SURFICIAL GEOLOGY AND STRATIGRAPHY

OF THE

KILLARNEY-HOLMFIELD AREA, SOUTHWESTERN MANITOBA

A THESIS

PRESENTED TO

THE FACULTY OF GRADUATE STUDIES

UNIVERSITY OF MANITOBA

IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF SCIENCE

© GLENN G. CONLEY

AUGUST 1986

ISBN 0-315-34074-6

SURFICIAL GEOLOGY AND STRATIGRAPHY OF THE KILLARNEY-HOLMFIELD AREA, SOUTHWESTERN MANITOBA

BY

GLENN G. CONLEY

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Seven tills, ranging in age from pre-Wisconsinan to late Wisconsinan, were identified in the Killarney-Holmfield area. The pre-Wisconsinan glaciations are represented by the Largs, Tee Lakes and Shell Formations, and the Early Wisconsinan glaciation, by the Minnedosa Formation. A widespread unconformity between the Shell and Minnedosa Formations is represented by a cobble lag. A second widespread unconformity between the early Wisconsinan Minnedosa Formation and the Late Wisconsinan Lennard Formation is represented by a boulder pavement in Saskatchewan, southwestern Manitoba and northeastern North Dakota. In the Tiger Hills upland, the Late Wisconsinan Glenora and Belmont Formations overlie the Lennard Formation.

Tentative correlations have been made with the tills of the Riding and Duck Mountain area (Klassen, 1979), northeastern North Dakota (Bluemle, 1984), northwestern Minnesota (Fenton et al, 1983; Harris et al., 1974) and southeastern Manitoba (Fenton, 1984; Fenton et al., 1983).

Late Wisconsinan ice advanced into the Killarney-Holmfield area from the northwest, depositing the till of the Lennard Formation. The Keewatin ice reached western Iowa about 20 000 B.P. The glacier advanced and retreated several times before retreating north into the Killarney-Holmfield area, about 12 000 B.P. A brief readvance brought the glacier to the Cartwright moraine before the western ice retreated to the west for the last time. About 11 400 B.P., the Red River lobe

advanced to the Darlingford-Edinburg moraine from the northeast, depositing the till of the Glenora Formation. The ice crossed the Pembina spillway at Swan Lake, blocking the drainage of meltwater to the east. As the ice retreated, the ponded waters of Lake Souris drained rapidly through the spillway to Lake Agassiz. About 11 200 B.P. the Red River lobe readvanced to the Darlingford-Edinburg moraine, depositing the till of the Belmont Formation. The Pembina spillway was blocked for a second time and the level of the ponded meltwater in the Killarney-Holmfield area rose to 465 m. The ice retreated to the north and the ponded meltwater drained rapidly through the spillway. A brief readvance brought the glacier to the Baldur thrust moraine. After a short time, the ice retreated to the north and the Glenboro outwash formed along the north edge of the escarpment. This lower outlet drained meltwater from the west and the Pembina spillway was soon abandoned.

INTRODUCTION

The Killarney-Holmfield map-area is located in southwestern Manitoba to the north and east of Turtle Mountain (Figure 1). The area studied covers about 3890 square kilometres and is bounded by latitudes 49°00′N and 49°30′N and longitudes 99°00′ and 100°00′. The accompanying surficial geology map (Figure 2, in back pocket) is comprised of four 1:50 000 topographic map sheets: Holmfield (62 G/3), Killarney (62 G/4), Dunrea (62 G/5), and Baldur (62 G/6). The study area name was derived from the two lower maps, namely the Killarney and Holmfield map sheets.

General Setting

Relief. Elevation ranges from a height of 716 metres in the Turtle Mountain upland (SE 18-01-19) in the southwest, to a height of 381 m in the northeast in the Tiger Hills upland (NW 15-06-14) (Figure 2). The surface slopes northeastward from the base of Turtle Mountain at about 4.8 m/km. The Pembina spillway, a major glacial meltwater channel, crosses the map-area from west to east. This steep walled channel is 40 to 50 m deep and 1 to 3 km wide (Figure 3). Pelican Lake and Rock Lake are two major lakes in the valley. They are generally less than 5 m deep and are dammed by alluvial fans built out onto the valley floor. The bottom of the channel is at an elevation of 419 m a.s.l. near Ninette and slopes to 403 m at the east end of Rock Lake (Figure 2).

Drainage. The Souris River and Pembina River are the two major river systems in the area (Figure 2, Figure 4). The Souris River flows northeast through the elbow of capture, southwest of Wawanesa,

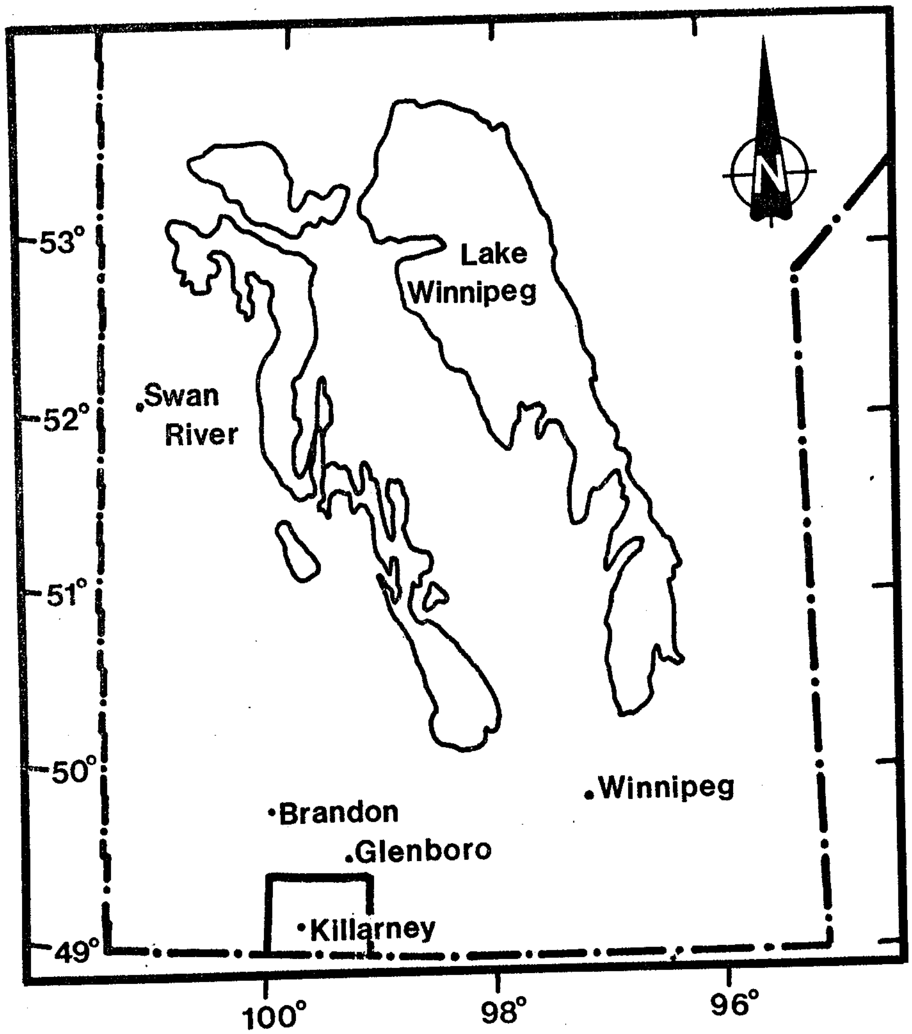


Figure 1. Location of the Killarney-Holmfield study area.

Figure 3. The south rim of the Pembina spillway, near the elbow of capture of the Souris River.

