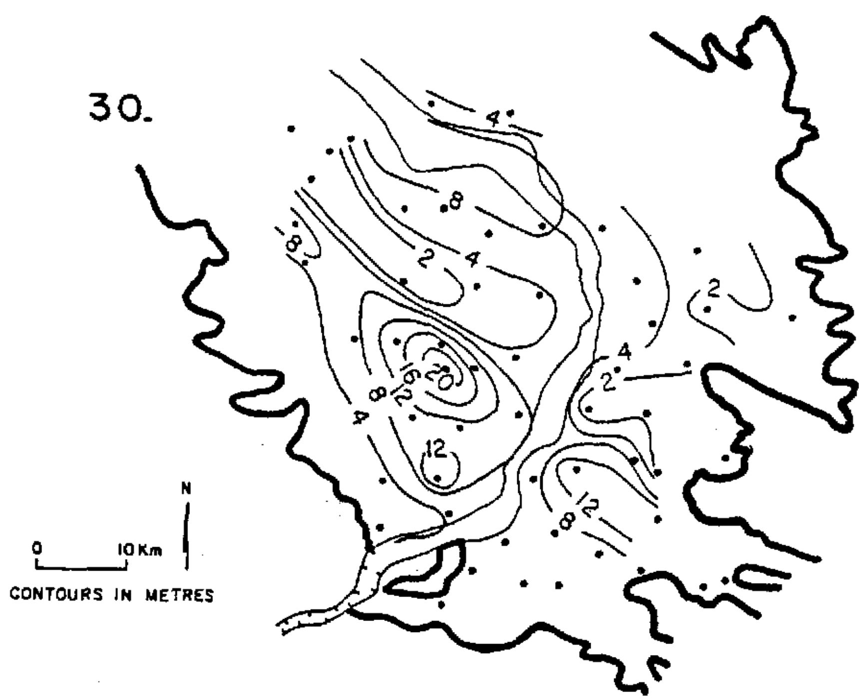

4
8
8
2
4
2
20
16
12
8
4
4
2
12
12
8
N
0 10 Km
CONTOURS IN METRES

Figure 31. Detailed structural cross section of the southern fan parallel to the Souris River. Hole data is from this study and the U. S. Bureau of Reclamation (USBR) (from Kehew and Lord, 1987).

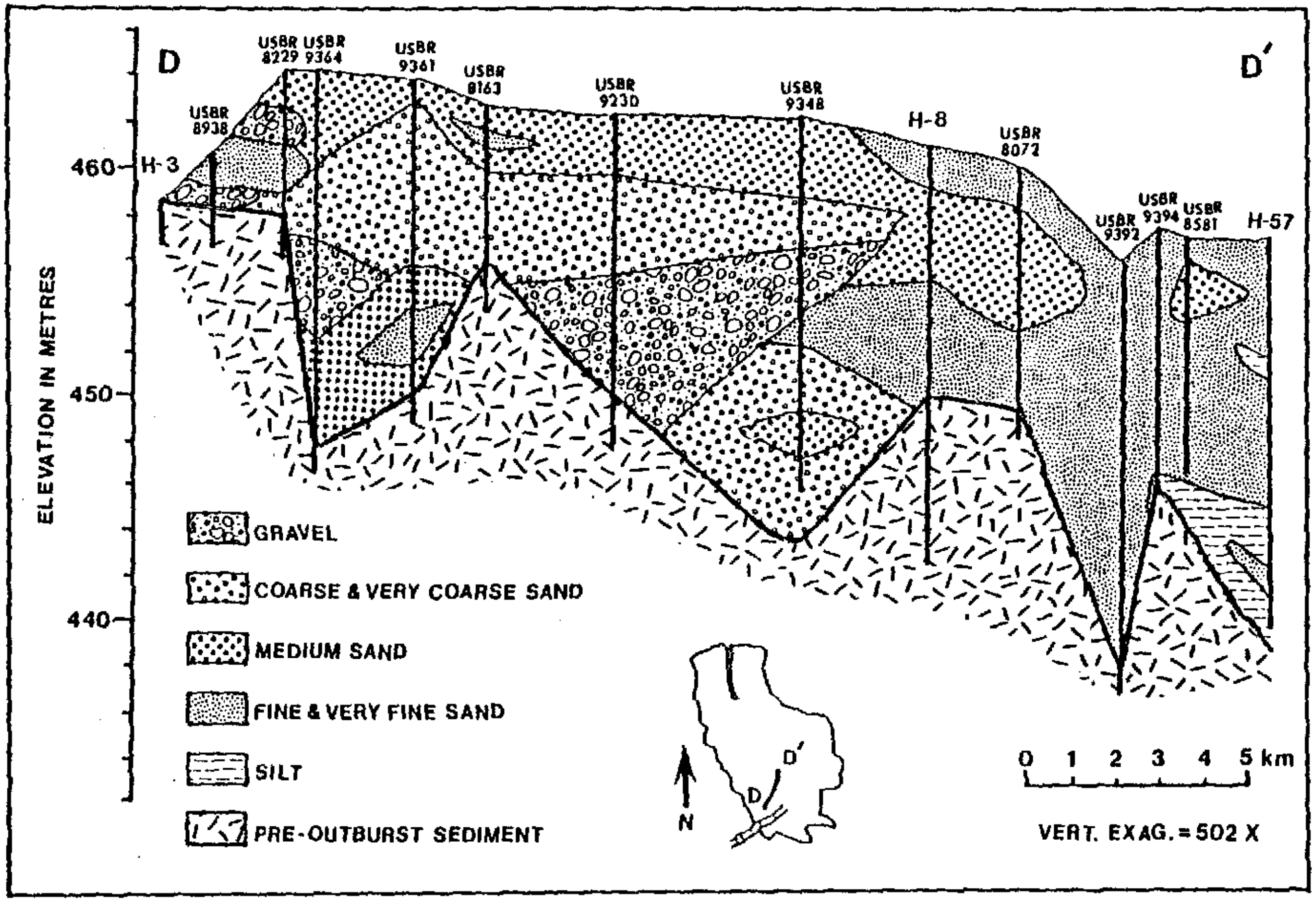

D
D′
USBR 8229
USBR 9364
USBR 9361
USBR 8163
USBR 9230
USBR 9348
H-8
USBR 8072
USBR 8938
H-3
USBR 9392
USBR 9394
USBR 8581
H-57
460
450
440
ELEVATION IN METRES
GRAVEL
COARSE & VERY COARSE SAND
MEDIUM SAND
FINE & VERY FINE SAND
SILT
PRE-OUTBURST SEDIMENT
N
D
D′
0 1 2 3 4 5 km
VERT. EXAG. = 502 X

Figure 32. Topographic profiles made perpendicular to the Souris spillway from the Lake Souris inlet area to the outlet area; probable water levels are also indicated.

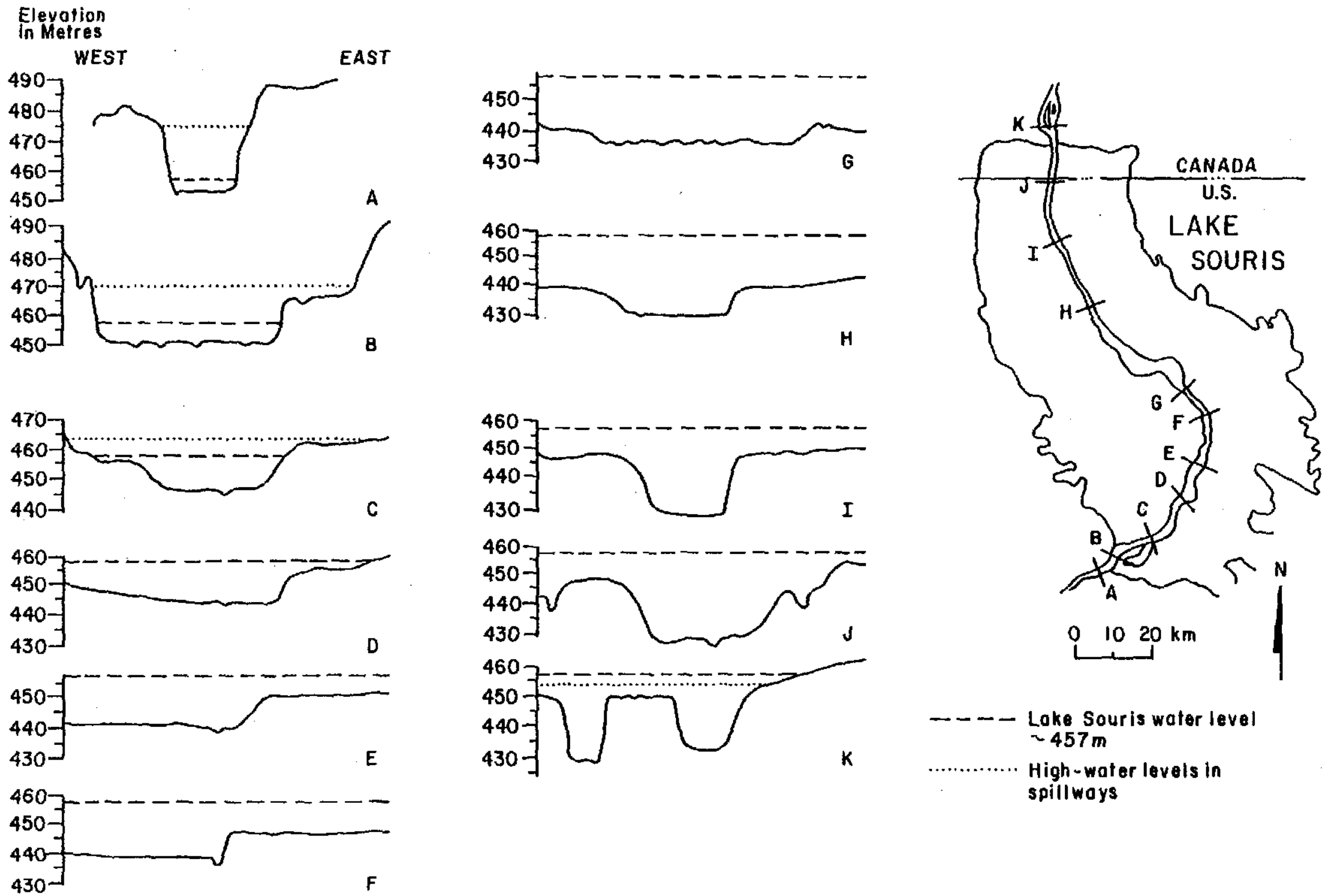
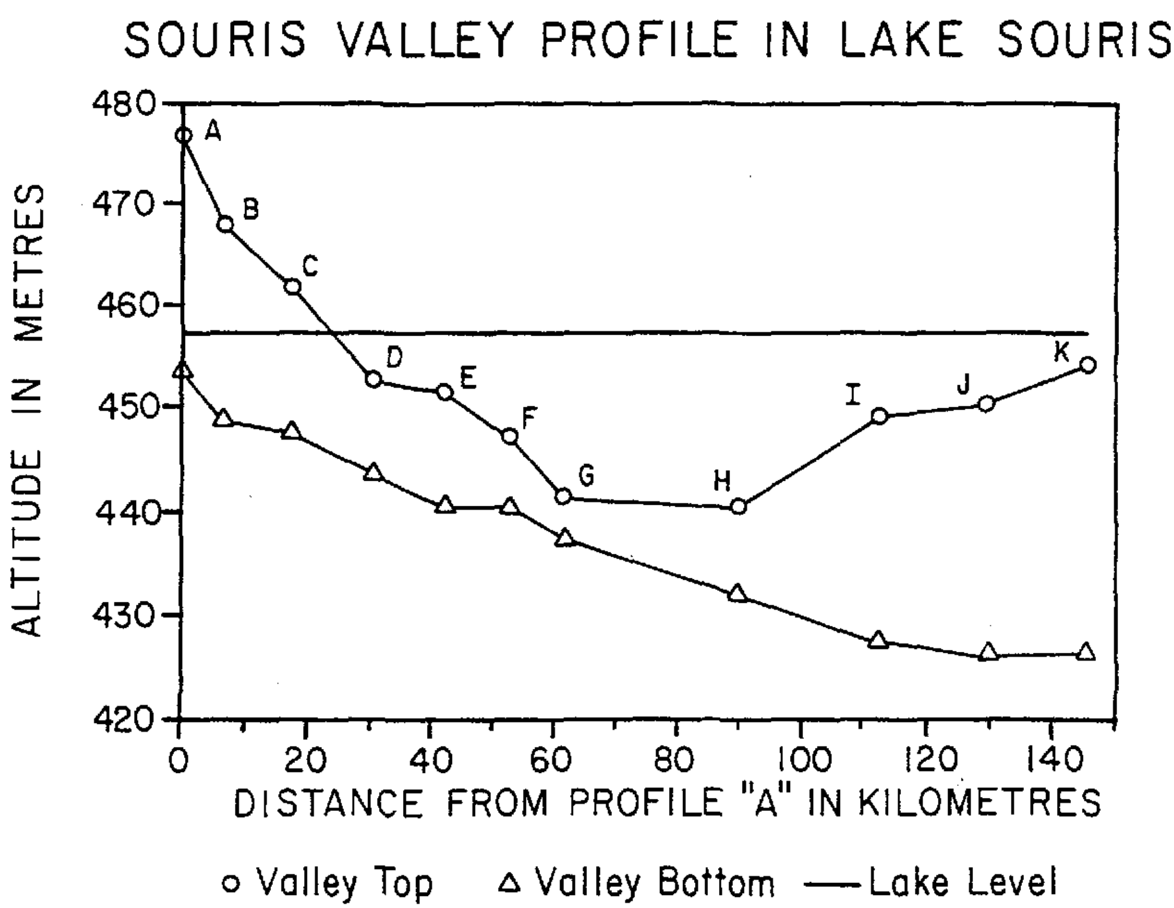

Elevation in Metres
WEST
EAST
490
480
470
460
450
A
B
440
430
C
D
E
F
G
H
I
J
K
CANADA
U.S.
LAKE SOURIS
0 10 20 km
N
Lake Souris water level ~457m
High-water levels in spillways

Figure 33. Longitudinal topographic profile of the Souris spillway through Lake Souris; letters refer to profiles locations shown in Figure 32. Note that the topographic relief of the valley is greatest at the basin edges.


SOURIS VALLEY PROFILE IN LAKE SOURIS
ALTITUDE IN METRES
480
470
460
450
440
430
420
A
B
C
D
E
F
G
H
I
J
K
0
20
40
60
80
100
120
140
DISTANCE FROM PROFILE "A" IN KILOMETRES
o Valley Top
Δ Valley Bottom
— Lake Level

Discussion of Depositional Processes

Introduction

An analysis of the depositional processes active in the development of the coarse-grained fan that formed in Lake Souris must include the lithologic, sedimentologic, and stratigraphic evidence. Furthermore, the depositional processes must be evaluated within a framework established by the probable conditions of the Lake Regina outburst, the geologic setting of Lake Souris, and processes known to be active in analogous geologic settings.

Interpretations of lithofacies made earlier were purposefully general. Detailed information presented subsequently on the textural characteristics of the outburst-deposited sediments and on the conditions in Lake Souris before and after inundation by the outburst permits further evaluation of depositional processes.

The Lake Souris fan is interpreted to have been formed by deposition from braided rivers and various types of sediment gravity flows. Distinguishing the sediments of different depositional environments in Lake Souris is difficult, first, because of the textural homogeneity of much of the sediment, and second, because of the almost complete lack of sedimentary structures available to the study. In this section, the characteristics and evidence for each of the modes of deposition will be described.

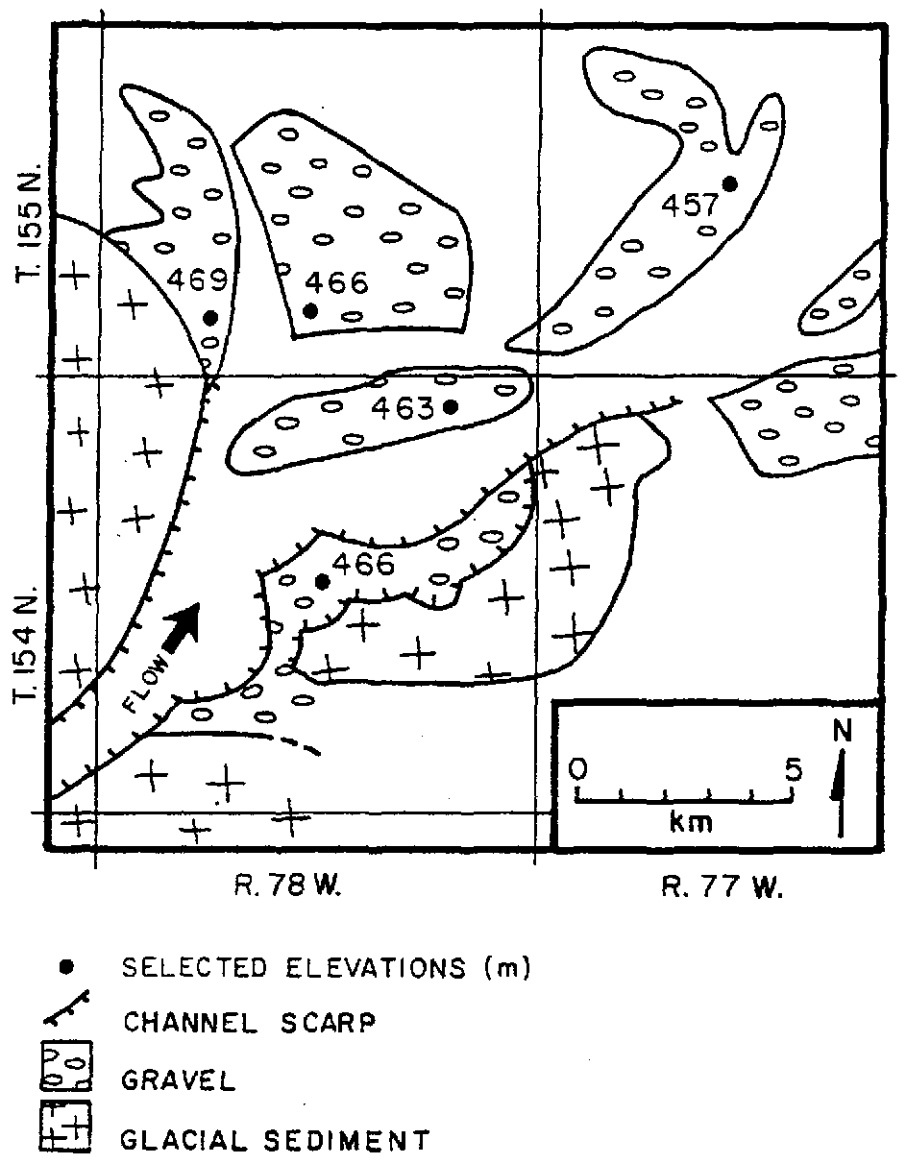
Braided Rivers

As discussed previously, the gravel exposed at and near the surface of the Lake Souris basin is interpreted to have been deposited by braided rivers because of 1) the presence of tabular cross-bedding, 2) the poor sorting of the sediment, and 3) the braided-channel scars on the surface. The sediments deposited by braided rivers, those of lithofacies Gmd, commonly have bimodal grain-size distributions; this characteristic and the others listed above are typical of braided river systems (Fahnestock, 1963; Williams and Rust, 1969; Miall, 1977). Other information also indicates that braided rivers should have been present. The water-level in Lake Souris probably was not higher than 457 m at the time of the outburst (Fig. 32, profile B), but near the inlet, braided-channel scars underlain by gravel occur at elevations up to about 468 m. The outburst flows probably went from confined conditions within the Souris spillway to unconfined, but not subaqueous, conditions within the Lake Souris basin (Fig. 34). In the unconfined reach, upslope from the 457 m lake level, braided river deposits accumulated in a fan shape. Because of the large differences in water levels between the spillway and lake, it is probable that this intermediate area was entirely inundated with water during the early stages of the outburst before braided rivers developed. In an analogous setting, the Charlotte Lobe delta, Alaska, was inundated by flows from the sudden release of water dammed within the Martin River Glacier (Erickson, 1967).

Sediment Gravity Flows

Sediment gravity flows are important in the formation of deep sea fans, marine deltas, and glacial-lake deltas (Gilbert, 1975; Rust, 1977; Hiscott and Middleton, 1979; Hein, 1982; Postma and others,

Figure 34. Selected elevations (in metres) on braided river gravel deposits at the Lake Souris inlet (modified from Lord, 1988).



T. 155 N.
T. 154 N.
469
466
457
463
466
FLOW
0
5
km
N
R. 78 W.
R. 77 W.
SELECTED ELEVATIONS (m)
CHANNEL SCARP
GRAVEL
GLACIAL SEDIMENT

1983; Smith and Ashley, 1985; Eyles and others, 1987). The importance of such flows is also recognized in models of delta progradation (Kenyon and Turcotte, 1985). Because of the relevance of sediment gravity flows to delta formation, and because the conditions in Lake Souris were conducive to the formation of sediment gravity flows (discussed below), a brief review of their characteristics is presented.

Sediment gravity flows are driven by the force of gravity acting on the particles in the flow (Lowe, 1979). Types of sediment gravity flows include turbidity currents, liquefied flows, grain flows, and debris flows (Middleton and Hampton, 1976; Lowe, 1979). The primary mechanism of sediment support is different for each type of flow; particles are supported by fluid turbulence in turbidity currents, upward moving pore fluid in liquefied flows, dispersive pressure due to particle collisions in grain flows, and a cohesive matrix in debris flows (Lowe, 1982). Turbidity currents and grain flows are probably of most importance to this study and will be emphasized. Turbidity currents may be divided into low-density flows and high-density flows. Low-density flows are typically comprised of clay- to medium sand-size sediment that is supported entirely by turbulence. Such flows may be generated by slumps or by continuous influx from a river (Houbolt and Jonker, 1968; Smith and Ashley, 1985). Deposition of the traction load occurs first and then is followed by deposition of the suspended load; deposits may conform to the Bouma's b through e divisions of turbidity current deposits (Lowe, 1982).

High-density flows may be comprised of clay- to cobble-size sediment; particle support mechanisms, in addition to turbulence, may include buoyant lift, hindered settling, and dispersive pressure (Bagnold, 1954; Lowe, 1982; Middleton and Southard, 1984). Dispersive pressure is of little importance to particles smaller than granule size except near the base of flows where particles are more concentrated. Lowe (1982) describes three stages of sedimentation: first, traction sedimentation; second, traction-carpet sedimentation; and third, suspension sedimentation. Traction sedimentation forms a layer of sand due to initial unsteadiness of flow. As flow continues, particles become increasingly concentrated near the bed causing an increase in grain to grain collisions with a concomitant rise in dispersive pressure (a "traction carpet"). This traction carpet continues to become more concentrated until frictional forces dominate and the traction carpet "freezes" causing en masse deposition (Hiscott and Middleton, 1979; Lowe, 1982). The third stage of sedimentation occurs directly from suspension without going through a traction phase; this stage occurs rapidly and probably accounts for most of the deposition from high-density flows (Lowe, 1982; Middleton and Southard, 1984).

Grain flows are composed of concentrated sediments supported almost entirely by grain-to-grain interactions (Stauffer, 1967; Middleton and Hampton, 1976). Such flows are thought to be restricted to high-angle slopes, near the angle of repose, and result in deposits only centimetres thick (Middleton and Southard, 1984). Rapid sedimentation of particles in the flow occurs when frictional forces cause "freezing" of sediment, similar to that of traction carpets

(Lowe, 1982). Grain-flow deposits commonly contain outsize clasts "floated" by dispersive pressure (Stauffer, 1967). Modified grain flows may occur on lesser slopes and produce thicker deposits when there is a muddy matrix that can provide buoyant lift, or where the overriding fluid applies shear stress to cause high dispersive pressures (Lowe, 1979; Hein, 1982).

Transition or residual currents also are important in sediment gravity flows. Higher concentration sediment gravity flows commonly will evolve to a lower concentration flow (Hiscott and Middleton, 1979; Nelson, 1984). For example, a high-density turbidity current may, after some coarse-grained deposition, become a low-density flow that accelerates downslope and may apply enough shear stress to loosely packed sediment that another sediment gravity flow is triggered (Lowe, 1982). It is unlikely that finer sands and gravels of the same high-density flow will be deposited in the same place; finer material is deposited downcurrent of the area of coarse-grained deposition.

The conditions in Lake Souris were favorable for the formation of sediment gravity flows. The flows from the Lake Regina outburst were highly erosive and consequently transported large amounts of sediment. The majority of the sediment carried into Lake Souris consisted of silt and montmorillonite-rich clay (Table 1) (Kehew and Lord, 1987; Lord and Kehew, 1987). Although the sediment-concentration hydrograph is not known for the outburst flows, it is probable that the peak sediment concentration preceded the peak discharge, based on analogies from alpine glacial-lake outbursts (Beecroft, 1983) and the geology of the spillways (Lord and Kehew, 1987). It is likely that the outburst flows entering Lake Souris would have had sufficient sediment concentrations to act as low-density turbidity currents for their entire duration, and possibly as high-density flows at times.

In addition to the continuous turbidity current caused by the influx of flow into Lake Souris, conditions on the fan of sediment prograding into Lake Souris would have been conducive to the formation of discrete sediment gravity flows. Rapid sedimentation of particles, especially coarse-grained clasts, would have occurred within a short distance of the inlet. Moreover, deposited sediments must have been subjected to continual shear stresses applied by the high-discharge flow into Lake Souris, especially along areas of channelized flow. Such shear stresses facilitate the development of high dispersive pressures in the sediments (Hein, 1982).

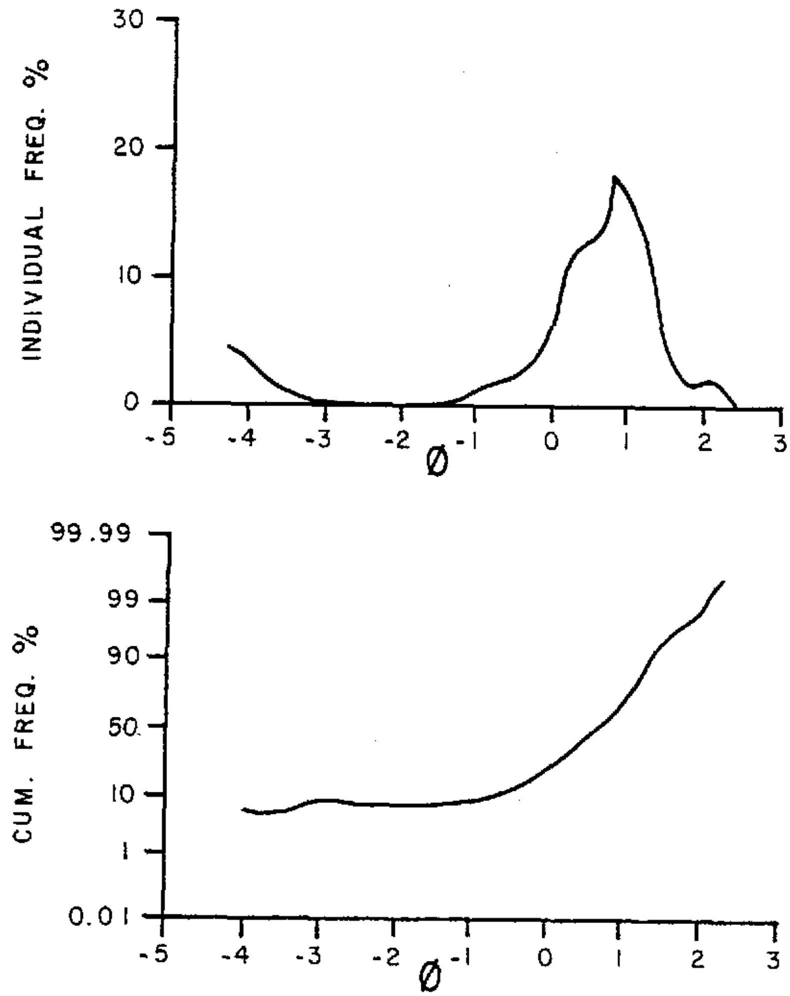
The origin of sediments of the matrix-rich gravel lithofacies is most easily explained by deposition from either high-density turbidity currents or modified grain flows. Some evidence supportive of this interpretation was listed previously, namely, the long transport distance of facies Gmr from the inlet, the large depth at which this facies occurs, and the presence of fragile clasts. The flatness of the individual frequency grain-size curves of facies Gmr sediments (Fig. 21b) indicates that selective deposition did not occur and that sediments deposited were approximately equally transportable. This is consistent with particle transport in a concentrated basal dispersion followed by en masse deposition.

Much more sand than gravel was delivered to Lake Souris by the outburst flows (Table 1); therefore, it should be expected that a large portion of the sand was deposited by high-density flows in a manner similar to the matrix-rich gravels. Because of the abundance of similar size sand in the basin, distinguishing deposits of different origin is difficult. The strongest physical evidence for deposition of some sands from concentrated basal dispersion is the presence of outsize clasts, most commonly lignite, in the deposits. Outsize clasts are an indicator of deposition from grain flows (Stauffer, 1967). To determine if the outsize lignite clasts were hydraulic equivalents of the rest of the particles in the samples, their settling velocities were compared in a representative sample (sample 9-22.5). The settling velocity of the 7 largest lignite clasts averaged about 3 times faster than the fastest one percent of the rest of the sample (about 17 versus 5 cm s^{-1}); hence, the outsize lignite clasts were not in hydraulic equivalence with the rest of the sand. Instead, the lignite probably was "floated" up from the high-shear stress zone at the base of the flow by dispersive pressure (Lowe, 1982; Eyles and others, 1987).

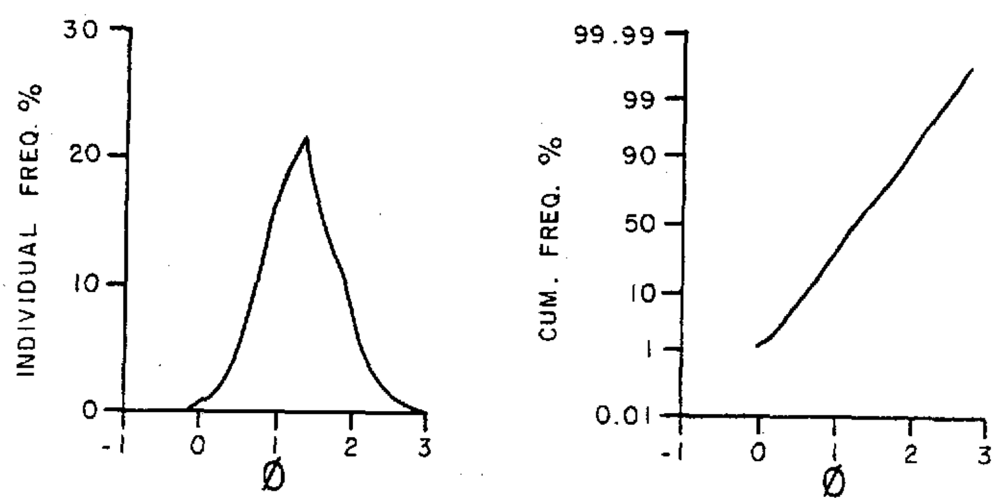
The individual frequency grain-size curves for sands containing outsize lignite clasts, as expected, are more irregular and negatively skewed than those for sands not containing outsize lignite (Fig. 35). The well-sorted sands with normal distributions are inferred to have been deposited from low-density turbidity flows. It is possible (if not likely), however, that some of the sands without outsize lignite clasts may also be high-density flow deposits, except that no lignite was available. Accepting this possibility, low-density turbidity

Figure 35. Individual and cumulative frequency grain-size curves of a) a sand sample with outsize lignite clast present (skewness = -2.50), and b) a sand sample without outsize lignite present (skewness = 0.05).

a. HOLE 4 3.7 m



b. HOLE 4 0.7 m



currents could have originated directly from the influx of the sediment-laden outburst flows or from the residual stage of a high-density flow or a grain flow (Middleton and Hampton, 1976; Gilbert, 1975; Hein, 1982; Lowe, 1982). The abundance of thick, homogeneous sections of sand throughout much of the Lake Souris basin is suggestive of deposition by turbidity currents (Gilbert, 1975; Lowe, 1982; Eyles, 1987; Liverman, 1987).

Summary

To summarize, the majority of the coarse-grained sediments in Lake Souris are interpreted to have been deposited by sediment gravity flows; the exception to this are the braided-river deposits. Sediment was transported predominantly in suspension. Sediment support mechanisms included fluid turbulence and dispersive pressure. Probably matrix support also was important; waters with clay concentrations as low as 2 percent can support fine sand in suspension (Hampton, 1975). The relative dominance of low-density flows versus high-density flows may be estimated by comparing the sum thickness of sand without outsize lignite clasts with that of sand with outsize lignite clasts plus matrix-rich gravel; the ratio is about 4 to 1. Low-density turbidity currents, therefore, are interpreted to have been the dominant depositional process in Lake Souris.

Discussion of Fan Development

Introduction

The precise development of the coarse-grained sediment fan that formed in Lake Souris cannot be determined, but some general inferences can be made based on the information presented and current knowledge of fan-forming processes. In this section, then, the sequence of fan development, the distribution of different depositional processes, the paleoflow conditions and, finally, a general depositional model will be discussed.

Reconstruction of the order of development of the coarse-grained fan in the Lake Souris basin must remain speculative because 1) many of the outburst sediments that were initially deposited near the inlet were probably reworked by sediment gravity flow processes, and 2) inferences based on vertical relationships between sections are severely restricted because of the inherent tendency for density flows to occur at topographic lows and for braided river deposits to be surficial. Indirect evidence may be used to establish a general basis for the sequence of fan development. Among the sediments deposited by sediment gravity flows (all but the braided river deposits), the coarse-grained sediments occur predominantly at the bottom of vertical sections. Also, because the spillways are incised into till that is directly underlain by fine-grained bedrock, it is likely the majority of the gravel transport and deposition occurred in the earlier stages of the outburst when most erosion was into till. Furthermore, the sediments adjacent to the Souris spillway, which are mostly coarse-grained, must have been deposited before outburst discharges had declined substantially, because the deposits were subsequently deeply incised by the outburst flows (Fig. 5; Appendix D).

Vertical Sequences

Vertical sections in the outburst sediment may be used to interpret the prevalence of different sedimentation patterns present in the Lake Souris basin. Information obtained from the analysis of the vertical patterns may later be combined with that of the lateral trends to develop a model for outburst sedimentation in Lake Souris. The prevalent vertical trend in the basin is a simple sequence that exhibits little textural variation (Fig. 22a). This trend is most common in areas away from the Souris spillway where coarse-grained sedimentation was more common. Although the textural variation in the simple sequences is small, most sections coarsen upward (Fig. 27a). Typically, the sections are composed of well-sorted fine to medium sand.

The homogeneity of these sequences indicates little variation in the character of the depositional flows. The simplest explanation for these sediments is deposition dominated by a single process, probably low-density turbidity currents. The coarsening upward trend may be attributed to 1) a decreasing distance of a given site from an area of channelized flow (thus, sections would represent levee or overbank deposition), 2) growth of the sediment fan causing deposition to become increasingly more proximal to the influx of flow, or 3) increasing discharge of the outburst flows causing an increase in flow competence. Evaluation of the first two possibilities requires some conjecture about the fan morphology and development. If the sediments are subaqueous overbank or levee deposits, such as form on glacial-lake bottoms due to underflow transport (Gilbert, 1973) and on deep-sea fans (Shanmugam and Moiola, 1988), it would imply that channels were present over much of the fan. Also implied is the unlikely situation that the channels migrated towards, but not through, all of the coarsening upward sections, thereby causing the coarsening upward sequences. Presumably, there would be some textural evidence if a channel had migrated through a section.

The growth of the fan in the Lake Souris basin, whether it was by progradation or vertical aggradation, would have probably resulted in a coarsening upward sequence. Progradation of a Gilbert-type delta results in coarser grained topset beds (channel deposits) overlying finer grained foreset beds (Axelsson, 1967). Fan growth by vertical aggradation also can result in coarsening-upward sequences, although typically to a lesser degree than with progradation. Such trends have been documented in deep-sea fans (Shanmugam and Moiola, 1988). The morphology and sedimentary sequences in deep-sea fans are considered to be a suitable analogy for the fan in the Lake Souris basin because, similar to Lake Souris, sediment gravity flows are the dominant process in their construction. The efficacy of this analogy is diminished somewhat by the scale differences of these two environments; the effects of the differences are uncertain.

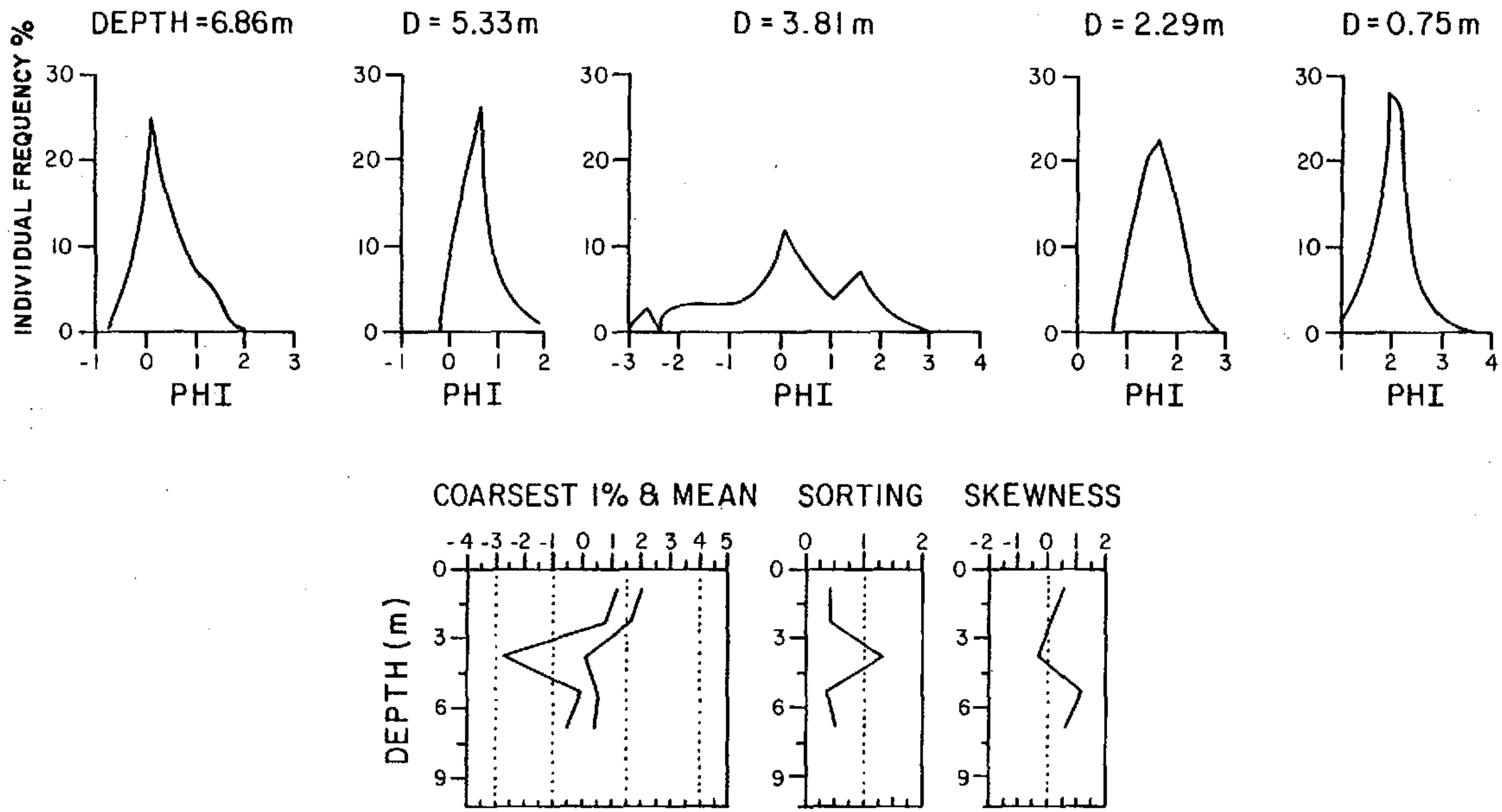
The last possible cause listed for the coarsening-upward sequence throughout much of the Lake Souris basin is increasing discharge during the outburst event. Small glacial-lake outbursts in alpine areas show a steady, comparatively gentle increase in discharge on the rising limb of the hydrographs, with an abrupt decline in discharge on the falling limb (Marcus, 1960). If it is assumed that the hydrograph for the Glacial Lake Regina outburst was similar to that of alpine glacial lakes (accepting a difference in scale), a coarsening upward sediment sequence would be expected, even with no fan progradation. The determination of whether the coarsening upward tendency over much of the basin is due to fan growth or an increase in discharge is not possible with the information available; it is likely that both may have been contributive.

The second most common vertical sequence in the outburst-deposited sediments shows a coarse-grained spike at the bottom of the section, overlain by finer-grained sediments that exhibit little textural variation (Fig. 22b). The upper portions of these sections are similar to the simple, homogeneous sequences described above and, therefore, are interpreted to be similar in origin. The sediments comprising the coarse-grained spikes are matrix-rich, lignite-bearing gravels (lithofacies Gmr) that, as discussed previously, are thought to have been deposited by high-density flows. These vertical sections, then, represent two modes of deposition; initial outburst sedimentation was from high-density flows, succeeded by sedimentation from low-density turbidity currents.

Vertical sections that show irregular patterns of sedimentation are uncommon; they presumably represent deposition by two or more processes. It is instructive to examine one such section to elucidate mechanisms of fan development and the interaction of different depositional processes. Hole 42 is located immediately northeast of the northern fan (Fig. 6 and 4); the sediments display a systematic fining-upward trend that is disrupted by a coarse-grained spike in the middle of the section (Fig. 36). The grain-size frequency curves for the bottom two samples (depth = 6.86, 5.33 m) and the top two samples (depth = 2.29, 0.75 m) are similar to those interpreted to have been deposited by low-density turbidity currents. The disruption of the fining-upward pattern may be ascribed to the migration of a channel through the area (Shaw, 1975) or a slump-generated, high-density flow deposit. The latter explanation is preferred for two reasons: (1) If the coarse-grained sediments of the mid-section represent a deposit from a channel that migrated through the area, the sediments beneath would be expected to show a coarsening-upward trend due to the approach of the channel. (2) The coarse-grained sediments contain outsize lignite clasts and have a grain-size frequency distribution similar to what has previously been interpreted to be a high-density flow deposit.

The last type of vertical sequence, a marked coarsening-upward trend (where grain size varies over several phi interals) (Fig. 23a), occurs in just two holes (number 5 and 35; Fig. 6), located in the vicinity of matrix-deficient gravels (lithofacies Gmd). These sections are interpreted to have resulted from the progradation of braided river deposits into Lake Souris. Such sequences of similar origin are common in glacial lakes (Smith and Ashley, 1985).

Figure 36. Textural data (hole 42) for a fining upward succession interrupted by deposition from a high-density flow.


DEPTH=6.86m
D = 5.33m
D = 3.81m
D = 2.29m
D = 0.75m
INDIVIDUAL FREQUENCY %
PHI
COARSEST 1% & MEAN
SORTING
SKEWNESS
DEPTH (m)

HOLE 42

Areal Trends and Paleoflow Conditions

The outburst-deposited sediments show a fining trend away from the Lake Souris inlet towards the northern, deeper portions of the basin (Fig. 25, 26 and 29). The coarse-grained sediment at the apex of the northern fan (Fig. 4) also is evident from the textural analyses (Fig. 25 and 26). The third-order trend surface of the averaged mean (Fig. 26) is useful to view the patterns of sedimentation because the pattern is not obscured by local influences. The outburst sediments in Lake Souris, as are any sediments, are directly related to the hydraulic characteristics of the flows from which they were deposited. Accordingly, a perusal of the sediment patterns demonstrates that the highest energy flows occurred at the inlet to Lake Souris and were concentrated from the inlet in an elongate pattern along the Souris spillway (Fig. 25 and 26).

Interpretation of fan development is strongly influenced by the presumed hydraulic conditions that formed it. Although several hydraulic characteristics of the flow conditions are uncertain, a simple hydraulic analysis of the flows is presented, based on a grain-suspension criterion. A grain-suspension criterion defines the threshold conditions required for suspension of grains. The purpose of this hydraulic evaluation is to obtain information that may aid in the interpretation of fan development, not to speculate on precise paleoflow conditions. The approach used follows the methodology Komar (1985) used in a study on the hydraulic interpretation of turbidites. In that, he discussed the validity of the approach and the conditions to which it is applicable.

Inherent in the use of a grain-suspension criterion to estimate paleoflow conditions is the assumption that the sediments were transported in suspension and underwent little or no traction transport upon deposition. These conditions are presumed to have been met for the outburst sediments of Lake Souris: arguments for transport by suspension have already been presented and the rapid sedimentation associated with the outburst event probably would have precluded significant transport of grains subsequent to initial deposition.

The density of the fluid is important to hydraulic studies because the value is required in most hydraulic formulas and because density is an indicator of flow type (Newtonian or non-Newtonian). The fluid density of the Lake Regina outburst flows in the Souris and Des Lacs spillways is estimated to have been as high as 1.3 gm cm^3 (Lord and Kehew, 1987). The density of the outburst flows, upon entering Lake Souris, probably would have decreased some, but, because fluid mixing is inhibited in density currents (Albertson and others, 1950), the decrease may have been small. The ensuing calculations are made using a fluid density value of 1.2 gm cm^3; this is comparable to that estimated by Lord and Kehew (1987) and to estimates used for turbidity currents (Hein, 1982).

The grain-suspension criterion used in this study is

$$w_m / u_* = 1.0 , \qquad (1)$$

where w_m is the grain settling velocity and u_* is the shear velocity of flow (Komar, 1985). The shear velocity is represented as

$$u_* = (T / p)^{0.5} , \qquad (2)$$

where T is the frictional drag or boundary shear stress and p is the fluid density (see Komar, 1985). This criterion has been widely used in studies of turbidites (Komar, 1985) and in other hydraulic studies of sand (Middleton, 1975; Middleton and Southard, 1984). Combining equations (1) and (2) yields

$$T = p \quad (w_m)^2. \tag{3}$$

The grain-suspension criterion (eq. 3) was applied to the values on the contoured map of the averaged coarsest one percent (Fig. 25b) for three reasons: (1) In Komar's (1985) study, the hydraulic evaluation of the coarsest particles in samples showed the best agreement with hydraulic estimates based on sedimentary structures. (2) The vertically averaged textural data for Lake Souris basin sediments were used to obtain a representative overview of the flow conditions in Lake Souris. Because the majority of the holes exhibit little textural variation, inaccuracies introduced by averaging should be minimal. Although this approach will not yield hydraulic information as precise as any one set of samples treated individually, it is more valuable in evaluating fan development because it uses all samples. (3) The averaged coarsest one percent do not include the coarse-grained spike samples presumably deposited by high-density flows. Inclusion of samples deposited by non-Newtonian flows may invalidate the approach used.

The results of paleohydraulic calculations are shown in Figure 37. The values on the map are presented in terms of mean velocity, u, mainly because velocity values are more easily visualized than shear stresses. The boundary shear stress is related to mean velocity by

Figure 37. Contour map of paleovelocities in Lake Souris based upon the application of equations (3) and (4) to the averaged coarsest one percent textural data (see Fig. 25b). Values in parentheses are the percentage of initial influx velocity, assuming an initial velocity of 260 cm s^{-1}. The contour intervals are irregular. A conversion table from velocity to shear stress, based on equation (4), is given beneath the map.

PHI SIZE	u (cm s^{-1})	τ (dyne cm^{-2})
0.0	243	284
0.5	175	146
1.0	121	71
1.5	81	32
2.0	52	13
2.5	32	5

$$T = C_f \quad \rho \quad u^2 , \qquad (4)$$

where C_f is a dimensionless drag coefficient taken to be equal to about 0.004 (Komar, 1985). The precise value of C_f is not known, thus more confidence should be placed on the T values provided in the conversion table, based on equation (4), beneath the map on Figure 37.

The paleovelocity estimates demonstrate a pattern of decreasing velocity away from the inlet and from the spillway, as expected. If it is assumed that the initial influx velocity of the outburst flows was 260 cm s^{-1} as calculated by Komar (in press, b), then the paleovelocity estimates may be recalculated as a percentage of the initial influx velocity. The percentage values are given in parentheses on Figure 37. These calculations indicate a relatively small decrease in velocity along the spillway with more rapid decreases to the sides.