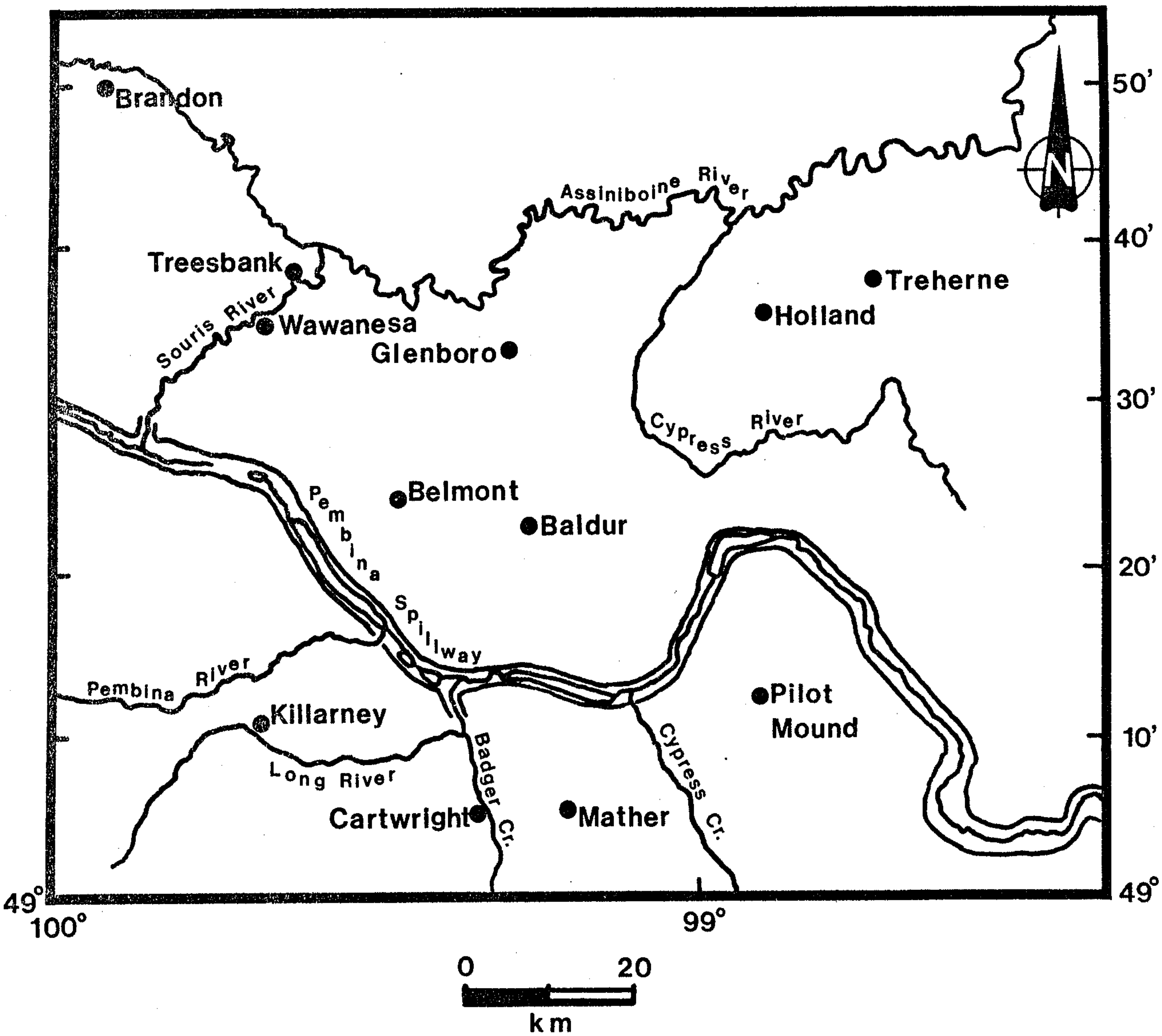


Figure 4. Drainage map of southwestern Manitoba.

and joins the Assiniboine River near Treesbank. Bone Lake and Overend Lake in the Pembina River valley drain west into the Souris River.

The Pembina River flows east from Whitewater basin near Boissevain. This river drains the area north of Killarney and enters the Pembina River valley south of Pelican Lake. Long River drains the area south of Killarney, including eastern Turtle Mountain. Lake Killarney forms part of Long River, that flows east where it joins Badger Creek and enters the spillway east of Louise Lake. Cypress Creek and Crystal Creek flow north into the spillway, east of Rock Lake. Cypress River, which crosses the northeast corner of the study area, flows north and joins the Assiniboine River near Holland (Figure 4).

Several rivers have been renamed since the publication of Elson's (1956) and Halsted's (1959) reports. These changes appear in the 1975 reprinting of the 1:50 000 map sheets used in this study. Long River was formerly called Wakopa Creek for that segment west of Killarney and Whitemud Creek for that segment between Killarney and Badger Creek; Cypress Creek was formerly known as Long River.

Approach and Scope

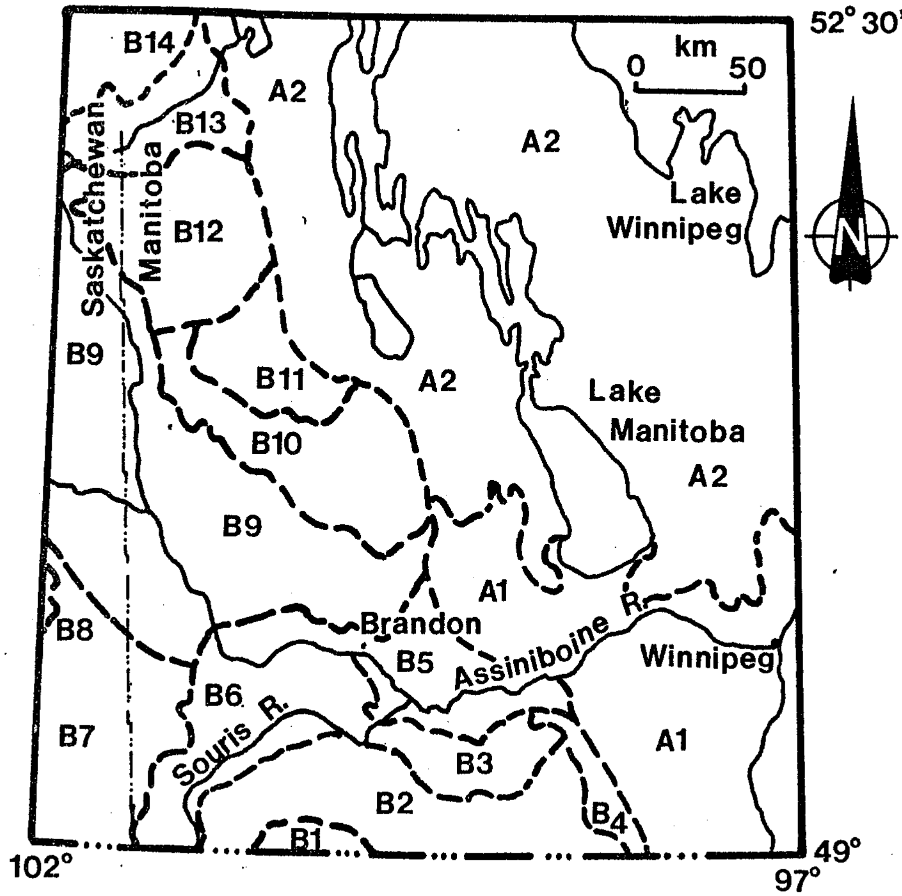
The purpose of this study is to map the surficial geology and interpret the Quaternary stratigraphy of the Killarney-Holmfield area. Field mapping at a scale of 1:50 000 was undertaken during the summers of 1981 and 1982 with the aid of aerial photographs. River and road sections were examined for stratigraphic information and samples of tills were taken for laboratory analysis. The analyses consisted of grain size determination, carbonate analyses of the silt plus clay fraction, and lithological determinations of the 4 to 16 mm size range.

Physiographic Divisions

The Manitoba Escarpment provides a natural boundary between two major physiographic divisions, the Manitoba Plains to the east and the Saskatchewan Plains to the west (Figure 5). The Manitoba Plains are subdivided into the Red River Plain to the south and the Interlake-Westlake Plain to the north (Klassen, 1979). Teller and Bluemle (1983) state that drift thickness is commonly more than 30 m thick in the Red River Plain but in the Interlake-Westlake plains it is less than 10 m thick.

The Killarney-Holmfield map-area is located entirely within the Saskatchewan Plains and includes the Turtle Mountain upland, the Boissevain plain, and the Tiger Hills upland (Figure 5). The Saskatchewan Plains are mantled by glacial drift ranging in thickness from a few metres in the Boissevain plain and the Tiger Hills upland, to several hundred metres in the Turtle Mountain upland. Halstead (1959, p. 10) thought that the preglacial topography in southwestern Manitoba was modified relatively little by glacial erosion, and although tens of metres were removed from the highlands, the larger landforms such as Turtle Mountain were only smoothed by glacial erosion.

The Tiger Hills upland is separated from the Boissevain plain by the Pembina spillway. The northern portion of the Tiger Hills upland consists of a series of prominent hills and arcuate ridges adjacent to closed depressions or lakes. Between the lakes and north of the arcuate ridges are a number of tightly looped, low washboard moraines, and well developed flutings, formed of bedrock draped by a thin veneer



A. MANITOBA PLAINS
   1. Red River plain
   2. Interlake-Westlake plain

B. SASKATCHEWAN PLAINS
   1. Turtle Mountain upland
   2. Boissevain plain
   3. Tiger Hills upland
   4. Pembina Hills upland
   5. Assiniboine delta
   6. Souris basin
   7. Souris River plain
   8. Moose Mountain upland
   9. Assiniboine River plain
   10. Riding Mountain upland
   11. Valley River plain
   12. Duck Mountain upland
   13. Swan River plain
   14. Porcupine Hills upland

Figure 5. Physiographic divisions of southwestern Manitoba (modified from Klassen, 1979, p. 3).

of glacial drift. The washboard moraines and flutings are mutually exclusive. Drift thickness is extremely variable and bedrock outcrops at the surface in places. In the southern part of the Tiger Hills upland, along the north rim of the Pembina spillway, is the Darlingford moraine (Figure 2). The moraine, which rises to an elevation of over 500 m a.s.l. may be delineated by the 472 m contour line (SE 02-04-15).

The Boissevain plain, occupying the area between the Tiger Hills upland and the Turtle Mountain upland, is flat to gently undulating. It can be subdivided into several smaller units. The area north of the Pembina River, from Boissevain to Killarney and north of a line from Killarney to Cartwright, is dominated by corrugated washboard moraines (Figure 2). The corrugation is best developed north of Cartwright where the southernmost limit of the moraines is marked by an end moraine. Farther north, and downslope towards the Pembina spillway, the washboard moraines are truncated at an elevation of 472 m by a flat outwash plain. The outwash extends in a band 5 to 10 km wide south of the spillway.

The southern part of the Boissevain plain, between Killarney and the International Boundary is flat to gently undulating. The undulations increase in height toward the Turtle Mountain upland, and decrease in height toward the east (Figure 2). Drainage in the western part of the plain is poorly integrated and many channels are partially filled by drift, indicative of an ice contact origin. Elson (1956, p. 15) reported that, although wells penetrated up to 109 m of glacial drift in a preglacial valley in township 1, range 15, the average drift thickness ranges from 23 to 31 m in the western part of the Boissevain Plain south of Killarney, and thins to 8 to 16 m near

Cartwright.