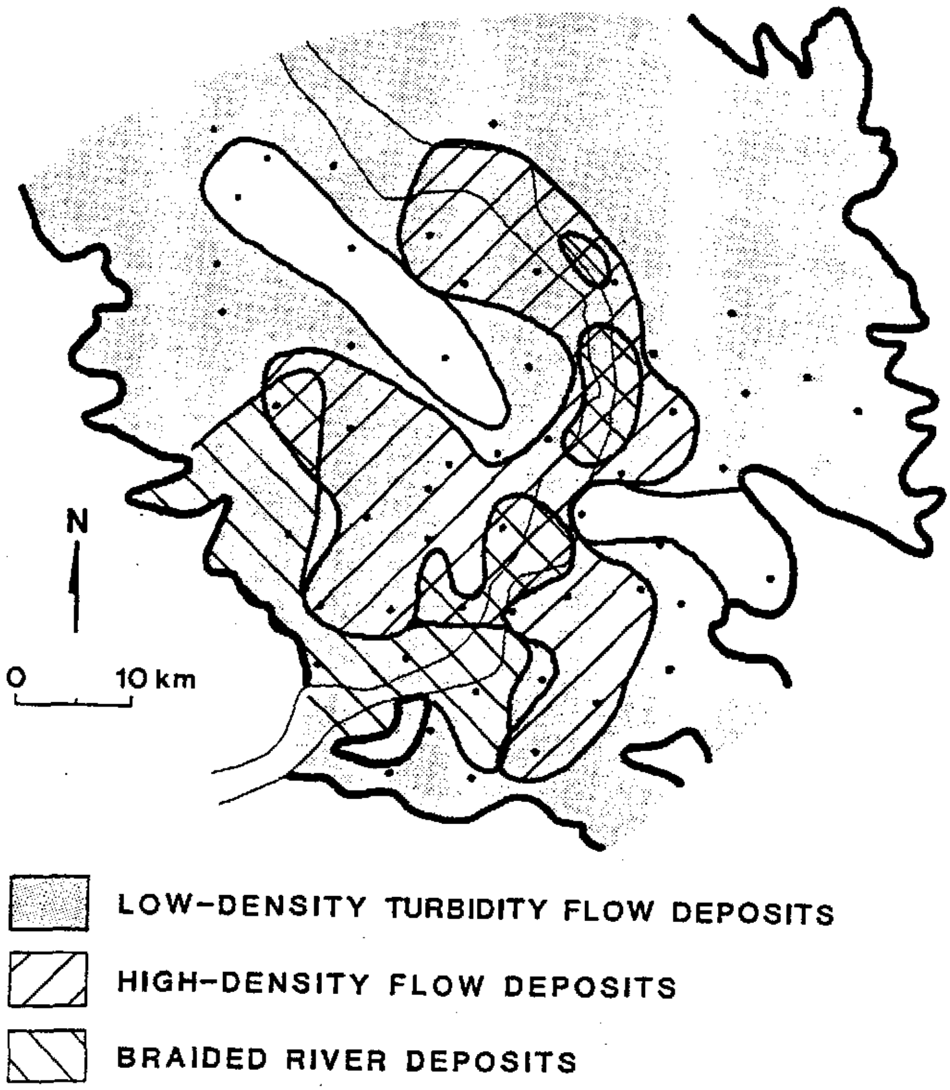
The theory of fluid jet flow has been applied to the formation of deltas (Bates, 1953). Jet-flow theory is useful in predicting the effects of density differences between fluids and of initial influx velocity on the mixing patterns of the jet upon entering a standing body of water. The velocity reduction patterns indicated by the Lake Souris sediments (Fig. 37) are consistent with what is expected for a jet of high density and high discharge (Bates, 1953; Wright, 1977).

Depositional Model

A model of deposition for the Glacial Lake Souris sediment fan constructed by the flows of the Glacial Lake Regina outburst may now be considered. Data concerning the stratigraphy and sedimentology of the outburst-deposited sediments have been presented, as well as interpretations of several aspects of their origin, development, and interrelationships. At this juncture it is beneficial to review some major points that a depositional model for the Lake Souris fan must embody. First, there is little evidence from the sedimentary record that flow energy decreased with duration; most vertical sections coarsen upward. Also, only a relatively small amount of silt-size sediment was deposited by the outburst in Lake Souris and virtually no clay-size sediment, yet most of the sediment delivered to Lake Souris by the outburst flows was silt and clay size (Table 1). Second, the majority of holes sampled have simple textural patterns, indicating little migration of the areas where specified depositional processes were active. Third, the depositional processes interpreted to have been active in the formation of the fan are braided rivers, low-density turbidity currents, and high-density turbidity currents or modified grain flows. Braided river deposits occur along the Souris spillway, especially near the inlet, and at the mouths of the overflow channels (Kehew, 1982) along the western edge of Lake Souris (Fig. 38). The high-density flow deposits occur away from the margins of the lake basin and the low-density flow deposits are widespread throughout the basin (Fig. 38).

The coarse-grained sediments of Lake Souris may be explained by various types of depositional processes resulting from rapid sedimentation by sediment-laden outbursts flows that catastrophically inundated the Lake Souris basin. The three depositional processes responsible for the Lake Souris fan probably were all active

Figure 38. Generalized distribution of deposits by the three depositional processes listed. The boundaries are drawn based on sample hole lithologies the geologic map of Glacial Lake Souris (Appendix D).


N
0 10 km
LOW-DENSITY TURBIDITY FLOW DEPOSITS
HIGH-DENSITY FLOW DEPOSITS
BRAIDED RIVER DEPOSITS

concurrently for most of the duration of the outburst. Sedimentation at the inlet was primarily by a braided river; much of the deposition occurred above the pre-outburst water level of Lake Souris (Fig. 28, 29, and 31). This part of the fan is envisioned to have been similar to a 'supraaquatic delta', a term used by Hjulstrom (1952) to describe glaciofluvial sequences he studied in Scandinavia and Iceland. Supraaquatic deltas accumulate above lake level and result from rapid sedimentation and high competence (Church and Gilbert, 1975). They may be considered to be a transitional form between high slopes upstream and the low slope of the river mouth (Axelsson, 1967).

The braided river deposits on the north side of the till high probably formed in a similar manner as those near the inlet. The till high may have at first been a barrier to outburst flows that subsequently was cut, thereby initiating similar events in the northern fan as the southern fan.

The outburst flows, upon entering Lake Souris, probably caused continuous, rapid sedimentation from both high- and low-density currents. The constancy of the processes is attested to by the simple, non-repetitive sediment sections. For example, most of the high-density flow deposits occur at the bottom of the outburst-deposited sections and are not repeated above (Fig. 22b). The majority of the density current deposits, therefore, were probably not generated by discrete slumps as is most common in glacial lakes and on submarine fans (Smith and Ashley, 1985; Shanmugam and Moiola, 1988). Exceptions to this do occur, such as previously discussed in conjunction with hole 42 (Fig. 36). Whether the high-density flows resulted directly from the initial inflow or from continuous avalanching due to rapid sedimentation (Allen, 1968) is uncertain.

Low-density turbidity currents became more predominant throughout the duration of the outburst flows, as evidenced by sedimentary record and inferences based on the sediment concentration hydrograph for outburst and geology of the spillways (summarized earlier). High-density flow deposits still occurred, but were less common and probably were slump-generated (e.g., hole 42). A diagrammatic representation of the locations of the different types of deposits, which summarizes what has been discussed above, is given in Figure 39.

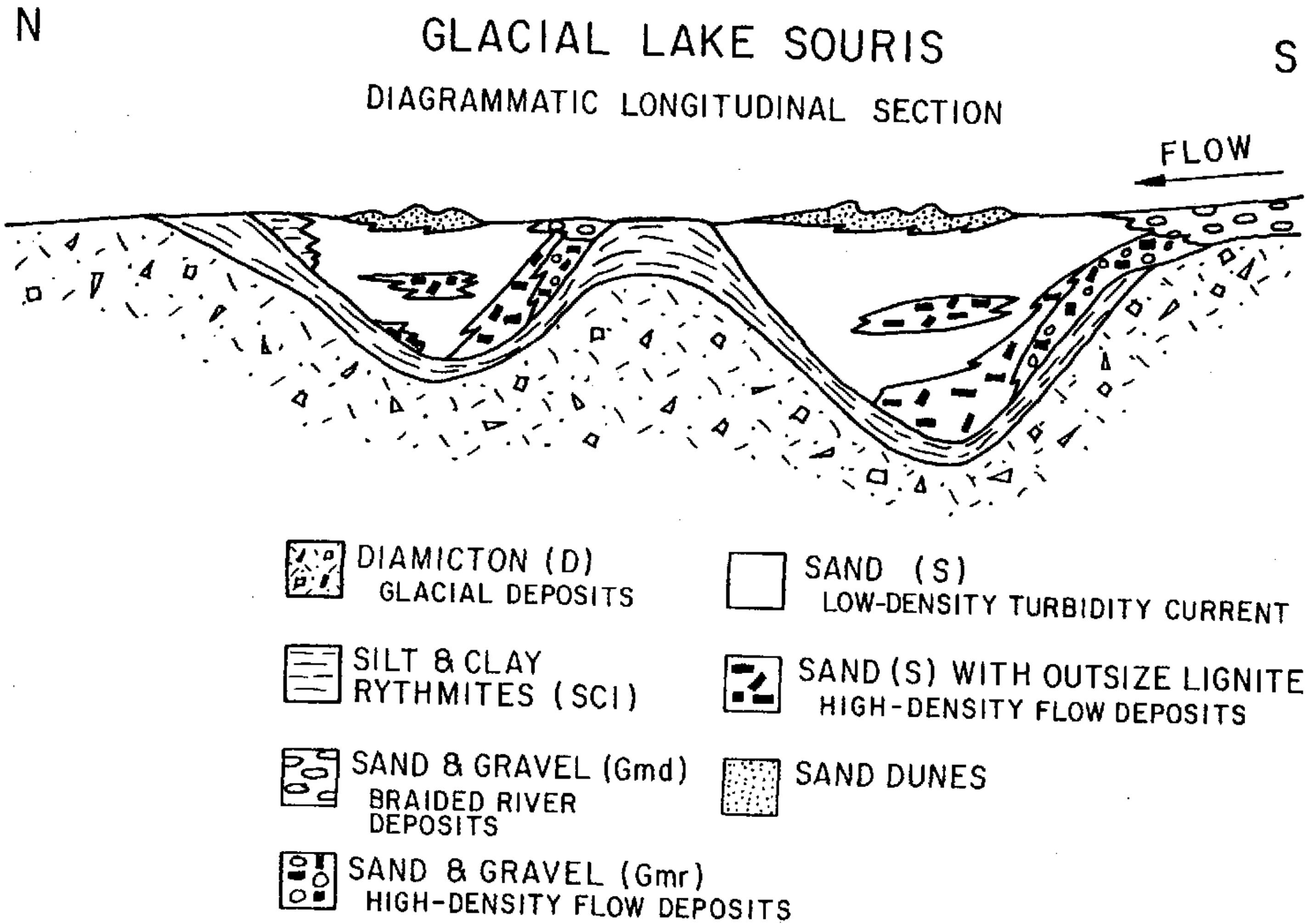
The duration of the Lake Regina outburst is estimated to have been very short, no more than a few weeks (Kehew and Clayton, 1983); the brevity of this event is also indicated by the deficiency of silt-size and clay-size particles among the outburst sediments, but which were abundant in the flows. From this, it may be concluded that the retention time of outburst flows in Lake Souris must have been short and, accordingly, the catastrophic drainage of Lake Souris must have been triggered before the majority of the silt- and clay-size sediment had sufficient time to settle out. Once the drainage of Lake Souris began, conditions would have changed from ponding to through-flow, thus permitting the passage of the silt and clay through the basin. The geomorphologic effects of the drainage of Lake Souris will be discussed in the following section.

There is no evidence that Lake Souris reformed after the drainage induced by the outburst flows. If Lake Souris had reformed, braided river deposits near the inlet would have obscured the trench-shape

Figure 39. Diagrammatic longitudinal section through the Lake Souris basin depicting relationships of sediments deposited by different depositional processes.

GLACIAL LAKE SOURIS

DIAGRAMMATIC LONGITUDINAL SECTION



form of the spillway, and fine-grained sediments typical of glacial lakes would overlie the outburst sediments (Liverman, 1987). It also may be concluded, then, that the inundation of Lake Souris by the glacial-lake outburst was the last glacial event to directly affect Lake Souris.

GEOMORPHOLOGIC EFFECTS OF THE OUTBURST

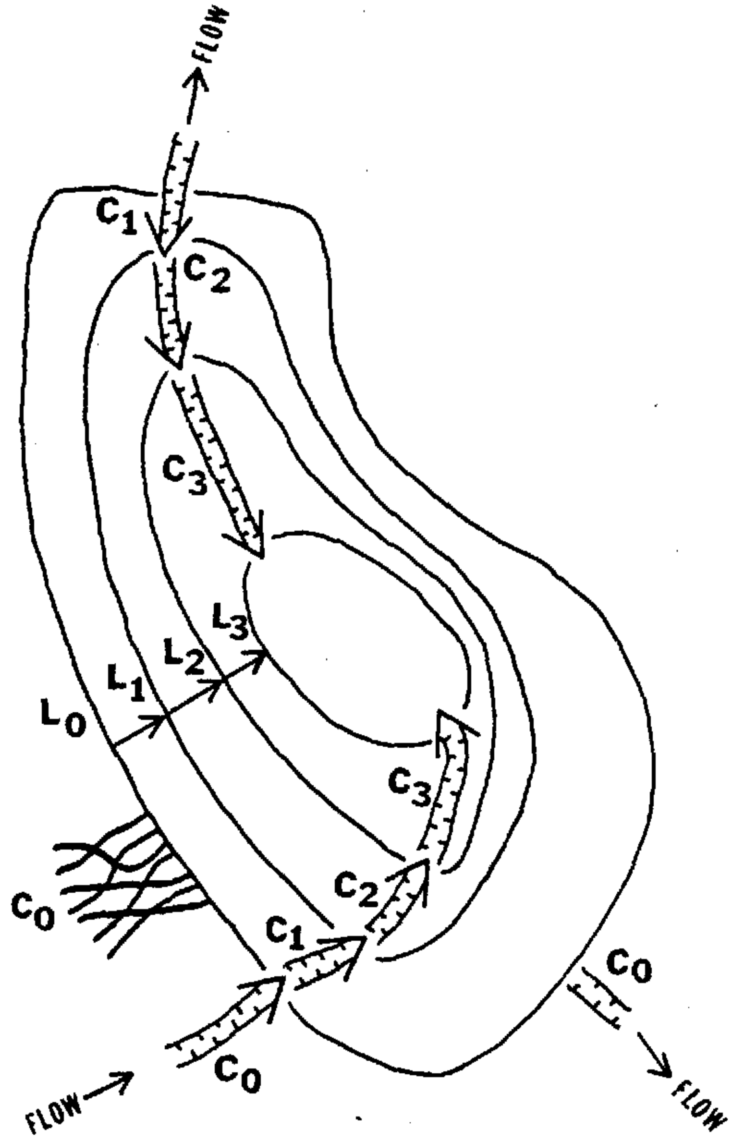
The surface of the Lake Souris plain and the outlets of the lake both were markedly affected by the events resulting from the inundation of the basin by flows from the Lake Regina outburst. Prior to the arrival of the outburst discharges in Lake Souris, there was no active outlet to the north so that, initially, discharges from Lake Souris were through the Girard Lake spillway (Fig. 3). The morphology of the Girard Lake spillway indicates that it conveyed only relatively small discharges for a short duration (see Kehew and Clayton, 1983); consequently, the northern outlet of Lake Souris, which leads to Glacial Lake Hind (Fig. 2), must have become active soon after arrival of the outburst flows. Once incision of the northern outlet began, flow probably became more directed towards the north and flows to the topographically higher southeast portion of the lake basin may have ceased. This is supported by the presence of channel scars to the north and north-northwest and the absence of them to the east (Fig. 5).

The response of the water level of Lake Souris to the continued incision of the Souris-Hind spillway (the northern outlet) must remain speculative. The water level in Lake Souris presumably continued to rise in response to the great influx of outburst waters until the

Souris-Hind spillway was incised sufficiently to permit an equal discharge from Lake Souris. The water level of Lake Souris must have begun to fall when the easily eroded Souris-Hind spillway enlarged so that the discharge rate was greater leaving Lake Souris than entering. The sediments of the Lake Souris plain are incised by the Souris spillway, except at the basin center, over much of its length (Figs. 5 and 32; Appendix D); because this channel is very large (comparable to the Souris spillway upstream from Lake Souris), substantial discharges must have formed it. It may be concluded, then, that although discharge through the Souris-Hind spillway was greater than that entering Lake Souris, causing the lake level to drop and expose portions of the basin floor, the outburst flows entering the lake were still great enough to carve large channels. Before incision of the floor of Lake Souris was complete, discharges from the outburst of Lake Regina had tapered off to negligible rates.

The information on fluctuations in lake level may be used to explain the development of channels associated with the outburst event. The channels existing at the onset of the outburst were the overflow channels entering Lake Souris on the western edge and the Girard Lake spillway to the southeast (Fig. 40). As the northern outlet enlarged and lake level began to decline, exposing some of the basin floor, incision by the Souris spillway progressed towards the basin center concurrently with headward knickpoint migration of the Souris-Hind spillway (Fig. 40). This migration stopped when the influx of outburst waters stopped. The result of this pattern of channel development is a consistent increase in relief from the basin

Figure 40. Diagrammatic model of incision migration by the Souris spillway into the Lake Souris basin in response to falling lake level. The onset the outburst is indicated by the most extensive lake level (L_0) and channels (C_0). Higher numbers indicate succeeding stages as channels migrated towards the center of the basin concurrently with drops in lake level.



FLOW
C1
C2
C3
L0
L1
L2
L3
C3
C2
C1
C0
C0
C0
FLOW
FLOW

center towards the margins of the lake (Fig. 33). The lake had to have completely drained because the northern outlet is incised below the lowest elevation in the lake basin (Kehew and Clayton, 1983).

The erosional capacity of the flows during drainage of Lake Souris also is attested to by the large area of eroded till, up to 20 km wide, in the northern portion of the lake basin (Fig. 5; Appendix D). This area is covered with dozens of what appear as shallow channels, which are generally oriented towards the Souris spillway. A boulder lag that becomes more concentrated towards the spillway is present over much of this area (Lord, 1988). The area is analogous to the outer zone described by Kehew and Lord (1986), probably representing an early stage of spillway development. An anomalous feature of this area is that the general slope of the eroded surface rises to the north, rising about 15 m over a 30 km distance (The actual rise probably was somewhat less during the outburst because of differential isostatic rebound since the event). There must have been a large head of water to provide the energy slope necessary to drive flow upslope.

Other geomorphologic effects, direct and indirect, of the Lake Regina outburst include: 1) the initiation of events similar to those in Lake Souris in the downstream Lake Hind, and 2) the formation of sand dunes over much of the lake basin during the Holocene. Both of these have been described by Kehew and Clayton (1983).

FURTHER STUDY AND IMPLICATIONS

In this paper the sedimentology and stratigraphy of the outburst sediments in the Glacial Lake Souris basin have been described and interpreted. During the Pleistocene, hundreds of channels were deeply incised by glacial-lake outbursts along the midcontinent margins of the Laurentide Ice Sheet (Kehew and Lord, 1987). Whereas flood waters initially were dumped into downstream glacial lakes, such as Lake Souris, the ultimate destination of outburst flows was the ocean. Because many of the discharges of major outbursts funneled into the Mississippi River, sedimentation by outburst flows probably dominated deposition on the Mississippi fan and Louisiana offshore during glacial intervals (Kehew and others, 1986; Kehew and Lord, 1987).

It is appropriate to consider the applicability and implications of the conclusions drawn from the study of Lake Souris to other areas. To do this, one must first consider what is fundamental about the outburst deposits that will permit their recognition in geologic settings that may differ from those of Lake Souris. Because the outburst flows inundated Lake Souris after active glaciation in the area, the resulting deposits and patterns of sedimentation are not obscured by the presence of normal glacial outwash deposits. The most striking characteristics of the outburst sediments are 1) the constancy of vertical sections, commonly up to 10 m thick, indicating little change in flow conditions, 2) the pervasiveness of anomalously coarse-grained sediments over most of the lake basin, and 3) the abundance of high-density flow deposits formed by continual sedimentation rather than discrete slump-generated deposition.

Fans formed by outburst flows have been recognized in Glacial Lakes Agassiz, Dakota, and Hind (Fig. 2) because they occur at the mouths of glacial-lake spillways and because their surficial geology is similar to that of Lake Souris (Kehew and Clayton, 1983; Kehew and Lord, 1987). The recognition of outburst deposits on the marine offshore is considerably more complicated. Nonetheless, on the Mississippi Fan, discrete, large fresh-water pulses indicated by negative oxygen isotope anomalies (Emiliani and others, 1978; Leventer and others, 1982), anomalously coarse-grained sediments, and channelized density-flow deposits (Feeley and others, 1985) suggest that sedimentation from glacial-lake outbursts in the midcontinent region did affect the offshore (Kehew and others, 1986). Also, deep-sea gravels in the Cascadia Channel, off the northwest coast, are interpreted to have been deposited by high-density turbidity currents that were transported hundreds of kilometres offshore by outburst flows from Glacial Lake Missoula (Griggs and others, 1970).

If detailed studies of offshore fans in North America, Europe, and Asia, can differentiate glacial-lake outburst deposits from normal glacial-meltwater deposits, the relative roles of each as a glaciofluvial process may be assessed. Furthermore, if glacial-lake outbursts are found to be a significant process on a global scale, interpretation of ice volumes and climatic variations based on oxygen isotope data should be reevaluated. Glacial lakes, by temporarily storing glacial meltwater (up to hundreds of years), act as a buffer between glacier melting and delivery of that meltwater to the ocean. Also, the possibility exists of misinterpreting large, negative isotopic peaks as sudden climatic warmings rather than one or more large glacial-lake outbursts.

Information from this study may also be useful in interpreting parts of the Martian surface. Large outflow channels probably formed by catastrophic floods, yet the sinks for the floods lack features typical of lakes (Baker and Kochel, 1979). Broad, light-albedo patches at the mouths of some outflow channels may represent fan deposits (Baker and Kochel, 1979) that are genetically similar to that of Lake Souris.

SUMMARY AND CONCLUSIONS

The purpose of this study has been to demonstrate the effects of a glacial-lake outburst on a lake that received the outburst flows, specifically, the effects of the Glacial Lake Regina outburst on Lake Souris. This topic previously has not been examined in detail. Study of the sedimentology and stratigraphy of the Lake Souris basin sediments, the geomorphology of the lake plain, and previous work related to the subject each demonstrate that the Lake Regina outburst had a dramatic effect on Lake Souris. Each of these approaches independently supports the following general conclusions: the outburst flows were large of magnitude, representing a much higher energy hydrologic regime than immediately prior to it, the outburst was short-lived, and the sediment concentrations in the outburst flows were high. Specific conclusions of this study are:

1. The sediments of the Lake Souris basin are composed of five lithofacies: diamicton, laminated silt and clay, matrix-rich gravel, matrix-deficient gravel, and sand.

a) The diamicton and the laminated silt and clay lithofacies underlie the outburst sediments. The diamicton lithofacies consist of unsorted to very poorly sorted gravelly sand, silt, and clay, deposited directly by the glacier or by mass movement off the ice.

The laminated silt and clay lithofacies represents deposition in a low-energy lake environment, probably isolated glacial lakes that had coalesced into one larger lake by the time of the outburst.

b) The outburst sediments are comprised of three lithofacies: matrix-rich gravel, matrix-deficient gravel, and sand. The matrix-rich gravel lithofacies consists of lignite-bearing, poorly sorted gravels with a fine-grained matrix. These gravels tend to occur at the base of the outburst sediments and are limited to the inlet area and adjacent to the Souris spillway. The matrix-deficient gravel lithofacies typically has a coarser grained matrix than the matrix-rich gravels and no lignite. This facies occurs at and near the ground surface adjacent to the Souris spillway. Sand, the most widespread and abundant lithofacies, tends to occur on top of other lithofacies. Most sand contains some lignite particles; at depth, outsize lignite clasts are common in the sand.