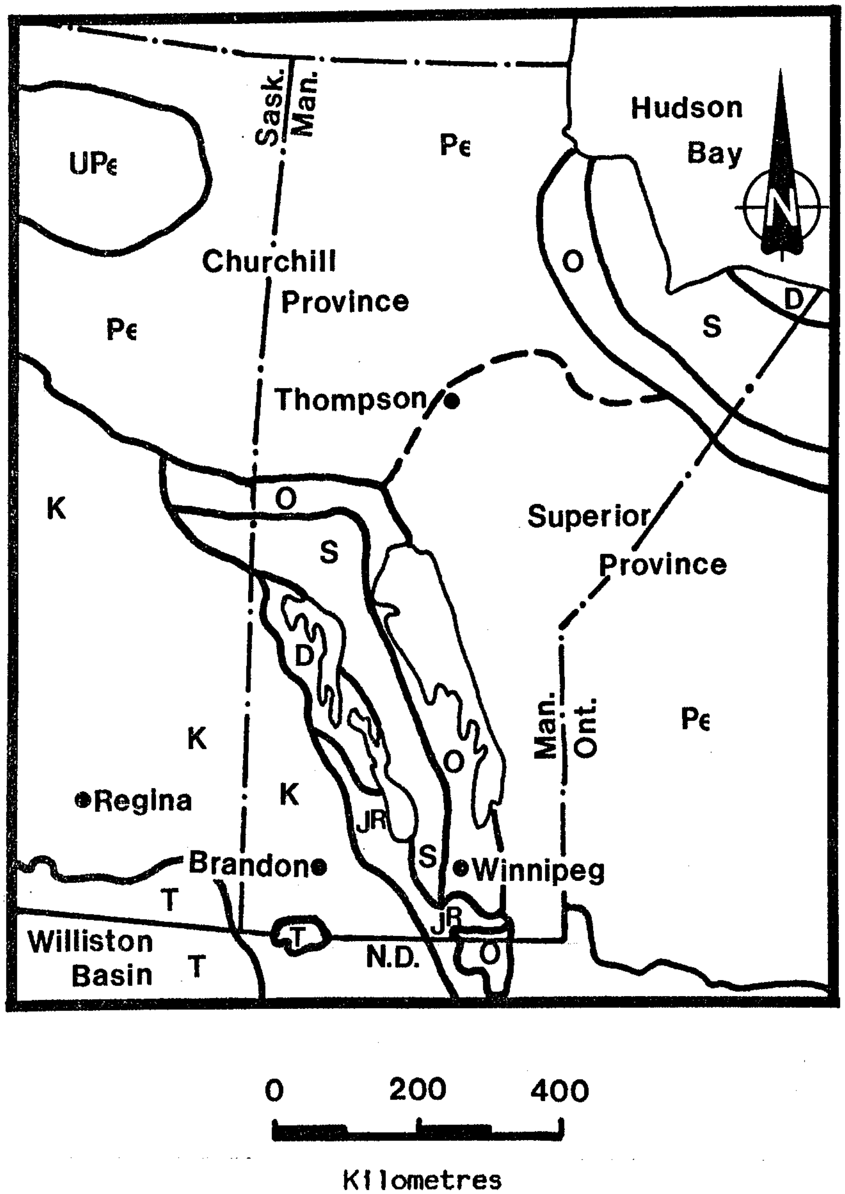
The Turtle Mountain upland in the southwest is the smallest physiographic subdivision. Elevations range from 590 m to 730 m, a.s.l. Local relief is highly variable, typical of stagnation moraine. Elson (1956, p. 14) reported that two drill holes on the east side of Turtle Mountain penetrated 75 m and 109 m of glacial drift before reaching bedrock.

Bedrock Geology

The texture and composition of tills deposited in southwestern Manitoba is dependent upon the composition of the bedrock and surface sediments along the flow of the ice sheets. In order to discuss provenance, it is important to discuss the bedrock geology of an area much larger than that of the immediate study area.

The bedrock geology of the region can be divided into three major lithological groups (Figure 6). To the north and east is the Precambrian region, composed of granites, greenstones, and gneisses. Paleozoic carbonate bedrock occurs in the area between Lakes Winnipeg and Manitoba and along the southwestern edge of the Precambrian Shield. Paleozoic carbonates also underlie the Hudson Bay Lowland. The western part of the region is dominated by Mesozoic and Tertiary shales. Mesozoic shales and sandstones extend westward into Saskatchewan, but Tertiary shales and sandstones are found in the Turtle Mountain uplands along the International Boundary in Manitoba.

Precambrian. The Precambrian rocks of Manitoba belong to two geological or structural provinces, the Churchill Province of northwestern Manitoba and northern Saskatchewan, and the Superior Province of eastern Manitoba and northwestern Ontario. The older



UPЄ	Proterozoic	D	Devonian	T	Tertiary
PЄ	Archean	S	Silurian	K	Cretaceous
		O	Ordovician	JR	Jurassic

Figure 6. Bedrock geology of Manitoba (Modified from Teller and Bluemle, 1983, Figure 1).

Archean rocks of the Superior Province are dominated by granitic rocks. The Archean and Proterozoic-aged rocks of the Churchill Province can be grouped into two broad types - those characterized by metavolcanic granulites and granitoid rocks and those dominated by metasedimentary supracrustal rocks (Manitoba Mineral Resources Division, 1979).

A greywacke, characteristic of the Proterozoic Omarolluk Formation (Nielsen, pers. comm. 1986) is an erratic in the tills of Manitoba. The Omarolluk greywacke, a distinctive unmetamorphosed greywacke with light circular concretions, originate in the greywacke beds of the Omarolluk Formation of the Belcher Group. The Belcher Group outcrops in the Belcher Islands along the east side of Hudson Bay (Ricketts and Donaldson, 1981, p. 245).

Paleozoic. Paleozoic strata consist almost entirely of dolomite, dolomitic limestone, and limestone, with only minor argillaceous and/or sandy intervals; the main exception is the basal sandstone-shale of the Winnipeg Formation (Manitoba Mineral Resources Division, 1979).

Mesozoic and Tertiary. Quaternary sediments everywhere overlie Mesozoic or early Tertiary bedrock in the Killarney-Holmfield region. The bedrock of the Killarney-Holmfield map-area was mapped by Bamburak (1978) and is discussed in detail by Bannatyne (1970). The oldest formation exposed in the area is the Upper Cretaceous Vermillion River Formation found in the Tiger Hills upland, near Glenboro (SE 22-06-14). The Vermillion River Formation consists of three members, in ascending order: the Morden Member, a black carbonaceous shale; the Boyne Member, a grey calcareous speckled shale and carbonaceous shale, and; the Pembina Member, a thinly interbedded carbonaceous shale, bentonite, and bentonitic shale.

The Vermillion River Formation is overlain by the Upper Cretaceous Riding Mountain Formation which underlies most of the Tiger Hills upland and the Boissevain Plain. The Riding Mountain Formation consists of three members, in ascending order: the Millwood Member, a soft greenish brown, bentonitic slightly silty clay; the Odanah Member, a hard grey siliceous clay shale; and the Coulter Member, a soft grey bentonitic clayey siltstone (Bamburak, 1978). The Riding Mountain Formation outcrops along major valleys and spillways. In the Pembina spillway near Ninette (NE 13-05-17) it is overlain by only a thin veneer of Quaternary sediments (Figure 7).

The Upper Cretaceous Boissevain Formation occurs between the Riding Mountain Formation and the overlying Paleocene Turtle Mountain Formation. The Boissevain Formation is dominantly sand with minor clay, silt and sandstone (Bamburak, 1978). Bamburak (1978, p. 8) describes the formation as composed of a thick lower unit of crossbedded, buff, quartz-rich, medium grained, "salt and pepper" sand, and a thin upper unit of massive white kaolinitic, fine-grained silt or clay. The Boissevain Formation outcrops about 18 km west of Killarney along Highway 3 (NW 35-02-19), and about 2 km southeast of Boissevain (NW 8-03-19).

The Paleocene Turtle Mountain Formation consists of two members, in ascending order: the Goodlands Member, an assemblage of thin, discontinuous lignite seams, erratically distributed within bentonitic sands, silts, and clays, and; the Peace Garden Member, an upper assemblage of grey silty clays with minor glauconitic sand and silt beds (Bamburak, 1978).

Figure 7. Shale bedrock of the Riding Mountain Formation outcropping in the south wall of the Pembina spillway at Rock Lake. Many thin bentonite beds are present.

Acknowledgments

I would like to express my sincere thanks to Dr. E. Nielsen of the Geological Services Branch, Manitoba Department of Energy and Mines for his guidance in the preparation of this manuscript and for providing the carbonate analysis of the silt plus clay fraction. Special thanks are directed to my advisor, Dr. J. Teller, Department of Geological Sciences, University of Manitoba, for his advice in the field and his guidance and encouragement in the preparation of this document. Funding for the 1981 field season was provided by Bob Young of the Aggregate Resources Section, Manitoba Department of Energy and Mines. Last, but certainly not least, I would like to thank my mother, without whose assistance the completion of this project would not have been possible.

TILL ANALYSES

Seven tills were identified in the map-area on the basis of lithology, carbonate content, texture, colour, and stratigraphic position. Ninety-one samples from forty-five locations were analyzed in the laboratory.

Field Methods

Samples of till were obtained with a shovel. The sample weight averaged 15 kg, a weight considered adequate to sample particle sizes up to 64 mm (-5 Phi). Clasts larger then 64 mm were not collected, but their presence was noted.