2. Two coarse-grained sediment fans, with gravel apexes, are apparent in the outburst sediments, one at the Lake Souris inlet and a smaller one near Towner just north of a till high. Sediments generally show a gradual fining away from the fan apexes to the northwest. Most outburst sediments are well sorted to moderately well sorted fine to medium sand. Vertically, most outburst sediments become coarser upward; the most prominent exception is the sediments immediately adjacent to the Souris spillway that have gravel at the base and are sand at the top.

3. Three major depositional processes probably are responsible for deposition of the outburst sediments: braided rivers, low-density

turbidity currents, and high-density turbidity currents or modified grain flows. Braided river deposition occurred primarily near the inlet and migrated basinward as the flood continued. Most high-density flows resulted directly from the influx of outburst flows or from continuous avalanching due to rapid sedimentation. Low-density turbidity currents occurred for the entire duration of the outburst and were caused by the continuous influx of sediment-laden flows and by residual currents from high-density flows. Low-density turbidity currents were the dominant sedimentary process during the outburst.

4. Outburst sedimentation in Lake Souris was short-lived. Most of the sand- and gravel-size sediment delivered to Lake Souris by the outburst was deposited in the basin. Most silt- and clay-size sediment, however, was transported through the basin because drainage of Lake Souris was occurred before the silt and clay had time to settle out from suspension.

5. The water level in Lake Souris declined as the northern outlet, the Souris-Hind spillway, conveyed more water than was entering the inlet. Incision of the lake bottom by the Souris spillway occurred concurrently with falling lake level; incision stopped when the Lake Regina outburst flows became negligible.

It is appropriate to reiterate some limitations of this study in order to keep the results in perspective. Foremost, only a relatively small number of sample holes was made for a large study area. The influence of this limitation is that major trends are emphasized by the data; small-scale complexities are obscured. Thus, areal patterns presented are probably much more simple than would be obtained if more sample holes were used, especially because of the irregular pre-outburst surface. Although this limitation probably does not significantly affect the interpretation of sedimentary processes, it may affect specific interpretations about Lake Souris geology. Detailed studies of a small part of Lake Souris would help clarify possible discrepancies.

An additional limitation of this study is that only a few undisturbed sedimentary structures were observed. Complete descriptions of sedimentary structures associated with the different lithofacies probably would have permitted more detailed (and possibly more accurate) interpretations of sedimentary processes. The best way to observe sedimentary structures would be in an excavation. The depth of such excavations would be limited by the commonly high groundwater table in the Lake Souris plain.

APPENDICES

APPENDIX A

Locations and descriptions of samples collected for this study. Diamictons are noted but not described; see Remple (1987) for their descriptions. The N-File numbers given for each hole are unique labels used in a near-surface data set maintained by the North Dakota Geological Survey.

Key to Abbreviations

vfS = very fine sand
fS = fine sand
mS = medium sand
cS = coarse sand
vcS = very coarse sand
Gv = gravel

saa = same color as above
lam. = lamination
lams. = laminations
mod. = moderately

Hole no. 1 N-File no. 4201 Surface Elevation: 454.7 m
T. 156 N., R. 76 W., sec. 22 ddd Total Depth Drilled: 13.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.0	Clayey silt, moist, indistinct lams. 4-15 mm.	10YR 7/1	10YR 5/2
1.0-2.3	Silt with vfS, some clay, moist, lams. ~1 mm.	2.5Y 7/3	2.5Y 5/4
2.3-4.0	Clayey silt, lams. 1-3mm.	saa	
4.0-9.8	Diamicton		
9.8-10.4	mS-cS, mod. sorted		
10.4-13.7	Diamicton		

Hole no. 2 N-File no. 4202 Surface Elevation: 456.0 m
T. 155 N., R. 77., sec. 31 dbb Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.2	mS, mod. cohesive with some silt.	5Y 5/3	10YR 3/4
1.2-2.0	mS, very cohesive, fine silt cement.	2.5Y 5/4	2.5Y 6/6
2.0-2.7	mS-cS, very cohesive, scattered vcS.	saa	
2.7-4.3	Gv, very cohesive, clasts to 3 cm, vcS with silt cement.	5Y 6/2	5Y 4/2
4.3-5.0	vfS with scattered gravel up to 1.5 cm, lams. 1-3 mm.	5Y 6/2	5Y 4/2
5.0-6.7	Diamicton, sandy.		

Hole no. 3 N-File no. 4203 Surface Elevation: 461.7 m
T. 155 N., R. 78 W., sec. 16 ddd Total Depth Drilled: 1.5 m

Depth (m)	Description	Color: Dry	Wet
0-1.5	Diamicton		

Hole no. 4 N-File no. 4204 Surface Elevation: 461.7 m
T. 155 N., R. 78 W., sec. 16 ccd Total Depth Drilled: 4.9 m

Depth (m)	Description	Color: Dry	Wet
0-0.5	cS, clean, noncohesive.	10YR 5/4	10YR 3/3
0.5-1.2	vcS, some fine gravel up to 0.8 cm, slightly cohesive.	saa	
1.2-2.0	Gv, clasts to 1.3 cm, noncohesive.	saa	
2.0-2.7	vcS, some granules, lignite common with clasts to 1.0 cm.	saa	

Hole no. 4 continued:

Depth (m)	Description	Color: Dry	Wet
2.7-3.7	Gv, matrix of cS, outsize lignite clasts common, up to 5 cm. Bottom 0.3 m is lignite gravel.	saa	
3.7-4.9	Diamicton		

Hole no. 5 N-File no. 4101 Surface Elevation: 463.6 m
T. 155 N., R. 78 W., sec. 13 ddd Total Depth Drilled: 16.2 m

Depth (m)	Description	Color: Dry	Wet
0-0.3	mS, noncohesive, well sorted.	10YR 5/3	10YR 3/2
0.3-5.0	Gv, noncohesive, some caliche at 4 m, clasts to 6 cm.	saa	
5.0-5.8	cS, with scattered gravel to 3 cm, clean.	2.5Y 6/2	2.5Y 4/2
5.8-6.6	mS-cS with scattered Gv to 5 cm.	saa	
6.6-8.1	fS with scattered Gv to 2 cm, outsize lignite common, obscure lams. ~1 mm in fS.	saa	
8.1-9.6	vfS, noncohesive, lams. ~1 mm.	saa	
9.6-11.9	fS, well sorted except for outsize lignite to 0.6 cm.	saa	
11.9-12.6	vfS with silt, lignite abundant.	saa	
12.6-13.4	Silt, lignite abundant.	saa	
13.4-14.2	vfS with silt, lignite abundant.	saa	
14.2-14.7	Diamicton, massive		
14.7-14.8	Silt and clay couplets with light and dark lams. 0.2-8.0 mm.	saa	
14.8-14.9	Diamicton, layered, ~1 cm thick.		
14.9-16.2	Diamicton, massive.		

Hole no. 6 N-File no. 4205 Surface Elevation: 458.9 m
T. 155 N., R. 76 W., sec. 18 ccc Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.7	mS, mod. to poorly sorted, noncohesive, scattered Gv to 0.8 cm.	10YR 6/3	10YR 3/3
2.7-3.5	fS, well sorted, clean, lignite common	saa	
3.5-5.0	mS, clean, noncohesive, outsize lignite common, up to 1.3 cm.	saa	
5.0-6.7	Diamicton, layered from 5.0-5.5 m, massive below, clasts to 1 cm.		

Hole no. 7 N-File no. 4206 Surface Elevation: 448.9 m
T. 156 N., R. 77 W., sec. 25 dda Total Depth Drilled: 12.8 m

Depth (m)	Description	Color: Dry	Wet
0-1.7	mS, mod. sorted, obscure lams. 1-10 mm, mod. cohesive.	5Y 5/3	5Y 4/3
1.7-4.5	mS, mod. to well sorted, noncohesive	2.5Y 3/2	2.5Y 2/0
4.5-5.1	fS, well sorted, lignite common, obscure lams. ~1-6 mm, slightly cohesive.	5Y 5/3	5Y 3/3
5.1-9.7	mS-cS, mod. sorted, slightly cohesive, obscure lams. 1-5 mm.	5Y 6/3	5Y 4/3
9.7-11.1	Gv, clasts up to 3 cm, clean, very poorly sorted.	saa	
11.1-12.8	Diamicton.		

Hole no. 8 N-File no. 4207 Surface Elevation: 461.7 m
T. 156 N., R. 77 W., sec. 32 aaa Total Depth Drilled: 18.9 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	fS, mod. to well sorted, noncohesive, scattered vcS at 1.5-2.0 m.	2.5Y 4/2	2.5Y 2/2
2.0-3.6	vfS to fS, mod. to well sorted, slightly cohesive, obscure lams. 1-2 mm marked by lignite concentrations.	2.5Y 7/4	2.5Y 4/4
3.6-6.8	mS, well sorted, clean, lignite common, cS to vcS at 6.3 to 6.8 m.	5Y 5/1	5Y 3/2
6.8-8.0	vfS, some silt, indistinct lams. 1-5 mm, mod. to poorly sorted.	saa	
8.0-11.2	fS, mod. well sorted, lignite particles up to 6 mm, slightly cohesive, lams. 2-12 mm thick.	saa	
11.2-16.5	silt and clay, alternate dark and light lams. 0.2-1.2 mm, well consolidated.	saa	
16.5-18.9	Diamicton.		

Hole no. 9 N-File no. 4208 Surface Elevation: 461.7 m
T. 156 N., R. 78 W., sec. 26 bba Total Depth Drilled: 15.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.7	mS, very well to well sorted, unconsolidated except slightly at surface, lignite common, outsize lignite up to 5 mm.	2.5Y 6/3	2.5Y 4/3

Hole no. 9 Continued:

Depth (m)	Description	Color: Dry	Wet
2.7-5.0	cS with abundant outsize lignite gravel up to 3 cm, poorly sorted.	5Y 6/1	5Y 3/1
5.0-7.5	fS, very well to well sorted, unconsolidated, outsize lignite scarce except common at 7 m (up to 2 cm).	5Y 7/1	5Y 4/2
7.5-10.3	fS, some silt, slightly to mod. consolidated, outsize lignite to 1 cm, some mS-cS at 9.9 m with 3 cm silt-clay outsize clasts, lams. .3-1.4 cm.	5Y 5/2	5Y 2.5/2
10.3-13.6	Silt and clay, lams. 0.5-1.2 mm, alternating dark and light layers.	saa	
13.6-15.8	Diamicton.		

Hole no. 10 N-File no. 4209 Surface Elevation: 458.4 m
T. 156 N., R. 78 W., sec. 31 bba Total Depth Drilled: 4.9 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS, very well sorted, noncohesive.	2.5Y 6/2	2.5Y 3/2
0.8-2.0	fS, mod. sorted, slightly cohesive, scattered vcS, mottled color, obscure lams. 1-3 mm, lignite common.	2.5Y 7/2	2.5Y 4/2
2.0-3.0	Gv, very dirty, mod. to well consolidated, some angular clasts to 3 cm, carbonate clasts common.	saa	
3.0-4.9	Diamicton.		

Hole no. 11 N-File no. Surface Elevation: 450.2 m
T. 156 N., R. 76 W., sec. 12 ada Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	mS, mod. to very well sorted, noncohesive, scattered vcS and granules at surface, lignite common at 1.5 m.	2.5Y 6/4	2.5Y 4/4
2.0-3.7	cS-vcS, mod. sorted, clean, coarser at bottom with some granules, outsize lignite up to 8 mm common.	2.5Y 6/2	2.5Y 4/2
3.7-6.7	Diamicton.		

Hole no. 12 N-File no. 4102 — Surface Elevation: 456.6 m
T. 156 N., R. 77 W., sec. 1 ccb — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	fS, mod. to well sorted, slightly to mod. cohesive.	5Y 6/3	5Y 4/3
2.0-6.5	vfS to fS, noncohesive to weakly cohesive, scattered lams. 1-6 mm, scattered lignite particles up to 4 mm.	5Y 6/1	5Y 6/4
6.5-7.2	coarse silt, massive, cohesive.	5Y 6/2	5Y 4/2
7.2-9.8	clayey silt, finely lam., alternating dark and light, 0.3-3 mm; light lams. thinner than dark.	saa	

Hole no. 13 N-File no. 4103 — Surface Elevation: 458.4 m
T. 157 N., R. 77 W., sec. 33 cbb — Total Depth Drilled: 28.0 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	fS, well sorted, noncohesive, indistinct lams. ~2 mm, sediment plastic at 1.5 m.	2.5Y 3/2	2.5Y 3/1
2.0-3.2	Clayey silt, well-sorted, lams. ~1 mm.	saa	
3.2-25.2	fS and vfS, mod. to well sorted, lignite common, scattered obscure lams. 1-3 cm, some lignite is vcS, noncohesive.	5Y 6/2	5Y 3/2
25.2-26.7	vfS and some silt, mod. cohesive, scattered vcS, poorly sorted.	saa	
26.7-28.0	fS, mod. to poorly sorted, scattered cS.	saa	

Hole no. 14 N-File no. 4211 — Surface Elevation: 445.9 m
T. 157 N., R. 76 W., sec. 35 ccc — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS, mod. sorted, some silt.	2.5Y 5/2	2.5Y 2/2
0.8-2.0	mS, mod. to poorly sorted, slightly to mod. cohesive.	2.5Y 6/2	2/5Y 4/3
2.0-4.1	vcS and Gv, Gv to 1 cm at 3.8 m, poorly sorted, lignite and diamicton clasts present, noncohesive.	2.5Y 6/3	2.5Y 4/4

Hole no. 14 Continued:

Depth (m)	Description	Color: Dry	Wet
4.1-6.7	Diamicton.		

Hole no. 15 N-File no. 4212 — Surface Elevation: 472.4 m
T. 154 N., R. 78 W., sec. 36 aaa — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-1.4	mS, well sorted, unconsolidated, clean.	10YR 5/3	10YR 4/3
1.4-8.1	vcS and Gv, poorly sorted, clasts to 3.5 cm, lignite common 5-6.5 m, unconsolidated.	saa	
8.1-9.8	Diamicton.		

Hole no. 16 N-File no. 4213 — Surface Elevation: 468.5 m
T. 154 N., R. 77 W., sec. 25 bba — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-3.5	mS to cS, mod. to well sorted, unconsolidated, clean, some scattered granules.	10YR 5/3	10YR 3/2
3.5-6.7	Diamicton.		

Hole no. 17 N-File no. 4214 — Surface Elevation: 458.4 m
T. 154 N., R. 77 W., sec. 2 ccc — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.6	Gv, large clasts ~1 cm except up to 3.5 cm at 0.8 m, poorly sorted, unconsolidated; organic (?) layer at 2.5-2.6 m.	10YR 5/3	10YR 3/2
2.6-5.0	Gv, clean, poorly sorted, large clasts ~1.5 cm.	10YR 4/2	10YR 3/2
5.0-5.9	mS to cS with scattered granules, mod. to mod. well sorted, clean.	2.5Y 6/2	2.5Y 4/2
5.9-8.0	Diamicton.		
8.0-8.6	mS, well sorted, mod. consolidated, some granules.	2.5Y 6/2	2.5Y 4/2
8.6-9.8	Gv, clasts up to 2.5 cm, dirty, mod. to well consolidated.	saa	

Hole no. 18 N-File no. 4215 — Surface Elevation: 461.1 m
T. 156 N., R. 75 W., sec. 28 ccc — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.7	vfS, some silt, slightly cohesive, mod. sorted, lams. ~1 mm at 2.3 m.	5Y 6/3	5Y 4/3
2.7-5.9	Silty clay, alternating dark and light lams. 0.1-0.7 mm, massive from 4.3-4.8 m, scattered vcS and granules 5.5 to 5.9 m.	5Y 6/2	5Y 3/2
5.9-6.7	Diamicton.		

Hole no. 19 N-File no. 4104 — Surface Elevation: 454.4 m
T. 156 N., R. 75 W., sec. 12 bbb — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	vfS, mod. well sorted, slightly to mod. cohesive,	2.5Y 7/4	2.5Y 5/4
2.0-6.7	silt and clay, lams. 1-2 mm, cohesive.	5Y 6/2	5Y 4/2

Hole no. 20 N-File no. 4111 — Surface Elevation: 456.3 m
T. 154 N., R. 73 W., sec. 33 dcc — Total Depth Drilled: 18.9 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	mS, clean except silty at surface, very well sorted, obscure lams. ~1 cm.	2.5Y 7/3	2.5Y 6/5
2.0-2.8	vcS and Gv up to 3 cm, poorly sorted, unconsolidated.	saa	
2.8-6.5	mS, mod. well sorted, clean, lignite common, outsize lignite up to 2 cm at 3.8 m.	5Y 6/2	5Y 4/2
6.5-8.0	vcS and Gv up to 2 cm, poorly sorted, noncohesive.	saa	
8.0-12.0	cS-vcS, mod. to mod. well sorted, some pebbles 11-12 m.	saa	
12.0-18.9	Silt, well sorted, hard, well indurated, (bedrock?).	5Y 4/1	5Y 3/2

Hole no. 21 N-File no. 4112
T. 153 N., R. 74 W., sec. 33 aaa

Surface Elevation: 474.2 m
Total Depth Drilled: 15.8 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS, very well sorted, unconsolidated.	10YR 5/2	10YR 4/2
0.8-2.0	mS, well to very well sorted, unconsolidated.	2.5Y 6/3	2.5Y 4/3
2.0-11.2	mS to vcS, mod. to poorly sorted, some lignite present, pebbles to 1 cm. Silty, cohesive sediment at 2.7-2.8 m with vcS, very poorly sorted.	5Y 5/2	5Y 3/2
11.2-13.5	Pebbly, sandy, silt, cohesive, very poorly sorted.	saa	
13.5-15.8	vcS and Gv up to 2 cm, unconsolidated, clean, poorly sorted.	saa	

Hole no. 22 N-File no.
T. 154 N., R. 74 W., sec. 21 ccc

Surface Elevation: 470.9 m
Total Depth Drilled: 3.7 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS with some clay, mod. cohesive, poorly sorted.	10YR 5/2	10YR 3/2
0.8-2.0	fS-mS, slightly cohesive, lams. 0.5-2 mm, mod. well sorted, lignite common, some silt or clay.	5Y 6/3	5Y 5/2
2.0-3.7	Diamicton.		

Hole no. 23 N-File no. 4217
T. 155 N., R. 75 W., sec. 24 ddd

Surface Elevation: 466.9 m
Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.6	fS-mS, well sorted, obscure lams. ~1 cm, unconsolidated.	10YR 5/1	10YR 4/1
1.6-2.8	cS to granules, cohesive, some silt and clay, mod. to poorly sorted, layers. 0.5-1.5 cm.	saa	
2.8-3.6	fS, silt, and clay, alternating layers dark and light, lams. 1-5 mm.	5Y 6/3	5Y 4/3
3.6-6.7	Diamicton.		

Hole no. 24 N-File no. 4218 — Surface Elevation: 471.2 m
T. 155 N., R. 74 W., sec. 4 ccd — Total Depth Drilled: 3.7 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	Silty loam, organic.	10YR 4/2	10YR 3/2
0.8-1.4	Silt and clay, lams. 0.5-3 mm, cohesive, well sorted.	5Y 6/2	5Y 4/2
1.4-2.1	mS-cS, some Gv to 75 mm, slightly to mod. cohesive, poorly sorted.	5Y 7/4	5Y 5/4
2.1-3.7	Diamicton.		

Hole no. 25 N-File no. 4219 — Surface Elevation: 460.5 m
T. 157 N., R. 74 W., sec. 13 aaa — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-4.4	vfS to fS with silt, mod. cohesive, well sorted, lams. ~1 cm, lignite present 2.0-4.4.	5Y 6/2	5Y 5/3
4.4-6.7	Clay, massive, hard, impermeable.	5Y 3/2	5Y 2.5/2
6.7-9.8	Diamicton.		

Hole no. 26 N-File no. 4113 — Surface Elevation: 446.8 m
T. 158 N., R. 74 W., sec. 32 — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	fS-mS, well sorted, slightly to mod. cohesive, lams. 1-2 mm.	5Y 7/4	5Y 5/4
2.0-4.4	vfS and silt, some clay, well sorted, lams. 1-4 mm, mod. cohesive.	5Y 6/1	5Y 4/1
4.4-6.7	Clay, massive, gypsum crystals, very cohesive.	5Y 4/2	5Y 3/3

Hole no. 27 N-File no. 4220 — Surface Elevation: 478.5 m
T. 153 N., R. 75 W., sec. 23 ddd — Total Depth Drilled: 3.7 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS, very well sorted, clean.	2.5Y 7/4	2.5Y 5/4
0.8-1.4	mS with scattered granules, poorly sorted, unconsolidated.	saa	
1.4-3.7	Diamicton, sandy in upper part.		

Hole no. 28 N-File no. 4221 — Surface Elevation: 471.8 m
T. 154 N., R. 75 W., sec. 29 aaa — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	fS-mS, very well sorted, unconsolidated, obscure lams.	10YR 6/4	10YR 4/3
2.1-6.7	Silty clay, gravelly, layered and massive, very poorly sorted; organic-rich layer (snails, gastropods, plant fragments) at 3.0 m.	5Y 7/3	5Y 6/4

Hole no. 29 N-File no. 4114 — Surface Elevation: 458.7 m
T. 155 N., R. 75 W., sec. 33 ddc — Total Depth Drilled: 12.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	mS, well sorted to very well sorted, some silt, obscure lams. 1-3 mm, slightly plastic.	10YR 6/3	10YR 5/3
2.1-3.4	Silty clay, generally massive, small pockets of sand 1 cm in diameter.	5Y 4/1	5Y 3/1
3.4-12.0	cS-vcS, mod. to poorly sorted, scattered larger clasts present up to 2 cm (mostly lignite), noncohesive.	5Y 6/2	5Y 5/1
12.0-12.8	Silty clay, well sorted, cohesive.	saa	

Hole no. 30 N-File no. 4222 — Surface Elevation: 465.4 m
T. 154 N., R. 76 W., sec. 29 aaa — Total Depth Drilled: 17.4 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	fS-mS, mod. cohesive, mod. to poorly sorted.	5Y 6/2	5Y 4/2
2.0-2.2	vcS and Gv up to 1 cm, poorly sorted, lignite clasts abundant.		
2.2-9.7	fS-mS, well sorted, clean, unconsolidated.	5Y 6/1	5Y 4/1
9.7-13.5	vfS-fS, mod. sorted, clean, lams. 0.7-2 mm; scattered granules and mod. cohesive at 12.8-13.5.	saa	
13.5-17.4	Diamicton.		

Hole no. 31 N-File no. 4223 — Surface Elevation: 458.7 m
T. 154 N., R. 76 W., sec. 31 aaa — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-1.8	mS, some silt, mod. cohesive, mod. sorted, mottled color; mS-cS at 1.3-1.8 m.	2.5Y 5/4	2.5Y 4/4
1.8-7.4	cS-vcS, poorly sorted, Gv clasts up to 2 cm, lignite common 5.0-7.4 m.	5Y 6/2	5Y 4/2
7.4-9.8	Diamicton.		

Hole no. 32 N-File no. 4115 — Surface Elevation: 460.2 m
T. 155 N., R. 76 W., sec. 15 bbb — Total Depth Drilled: 12.8 m

Depth (m)	Description	Color: Dry	Wet
0-0.8	fS-mS, mod. sorted, unconsolidated.	2.5Y 3/2	5Y 2.5/2
0.8-9.7	vfS-fS, very well sorted, lignite common, obscure lams. ~1 cm, clean.	5Y 6/3	5Y 5/4
9.7-12.8	Fine silt, some clay, well sorted, distinct lams. 0.2-1 mm, very cohesive.	5Y 6/2	5Y 3/2

Hole no. 33 N-File no. 4224 — Surface Elevation: 460.5 m
T. 155 N., R. 75 W., sec. 15 bbb — Total Depth Drilled: 5.2 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	fS, well to very well sorted, noncohesive to slightly cohesive.	5Y 6/3	5Y 4/3
2.1-5.2	Diamicton, layered from 2.1-3.7, massive 3.7-5.2.		

Hole no. 34 N-File no. 4116 — Surface Elevation: 450.2 m
T. 157 N., R. 74 W., sec. 21 bbb — Total Depth Drilled: 3.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.3	fS, very well sorted, obscure lams. ~0.5 mm.	5Y 7/2	5Y 5/3
1.3-3.7	Clay, some silt, alternate light and dark lams. 0.2-1.5 mm, very cohesive.	5Y 6/2	5Y 3/2

Hole no. 35 N-File no. — Surface Elevation: 453.5 m
T. 157 N., R. 78 W., sec. 33 bbb — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Gv, clasts up to 3 cm, poorly sorted, clean.	10YR 6/3	10YR 3/3
2.1-7.4	vfS-fS, well sorted, noncohesive, outsize lignite common; some mS at 2.3 m.	5Y 6/1	5Y 3/1
7.4-9.8	Diamicton.		