River and road cuts were used for gathering stratigraphic data. The river cuts offered the greatest vertical and lateral sections, although many sections, particularly along the Pembina spillway, consist of shale with only a thin capping of Quaternary sediments. Many rivers and streams are now undersized, or misfit streams, and their banks are vegetated.

Older road cuts are weathered, but in places their steep surfaces expose good sections. Many sections are, however, vegetated, and even with extensive clearing, only a small part of the Quaternary record can be observed.

Samples were generally taken from the middle of each identifiable till unit, avoiding the upper and lower contacts. Dreimanis (1982 p. 40) suggested that the basal 0.5 to 1.5 m of subglacial till should not be sampled, as it commonly consists of "mixed" material: reworked substratum plus the drift of the stratigraphic unit to be correlated.

It was not always possible to avoid these lower zones particularly where the till unit is very thin, as is typical of the highly calcareous till north of the Pembina spillway. All highly weathered, crumbly igneous and metamorphic clasts were excluded during sampling. Duplicate samples were taken to test accuracy of sampling and laboratory analyses.

Till fabrics were measured to determine the direction of ice flow that deposited the till. A fresh vertical exposure was prepared by removing all loose matrix and pebbles. The matrix surrounding the pebble was gently removed until the orientation of the long axis of the pebble could be determined. The pebble was then removed and replaced by a non-magnetic brass rod which was aligned with the pebble socket. The orientation of the rod was measured with a Silva compass and the dip was measured with a clinometer. The data was plotted on a Schmidt equal area net. A minimum of 50 pebbles at each site were measured. Disturbance of the till units by thrusting was evident throughout Killarney-Holmfield so several till fabrics were measured west of the map-area in sections where thrusting was not evident.

Colour was measured using the Munsell Color chart. To maintain uniformity, colour was measured on fresh, moist or moistened till.

Laboratory Analysis

Sample Preparation. Till samples were air dried on plastic sheets prior to weighing and disaggregation. Disaggregation consisted of breaking lumps by hand or by gentle hammering, taking care to prevent breaking the fragile shale clasts. Samples were hand sieved on a 4 mm (-2 Phi) sieve. The less than 4 mm size fraction was set aside for fine sediment and carbonate analysis. The fraction coarser than 4 mm was placed in a pail of water and allowed to soak for several days to break down the matrix. Once the sample had been reduced to a slurry of mud, sand and gravel, the mixture was washed through a 4 mm sieve. The coarse clasts, retained on the sieve were dried and sieved at one phi intervals. The 4 to 16 mm size range was retained for pebble counts.

Fine Sediment Analysis. About 150 g of the less than 4 mm fraction was obtained by passing the less than 4 mm fraction through a sample splitter. This portion was then precisely weighed, disaggregated in water and washed on a 0.0625 mm sieve to separate the sand and granules from the silt and clay. The sand and granule portion was then dried and sieved at one Phi intervals. The amount of sample retained on each sieve was precisely weighed and the amount of silt plus clay was calculated.

Selenite crystals were observed in most of the sand-sized fraction, particularly in the medium sand sizes. The selenite crystals are considered to have formed secondarily, from groundwater, after the till was deposited. After sieving, each sample was scanned with a binocular microscope. Generally, the selenite crystals constitute less than 2 to 3% of the total sand fraction, although in some samples, they represent over 30% of the medium sand size range. Removal of the selenite crystals by chemical means was considered, but research suggested that any chemical which would effectively remove the selenite crystals, would also remove some, if not all of the carbonate fraction. Samples with more than 30% selenite crystals were not analysed further.

Silt and Clay Analysis. Pipette analysis of the silt and clay fraction was performed according to the methods of Folk (1968 p. 37).

Flocculation was a major problem in most samples which prevented accurate analysis of the silt and clay fraction by the pipette method. The flocculation problem could not be solved due to the presence of selenite.

Silt and clay analyses were completed using a Sedigraph 5000D Analyzer. Only a very small amount of sample (about 1 - 2 grams) dispersed in about 25 ml of Calgon solution (0.0050 g/ml) was required for the analyses. Some samples appeared to be completely dispersed, but flocculation was observed in most. Duplicate samples were run and the results showed very little variance. Only 41 samples were processed using the Sedigraph and the results of the analyses are presented in Appendix II. However, because of the flocculation problem, the analyses are not considered to be accurate. Comparison of the silt and clay values for equivalent tills as described by Klassen (1979) indicate that the tills of the Killarney-Holmfield map-area consistently contain 10 to 20% less clay. Flocculation problems were not reported by Elson (1956) or Klassen (1969, 1971, 1979).

Carbonate Analysis. Carbonate analysis was performed on the less than 0.0625 mm fraction. Analysis was done at the Manitoba Department of Energy and Mines laboratory using a Leco Induction Furnace.

Petrography of the Pebble Fraction. Pebble counts were done on the 4 to 16 mm fraction. Samples were thoroughly mixed and quartered to obtain about 500 to 600 pebbles. The pebbles were separated into three categories: crystalline clasts, which included all igneous and metamorphic rock fragments derived from the Canadian Shield; carbonate clasts, which included both limestone and dolomite clasts from the Paleozoic carbonate bedrock; and shale clasts, derived from the underlying Mesozoic shales. Greywacke clasts, characteristic of the

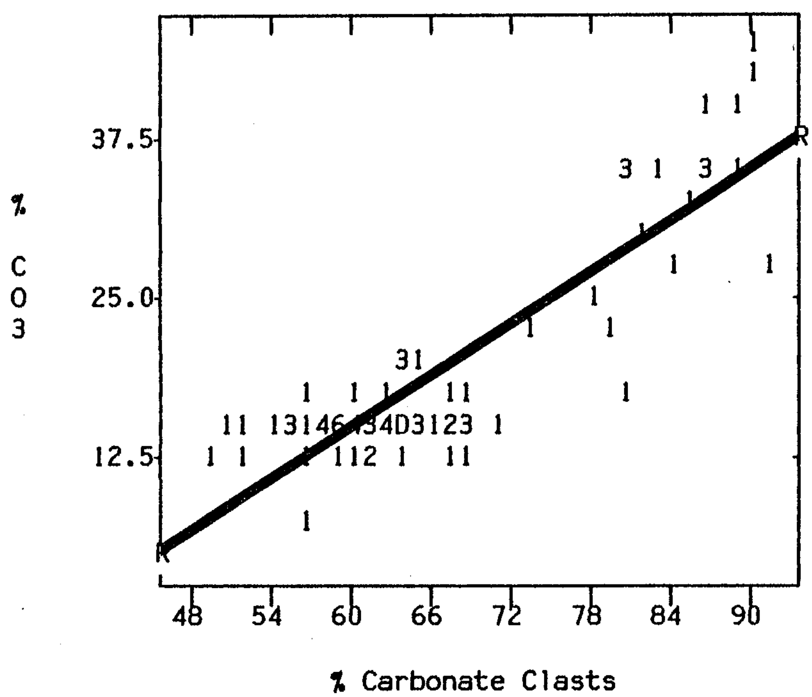
Proterozoic Omarolluk Formation, were counted separately and included with the Precambrian crystalline clasts.

Shale clasts, which fragmented and shattered, could not be counted accurately. Pebble counts were restricted to crystalline and carbonate clasts and the values are expressed as a percent of the total number of clasts counted.

To determine the proportion of shale, the crystalline, carbonate and shale pebble fractions were weighed and their presence expressed as a percent of their combined weight. Shale weight percentages within a single formation ranged from 0% to more than 85%.

A linear regression, performed to test the relationship between the percent carbonate of the 4 to 16 mm fraction and the less than 0.0625 mm fraction, resulted in a correlation coefficient of 0.87 and a coefficient of determination of 0.75, indicating that the relationship between the results derived by the two methods is strong (Figure 8). This suggests that in the absence of carbonate analyses for the less than 0.0625 mm fraction, similar inferences can be made using the results of the pebble counts of the 4 to 16 mm fraction. Some tills, from south of the Pembina spillway, exhibit the greatest variance between the two methods and have exceptionally high values for carbonate in the less than 0.0625 mm fraction. Excluding these tills from the regression would result in an even higher correlation.

Plot of Carbonate (<0.0625) vs Carbonate Clasts (4-16 mm)



Correlation	0.87	R Squared	0.75
Intercept	-25.30	Slope	0.68

Figure 8. Linear regression analysis of carbonate content of the less than 0.0625 mm fraction vs the carbonate content of the 4 to 16 mm fraction.

TILL STRATIGRAPHY OF THE STUDY AREA AND CORRELATION

Elson (1956) completed the first detailed study of the Pleistocene geology of southwestern Manitoba including the Brandon and the Virden 1:250 000 map sheets (Elson 1956; Halsted 1959). In the Brandon map-area Elson (1956, p. 175) identified three tills. He concluded that two tills separated by a boulder pavement in the southern half of the region had been deposited by ice that flowed southeastward, and a third till deposited north of the Darlingford moraine by a southwest and south-flowing sublobe situated in the Lake Agassiz basin.

The Pleistocene stratigraphy and surficial geology of the Riding Mountain and Duck Mountain area was mapped by Klassen (1969, 1971, 1979). Klassen (1979) identified seven formations in southwestern Manitoba and adjoining southeastern Saskatchewan, namely the Largs, Tee Lakes, Shell, Minnedosa, Lennard, Zelena and Arran Formations.