Hole no. 36 N-File no. — Surface Elevation: 448.6 m
T. 158 N., R. 79 W., sec. 35 ccc — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.8	fS, very well sorted, clean, lignite common.	5Y 7/3	5Y 4/3
2.8-3.6	vfS, very well sorted, obscure lams. ~1 cm, unconsolidated.	5Y 6/1	5Y 3/2
3.6-6.7	Clay, mostly finely laminated (1-2 mm), some massive, dispersed sand grains at 6.1 m.	5Y 5/1	5Y 3/2

Hole no. 37 N-File no. 4226 — Surface Elevation: 454.7 m
T. 157 N., R. 78 W., sec. 12 bbb — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.7	vfs-fS, well sorted except at 1.4-1.7 where sediments are poorly sorted, noncohesive.	2.5Y 6/2	2.5Y 4/2
1.7-3.6	Silty clay, lams. ~1 mm.	5Y 7/3	5Y 4/3
3.6-5.1	Diamicton.		
5.1-6.7	Clay with scattered cS more common upward, lams. ~3 mm, well consolidated.	5Y 7/1	5Y 2.5/2

Hole no. 38 N-File no. 4118 Surface Elevation: 446.2 m
T. 158 N., R. 77 W., sec. 24 ccc Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	fS, well to very well sorted, obscure lams. ~2 mm, unconsolidated, lignite common.	2.5Y 6/3	2.5Y 4/4
3.6-5.1	mS, mod. sorted except for outsize lignite clasts up to 2 cm, scarce clay clasts, unconsolidated.	5Y 7/1	5Y 4/1
5.1-6.7	Silt and clay, lams. 0.2-1 mm, alternate light and dark lams., cohesive; clay from 6.2-6.7.	5Y 6/1	5Y 3/1

Hole no. 39 N-File no. 4227 Surface Elevation: 449.3 m
T. 157 N., R. 77 W., sec. 11 ccc Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	Silt, well sorted, lams. 0.5-1.5 mm, cohesive, concentric weathering spheres; vfS and silt at 0.8-2.1 m.	2.5Y 6/4	2.5 4/3
3.6-6.7	Diamicton.		

Hole no. 40 N-File no. 4228 Surface Elevation: 451.1 m
T. 157 N., R. 76 W., sec. 16 aaa Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	fS-mS, mod. sorted, slightly cohesive.	2.5Y 5/2	2.5Y 4/3
2.1-3.6	cS-vcS, poorly sorted, lignite common, obscure lams. ~3 mm.	5Y 5/1	5Y 4/1
3.6-6.7	Diamicton except laminated silt from 4.5-5.4 m.		

Hole no. 41 N-File no. 4119 Surface Elevation: 451.4 m
T. 157 N., R. 75 W., sec. 10 baa Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	fS, very well sorted, mS at surface, unconsolidated.	2.5Y 6/6	2.5Y 4/3
2.1-3.6	mS, well sorted, lignite common, unconsolidated.	5Y 6/1	5y 4/1

Hole no. 41 Continued:

Depth (m)	Description	Color: Dry	Wet
3.6-6.7	Silt with clay at 5.2-6.7 m, lams, 0.2-1.0 mm, alternate light and dark layers.	5Y 5/1	5Y 2.5/1

Hole no. 42 N-File no. 4120 Surface Elevation: 447.4 m
T. 158 N., R. 75 W., sec. 20 ccc Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	fS-mS, well sorted above 2.1 m, poorly sorted below with scattered Gv up to 1.8 cm, unconsolidated.	2.5Y 6/3	2.5Y 4/3
3.6-7.4	cS-vcS with Gv up to 1.8 cm at 3.6 to 5.9 m, poorly sorted, clean.	5Y 6/1	5Y 4/1
7.4-9.8	Clay, lams. 0.1-1.0 mm, alternating light and dark lams., very cohesive.	5Y 7/2	5Y 4/1

Hole no. 43 N-File no. 4121 Surface Elevation: 444.7 m
T. 158 N., R. 77 W., sec. 10 bcc Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-4.4	fS, well sorted, some mS at 0.8 m, outsize lignite up to 1 cm at 3.8 cm, unconsolidated.	2.5Y 6/3	2.5Y 4/3
4.4-5.9	vfS, well sorted, lignite common, lams. 0.8-1.3 mm.	5Y 6/1	5Y 3/2
5.9-6.7	Coarse silt, lams. 0.5-1.5 mm, well sorted.	5Y 7/2	2.5Y 4/2
6.7-7.4	cS with outsize lignite up to 1.3 cm, unconsolidated, mod. sorted.	saa	
7.4-9.8	Clay, mottled in color, some silt at 8.4 m, alternating light and dark lams. 0.2-2.0 mm.	5Y 6/1	5Y 3/1

Hole no. 44 N-File no. 4122 Surface Elevation: 442.5 m
T. 158 N., R. 78 W., sec. 13 bbb Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Silty, sandy clay, poorly sorted, mottled, wavy lams. ~0.8 mm.	5Y 7/1	5Y 5/3

Hole no. 44 Continued:

Depth (m)	Description	Color: Dry	Wet
2.1-6.7	fS with silt, mod. sorted, lams. ~1 mm, cohesive, some lams. alternating light and dark.	5Y 6/3	5Y 4/3
6.7-9.8	Clay and silt, alternate light and dark lams. 0.1-0.5 mm.	5Y 6/2	5Y 4/2

Hole no. 45 N-File no. 4123 — Surface Elevation: 442.2 m
T. 159 N., R. 79 W., sec. 35 ddd — Total Depth Drilled: 3.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Silt, well sorted, cohesive, lams. ~1 mm.	5Y 7/3	5Y 4/3
2.1-3.7	Clay, fine laminations marked by small gypsum crystals, cohesive.	5Y 6/1	5Y 3/1

Hole no. 46 N-File no. 4229 — Surface Elevation: 444.4 m
T. 159 N., R. 79 W., sec. 16 bbb — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	fS, well sorted, lignite common, slightly cohesive; some mS at 0.8 m, some vfS at 2.0 m.	5Y 7/1	5Y 4/1
2.1-6.7	Silt and clay, lams. 0.5-1.2 mm, alternating light and dark lams., mostly clay from 3.6-6.7.	5Y 7/4	5Y 4/3
6.7-9.8	Diamicton.		

Hole no. 47 N-File no. 4124 — Surface Elevation: 438.6 m
T. 159 N., R. 78 W., sec. 19 ccc — Total Depth Drilled: 5.2 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Silt, some clay, mottled, lams. 0.2-0.7 mm, some vfS at 0.8, some gypsum crystal layers ~1 mm thick.	5Y 6/4	5Y 5/4
2.1-5.2	Clay, alternate dark and light lams. ~0.3 mm.	2.5Y 7/2	2.5Y 4/2

Hole no. 48 N-File no. 4125 — Surface Elevation: 441.9 m
T. 159 N., R. 77 W., sec. 5 cdc — Total Depth Drilled: 6.7 m

Depth (m)	Description	Color: Dry	Wet
0-4.4	fS, well sorted, noncohesive, some mS at 0.8 m, some vfS from 2.9-4.4.	5Y 6/3	5Y 4/3
4.4-6.7	Clay, mottled, lams. 0.5-1.0 mm, some silt and vfS from 5.9-6.7.	5Y 6/2	5Y 3/2

Hole no. 49 N-File no. 4230 — Surface Elevation: 448.0 m
T. 159 N., R. 76 W., sec. 17 aaa — Total Depth Drilled: 9.8 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	vfS, some silt, fine sand at surface, mod. cohesive, lams. ~1 mm, mod. sorting.	5Y 7/3	5Y 5/4
3.6-5.9	Clay, mostly massive, some obscure lams. 0.5-1.0 mm; small (1 cm) pods of sand.	5Y 6/1	5Y 3/2
5.9-9.8	Diamicton.		

Hole no. 50 N-File no. 4126 — Surface Elevation: 461.1 m
T. 155 N., R. 75 W., sec. 8 cbb — Total Depth Drilled: 17.4 m

Depth (m)	Description	Color: Dry	Wet
0-7.4	fS, well to very well sorted, obscure lams. 1-7 mm, lignite common, sand is vfS 6.0-7.1; color is 10YR 3/2 (dry) and 10YR 2/2 (wet) above 2.1 m.	5Y 7/2	5Y 5/3
7.4-11.2	mS-vcS, mod. to poorly sorted, outsize lignite (up to 2.5 cm) common.	5Y 5/1	5Y 3/1
11.2-12.0	fS, very well sorted, lams. ~1 mm.	5Y 6/2	5Y 4/2
12.0-17.4	Silt and clay, very well sorted, distinct lams. 0.1-2.0 mm.	5Y 7/2	5Y 4/3

Hole no. 51 N-File no. 4231 — Surface Elevation: 463.3 m
T. 154 N., R. 76 W., sec. 11 ddd — Total Depth Drilled: 10.1 m

Depth (m)	Description	Color: Dry	Wet
0-2.8	fS-mS, well sorted, slightly cohesive.	5Y 7/2	5Y 5/3
2.8-6.7	mS, well sorted except for outsize lignite up to 1 cm, noncohesive.	5Y 6/3	5Y 4/3

Hole no. 51 Continued:

Depth (m)	Description	Color: Dry	Wet
6.7-10.1	Diamicton.		

Hole no. 52 N-File no. 4232 — Surface Elevation: 466.6 m
T. 154 N., R. 77 W., sec. 20 aaa — Total Depth Drilled: 8.5 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	fS-mS, well sorted, unconsolidated, lignite common below 1,6 m.	10YR 4/3	10YR 3/3
3.6-4.4	mS, mod. sorted, some vcS and scattered granules.	10YR 6/4	10YR 3/3
4.4-5.9	vcS-Gv, clasts to 2 cm, lignite common, very lignite-rich layer at 4.9 m, poorly sorted, unconsolidated.	saa	
5.9-8.5	Diamicton.		

Hole no. 53 N-File no. 4233 — Surface Elevation: 449.6 m
T. 158 N., R. 79 W., sec. 22 aaa — Total Depth Drilled: 14.6 m

Depth (m)	Description	Color: Dry	Wet
0-1.3	fS, very well sorted, clean.	10YR 3/1	10YR 2/1
1.3-2.1	mS, obscure lams. 1-4 mm, lignite common, unconsolidated.	2.5Y 7/4	2.5Y 5/4
2.1-8.9	vfS, very well sorted, very obscure lams. ~1 mm, lignite common.	2.5Y 6/2	2.5Y 4/2
8.9-14.0	Clay, light and dark couplets, lams. 0.1-2 mm., cohesive.	5Y 4/2	5Y 3/2
14.0-14.6	Diamicton.		

Hole no. 54 N-File no. 4127 — Surface Elevation: 441.9 m
T. 159 N., R. 78 W., sec. 22 ddd — Total Depth Drilled: 8.5 m

Depth (m)	Description	Color: Dry	Wet
0-1.3	fS, very well sorted, clean, noncohesive.	2.5Y 3/2	2.5Y 2/2
1.3-8.2	vfS and silt, well sorted, lignite common, lams. 0.2-1.1 mm, mod. cohesive.	2.5Y 6/2	2.5Y 3/4
8.2-8.5	Clay, massive clay layers (1.2 cm) separated by lighter silty lam.	5Y 3/2	5Y 2.5/2

Hole no. 55 N-File no. 4128
T. 157 N., R. 75 W., sec. 26 bba

Surface Elevation: 451.4 m
Total Depth Drilled: 20.7 m

Depth (m)	Description	Color: Dry	Wet
0-1.3	mS, mod. to well sorted, unconsolidated excepted for silty cohesive layer at 0.8 m.	10YR 4/2	10YR 2/2
1.3-12.0	mS-cS, mod. to well sorted, outsize lignite common up to 3.0 cm, unconsolidated.	2.5Y 7/2	2.5Y 4/2
12.0-19.7	Silt, mostly fine-grained, partly massive and partly laminated with alternating light and dark lams. ~1 mm; pebble clay silt at 12.0-13.5 m; scattered sand grains towards bottom.	2.5Y 6/2	2.5Y 3/2
19.7-20.7	Diamicton.		

Hole no. 56 N-File no. 4234
T. 157 N., R. 78 W., sec. 36 ccb

Surface Elevation: 457.2 m
Total Depth Drilled: 17.7 m

Depth (m)	Description	Color: Dry	Wet
0-3.6	vfS and silt, well sorted, mod. cohesive, lams. 1-4 mm.	5Y 6/3	5Y 4/3
3.6-12.4	vfS-fS, obscure lams. 1-7 mm, outsize lignite up to 4 mm common, slightly to mod. cohesive.	5Y 5/2	5Y 3/2
12.4-17.7	Diamicton; fine, very poorly sorted Gv from 13.7-15.0 m.		

Hole no. 57 N-File no. 4129
T. 156 N., R. 77 W., sec. 9 ada

Surface Elevation: 457.8 m
Total Depth Drilled: 17.7 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Silt and vfS, mod. cohesive, mottled, mod. sorted.	5Y 6/3	5Y 4/4
2.1-12.0	fS, very well sorted, lignite common, noncohesive, outsize lignite up to 1 cm at 11.6-12.0 m; vfS from 3.6-5.1 m.	5Y 6/1	5Y 3/1
12.0-15.0	Fine silt, some parts laminated (0.1-1 mm thick) and some parts massive.	saa	
15.0-17.7	vfS-fS, very well sorted, massive; silt at 15.8-16.6.	saa	

Hole no. 58 N-File no. 4130 — Surface Elevation: 440.1 m
T. 158 N., R. 76 W., sec. 22 bba — Total Depth Drilled: 16.2 m

Depth (m)	Description	Color: Dry	Wet
0-1.3	fS-mS, mod. well sorted, unconsolidated.	5Y 5/3	5Y 3/2
1.3-2.8	mS, mod. to poorly sorted, lignite common, slightly cohesive.	2.5Y 5/2	2.5Y 3/2
2.8-7.4	mS-cS, mod. sorted, noncohesive to slightly cohesive, lignite common, outsize lignite up to 2.5 cm from 5.1-6.7.	5Y 6/3	5Y 4/4
7.4-8.2	vfS, well sorted, lignite common, slightly to mod. cohesive.	5Y 5/1	5Y 3/2
8.2-11.2	Gv, poorly sorted, lignite abundant (some outsize up to 7 cm), dirty, slightly to mod. cohesive.	saa	
11.2-16.2	Fine silt and clay, very cohesive and hard, massive.	5Y 5/1	5Y 3/2

Hole no. 59 N-File no. 4235 — Surface Elevation: 457.2 m
T. 157 N., R. 73 W., sec. 28 bab — Total Depth Drilled: 10.1 m

Depth (m)	Description	Color: Dry	Wet
0-2.0	Silt, clayey and sandy, well sorted, slightly to mod. cohesive, lams. 0.7-1.3 mm.	2.5Y 6/6	2.5Y 5/4
2.0-5.9	Clay, mottled, massive to finely laminated, rock particles up to 1.5 cm present but scarce.	2.5Y 6/2	2.5Y 4/2
5.9-9.7	Diamicton.		
9.7-10.1	Silty clay, alternating light and dark lams. 0.2-1.4 mm, cohesive.	5Y 6/2	5Y 4/2

Hole no. 60 N-File no. 4131 — Surface Elevation: 455.7 m
T. 153 N., R. 72 W., sec. 19 ddd — Total Depth Drilled: 19.2 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	Silt to vfS, some clay, mod. to very well sorted, slightly to mod. cohesive.	5Y 7/3	5Y 5/2
2.1-8.2	fS, very well sorted, lignite common, noncohesive to slightly cohesive.	5Y 5/2	5Y 4/1
8.2-8.9	Clay, lams. 1-2 mm, cohesive.	10YR 3/2	10YR 2/2

Hole no. 60 Continued:

Depth (m)	Description	Color: Dry	Wet
8.9-10.5	Silt, mod. to well sorted, cohesive.	5Y 5/2	5Y 4/1
10.5-12.8	Gv, poorly sorted, lignite common, clasts up to 3 cm.	10YR 4/2	10YR 3/2
12.8-15.0	fS-mS, very well sorted, lignite common, clean, vfS from 12.8-13.2.	saa	
15.0-18.1	Gv, coarser at bottom with clasts up to 15 cm, lignite common in sand fraction.	saa	
18.1-19.2	Silt and clay, hard, very cohesive, well sorted.	5Y 6/1	5Y 4/2

Hole no. 61 N-File no. 4236
T. 152 N., R. 73 W., sec. 15 bda

Surface Elevation: 470.0 m
Total Depth Drilled: 13.1 m

Depth (m)	Description	Color: Dry	Wet
0-2.1	mS, well sorted, unconsolidated.	2.5Y 6/2	2.5Y 5/2
2.1-4.0	Organic muck in fS, strong odor.	5Y 2.5/1	5Y 2.5/1
4.0-4.4	Clay, silty, lams. 1-3 mm, cohesive.	5Y 6/1	5Y 4/2
4.4-12.0	Diamicton.		
12.0-13.1	mS, very well sorted, mod. cohesive.	saa	

APPENDIX B

Table 3: Phi values of sediment sample textural statistics.

HOLE	SAMPLE	DEPTH (m)	COARSEST 1 PERCENT	MEDIAN	MEAN	SORTING	SKEWNESS
2	2-02.5	0.8	0.93	2.27	2.24	0.68	-0.18
2	2-07.5	2.3	0.54	2.01	1.98	0.63	-0.09
2	2-10.0	3.0	-3.29	-0.06	-0.09	1.65	-0.02
4	4-02.5	0.8	0.10	1.33	1.33	0.51	0.05
4	4-07.5	2.3	0.14	1.16	1.17	0.46	0.31
4	4-12.0	3.7	-4.08	0.77	0.49	1.23	-2.50
5	5-02.5	0.8	-3.84	0.54	-0.15	1.73	-1.01
5	5-07.5	2.3	-4.34	-0.32	-0.83	2.00	-0.33
5	5-12.5	3.8	-3.81	-0.04	-0.64	1.60	-0.55
5	5-17.5	5.4	-1.82	1.20	1.03	0.83	-1.37
5	5-22.5	6.9	0.89	2.66	2.63	0.51	-1.02
5	5-27.5	8.4	0.39	2.87	2.77	0.67	-1.39
5	5-32.5	9.9	2.14	3.11	3.11	0.46	0.06
5	5-40.0	12.2	1.34	4.25	4.29	0.89	-0.52
6	6-02.5	0.8	0.37	1.88	1.85	0.48	-0.84
6	6-07.5	2.3	0.22	2.22	2.12	0.61	-0.98
6	6-10.0	3.0	1.45	2.56	2.55	0.40	-0.29
6	6-12.5	3.8	0.65	1.85	1.83	0.47	-0.15
7	7-22.5	6.9	0.95	1.80	1.83	0.47	0.42
7	7-27.5	8.4	0.23	1.38	1.45	0.61	0.30
7	7-32.5	9.9	-4.09	-0.06	-0.71	1.97	-0.30
8	8-02.5	0.8	0.92	2.26	2.23	0.51	-0.48
8	8-07.5	2.3	1.46	3.16	3.13	0.79	-0.06
8	8-12.5	3.8	0.92	1.93	1.96	0.47	0.32
8	8-17.5	5.4	1.12	1.78	1.78	0.30	0.14
8	8-25.0	7.6	1.43	3.82	3.66	0.78	-1.23
8	8-30.0	9.1	1.80	2.91	2.92	0.45	0.04
9	9-02.5	0.8	1.34	2.30	2.34	0.47	0.28
9	9-07.5	2.3	0.93	1.81	1.79	0.46	0.15
9	9-10.0	3.0	0.22	1.43	1.43	0.59	0.10
9	9-17.5	5.4	1.10	2.26	2.23	0.39	-0.50
9	9-22.5	6.9	1.62	2.73	2.73	0.39	-0.12
9	9-27.5	8.4	1.44	2.63	2.63	0.39	-0.40
10	10-00.0	0.0	0.43	2.30	2.31	0.68	-0.24
10	10-05.0	1.5	1.45	3.11	3.13	0.51	-0.30
11	11-02.5	0.8	0.69	1.48	1.52	0.37	0.73
11	11-07.5	2.3	0.43	1.57	1.54	0.39	-0.59
11	11-10.0	3.0	-1.74	1.33	1.13	0.82	-1.46

HOLE	SAMPLE	DEPTH (m)	COARSEST 1 PERCENT	MEDIAN	MEAN	SORTING	SKEWNESS
12	12-02.5	0.8	1.62	2.42	2.51	0.50	1.06
12	12-07.5	2.3	1.21	2.59	2.56	0.41	-0.76
12	12-12.5	3.8	1.73	2.52	2.51	0.35	0.06
12	12-17.5	5.4	2.26	3.06	3.06	0.36	-0.06
13	13-12.5	3.8	2.53	4.03	4.04	0.45	-0.86
13	13-17.5	5.4	2.53	3.64	3.65	0.49	-0.04
13	13-22.5	6.9	2.60	3.80	3.83	0.49	-0.18
13	13-27.5	8.4	2.39	2.94	2.94	0.26	0.07
13	13-32.5	9.9	2.32	3.14	3.17	0.43	0.32
13	13-37.5	11.4	2.36	3.33	3.33	0.32	-0.44
13	13-42.5	13.0	1.85	3.32	3.27	0.47	-0.71
13	13-50.0	15.2	2.59	3.92	3.97	0.54	0.03
13	13-57.5	17.5	2.13	2.88	2.93	0.42	0.49
13	13-65.0	19.8	2.30	3.40	3.44	0.49	0.16
13	13-70.0	21.3	2.11	3.46	3.47	0.59	-0.03
13	13-77.5	23.6	2.34	3.22	3.25	0.47	0.17
13	13-82.5	25.1	2.19	3.24	3.24	0.50	0.18
14	14-02.5	0.8	0.47	2.48	2.29	0.81	-0.41
14	14-07.5	2.3	0.28	1.42	1.40	0.52	-0.06
14	14-12.5	3.8	-3.85	1.40	0.69	1.81	-1.60
18	18-17.5	5.4	0.14	1.51	1.46	0.53	-0.29
30	30-02.5	0.8	0.40	1.49	1.63	0.69	0.51
30	30-07.5	2.3	1.24	1.99	2.04	0.38	0.65
30	30-12.5	3.8	1.00	2.09	2.10	0.43	-0.05
30	30-17.5	5.4	0.99	1.98	1.98	0.41	-0.11
30	30-22.5	6.9	0.84	1.75	1.75	0.39	0.07
30	30-27.5	8.4	0.79	1.85	1.83	0.45	-0.13
30	30-32.5	9.9	1.33	3.12	2.92	0.81	-0.21
30	30-37.5	11.4	2.26	3.05	3.05	0.36	-0.09
30	30-42.5	13.0	-2.57	0.29	0.21	1.70	0.03
31	31-02.5	0.8	0.69	1.56	1.55	0.38	0.23
31	31-07.5	2.3	0.23	1.13	1.12	0.46	0.00
31	31-12.5	3.8	0.00	0.98	1.06	0.54	0.20
31	31-17.5	5.4	0.24	1.06	1.14	0.48	0.58
32	32-02.5	0.8	0.94	2.41	2.33	0.59	-0.59
32	32-07.5	2.3	1.26	2.46	2.46	0.37	-0.42
32	32-12.5	3.8	1.69	2.70	2.72	0.40	-0.01
32	32-17.5	5.4	1.49	2.63	2.62	0.42	0.00
32	32-22.5	6.9	1.21	1.99	2.20	0.61	0.44
32	32-27.5	8.4	1.27	1.96	1.98	0.30	0.53
32	32-37.5	11.4	3.15	4.59	4.66	0.79	0.13