Seven tills have been identified in the Killarney-Holmfield area. Several of these tills, particularly in the area south of the Darlingford moraine, exhibit similarities in color and texture, and when observed alone in outcrop, cannot be positively identified. Klassen (1979 p. 7) stated that correlation of the till units seen in outcrop in the Riding and Duck Mountain areas is more reliable as it is based on physical properties such as jointing, weathered colour, stone fabric, carbonate content and stratigraphic position. In the Killarney-Holmfield area, the three main determinants were stratigraphic position, carbonate content of the pebble and silt plus clay fractions, and weathered colour. The silt and clay analyses are not considered to be accurate because of flocculation due to the presence of selenite. Grain size analyses show little variation between till units. The amount of shale clasts present in the pebble fraction is only indicative of the proximity of bedrock to the sampling location and cannot reliably be used for correlation purposes.

The diagnostic properties of the tills are summarized in the following sections and in Table 1 and Figure 9. Detailed descriptions of the sections are presented in Appendix I and grain size and petrographic data are presented in Appendix II.

Largs Formation

The stratigraphically lowest exposed till in the Killarney-Holmfield area overlies shale bedrock at the base of the Long River Section (Section GC494, Appendix I). In this section it is overlain by tills of the Shell, Minnedosa, and Lennard Formations. It also outcrops to the west of the study area, at the base of a section along a short tributary south of the Souris River valley, south of Bunclody (Section GC589, Appendix I). At this location it is overlain by till of the Shell Formation. A till fabric measured at the Bunclody section indicates that glacier flow was to the south-southwest (Figure 10). This till is generally less than 2 metres thick.

The colour is typically light olive brown (2.5Y 5/4) or olive brown (2.5Y 4/4) and it is strongly oxidized along joints. It is a very compact, clayey-silt till (Figure 11a, b). The shale clast content ranges from 63% to 71%, noticeably higher than the other tills (Figure 11c). The carbonate content of the silt plus clay fraction ranges from 8 to 11%, noticeably lower than the overlying tills (Table 1, Figure 9).

Formations	Grain Size Analysis Gravel (%)	Sand (%)	Si+Cl (%)	Pebble Lithology of 4-16 mm Fraction Cryst. (%)	Carb. (%)	Gwke. (%)	Carb. <0.0625 mm CO3 (%)
Belmont (n=16)	11 6-15	35 23-53	54 39-63	14 9-20	86 80-91	0.6 0.0-1.4	35 27-44
Glenora (n=8)	9 6-12	36 19-44	57 50-72	30 19-37	70 63-81	1.2 0.3-2.5	21 18-25
Lennard (n=34)	10 4-21	38 29-50	52 36-66	37 31-45	63 55-69	1.6 0.0-4.2	15 13-16
Minnedosa (n=23)	10 3-13	37 27-44	53 45-68	40 29-50	60 50-71	1.9 0.3-3.9	16 14-17
Shell (n=7)	9 7-16	36 29-43	55 49-63	43 38-51	57 49-62	2.5 1.3-5.1	13 12-16
Tee Lakes (n=1)	12	36	52	27	73	0.9	23
Largs (n=2)	15 11-19	35 32-38	50 49-51	39 33-44	62 56-67	1.5 0.8-2.1	10 8-11

Table 1. Texture, pebble lithology, and carbonate analysis for the tills of the Killarney-Holmfield area. The upper number is the mean, the lower number is the range. n is the number of observations.

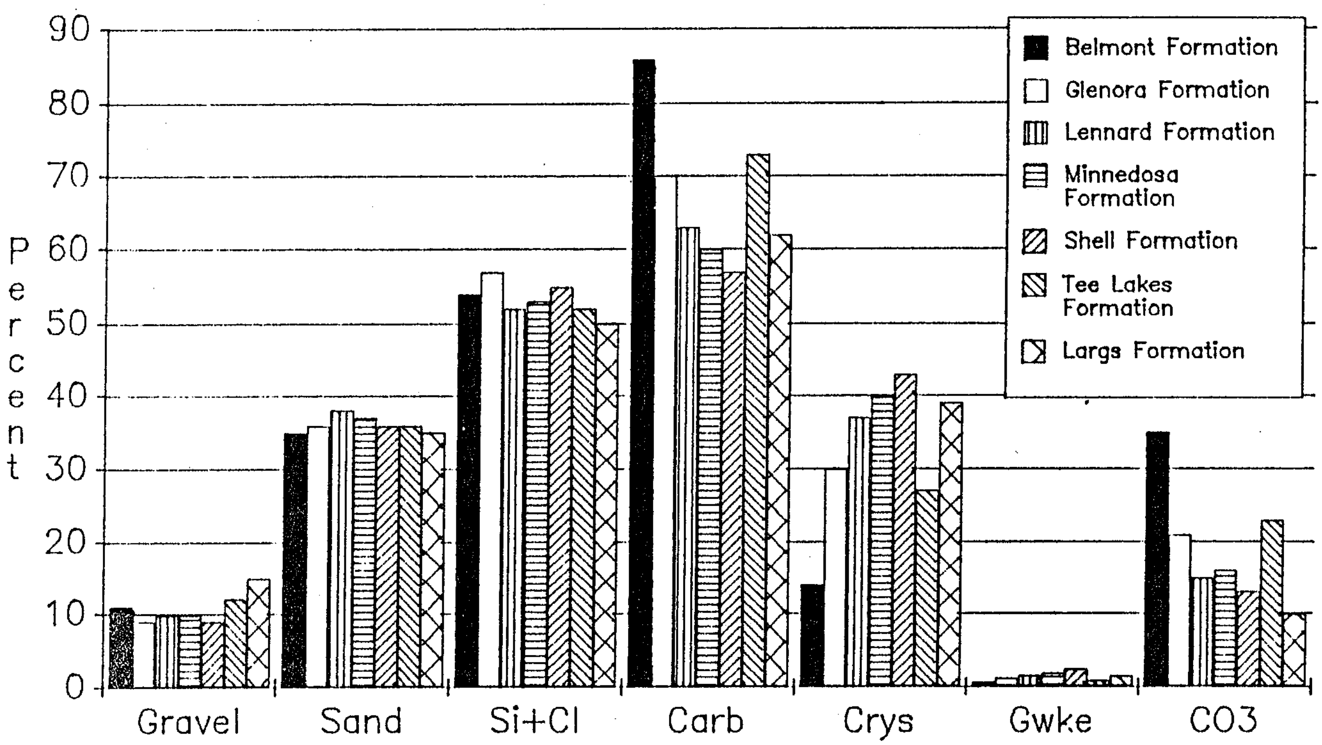


Figure 9. Histograms of mean values from the analysis of tills of the Killarney-Holmfield area.

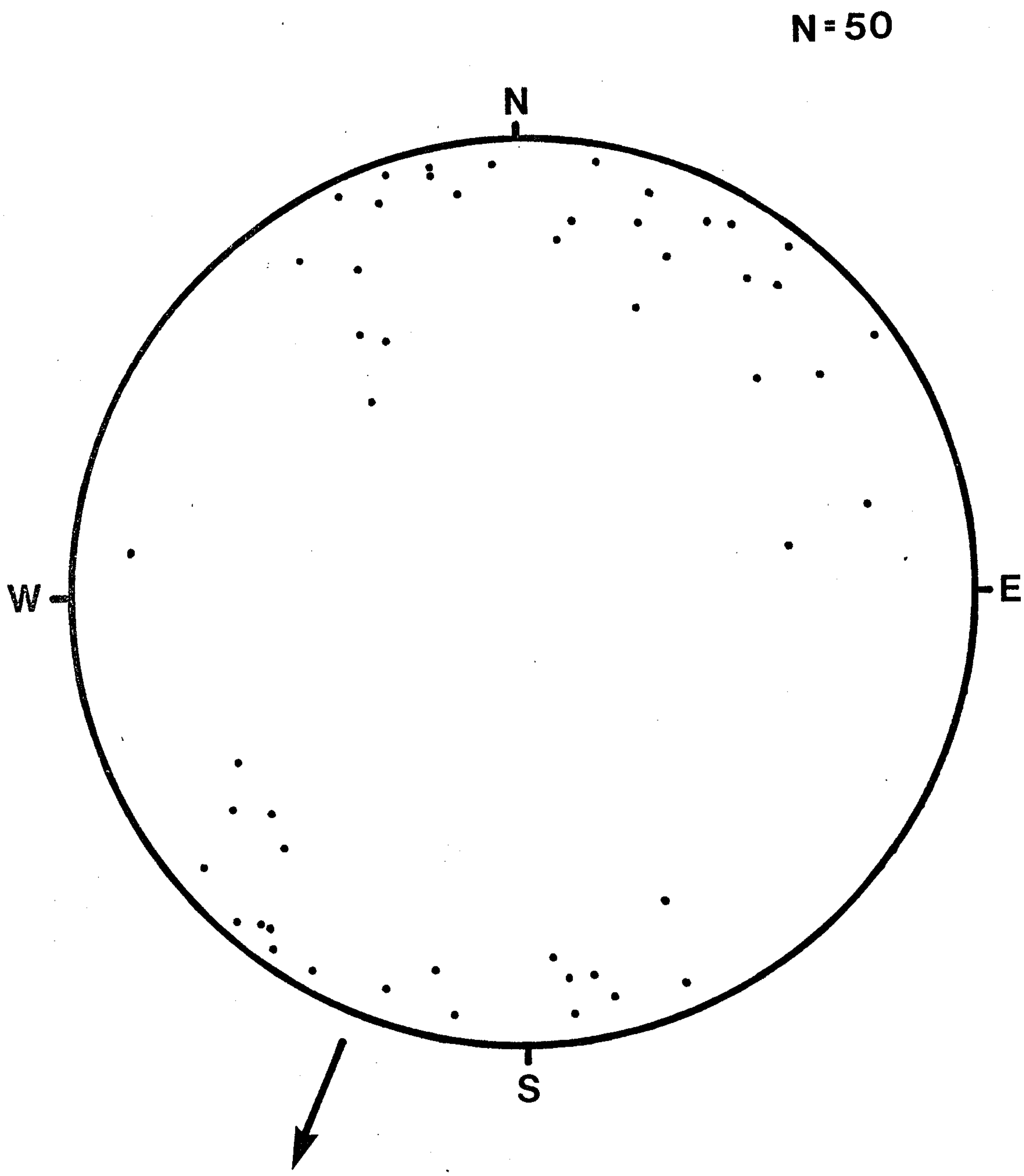


Figure 10. Lower heimisphere equal-area projection of pebble orientations in the Largs Formation (Section GC589, Appendix I).

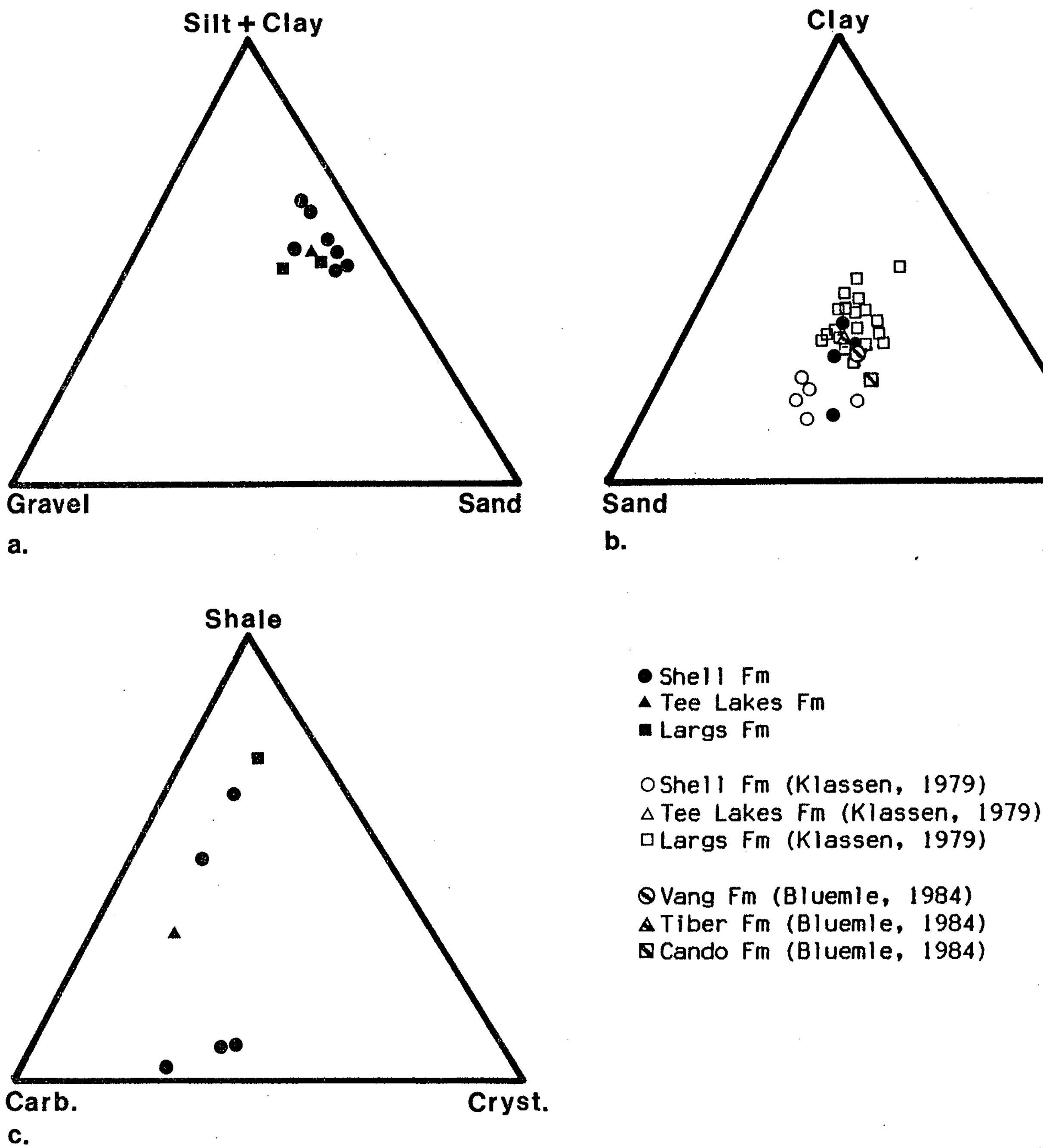


Figure 11. Ternary diagrams for Largs, Tee Lakes, and Shell Formations of southwestern Manitoba and the Cando, Tiber, and Vang Formations of northeastern North Dakota: a) Gravel, sand, silt plus clay; b) sand, silt, clay; c) Clast analysis, carbonate, crystalline, shale, expressed as a percent of the total weight.

This till is considered to be equivalent to Klassen's (1979) Largs Formation on the basis of stratigraphic position, a typically low carbonate content of the silt plus clay fraction (Table 2) and a high shale content.

Klassen (1979) believed that the stratigraphic position of this formation indicates that it is of pre-Wisconsinan age and probably is early Pleistocene.

Tee Lakes Formation

An oxidized very dark grey (10YR 3/1) till is exposed 3.2 km west of Killarney and 0.6 km south of Highway 3 (Section GC593, Appendix I). It is overlain by till of the Minnedosa Formation. The carbonate content of the silt plus clay fraction is 23% and it contains 73% carbonate clasts in the pebble fraction, significantly higher than any of the other tills found south of the Pembina Spillway (Table 1). The till fabric measured at this site indicates that the glacier flow was to the south or south-southeast (Figure 12). Only one outcrop of this till was observed.

This till is considered to be equivalent to Klassen's (1979) Tee Lakes Formation on the basis of stratigraphic position and the high carbonate content (Table 2).

Klassen (1979) considered the Tee Lakes Formation to be of probable pre-Wisconsinan age.

Shell Formation

A distinctive black till is observed in seven sections scattered throughout the area. Characteristic colours are dark grey (10YR 4/1) or very dark grey (10YR 3/1) or brown-dark brown (10YR 4/3) or dark yellowish brown (10YR 4/4) or light greyish brown (2.5Y 4/3) or very

Formations	Killarney-Holmfield (this paper) Carbonate Content of the <0.0625 mm size fraction (Leco Induction Furnace)	Formations	Riding and Duck Mountains (Klassen, 1979) Carbonate Content of the silt fraction (Chittick Method)
Belmont	27 – 44	Arran	34 – 65
Glenora	18 – 25	Zelena	26 – 36
Lennard	13 – 16	Lennard	14 – 19
Minnedosa	14 – 17	Minnedosa	18 – 24
Shell	12 – 16	Shell	13 – 18 * 24 – 36 **
Tee Lakes	23	Tee Lakes	20 – 26
Largs	8 – 11	Largs	9 – 21

Table 2. Comparison of the carbonate content of the less than 0.0625 mm fraction of the tills of the Killarney-Holmfield area and the carbonate content of the silt fraction of the tills of the Riding and Duck Mountain areas of Klassen (1979). Klassen (1979) p. 2) analyzed the silt fraction for carbonate content by the Chittick Method. The numbers are the range of values for each till unit, expressed as a percent. (* Weathered zone, ** Unweathered zone)