HOLE	SAMPLE	DEPTH (m)	COARSEST 1 PERCENT	MEDIAN	MEAN	SORTING	SKEWNESS
33	33-02.5	0.8	1.15	2.89	2.82	0.69	-0.31
33	33-05.0	1.5	1.24	2.81	2.75	0.61	-0.15
35	35-02.5	0.8	-3.55	-0.02	-0.16	1.49	-0.35
35	35-07.5	2.3	0.63	1.89	2.01	0.67	0.28
35	35-12.0	3.7	0.99	3.03	2.86	0.78	-0.35
35	35-17.5	5.4	1.31	3.65	3.55	0.77	-1.02
35	35-22.5	6.9	1.79	4.66	4.66	0.96	-0.65
36	36-02.5	0.8	1.74	2.53	2.57	0.41	1.53
36	36-10.0	3.0	2.46	3.47	3.49	0.38	-0.21
37	37-02.5	0.8	1.66	2.93	2.87	0.47	-0.45
38	38-02.5	0.8	1.69	2.47	2.49	0.34	0.17
38	38-07.5	2.3	1.49	2.43	2.42	0.34	-0.42
38	38-12.5	3.8	0.89	1.71	1.78	0.43	0.61
38	38-17.5	5.4	1.54	4.54	4.45	0.74	-1.36
39	39-02.5	0.8	2.78	3.77	3.81	0.41	-0.14
40	40-02.5	0.8	1.24	2.42	2.44	0.56	0.02
40	40-07.5	2.3	0.47	1.40	1.49	0.61	0.69
40	40-10.0	3.0	0.29	1.31	1.40	0.62	0.47
41	41-07.5	2.3	1.06	2.10	2.08	0.40	-0.28
42	42-02.5	0.8	1.19	1.97	1.99	0.41	0.58
42	42-07.5	2.3	0.85	1.62	1.64	0.41	0.13
42	42-12.5	3.8	-2.78	0.18	0.10	1.29	-0.32
42	42-17.5	5.4	-0.05	0.49	0.56	0.36	1.15
42	42-22.5	6.9	-0.52	0.33	0.42	0.52	0.63
43	43-02.5	0.8	1.86	2.73	2.75	0.40	0.45
43	43-07.5	2.3	1.82	2.68	2.68	0.37	0.15
43	43-12.5	3.8	1.50	2.96	2.91	0.60	0.08
43	43-17.5	5.4	3.26	4.31	4.41	0.66	0.41
43	43-22.5	6.9	0.50	1.44	1.58	0.58	1.28
44	44-07.5	2.3	2.00	3.71	3.77	0.61	-0.27
44	44-12.5	3.8	2.71	3.94	4.08	0.77	0.55
46	46-02.5	0.8	1.37	2.52	2.50	0.51	0.21
49	49-00.0	0.0	1.77	2.79	2.78	0.40	0.03
49	49-10.0	3.0	2.38	4.25	4.37	0.86	0.16

HOLE	SAMPLE	DEPTH (m)	COARSEST 1 PERCENT	MEDIAN	MEAN	SORTING	SKEWNESS
50	50-02.5	0.8	1.55	2.69	2.68	0.50	-0.11
50	50-12.5	3.8	1.90	2.76	2.81	0.45	0.62
50	50-17.5	5.4	1.71	2.70	2.67	0.41	0.18
50	50-22.5	6.9	2.44	3.29	3.32	0.35	0.76
50	50-30.0	9.1	0.94	1.75	1.77	0.40	0.51
50	50-35.0	10.7	0.85	1.62	1.64	0.41	0.13
50	50-37.5	11.4	1.40	3.15	3.12	0.46	-1.26
51	51-02.5	0.8	0.83	1.87	1.88	0.52	0.75
51	51-07.5	2.3	0.44	1.46	1.50	0.52	1.15
51	51-12.5	3.8	0.43	1.44	1.44	0.37	0.23
51	51-17.5	5.4	0.79	1.64	1.68	0.41	0.46
52	52-02.5	0.8	0.56	1.75	1.74	0.47	-0.21
52	52-07.5	2.3	0.85	1.85	1.83	0.38	-0.14
52	52-12.5	3.8	0.40	1.81	1.72	0.53	-0.67
52	52-17.5	5.4	-3.35	0.60	0.09	1.57	-0.83
53	53-02.5	0.8	1.64	2.49	2.54	0.40	0.36
53	53-07.5	2.3	2.14	3.10	3.11	0.39	-0.02
53	53-12.5	3.8	2.37	3.58	3.63	0.54	0.31
53	53-17.5	5.4	2.66	3.41	3.43	0.34	0.13
53	53-22.5	6.9	2.24	3.05	3.05	0.34	0.06
54	54-02.5	0.8	2.25	3.30	3.29	0.40	-0.39
54	54-07.5	2.3	1.95	3.50	3.57	0.68	0.48
54	54-12.5	3.8	2.51	3.70	3.72	0.52	-0.05
54	54-22.5	6.9	3.01	4.35	4.46	0.76	0.32
55	55-00.0	0.0	0.18	1.53	1.52	0.63	0.07
55	55-10.0	3.0	0.39	1.17	1.20	0.44	0.70
55	55-15.0	4.6	0.96	1.55	1.55	0.28	0.21
55	55-20.0	6.1	0.95	1.60	1.62	0.35	0.34
55	55-25.0	7.6	0.90	1.62	1.66	0.40	1.02
55	55-30.0	9.1	0.93	1.63	1.66	0.40	0.53
55	55-35.0	10.7	0.75	2.10	2.03	0.45	-0.77
56	56-02.5	0.8	2.74	4.36	4.52	0.86	0.37
56	56-12.5	3.8	2.89	4.21	4.37	0.73	0.49
56	56-17.5	5.4	2.95	4.05	4.09	0.54	0.14
56	56-22.5	6.9	2.10	2.74	2.76	0.32	0.40
56	56-27.5	8.4	2.02	2.75	2.78	0.37	0.40
56	56-32.5	9.9	2.04	3.14	3.09	0.33	-0.92
56	56-37.5	11.4	2.01	3.75	3.87	0.77	0.34

HOLE	SAMPLE	DEPTH (m)	COARSEST 1 PERCENT	MEDIAN	MEAN	SORTING	SKEWNESS
57	57-02.5	0.8	2.94	4.60	4.67	0.81	0.07
57	57-07.5	2.3	2.00	2.60	2.64	0.37	0.89
57	57-12.5	3.8	2.60	3.53	3.65	0.64	0.65
57	57-17.5	5.4	3.47	4.80	4.88	0.75	0.10
57	57-22.5	6.9	1.74	2.51	2.53	0.32	0.30
57	57-27.5	8.4	1.51	2.37	2.40	0.43	0.35
57	57-32.5	9.9	1.68	2.26	2.30	0.31	0.61
57	57-37.5	11.4	1.48	2.60	2.60	0.48	0.06
57	57-50.0	15.2	1.69	3.35	3.35	0.67	-0.06
57	57-57.5	17.5	2.60	4.21	4.23	0.63	-0.16
58	58-02.5	0.8	1.06	2.14	2.11	0.43	-0.25
58	58-07.5	2.3	0.46	1.97	1.78	0.66	0.01
58	58-12.5	3.8	0.35	1.64	1.67	0.57	0.12
58	58-15.0	4.6	0.94	1.72	1.75	0.40	0.15
58	58-20.0	6.1	1.20	1.84	1.90	0.37	1.09
58	58-27.5	8.4	1.01	3.15	3.08	0.56	-1.54
58	58-30.0	9.1	-2.48	0.66	0.67	0.94	-0.66
58	58-35.0	10.7	-4.85	0.22	-0.72	2.26	-0.56

APPENDIX C

Table 4: Percentage of sediments within one-quarter phi coarser than indicated phi size for all samples analyzed. Sample labels are at the top of the columns; the first number in the label is the hole number and the second number, after the hyphen, is the depth in feet at which the sample was collected from.