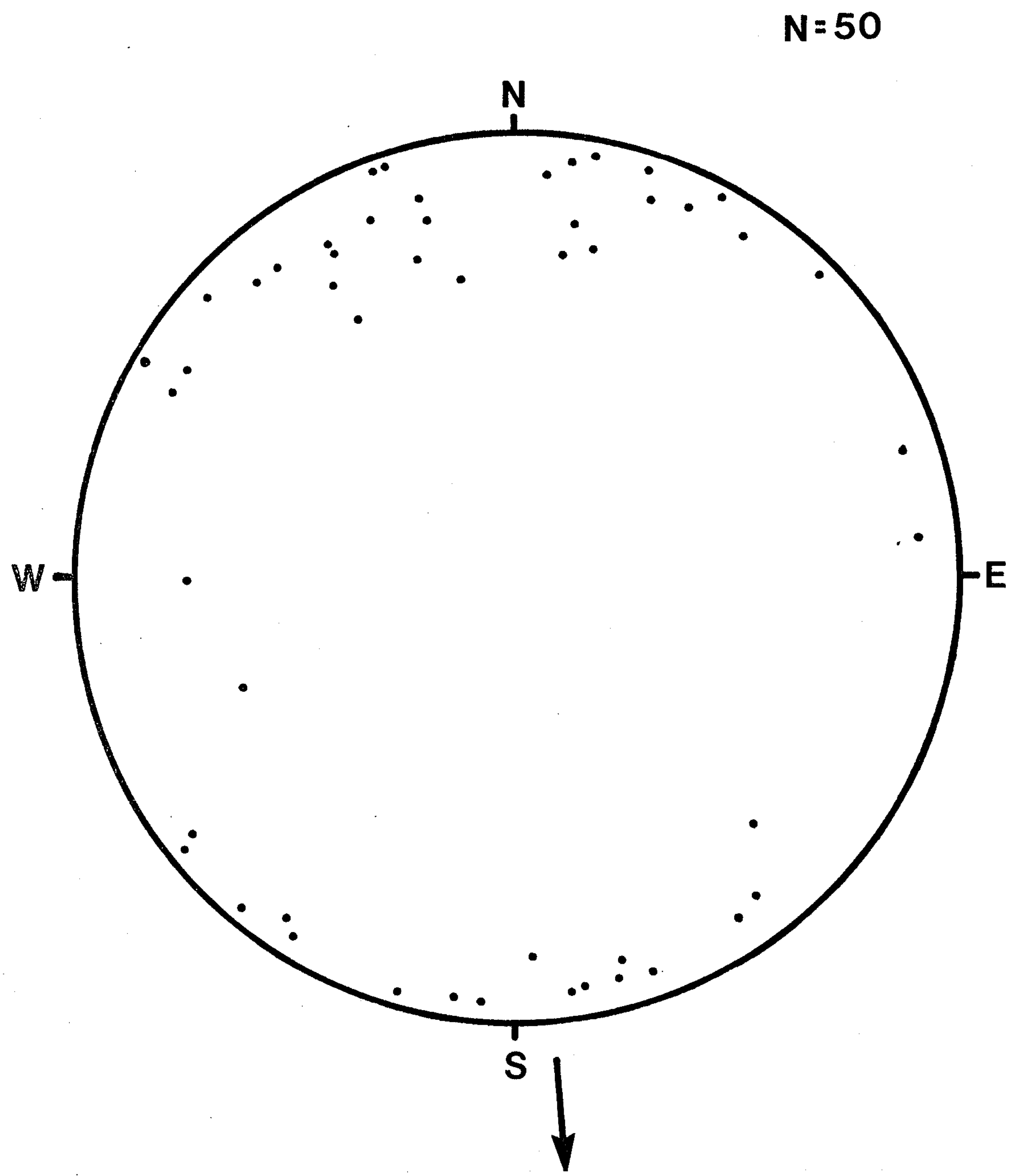


Figure 12. Lower heimisphere equal-area projection of pebble orientations in the Tee Lakes Formation (Section GC593, Appendix I).

dark greyish brown (2.5 Y 4/2) (Figure 13). This till is generally less than 2 metres thick in outcrop.

In the Long River Section (Section GC494, Appendix I), it is separated from the overlying Minnedosa Formation by a cobble lag (Figure 14) whereas in the Bunclody section, it is overlain by a thin cross-bedded sand and gravel bed (Section GC589, Appendix I). In both sections, it overlies till of the Largs Formation. The till fabric measured in the Bunclody section indicates that ice flow was to the east-southeast (Figure 15).

The till consists of 29 to 43% sand (Figure 11a, b). Carbonate content of the silt plus clay fraction ranges from 12 to 16% (Table 1). Shale constitutes less than 10% but rises to more than 60% where the till overlies shale bedrock (Figure 11c).

This till is considered to be equivalent to Klassen's (1979) Shell Formation, primarily on the basis of stratigraphic position, (underlying the Minnedosa Formation and overlying the Largs Formation), and the presence of a weathering zone between the overlying Minnedosa and the Shell Formation. Klassen (1979) however, noted considerable variation in carbonate content between the weathered (13 to 18%) and unweathered (24 to 36%) portion of the Shell Formation. The carbonate values for the Shell Till in the Killarney-Holmfield area are consistent with the weathered portion reported by Klassen (1979) (Table 2).

Klassen (1969, p. 11; 1975, p. 5) stated that the Shell Formation is of Early Wisconsinan or pre-Wisconsinan age and that at least two major glaciations and nonglacial intervals of interstadial or interglacial rank followed its deposition.

Figure 13. Photograph of the Shell Formation (Section GC607, Appendix I). A quarter is included for scale.

Figure 14. The cobble and boulder lag in the centre of the photograph marks the contact between the Shell Formation and the overlying Minnedosa Formation in the Long River Section (Section GC494, Appendix I). The thin boulder lag near the surface marks the contact between the Lennard Formation and overlying outwash sands and silts.

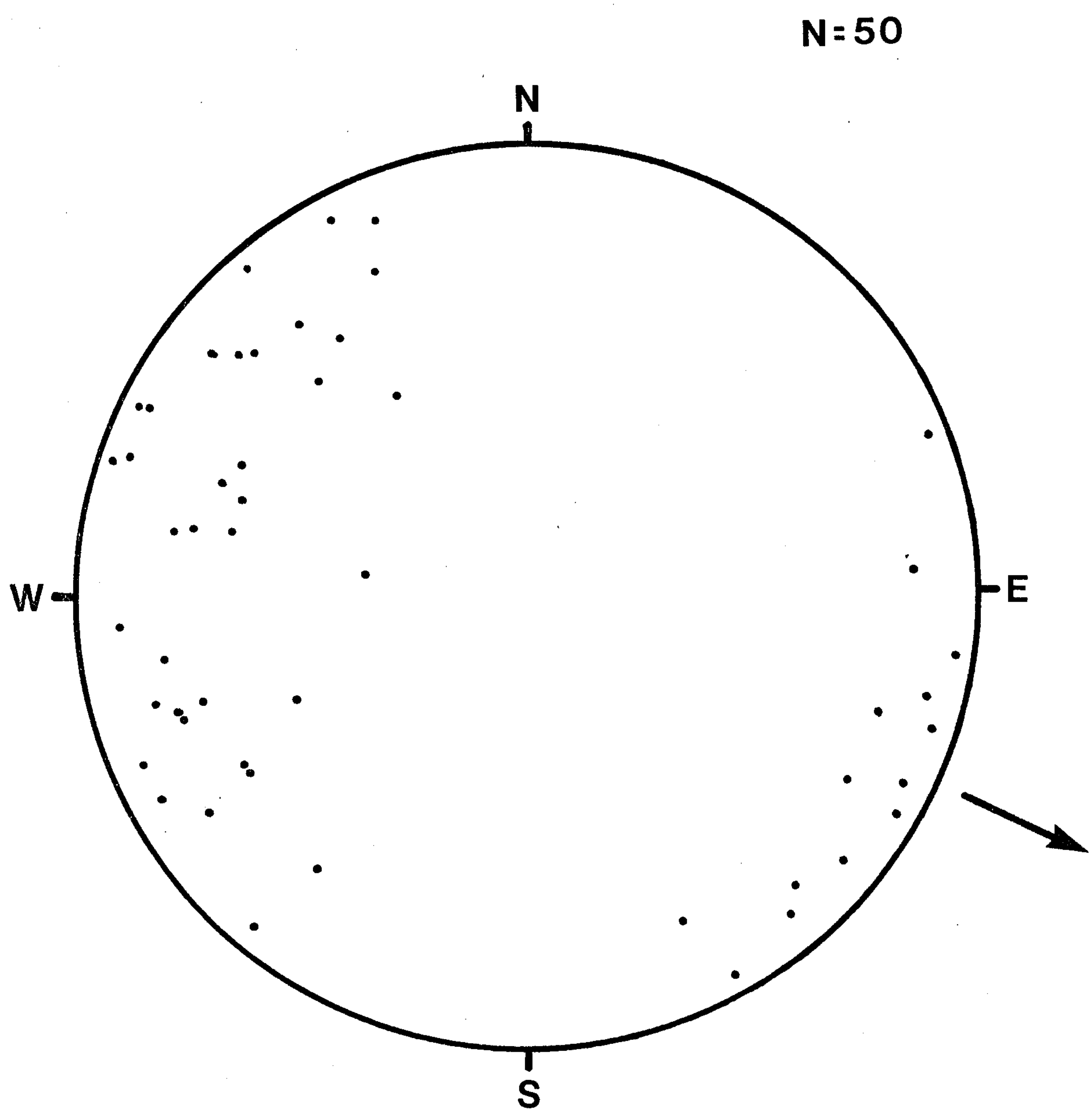


Figure 15. Lower heimisphere equal-area projection of pebble orientations in the Shell Formation (Section GC589, Appendix I).

Minnedosa Formation

Overlying the Shell Formation is a till that is widespread throughout the area. It is usually overlain by the Lennard Formation, but often outcrops at the surface. The contact with the overlying Lennard Formation is usually marked by a striated boulder pavement, as for example, in the Lena Section, 1.6 km north of Lena (Section GC345, Appendix I). The till fabric measured in the Lena Section indicates that glacier flow was to the south-southeast (Figure 16). Thicknesses of this till range from 0.4 m to greater than 4 m in outcrop.

The colour is typically olive brown (2.5Y 4/4) or dark greyish brown (2.5Y 4/2) or very dark greyish brown (2.5Y 3/2) or brown-dark brown (10YR 4/3). It is highly jointed and is usually oxidized (Figure 17). Sand and silt are present in near equal proportions (Figure 18a, b) and the carbonate content of the silt plus clay fraction ranges from 14 to 17% with a mean of 16% (Table 1, Figure 9). The shale content of the pebble fraction is highly variable, ranging from 0 to 51%, with a mean of 21% (Figure 18c).