PHI SIZE	2-2.5	2-7.5	2-10.0	4-2.5	4-7.5	4-12.0	5-2.5	5-7.5	5-12.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	6.538	-
-4.00	-	-	-	-	-	4.116	-	0.000	-
-3.75	-	-	-	-	-	0.000	5.954	7.051	2.967
-3.50	-	-	-	-	-	0.000	5.349	0.871	0.000
-3.25	-	-	1.990	-	-	0.810	0.000	0.000	3.188
-3.00	-	-	1.414	-	-	0.515	2.442	4.895	5.479
-2.75	-	-	3.155	-	-	0.000	1.434	4.560	4.447
-2.50	-	-	4.285	-	-	0.124	0.473	4.301	3.599
-2.25	-	-	2.615	-	-	0.029	1.667	1.758	2.795
-2.00	-	-	2.189	-	-	0.067	1.062	2.133	3.440
-1.75	-	-	1.826	-	-	0.048	1.140	2.548	2.617
-1.50	-	-	2.601	-	-	0.086	1.333	2.715	2.666
-1.25	-	-	3.659	-	-	0.114	1.589	2.104	2.918
-1.00	-	-	4.512	-	-	0.162	1.760	2.865	3.237
-0.75	-	-	3.958	-	-	1.496	1.551	1.920	2.402
-0.50	-	-	3.624	-	-	1.648	2.419	2.992	2.825
-0.25	-	-	8.406	-	-	2.601	3.954	3.845	2.924
0.00	-	-	7.582	0.709	0.266	4.011	3.512	5.125	5.362
0.25	-	-	7.966	0.887	2.128	6.622	4.613	4.376	6.726
0.50	-	0.773	9.230	3.014	3.989	12.292	7.691	6.302	8.777
0.75	-	2.320	2.800	7.447	11.170	13.473	12.962	5.552	14.330
1.00	3.678	4.639	2.473	13.475	15.426	17.961	15.590	5.656	9.944
1.25	5.517	5.412	2.970	17.731	26.862	15.846	10.319	5.875	6.240
1.50	8.276	9.021	3.624	21.631	21.277	10.405	5.272	5.875	1.560
1.75	7.126	12.629	2.146	15.248	9.840	4.021	3.078	4.485	0.584
2.00	9.655	14.433	3.297	10.993	4.521	1.420	1.977	2.560	0.584
2.25	14.483	16.237	4.121	5.319	1.862	1.658	1.101	1.603	0.197
2.50	13.793	15.722	2.636	2.128	1.862	0.476	0.659	0.853	0.197
2.75	12.414	8.763	2.146	1.064	0.798	-	0.659	0.427	-
3.00	9.425	4.897	2.800	0.355	-	-	0.442	0.213	-
3.25	9.655	2.577	1.151	-	-	-	-	-	-
3.50	5.517	2.062	0.824	-	-	-	-	-	-
3.75	0.460	0.515	-	-	-	-	-	-	-
4.00	-	-	-	-	-	-	-	-	-
4.25	-	-	-	-	-	-	-	-	-
4.50	-	-	-	-	-	-	-	-	-
4.75	-	-	-	-	-	-	-	-	-
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	5-17.5	5-22.5	5-27.5	5-32.5	5-40.0	6-2.5	6-7.5	6-10.0	6-12.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	0.509	-	-	-	-	-	-	-	-
-1.75	0.788	-	-	-	-	-	-	-	-
-1.50	0.509	-	-	-	-	-	-	-	-
-1.25	0.788	-	-	-	-	-	-	-	-
-1.00	1.326	-	-	-	-	-	-	-	-
-0.75	1.105	-	-	-	-	-	-	-	-
-0.50	1.547	-	-	-	-	-	-	-	-
-0.25	1.778	-	-	-	-	-	-	-	-
0.00	2.441	-	-	-	-	-	0.298	-	-
0.25	2.220	-	0.708	-	-	0.435	0.893	-	-
0.50	6.218	-	0.590	-	-	1.739	0.893	-	0.378
0.75	7.323	0.621	1.061	-	-	1.957	2.083	-	1.511
1.00	9.985	0.828	0.943	-	0.602	2.174	2.381	0.440	1.889
1.25	16.644	1.242	1.179	-	0.301	2.826	2.976	0.220	5.793
1.50	19.306	1.656	1.415	-	0.301	5.652	3.869	0.440	13.602
1.75	12.868	1.242	1.415	0.084	0.301	19.348	7.738	2.198	18.136
2.00	9.101	2.692	1.887	0.253	0.151	30.652	13.988	3.956	22.670
2.25	3.988	6.832	4.717	1.910	0.753	19.348	16.964	10.549	18.640
2.50	1.336	18.634	9.906	7.303	0.602	8.261	20.238	23.956	10.579
2.75	0.221	25.466	16.745	11.798	0.602	6.087	16.369	30.769	4.030
3.00	-	20.497	19.104	19.663	1.506	1.522	8.333	18.462	2.519
3.25	-	11.801	20.047	20.787	3.614	-	2.381	5.275	0.252
3.50	-	6.004	11.557	19.101	5.723	-	0.595	1.978	-
3.75	-	2.484	5.660	10.393	9.639	-	-	1.319	-
4.00	-	-	2.830	5.056	12.651	-	-	0.440	-
4.25	-	-	0.236	3.652	13.554	-	-	-	-
4.50	-	-	-	-	11.747	-	-	-	-
4.75	-	-	-	-	7.831	-	-	-	-
5.00	-	-	-	-	6.928	-	-	-	-
5.25	-	-	-	-	6.928	-	-	-	-
5.50	-	-	-	-	6.627	-	-	-	-
5.75	-	-	-	-	6.024	-	-	-	-
6.00	-	-	-	-	2.410	-	-	-	-
6.25	-	-	-	-	1.205	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	7-22.5	7-27.5	7-32.5	8-2.5	8-7.5	8-12.5	8-17.5	8-25.0	8-30.0
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	6.163	-	-	-	-	-	-
-3.75	-	-	3.790	-	-	-	-	-	-
-3.50	-	-	0.000	-	-	-	-	-	-
-3.25	-	-	4.338	-	-	-	-	-	-
-3.00	-	-	2.397	-	-	-	-	-	-
-2.75	-	-	6.742	-	-	-	-	-	-
-2.50	-	-	3.827	-	-	-	-	-	-
-2.25	-	-	1.836	-	-	-	-	-	-
-2.00	-	-	3.679	-	-	-	-	-	-
-1.75	-	-	2.903	-	-	-	-	-	-
-1.50	-	-	1.559	-	-	-	-	-	-
-1.25	-	-	1.159	-	-	-	-	-	-
-1.00	-	-	1.393	-	-	-	-	-	-
-0.75	-	-	1.738	-	-	-	-	-	-
-0.50	-	-	2.785	-	-	-	-	-	-
-0.25	-	-	2.785	-	-	-	-	-	-
0.00	-	-	3.827	-	-	-	-	-	-
0.25	-	1.476	6.267	-	-	-	-	-	-
0.50	-	4.428	7.660	-	-	-	-	-	-
0.75	0.212	5.535	7.833	0.426	-	0.278	-	0.110	-
1.00	1.274	8.118	7.488	1.064	0.050	1.389	0.213	0.000	-
1.25	8.280	20.295	4.523	2.340	0.449	3.333	3.617	0.256	-
1.50	15.074	19.188	4.523	5.532	0.623	9.444	8.936	1.099	-
1.75	20.594	15.498	2.607	8.723	2.868	19.167	33.617	1.465	0.870
2.00	22.930	6.273	2.434	12.128	4.489	23.611	31.702	2.930	0.870
2.25	14.013	4.797	2.262	18.723	6.733	19.722	15.957	3.663	3.478
2.50	8.705	6.273	2.089	18.085	7.980	11.389	4.468	2.930	12.464
2.75	4.671	7.011	0.869	15.957	8.479	5.278	1.489	1.832	17.971
3.00	2.972	1.107	0.524	14.043	9.476	3.611	-	1.465	22.319
3.25	1.274	-	-	2.979	13.716	2.500	-	2.930	20.580
3.50	-	-	-	-	14.464	0.278	-	7.326	11.304
3.75	-	-	-	-	8.978	-	-	17.949	6.377
4.00	-	-	-	-	6.733	-	-	20.879	3.188
4.25	-	-	-	-	5.985	-	-	15.751	0.580
4.50	-	-	-	-	4.988	-	-	10.623	-
4.75	-	-	-	-	3.242	-	-	7.692	-
5.00	-	-	-	-	0.748	-	-	1.099	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	9-2.5	9-7.5	9-10.0	9-17.5	9-22.5	9-27.5	10-10.0	10-5.0	11-2.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	1.579	-	-	-	0.601	-	-
0.50	-	-	3.158	-	-	-	0.601	-	0.340
0.75	-	-	8.947	-	-	-	0.601	-	1.020
1.00	0.332	3.500	12.368	0.624	-	0.438	1.502	0.192	3.175
1.25	0.332	10.250	13.158	1.247	0.294	0.328	2.703	0.383	12.472
1.50	1.329	14.250	15.000	2.287	0.294	0.328	3.604	0.575	36.054
1.75	6.645	16.250	13.421	5.405	1.176	0.438	8.408	0.383	29.705
2.00	14.618	23.250	16.579	14.345	1.471	2.845	13.213	0.575	6.122
2.25	23.256	19.250	7.895	24.532	4.706	7.659	15.616	1.341	6.803
2.50	18.771	7.500	4.737	29.938	15.588	22.538	15.616	3.065	2.494
2.75	15.449	3.000	1.842	14.553	28.824	29.540	11.411	10.728	1.134
3.00	10.631	2.250	0.789	5.405	27.647	23.195	9.910	23.180	0.680
3.25	4.983	0.500	0.526	1.663	14.706	7.659	7.207	22.605	-
3.50	2.658	-	-	-	2.941	3.063	4.505	17.625	-
3.75	0.664	-	-	-	0.882	1.751	4.204	9.579	-
4.00	0.332	-	-	-	0.882	0.219	0.300	4.789	-
4.25	-	-	-	-	0.588	-	-	2.682	-
4.50	-	-	-	-	-	-	-	1.916	-
4.75	-	-	-	-	-	-	-	0.383	-
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	11-7.5	11-10.0	12-2.5	12-7.5	12-12.5	12-17.5	13-12.5	13-17.5	13-22.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	0.698	-	-	-	-	-	-	-
-1.75	-	0.291	-	-	-	-	-	-	-
-1.50	-	0.611	-	-	-	-	-	-	-
-1.25	-	0.495	-	-	-	-	-	-	-
-1.00	-	0.893	-	-	-	-	-	-	-
-0.75	-	1.329	-	-	-	-	-	-	-
-0.50	-	1.504	-	-	-	-	-	-	-
-0.25	-	1.669	-	-	-	-	-	-	-
0.00	-	2.503	-	-	-	-	-	-	-
0.25	0.240	2.338	-	-	-	-	-	-	-
0.50	1.442	5.171	-	-	-	-	-	-	-
0.75	2.404	5.830	-	-	-	-	-	-	-
1.00	5.048	6.005	-	0.551	-	-	-	-	-
1.25	8.173	14.503	-	0.551	-	0.118	-	-	-
1.50	23.077	18.170	0.337	0.551	-	0.118	-	-	-
1.75	31.971	19.499	2.357	1.102	1.481	0.118	0.108	0.229	-
2.00	18.990	12.165	8.418	5.234	4.938	0.118	0.269	0.229	0.571
2.25	6.250	4.162	20.202	11.295	14.321	0.471	0.269	0.229	0.143
2.50	2.163	1.329	27.273	22.039	27.161	2.824	0.323	0.229	0.143
2.75	0.240	0.834	17.508	24.242	30.123	11.529	0.376	0.917	0.429
3.00	-	-	10.101	19.835	14.321	29.647	0.806	5.505	1.571
3.25	-	-	5.724	13.223	5.185	28.941	1.075	12.385	5.429
3.50	-	-	3.704	1.377	2.469	15.059	2.688	18.807	15.429
3.75	-	-	1.010	-	-	8.471	15.591	21.101	22.571
4.00	-	-	1.347	-	-	1.412	26.344	18.807	18.857
4.25	-	-	1.684	-	-	1.176	20.430	10.550	14.571
4.50	-	-	0.337	-	-	-	16.129	6.422	10.857
4.75	-	-	-	-	-	-	11.290	2.752	5.714
5.00	-	-	-	-	-	-	4.301	1.835	3.714
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	13-27.5	13-32.5	13-37.5	13-42.5	13-50.0	13-57.5	13-65.0	13-70.0	13-77.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	-	-	-
0.50	-	-	-	-	-	-	-	-	-
0.75	-	-	-	-	-	-	-	-	-
1.00	-	-	-	-	-	-	-	-	-
1.25	-	-	-	-	-	-	-	-	-
1.50	-	-	-	-	-	-	0.309	-	-
1.75	-	-	-	0.690	-	-	0.309	0.341	-
2.00	-	-	0.341	1.034	-	0.313	0.154	0.341	0.270
2.25	0.262	0.539	0.390	2.069	0.552	2.188	0.154	0.909	0.809
2.50	2.362	3.504	0.732	3.448	0.276	10.938	0.463	3.182	3.504
2.75	22.047	12.669	1.463	5.862	0.552	25.000	2.932	5.682	8.895
3.00	34.383	21.024	9.268	8.276	0.829	22.500	12.346	10.682	12.938
3.25	29.659	21.294	25.854	20.345	4.972	17.188	16.358	14.091	27.493
3.50	10.236	19.946	36.585	29.655	8.840	11.875	27.778	17.273	19.137
3.75	1.050	11.321	16.585	16.207	19.613	5.938	18.827	17.273	10.782
4.00	-	5.660	7.317	7.931	21.271	2.813	8.642	11.591	8.086
4.25	-	3.235	1.463	3.793	13.812	1.250	4.630	7.500	6.199
4.50	-	0.809	-	0.690	12.155	-	4.012	6.136	1.887
4.75	-	-	-	-	8.011	-	2.160	4.545	-
5.00	-	-	-	-	5.525	-	0.926	0.455	-
5.25	-	-	-	-	3.039	-	-	-	-
5.50	-	-	-	-	0.552	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	13-82.5	14-2.5	14-7.5	14-12.5	18-17.5	30-2.5	30-7.5	30-12.5	30-17.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	7.701	-	-	-	-	-
-3.50	-	-	-	0.000	-	-	-	-	-
-3.25	-	-	-	2.640	-	-	-	-	-
-3.00	-	-	-	0.000	-	-	-	-	-
-2.75	-	-	-	0.000	-	-	-	-	-
-2.50	-	-	-	1.447	-	-	-	-	-
-2.25	-	-	-	1.616	-	-	-	-	-
-2.00	-	-	-	0.000	-	-	-	-	-
-1.75	-	-	-	0.626	-	-	-	-	-
-1.50	-	-	-	0.508	-	-	-	-	-
-1.25	-	-	-	0.305	-	-	-	-	-
-1.00	-	-	-	0.533	-	-	-	-	-
-0.75	-	-	-	0.626	-	-	-	-	-
-0.50	-	-	-	0.423	-	-	-	-	-
-0.25	-	-	-	0.838	-	-	-	-	-
0.00	-	-	-	1.464	0.292	-	-	-	-
0.25	-	0.210	0.733	2.522	2.047	0.368	-	-	-
0.50	-	1.050	4.890	3.986	3.801	1.471	-	-	-
0.75	-	2.311	7.090	4.832	3.801	4.412	-	-	-
1.00	-	3.361	8.313	5.044	6.725	11.581	0.217	0.984	1.099
1.25	-	6.303	15.403	8.606	10.526	17.463	0.868	2.295	3.846
1.50	-	6.933	20.049	10.713	21.345	15.441	3.688	3.934	6.593
1.75	-	7.563	18.093	17.221	28.070	11.213	11.931	10.164	14.835
2.00	-	7.143	14.425	16.586	10.819	9.927	34.924	21.967	25.824
2.25	2.692	7.143	6.112	7.142	7.602	7.353	27.332	27.869	25.000
2.50	4.231	8.824	3.178	2.522	1.754	6.802	9.328	17.377	12.363
2.75	8.077	14.286	1.222	1.261	2.339	7.169	5.857	7.213	7.692
3.00	15.000	16.597	0.489	0.838	0.877	4.228	3.905	6.230	2.473
3.25	21.154	7.983	-	-	-	0.919	1.735	1.967	0.275
3.50	21.923	6.933	-	-	-	1.287	0.217	-	-
3.75	12.692	2.311	-	-	-	0.368	-	-	-
4.00	7.308	1.050	-	-	-	-	-	-	-
4.25	3.462	-	-	-	-	-	-	-	-
4.50	2.308	-	-	-	-	-	-	-	-
4.75	1.154	-	-	-	-	-	-	-	-
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	30-22.5	30-27.5	30-32.5	30-37.5	33-2.5	33-5.0	35-2.5	35-7.5	35-12.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	2.311	-	-
-3.25	-	-	-	-	-	-	2.040	-	-
-3.00	-	-	-	-	-	-	3.401	-	-
-2.75	-	-	-	-	-	-	0.572	-	-
-2.50	-	-	-	-	-	-	0.471	-	-
-2.25	-	-	-	-	-	-	1.561	-	-
-2.00	-	-	-	-	-	-	2.125	-	-
-1.75	-	-	-	-	-	-	1.986	-	-
-1.50	-	-	-	-	-	-	2.226	-	-
-1.25	-	-	-	-	-	-	2.543	-	-
-1.00	-	-	-	-	-	-	3.509	-	-
-0.75	-	-	-	-	-	-	4.575	-	-
-0.50	-	-	-	-	-	-	5.766	-	-
-0.25	-	-	-	-	-	-	6.098	-	-
0.00	-	-	-	-	-	-	11.693	-	-
0.25	-	-	-	-	-	-	12.203	-	-
0.50	-	0.389	-	-	-	-	8.641	0.630	0.208
0.75	0.597	0.389	-	-	-	-	6.268	0.840	0.208
1.00	1.791	2.335	-	-	0.332	-	4.235	2.101	0.624
1.25	6.866	7.004	0.682	-	1.661	1.111	2.535	6.723	1.247
1.50	17.313	12.840	1.364	-	2.326	1.481	1.523	14.286	2.079
1.75	23.284	19.066	7.273	0.150	3.987	3.704	2.373	17.647	3.326
2.00	25.672	20.233	8.864	0.150	3.987	4.074	3.045	13.655	8.316
2.25	14.627	20.623	10.455	0.599	7.309	10.000	2.373	9.454	8.316
2.50	6.567	12.062	6.364	4.790	9.967	12.593	2.373	7.353	9.979
2.75	2.687	3.113	3.864	14.072	12.625	13.333	1.863	10.714	6.861
3.00	0.597	1.556	4.773	25.449	13.621	15.185	1.182	9.034	7.069
3.25	-	0.389	13.864	24.252	16.611	19.630	0.510	3.782	14.345
3.50	-	-	15.227	20.359	14.286	11.481	-	2.941	17.879
3.75	-	-	14.091	7.784	7.309	4.444	-	0.840	8.940
4.00	-	-	5.909	2.395	1.993	1.111	-	-	5.198
4.25	-	-	4.318	-	2.326	0.741	-	-	3.119
4.50	-	-	2.045	-	1.329	0.370	-	-	2.079
4.75	-	-	0.909	-	0.332	0.741	-	-	0.208
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	35-17.5	35-22.5	36-2.5	36-10.0	37-2.5	38-2.5	38-7.5	38-12.5	38-17.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	-	-	-
0.50	-	-	-	-	-	-	-	-	-
0.75	-	-	-	-	-	-	-	0.310	-
1.00	-	-	-	-	-	-	-	1.858	-
1.25	0.735	-	-	-	0.272	-	0.353	4.025	-
1.50	1.838	0.448	0.259	0.074	0.272	0.282	0.707	16.099	0.888
1.75	1.838	0.448	0.777	0.148	0.817	1.127	2.473	34.056	0.888
2.00	2.206	0.896	2.850	0.148	2.452	4.507	5.654	18.885	0.592
2.25	2.206	0.896	11.658	0.185	6.812	16.620	18.375	10.217	0.592
2.50	1.838	0.896	30.570	0.554	11.717	30.986	31.802	6.192	0.296
2.75	2.574	0.896	30.311	1.476	14.169	27.606	26.148	5.573	0.296
3.00	2.941	0.896	14.508	4.059	18.529	10.423	11.661	2.477	0.592
3.25	6.250	0.896	5.181	14.760	24.251	6.479	2.474	0.310	0.296
3.50	14.338	2.687	1.036	32.472	13.896	1.972	0.353	-	0.296
3.75	22.794	4.179	0.259	27.306	5.450	-	-	-	3.550
4.00	15.441	7.463	0.518	9.963	1.090	-	-	-	10.947
4.25	9.926	11.343	1.036	5.535	0.272	-	-	-	18.047
4.50	8.088	11.343	0.777	2.583	-	-	-	-	16.272
4.75	4.412	10.448	0.259	0.738	-	-	-	-	14.497
5.00	2.206	8.657	-	-	-	-	-	-	10.355
5.25	0.368	8.060	-	-	-	-	-	-	8.580
5.50	-	8.358	-	-	-	-	-	-	7.988
5.75	-	6.567	-	-	-	-	-	-	5.325
6.00	-	8.358	-	-	-	-	-	-	-
6.25	-	5.075	-	-	-	-	-	-	-
6.50	-	1.194	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	39-2.5	40-2.5	40-7.5	40-10.0	41-7.5	42-2.5	42-7.5	42-12.5	42-17.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	1.528	-
-2.50	-	-	-	-	-	-	-	2.717	-
-2.25	-	-	-	-	-	-	-	0.509	-
-2.00	-	-	-	-	-	-	-	2.719	-
-1.75	-	-	-	-	-	-	-	3.227	-
-1.50	-	-	-	-	-	-	-	3.396	-
-1.25	-	-	-	-	-	-	-	3.566	-
-1.00	-	-	-	-	-	-	-	3.396	-
-0.75	-	-	-	-	-	-	-	3.193	-
-0.50	-	-	-	-	-	-	-	4.063	-
-0.25	-	-	-	-	-	-	-	4.934	-
0.00	-	-	-	-	-	-	-	8.126	2.163
0.25	-	-	-	0.809	-	-	-	11.899	11.779
0.50	-	-	1.767	2.426	-	-	-	8.997	38.221
0.75	-	-	6.714	11.321	-	-	0.227	6.966	26.683
1.00	-	0.350	12.014	16.442	0.676	-	5.669	5.224	9.375
1.25	-	0.699	20.495	15.903	2.703	3.113	12.245	4.063	5.769
1.50	-	4.196	14.841	12.668	5.068	7.393	20.635	5.514	3.606
1.75	-	3.147	16.254	11.590	10.135	14.786	22.676	6.675	1.202
2.00	0.130	15.035	6.007	10.782	19.595	28.405	18.594	4.063	1.202
2.25	0.130	14.336	10.954	7.547	28.378	24.903	13.379	2.612	-
2.50	0.390	17.832	4.947	5.391	19.932	12.062	4.989	1.451	-
2.75	0.260	15.035	2.473	2.426	10.135	5.058	1.361	0.580	-
3.00	1.169	10.839	1.413	2.156	2.703	2.335	0.227	0.290	-
3.25	3.117	9.441	1.413	0.539	0.338	0.778	-	0.290	-
3.50	13.506	6.993	0.353	-	0.338	0.778	-	-	-
3.75	29.351	1.748	0.353	-	-	0.389	-	-	-
4.00	23.636	0.350	-	-	-	-	-	-	-
4.25	12.987	-	-	-	-	-	-	-	-
4.50	9.091	-	-	-	-	-	-	-	-
4.75	6.234	-	-	-	-	-	-	-	-
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	42-22.5	43-2.5	43-7.5	43-12.5	43-17.5	43-22.5	44-7.5	44-12.5	46-2.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	1.460	-	-	-	-	-	-	-	-
-0.25	5.596	-	-	-	-	-	-	-	-
0.00	11.192	-	-	-	-	-	-	-	-
0.25	25.304	-	-	-	-	-	-	-	-
0.50	18.978	-	-	-	-	1.044	0.134	-	-
0.75	14.599	-	-	-	-	2.505	0.067	-	-
1.00	8.029	-	-	-	-	2.923	0.134	-	-
1.25	6.326	-	-	-	-	19.833	0.134	-	0.460
1.50	5.109	-	-	1.014	-	31.733	0.101	-	1.839
1.75	2.433	0.667	0.656	1.351	-	15.866	0.101	-	4.368
2.00	0.487	1.000	2.188	3.041	-	8.768	0.336	-	9.195
2.25	0.487	7.333	8.534	8.784	-	5.637	0.336	0.263	14.023
2.50	-	15.000	18.818	13.514	0.093	3.132	0.336	0.175	18.621
2.75	-	28.667	27.352	11.486	0.093	2.296	1.007	0.731	24.368
3.00	-	26.333	26.696	13.176	0.216	1.879	2.349	2.632	15.172
3.25	-	12.333	10.722	19.257	0.525	1.879	7.383	6.433	3.908
3.50	-	3.333	3.063	15.203	3.086	1.879	18.792	15.497	3.678
3.75	-	3.333	1.532	7.095	11.420	0.626	22.819	14.620	2.759
4.00	-	1.667	0.219	2.365	16.358	-	16.779	12.573	1.609
4.25	-	0.333	0.219	2.027	15.123	-	10.738	10.819	-
4.50	-	-	-	1.014	13.272	-	7.383	9.942	-
4.75	-	-	-	0.338	11.111	-	4.698	6.433	-
5.00	-	-	-	0.338	7.716	-	2.685	4.971	-
5.25	-	-	-	-	6.790	-	2.013	4.971	-
5.50	-	-	-	-	6.173	-	1.678	3.801	-
5.75	-	-	-	-	5.556	-	-	3.801	-
6.00	-	-	-	-	2.469	-	-	1.754	-
6.25	-	-	-	-	-	-	-	0.585	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	49-0.0	49-10.0	50-2.5	50-12.5	50-17.5	50-22.5	50-30.0	50-35.0	50-37.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	-	-	-
0.50	-	-	-	-	-	-	-	-	-
0.75	-	-	-	-	-	-	0.350	0.227	-
1.00	-	-	-	-	-	-	1.049	5.669	-
1.25	-	-	0.392	-	-	-	4.895	12.245	0.570
1.50	-	-	0.392	-	0.217	-	19.231	20.635	0.855
1.75	0.928	-	1.569	0.325	1.085	-	24.126	22.676	1.140
2.00	1.724	-	7.843	1.623	2.603	-	27.273	18.594	1.425
2.25	6.897	0.559	9.804	5.195	10.195	0.427	12.238	13.379	1.140
2.50	12.732	1.117	17.647	16.883	20.607	0.855	5.245	4.989	0.855
2.75	22.812	1.117	16.471	25.325	22.777	0.855	3.497	1.361	4.558
3.00	27.851	1.397	16.863	22.727	23.861	9.829	1.748	0.227	15.670
3.25	18.302	2.514	17.255	12.662	11.280	32.051	0.350	-	40.171
3.50	5.040	5.307	8.627	8.117	4.338	35.470	-	-	21.652
3.75	2.387	10.894	1.961	3.571	1.735	11.966	-	-	7.123
4.00	0.796	14.804	0.784	2.273	1.302	4.274	-	-	2.849
4.25	0.531	12.570	0.392	0.649	-	0.855	-	-	1.140
4.50	-	10.894	-	0.649	-	2.991	-	-	0.570
4.75	-	7.821	-	-	-	0.427	-	-	0.285
5.00	-	5.866	-	-	-	-	-	-	-
5.25	-	5.587	-	-	-	-	-	-	-
5.50	-	6.983	-	-	-	-	-	-	-
5.75	-	5.587	-	-	-	-	-	-	-
6.00	-	4.469	-	-	-	-	-	-	-
6.25	-	1.676	-	-	-	-	-	-	-
6.50	-	0.838	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	51-2.5	51-7.5	51-12.5	51-17.5	52-2.5	52-7.5	52-12.5	52-17.5	53-2.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	6.813	-
-3.00	-	-	-	-	-	-	-	0.000	-
-2.75	-	-	-	-	-	-	-	2.504	-
-2.50	-	-	-	-	-	-	-	1.868	-
-2.25	-	-	-	-	-	-	-	0.377	-
-2.00	-	-	-	-	-	-	-	1.789	-
-1.75	-	-	-	-	-	-	-	3.422	-
-1.50	-	-	-	-	-	-	-	2.064	-
-1.25	-	-	-	-	-	-	-	1.939	-
-1.00	-	-	-	-	-	-	-	3.085	-
-0.75	-	-	-	-	-	-	-	2.151	-
-0.50	-	-	-	-	-	-	-	2.543	-
-0.25	-	-	-	-	-	-	-	2.543	-
0.00	-	-	-	-	-	-	-	2.935	-
0.25	-	0.433	0.398	-	0.242	-	0.257	4.890	-
0.50	-	0.866	0.996	-	0.483	-	2.057	5.478	-
0.75	0.519	3.030	1.394	0.787	1.691	0.599	4.370	14.096	-
1.00	3.117	7.359	4.781	2.362	3.623	1.497	5.656	12.919	-
1.25	6.234	19.913	18.327	7.874	7.729	4.491	6.170	9.002	0.209
1.50	11.429	22.511	32.669	22.047	15.700	10.479	8.740	4.309	0.418
1.75	17.662	19.481	27.092	31.496	20.290	20.958	16.195	4.309	0.835
2.00	23.377	13.853	8.765	16.535	20.290	30.240	25.193	4.890	3.549
2.25	19.221	6.494	2.789	7.087	15.942	20.659	19.280	3.328	18.372
2.50	9.351	3.030	1.594	7.874	9.662	8.084	8.740	1.374	28.184
2.75	4.156	1.299	0.797	3.150	3.382	1.796	2.571	0.981	20.668
3.00	2.078	0.433	0.398	0.787	0.725	0.898	0.771	0.392	14.823
3.25	1.039	0.216	-	-	0.242	0.299	-	-	8.142
3.50	0.519	0.087	-	-	-	-	-	-	3.132
3.75	0.519	0.216	-	-	-	-	-	-	1.253
4.00	0.260	0.390	-	-	-	-	-	-	0.418
4.25	0.519	0.390	-	-	-	-	-	-	-
4.50	-	-	-	-	-	-	-	-	-
4.75	-	-	-	-	-	-	-	-	-
5.00	-	-	-	-	-	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-
5.50	-	-	-	-	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	53-7.5	53-12.5	53-17.5	53-22.5	54-2.5	54-7.5	54-12.5	54-22.5	55-0.0
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	0.236
0.25	-	-	-	-	-	-	-	-	1.418
0.50	-	-	-	-	-	-	-	-	2.600
0.75	-	-	-	-	-	-	-	-	7.329
1.00	-	-	-	-	-	-	-	-	11.348
1.25	-	-	-	-	-	0.399	-	-	12.530
1.50	-	-	-	-	0.286	0.186	-	-	13.002
1.75	-	-	-	-	0.286	0.213	-	-	14.894
2.00	0.341	-	0.078	-	0.171	0.266	0.322	-	13.948
2.25	1.706	0.580	0.039	1.176	0.257	0.266	0.322	-	10.402
2.50	1.706	1.159	0.349	3.529	0.429	1.330	0.322	-	5.910
2.75	14.676	2.609	1.085	12.157	5.429	3.723	0.965	-	3.783
3.00	22.184	5.507	6.589	26.275	14.571	10.904	5.466	0.971	1.891
3.25	23.549	10.725	22.481	30.588	23.143	14.628	10.289	0.971	0.709
3.50	20.819	21.739	31.395	18.039	28.857	20.745	18.650	8.252	-
3.75	9.556	23.478	20.930	5.490	17.143	16.223	17.685	8.738	-
4.00	4.778	12.754	12.016	2.353	5.429	10.106	16.399	10.680	-
4.25	0.683	8.986	3.876	0.392	3.143	6.649	12.540	15.291	-
4.50	-	5.217	1.163	-	0.857	4.521	8.682	12.864	-
4.75	-	3.768	-	-	-	2.926	6.752	9.709	-
5.00	-	2.319	-	-	-	2.394	1.608	6.796	-
5.25	-	1.159	-	-	-	1.596	-	6.796	-
5.50	-	-	-	-	-	2.660	-	4.854	-
5.75	-	-	-	-	-	0.266	-	8.495	-
6.00	-	-	-	-	-	-	-	3.883	-
6.25	-	-	-	-	-	-	-	1.699	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	55-10.0	55-15.0	55-20.0	55-25.0	55-30.0	55-35.0	56-2.5	56-12.5	56-17.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	0.216	-	-	-	-	-	-	-	-
0.50	2.808	-	-	-	-	-	-	-	-
0.75	9.935	-	-	0.253	-	1.064	-	-	-
1.00	22.030	1.972	2.353	2.020	4.059	2.837	-	-	-
1.25	22.246	10.986	10.882	9.091	9.225	3.546	-	-	-
1.50	20.518	29.577	25.882	24.495	21.771	3.901	-	-	-
1.75	12.959	37.465	27.941	30.303	29.520	10.284	-	-	-
2.00	5.616	15.211	18.824	18.687	18.450	17.376	-	0.072	-
2.25	1.080	3.380	9.118	7.576	9.594	28.723	0.506	0.143	-
2.50	1.080	1.408	4.118	4.545	4.428	22.340	0.253	0.143	0.239
2.75	1.080	-	0.882	1.010	1.845	7.092	0.253	0.251	0.239
3.00	0.432	-	-	0.758	0.738	2.128	0.253	0.824	0.716
3.25	-	-	-	0.758	0.369	0.709	1.266	1.434	3.341
3.50	-	-	-	0.505	-	-	5.316	1.792	9.308
3.75	-	-	-	-	-	-	10.886	13.620	14.320
4.00	-	-	-	-	-	-	12.405	18.638	18.377
4.25	-	-	-	-	-	-	13.924	15.412	17.422
4.50	-	-	-	-	-	-	11.139	11.111	12.411
4.75	-	-	-	-	-	-	8.101	10.394	10.740
5.00	-	-	-	-	-	-	7.089	6.093	6.683
5.25	-	-	-	-	-	-	6.582	4.301	5.012
5.50	-	-	-	-	-	-	6.076	4.659	1.193
5.75	-	-	-	-	-	-	5.316	5.735	-
6.00	-	-	-	-	-	-	3.797	3.943	-
6.25	-	-	-	-	-	-	4.051	1.434	-
6.50	-	-	-	-	-	-	2.025	-	-
6.75	-	-	-	-	-	-	0.759	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	56-22.5	56-27.5	56-32.5	56-37.5	57-2.5	57-7.5	57-12.5	57-17.5	57-22.5
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	-	-	-
0.50	-	-	-	-	-	-	-	-	-
0.75	-	-	-	-	-	-	-	-	-
1.00	-	-	-	-	-	-	-	-	-
1.25	-	-	-	-	-	-	-	-	-
1.50	-	0.146	-	-	-	0.100	-	-	-
1.75	0.226	0.146	-	-	-	0.100	-	-	1.105
2.00	0.226	0.583	0.880	0.974	-	0.798	-	-	2.210
2.25	2.715	4.082	1.173	0.649	-	9.182	0.179	-	12.983
2.50	16.290	16.327	3.519	0.325	0.295	27.745	0.179	0.108	32.873
2.75	32.127	28.863	7.918	2.597	0.295	32.136	3.750	0.043	30.111
3.00	28.507	24.490	20.821	6.169	0.590	15.968	9.821	0.065	14.088
3.25	12.670	15.743	27.859	8.442	0.885	6.387	15.179	0.324	4.420
3.50	4.977	6.414	33.138	15.260	2.655	4.192	18.929	0.540	1.657
3.75	1.810	2.041	4.399	15.909	7.375	2.395	16.786	3.024	0.552
4.00	0.452	0.583	0.293	12.013	11.799	0.798	10.536	8.423	-
4.25	-	0.583	-	9.091	11.799	0.200	6.250	11.231	-
4.50	-	-	-	8.117	10.619	-	5.536	12.095	-
4.75	-	-	-	5.519	9.735	-	4.286	12.311	-
5.00	-	-	-	4.870	7.965	-	4.107	9.071	-
5.25	-	-	-	3.896	7.965	-	4.464	9.503	-
5.50	-	-	-	3.571	9.145	-	-	8.639	-
5.75	-	-	-	1.948	7.670	-	-	8.855	-
6.00	-	-	-	0.649	6.195	-	-	7.127	-
6.25	-	-	-	-	4.425	-	-	7.127	-
6.50	-	-	-	-	0.590	-	-	1.512	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	57-27.5	57-32.5	57-37.5	57-50.0	57-57.5	58-2.5	58-7.5	58-12.5	58-15.0
-5.00	-	-	-	-	-	-	-	-	-
-4.75	-	-	-	-	-	-	-	-	-
-4.50	-	-	-	-	-	-	-	-	-
-4.25	-	-	-	-	-	-	-	-	-
-4.00	-	-	-	-	-	-	-	-	-
-3.75	-	-	-	-	-	-	-	-	-
-3.50	-	-	-	-	-	-	-	-	-
-3.25	-	-	-	-	-	-	-	-	-
-3.00	-	-	-	-	-	-	-	-	-
-2.75	-	-	-	-	-	-	-	-	-
-2.50	-	-	-	-	-	-	-	-	-
-2.25	-	-	-	-	-	-	-	-	-
-2.00	-	-	-	-	-	-	-	-	-
-1.75	-	-	-	-	-	-	-	-	-
-1.50	-	-	-	-	-	-	-	-	-
-1.25	-	-	-	-	-	-	-	-	-
-1.00	-	-	-	-	-	-	-	-	-
-0.75	-	-	-	-	-	-	-	-	-
-0.50	-	-	-	-	-	-	-	-	-
-0.25	-	-	-	-	-	-	-	-	-
0.00	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	-	0.541	-
0.50	-	-	-	-	-	-	1.903	1.892	-
0.75	-	-	-	-	-	0.126	4.228	2.162	-
1.00	-	-	-	-	-	0.631	8.034	5.946	2.703
1.25	0.304	-	-	-	-	1.515	9.302	10.000	7.862
1.50	0.608	0.505	1.429	0.680	-	6.566	10.359	19.730	14.251
1.75	4.559	0.505	1.905	0.454	-	11.111	13.531	17.027	28.501
2.00	10.334	13.131	7.381	1.361	0.167	17.424	15.645	15.676	21.130
2.25	20.365	30.303	11.905	3.401	0.333	22.222	12.051	12.432	13.514
2.50	28.875	33.333	19.524	4.535	0.333	23.232	8.457	7.027	8.108
2.75	17.933	15.152	19.762	6.122	0.500	11.364	9.091	3.784	3.686
3.00	6.991	5.556	17.619	9.751	0.667	4.545	4.440	2.432	0.246
3.25	6.687	1.010	12.857	15.873	2.667	1.263	2.537	1.081	-
3.50	2.128	0.505	4.286	20.408	6.333	-	0.423	0.270	-
3.75	1.216	-	2.381	13.379	10.333	-	-	-	-
4.00	-	-	0.476	7.029	15.000	-	-	-	-
4.25	-	-	0.476	7.029	16.667	-	-	-	-
4.50	-	-	-	4.535	15.000	-	-	-	-
4.75	-	-	-	2.948	10.667	-	-	-	-
5.00	-	-	-	2.494	7.333	-	-	-	-
5.25	-	-	-	-	7.333	-	-	-	-
5.50	-	-	-	-	6.667	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-
6.00	-	-	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-
6.50	-	-	-	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-
7.00	-	-	-	-	-	-	-	-	-

PHI SIZE	58-20.0	58-27.5	58-30.0	58-35.0
-5.00	-	-	-	-
-4.75	-	-	-	8.873
-4.50	-	-	-	0.000
-4.25	-	-	-	0.396
-4.00	-	-	-	2.518
-3.75	-	-	-	3.253
-3.50	-	-	-	2.750
-3.25	-	-	-	3.303
-3.00	-	-	-	2.411
-2.75	-	-	-	2.267
-2.50	-	-	0.955	2.480
-2.25	-	-	0.707	2.072
-2.00	-	-	0.334	1.991
-1.75	-	-	0.258	1.978
-1.50	-	-	0.822	1.570
-1.25	-	-	0.516	1.344
-1.00	-	-	0.869	0.973
-0.75	-	-	1.366	0.973
-0.50	-	-	2.341	1.149
-0.25	-	-	2.933	1.608
0.00	-	-	7.233	2.983
0.25	-	-	9.775	5.739
0.50	-	-	14.065	5.739
0.75	-	-	11.915	5.972
1.00	0.241	0.988	10.940	7.918
1.25	1.205	0.593	8.991	9.645
1.50	5.301	1.779	6.841	8.264
1.75	28.193	1.779	8.399	4.823
2.00	40.723	1.779	3.908	2.757
2.25	11.566	0.791	3.908	1.721
2.50	2.169	1.186	1.366	1.608
2.75	5.783	3.755	0.975	0.691
3.00	4.096	18.577	0.583	0.232
3.25	0.723	32.016	-	-
3.50	-	22.727	-	-
3.75	-	8.696	-	-
4.00	-	2.767	-	-
4.25	-	1.779	-	-
4.50	-	0.791	-	-
4.75	-	-	-	-
5.00	-	-	-	-
5.25	-	-	-	-
5.50	-	-	-	-
5.75	-	-	-	-
6.00	-	-	-	-
6.25	-	-	-	-
6.50	-	-	-	-
6.75	-	-	-	-
7.00	-	-	-	-

APPENDIX D

(In pocket)

Surface Geology of the Souris River Map Area, North Dakota. Copies of this map may be obtained through the North Dakota Geological Survey, University Station, Grand Forks, North Dakota, 58202-8156.

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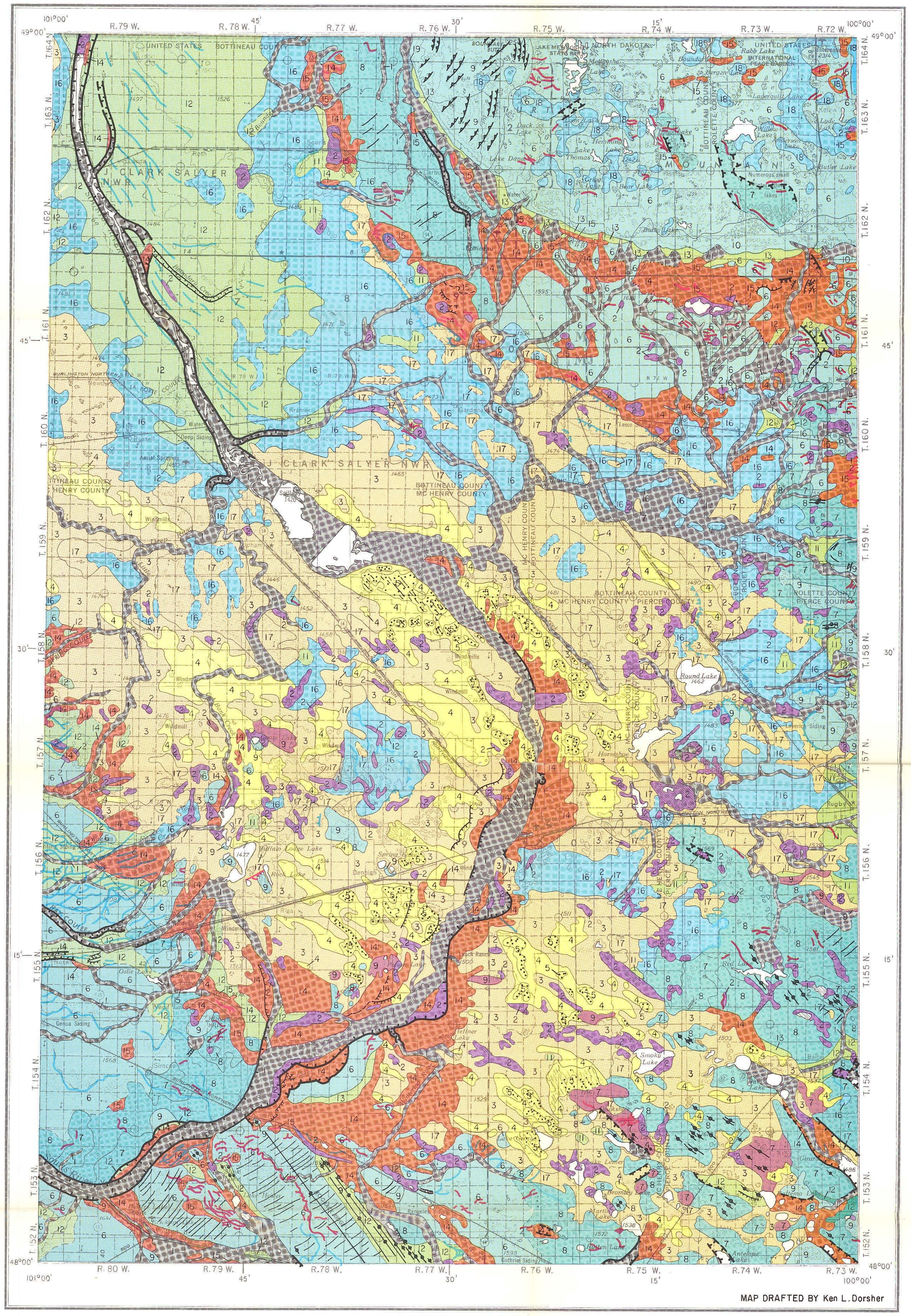
NORTH DAKOTA GEOLOGICAL SURVEY
Sidney B. Anderson, Acting State Geologist
AS-4-A1



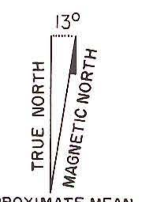
5 0 5 10 MILES
5 0 5 10 KILOMETERS
MAP SCALE 1:250,000

CONTOUR INTERVAL 100 FEET
WITH SUPPLEMENTARY CONTOURS AT 50-FOOT INTERVALS

LEGEND

POPULATED PLACES
25,000 to 100,000 — FARGO
5,000 to 25,000 — Jamestown
1,000 to 5,000 — Rugby
Less than 1,000 — Towner
RAILROADS — Standard gauge: Single track; Double or Multiple
BOUNDARIES — International; State; County; Park or reservation
Landplane airport
Landing area

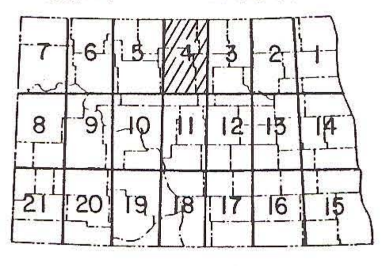
ROADS
Primary, all-weather, hard surface
Secondary, all-weather, hard surface
Light-duty, all-weather, hard or improved
Fair or dry weather, unimproved
Trail
Interchange
Route markers: Interstate, U.S., State
Landmark: School, Church, Other
Mine
Spot elevation in feet .225
Marsh or swamp
Intermittent or dry stream
Power line



13°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1987

SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36



ATLAS SERIES MAP AREAS

BASE MAP SUPPLIED BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225

SURFACE GEOLOGY OF THE SOURIS RIVER MAP AREA, NORTH DAKOTA

by Mark L. Lord
1988

MAP EXPLANATION

This map shows four elements of the geology of the Souris River Map Area: the lithology, topography, origin, and age of the surface sediment. Sediment characteristics are emphasized on this map; different lithologies are shown on the map by the use of color (Fig. 1). All Quaternary sediment of the same lithology is represented by map units of the same basic color. For example, two basic colors, orange and green, are used for ten different map units, but represent only two lithologies (sand and gravel; gravelly sand, silt, and clay). Because there are eight green map units of similar lithology, three different shades of green have been used to simplify use of the map.

The age and the origin of the sediment are shown with map-unit numbers. For example, a yellow map unit (sand) is interpreted to be either lake, river, or windblown sediment of a certain age. The specific interpretation is indicated by a map-unit number. Figure 2 shows the correlation diagram relating sediment age, origin, and lithology with map-unit number.

Detailed descriptions of the map units and line symbols used on this map are given in Figure 3. These descriptions include comments on the range of lithologic characteristics, possible origins, and mapping confidence of different map units.

In addition to the detailed map of the Souris River Map Area (left), three smaller, general maps are included on this sheet to aid the user in understanding the surface geology of the region. These three maps are 1) major landform areas (Fig. 4), 2) regional glacial margins (Fig. 5), and 3) regional glacial lakes and spillways (Fig. 6). The Souris River Map Area is divided into three landform areas, indicated by letters, based on the occurrence of similar or genetically related landforms (Fig. 4). During the last major glacial advance, ice covered the entire map area (Fig. 5; A). As the glacier thinned, it split into two lobes around the Turtle Mountains (Fig. 5; B); the ice remaining in the Turtle Mountains stagnated (Fig. 4; B). The Souris ice lobe flowed around the west side of the Turtle Mountains, forming some proglacial stream deposits to the north (Fig. 4; Ca) and molding topography to the south (Fig. 4; Cb). Glacial Lake Souris (Fig. 4; A) formed as meltwater ponded during the retreat of the Souris ice lobe. Sediment-laden water entered Lake Souris at the Souris River and deposited a coarse-grained delta (Fig. 4; Ac). Final drainage of Lake Souris occurred to the north (Fig. 4; Ae) into glacial Lake Hind in Manitoba (Fig. 6). During the Holocene Epoch, wind has reworked much of the sediment in Lake Souris (Fig. 4; Ad). Today, with the exception of occasional wind blowouts, sediment is reworked primarily by rivers (Fig. 4; Af, Cd).

The map of the surface geology is the result of an interpretation of the geology based on aerial photographs, field studies, and a compilation of previous work. The aerial photographs used were taken between 1951 and 1953 by the Army Map Service and printed at a scale of 1:63,400 (1 inch = 1 mile). Field studies were conducted during the summers of 1985, 1986, and 1987. Drilling data from about 600 holes, primarily from the North Dakota Geological Survey and the North Dakota State Water Commission, were used to assist this study.

This map has greatly benefited from many discussions with Ken Harris, who constructed the first map of the Atlas Series, and from a critical review by Lee Clayton. Review and comments by John Bluemle and Alan Kehew have also improved this map.

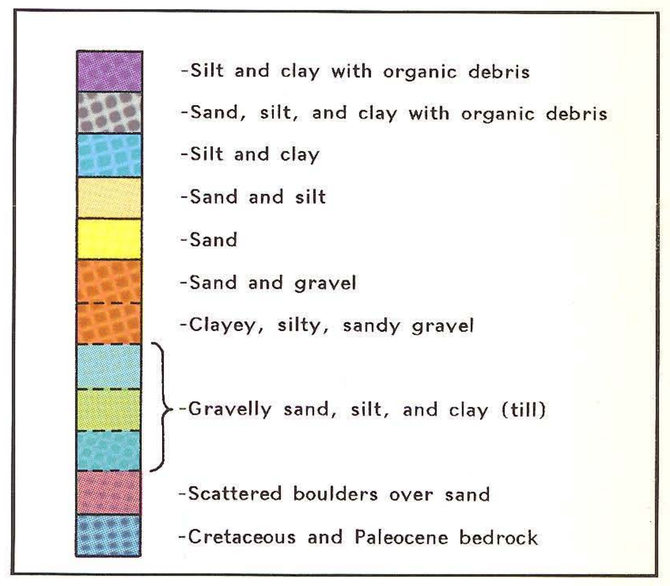


Figure 1. Sediment texture key.

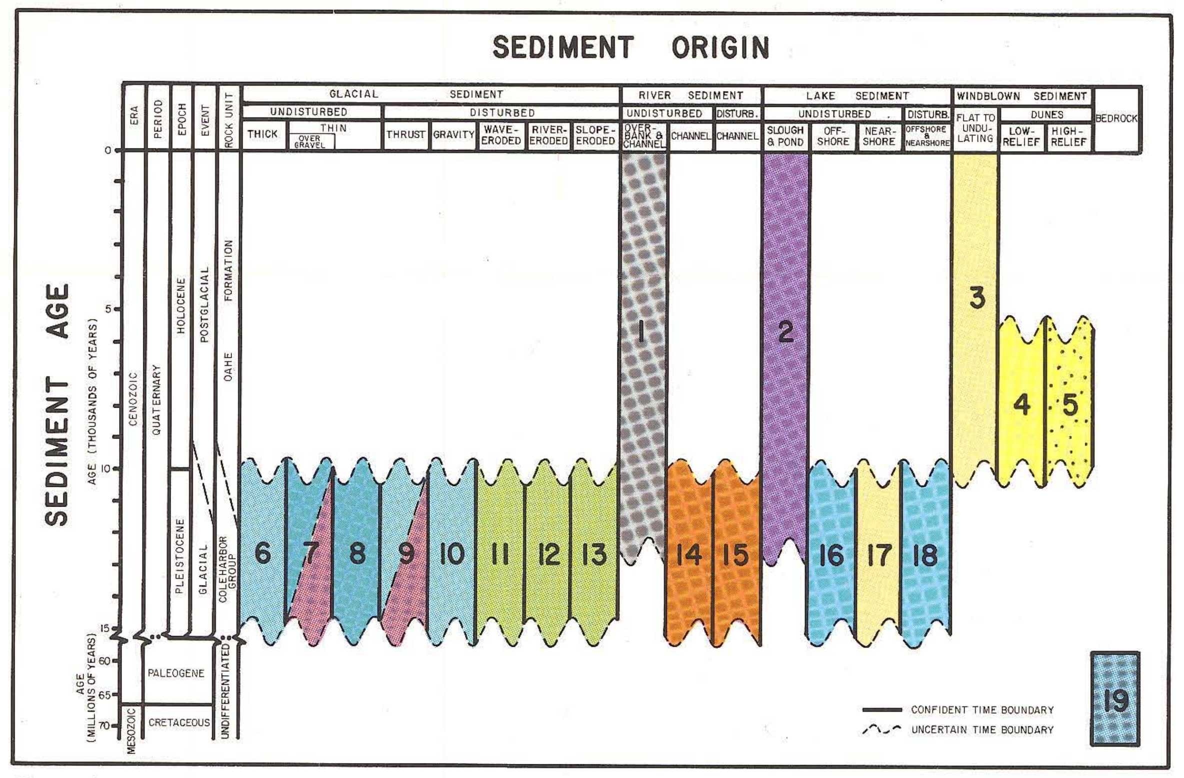


Figure 2. Correlation diagram relating sediment age, sediment origin, lithology, and map-unit number.

DESCRIPTION OF THE MAP UNITS

QUATERNARY

OAHE FORMATION

RIVER AND LAKE SEDIMENT

1 **OVERBANK SEDIMENT**: Clay, silt, sand, and disseminated organic debris; obscurely bedded; dark colored; commonly associated with sand and gravel of older, river-channel sediment. Where the sediment of this map unit occurs in alluvial fans, it commonly consists of poorly sorted to well sorted sand and gravel deposits.

2 **SLOUGH AND POND SEDIMENT**: Clay, silt, and disseminated organic debris; obscurely bedded; dark colored; generally less than 3 metres (10 feet) thick.

WINDBLOWN SEDIMENT

3 **FLAT TO UNDULATING**: Silt and sand, fine to medium grained; moderately to well sorted; obscurely bedded; surface commonly scoured and gradational to unit 4. Sediment is interpreted to be reworked sediment of unit 17.

4 **LOW-RELIEF DUNES**: Sand, fine to medium grained, well sorted; obscurely bedded; dunes are as high as 6 metres (20 feet) and generally stabilized by vegetation, but commonly have active blowouts.

5 **HIGH-RELIEF DUNES**: Same as unit 4, but dunes are commonly higher (up to 20 metres; 65 feet) and have the form of longitudinal dunes where indicated on the map by thin black lines.

COLEHARBOR GROUP

GLACIAL SEDIMENT

6 **GLACIAL SEDIMENT**: Gravelly sand, silt, and clay; unsorted, unbedded; contains some cobbles and boulders; as thick as 200 metres (600 feet) in multiple-advance deposits and as thick as 30 metres (100 feet) in single-advance deposits. The surface is flat to undulating except in the Turtle Mountains, where it is hilly.

7 **GLACIAL SEDIMENT, PALIMPSEST, OVER SAND AND GRAVEL**: Thin glacial sediment (1-5? m) consisting of unsorted, unbedded gravelly sand, silt, and clay draped over and only partially modifying the topography existing before the last glacial advance. The material underlying the thin glacial sediment is interpreted to be sand and gravel. In some areas, where this unit is shown in brown, the lithology is scattered boulders over sand. The origin of this lithology (brown) is interpreted to be similar to the gravelly sand, silt, and clay (green) except that the original deposit thickness was less and erosion during the Holocene has removed all but boulders from the thin till. Where the material underlying the boulder lag is composed of sand, blowouts are common.

8 **GLACIAL SEDIMENT, PALIMPSEST**: Same as unit 7, but lithology of underlying material is uncertain. Boundaries with this unit are commonly gradational with other glacial sediment map units.

9 **GLACIAL THRUST SEDIMENT**: Thin glacial sediment draped over slabs of older sediment that have been thrust by the glacier near its margin. The thrust sediment is highly variable in lithology (till, sand and gravel, bedrock), reflecting local geology. *In some areas this unit is shown in brown, indicating* as described for map-unit 7.

10 **GRAVITY-DISTURBED GLACIAL SEDIMENT**: Gravelly sand, silt, and clay; unbedded, unsorted. Topography is irregular with ridges that parallel the edge of the Turtle Mountains. Origin is uncertain, but is thought to result from mass movement, off the Turtle Mountains, facilitated by high rates of groundwater discharge in the area.

11 **WAVE-ERODED GLACIAL SEDIMENT**: Gravelly sand, silt, and clay; unsorted, unbedded. Surface was eroded by wave activity in glacial Lake Souris. Discontinuous patches of lake sediment are commonly present.

12 **RIVER-ERODED GLACIAL SEDIMENT**: Gravelly sand, silt, and clay; unsorted, unbedded. Surface has been eroded by rivers and in many places is dissected by small to large abandoned channels. In places, surface is veneered by a boulder lag or discontinuous patches of river or lake sediment.

13 **SLOPEWASHED GLACIAL SEDIMENT**: Gravelly sand, silt, and clay; unsorted, unbedded. Surface has been eroded by slopewash and other hillslope processes. Discontinuous outcrops of Cretaceous and Paleocene bedrock occur in this unit on the margins of the Turtle Mountains. Boundaries of this unit some places are gradational with sediment of alluvial fans.

RIVER SEDIMENT

14 **RIVER CHANNEL SEDIMENT**: Sand and gravel; well sorted to poorly sorted; crossbedded, planar bedded, or unbedded; up to 20 metres (65 feet) thick; deposited by glacial meltwater flowing directly from the glacier or by rivers flowing out of glacial lakes. In the vicinity of alluvial fans, boundaries are generally gradational and lithology is clayey, silty, sandy gravel.

15 **RIVER CHANNEL SEDIMENT, COLLAPSED**: Sand and gravel, well sorted to poorly sorted; faulted and contorted; hummocky topography; up to 20 metres (65 feet) thick; deposited by glacial meltwater on top of or within the glacier. The lithology is clayey, silty, sandy gravel where the river sediment is interbedded with mudflow deposits. This unit is commonly gradational with unit 14.

LAKE SEDIMENT

16 **OFFSHORE LAKE SEDIMENT**: Silt and clay; laminated; up to 10 metres (30 feet) thick. Deposited in calm-water (low-energy) areas of glacial Lake Souris.

17 **NEARSHORE LAKE SEDIMENT**: Sand and silt; planar bedded or crossbedded; well sorted; up to 30 metres (100 feet) thick. Deposited in moderate-energy areas of glacial Lake Souris, primarily by sediment-laden water carried into the lake by the Souris River. In many places, boundaries between unit 16 and 17 are uncertain, although not necessarily gradational.

18 **LAKE SEDIMENT, COLLAPSED OR ICE-WALLED**: Silt and clay, some sand; flat-bedded sediment at a higher elevation than surrounding glacial sediment or deformed sediment with a hummocky surface. The lakes in which these sediments were deposited were either surrounded by or underlain by ice.

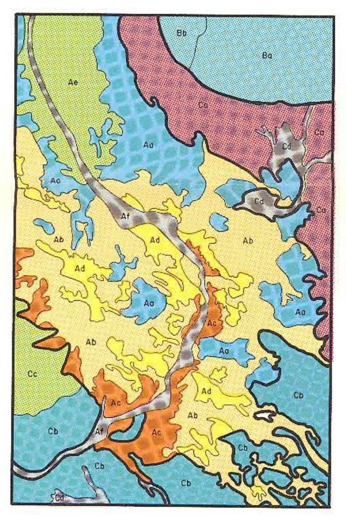
CRETACEOUS AND PALEOCENE

19 **FOX HILLS FM., HELL CREEK FM., FORT UNION GP.**: Clay, silt, sand, and lignite deposited in river, lake, or marine environments. Isolated exposures of bedrock occur on the margins of the Turtle Mountains and on river valley sides (not mappable at this scale) in the southern one-third of the map area. Bedrock units are not differentiated.

MAP SYMBOLS

- Confident map-unit boundary, judged to be within 0.4 km (0.25 mi) of the true boundary along most of its length.
- Approximate map-unit boundary, judged to be within 0.8 km (0.5 mi) from the true boundary along most of its length.
- Uncertain map-unit boundary, may be more than 0.8 km (0.5 mi) from true boundary; generally used with gradational units.
- High-relief, continuous scarp of abandoned river channel, scarps generally higher than 10 metres (30 feet).
- High-relief, discontinuous scarp of abandoned river channel; scarp disturbed by erosion or subsequent glacial advance.
- Low-relief, continuous scarp of abandoned river channel; scarps generally 3 to 10 metres (10 to 30 feet) in height.
- Low-relief, discontinuous scarp of abandoned river channel.
- Shallow, Pleistocene channel scar; identified from aerial photographs.
- Probable glacial-lake shoreline position; tick marks point lakeward. Small sediment accumulations are present at some shoreline positions.
- Lineation; in glacial sediment lines are a stylized selection of washboard ridges; in sand dunes lines mark crests of longitudinal dunes.
- Esker.
- Crest of glacial thrust ridges; sawteeth point to the direction the glacier advanced from.
- Drumlin.
- Alluvial Fan: An accumulation of stream, slopewash, and mudflow sediments in the shape of a segment of a cone, deposited where streams leaving high-relief areas enter plains.
- Mark at corner of townships to aid the user in land locations.

Figure 3. Description of map units and line symbols.



LEGEND

A. GLACIAL LAKE SOURIS
- a. Offshore sediments and landforms (flat to gently undulating; silt and clay).
- b. Nearshore sediments and landforms; commonly wind scoured (flat to undulating; sand and silt).
- c. Delta stream sediments and landforms (gently undulating surfaces with channel scars; sand and gravel).
- d. Windblown sediments; dunes (undulating to hilly; sand).
- e. River-eroded plain (channel scars; scattered boulder lag over till).
- f. Recent stream sediment in abandoned river channel (flat-bottomed valley; clay to sand with organics).

B. TURTLE MOUNTAINS
- a. Glacier-thrust landforms and sediments (hilly; glacial sediment and bedrock).
- b. High-relief, collapsed supraglacial sediment and landforms (perched lake plains, hilly; lake and glacial sediment).

C. GLACIATED PLAINS
- a. Proglacial stream sediments and landforms, and till plains (collapsed and non-collapsed meltwater channels and deposits; sand and gravel; gravelly sand, silt, and clay).
- b. Glacially molded sediments and landforms (drumlins, washboard ridges, thrust blocks; thin glacial sediment).
- c. Stream-dissected till plain (gently undulating plains with anastomosing stream valleys; gravelly sand, silt, and clay; boulder lag).

Figure 4. Major landform areas (uppercase letters) with typical landforms and sediments (lowercase letters).

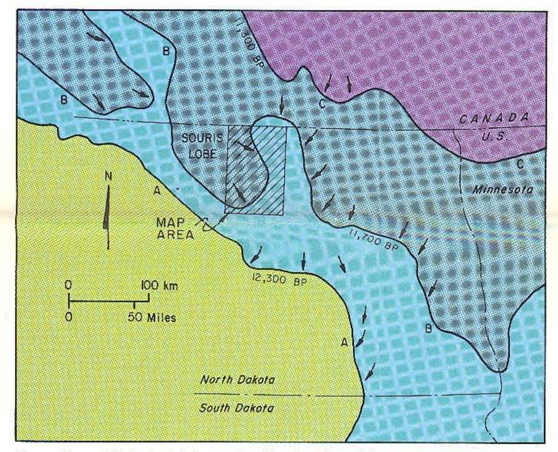


Figure 5. Selected glacial margins (A, B, C) and their approximate ages (in years before present) in the region of the Souris River Map Area; arrows show direction of ice movement (modified from Clayton and Moran, 1982).

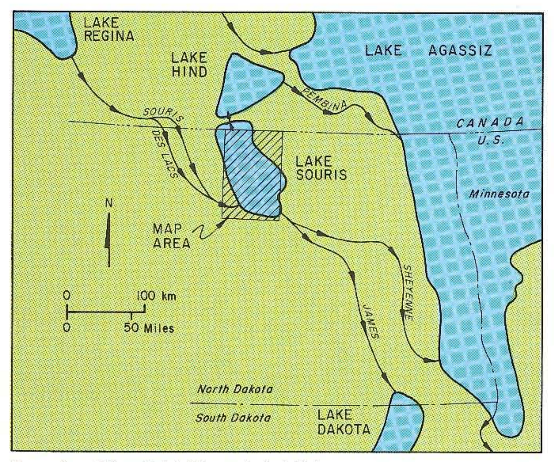


Figure 6. Major glacial lakes and glacial-lake spillways in the region of the Souris River Map Area.

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