This till is considered to be equivalent to Klassen's (1979) Minnedosa Formation primarily on the basis of stratigraphic position and association with the boulder pavement at the contact with the overlying Lennard Formation. Carbonate content of the silt plus clay fraction is slightly lower in the Killarney-Holmfield area (Table 2). Klassen (1979) noted that orientations of elongate till stones evident in several outcrops indicate that glacier flow likely was to the southwest. The difference between ice flow direction reported by Klassen (1979) in his study area to the northwest and this area can be attributed to deflection of the glacier by the Riding and Duck Mountain uplands to the north and the Turtle Mountain upland to the

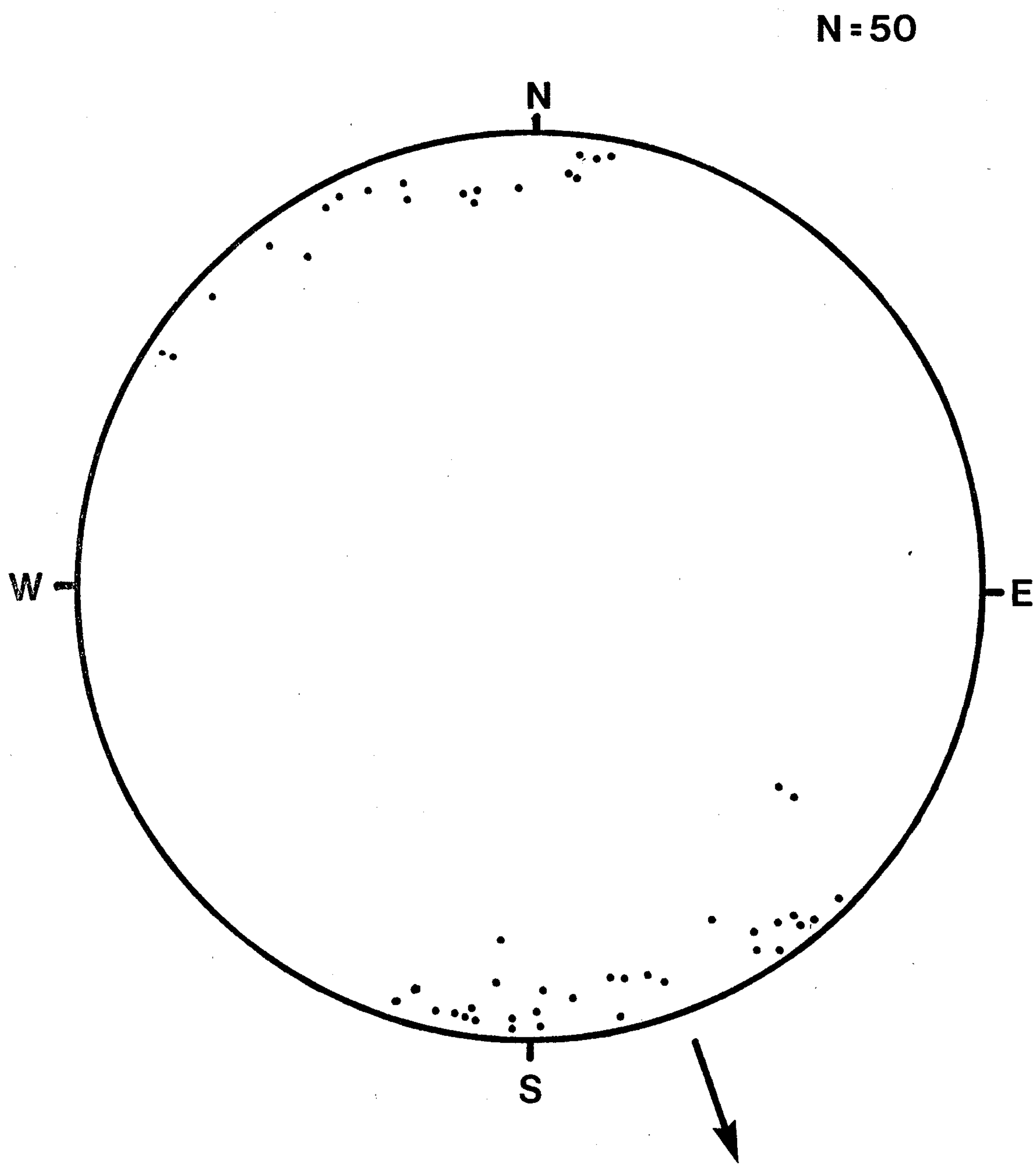


Figure 16. Lower heimisphere equal-area projection of pebble orientations in the Minnedosa Formation (Section GC345, Appendix I).

Figure 17. Minnedosa Formation exhibiting strong jointing and staining by iron and manganese (Section GC607, Appendix I). Silva Compass is included for scale.

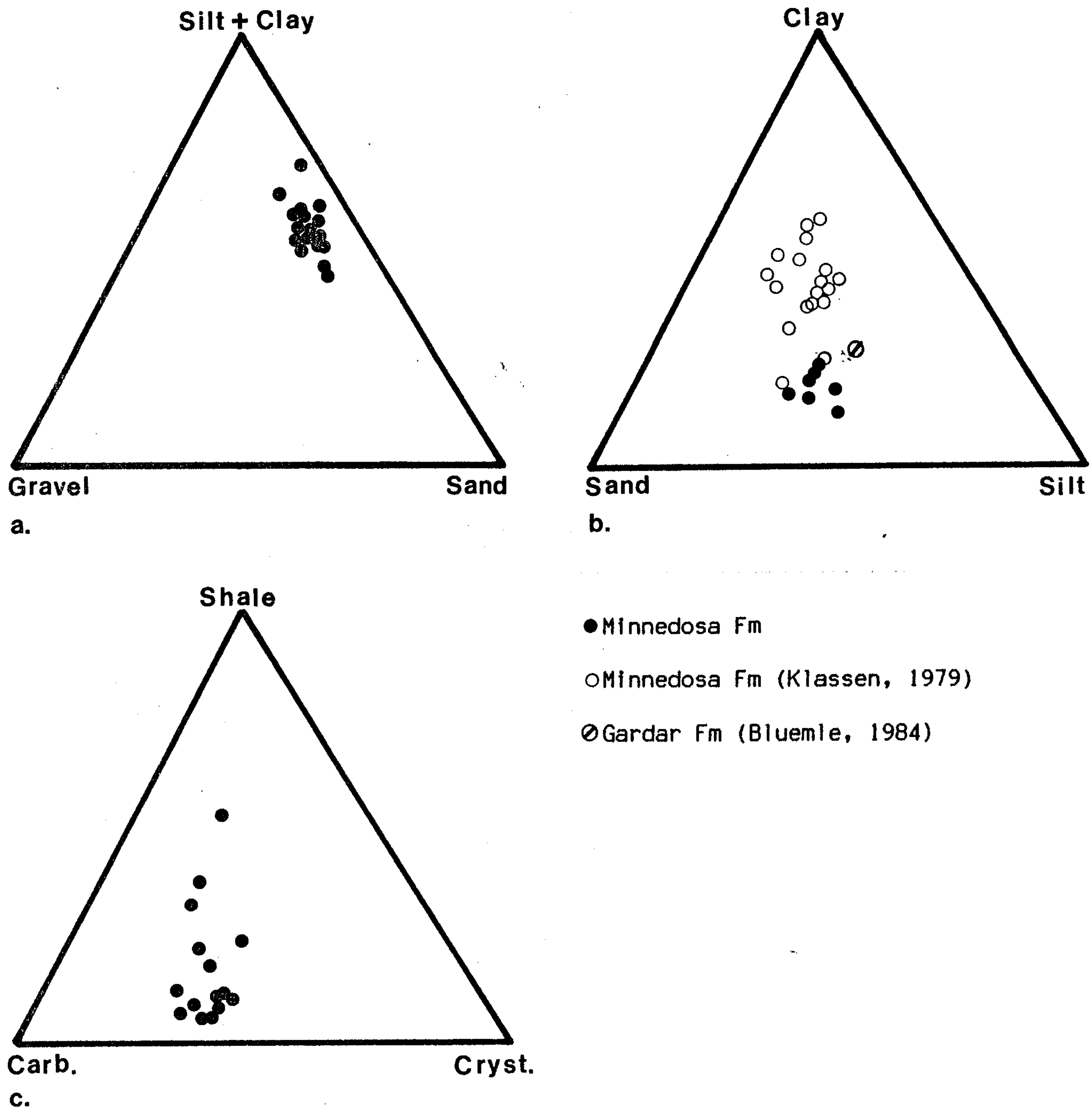


Figure 18. Ternary diagrams for the Minnedosa Formation of southwestern Manitoba and the Gardar Formation of northeastern North Dakota: a) Gravel, sand, silt plus clay; b) sand, silt, clay; c) Clast analysis, carbonate, crystalline, shale, expressed as a percent of the total weight.

south.

Klassen (1979) considered an Early Wisconsinan age most likely for this till. Finite radiocarbon dates were obtained by him from a silt and clay bed between the Minnedosa Formation and the overlying Zelena Formation in the Zelena Section on Duck Mountain. The dates obtained are 23 700$\pm$290 (GSC-1279) and 37 700$\pm$1500 (GSC-653) on charcoal, and 28 220$\pm$380 (GSC-711) on marl (Klassen, 1979).

Lennard Formation

This till is widespread throughout the area and is the uppermost till in the Boissevain plain, south of the Pembina Spillway. North of the Pembina Spillway it is overlain by tills of the Glenora and Belmont Formations.

The colour is typically olive brown (2.5Y 4/4) or light olive brown (2.5Y 5/4) and is generally unoxidized. It is a thin unit, usually less than 2 metres thick, but in some areas it is missing and the Minnedosa Formation, capped by a boulder pavement, outcrops at the surface. In other areas, it consists of several beds or diamictons and intertill sediments more than 10 metres total thickness (Section GC375, Appendix I).

The texture and pebble lithology is similar to that of the Minnedosa Formation. Sand and silt occur in almost equal amounts (Figure 19b) and the carbonate content of the silt plus clay fraction ranges from 13 to 16% with a mean of 15% (Table 1, Figure 9). Carbonate in the clast size fraction ranges from 55 to 69%, with a mean of 65% (Table 1). A diagnostic feature of this till is the presence of a striated boulder pavement at the contact with the underlying Minnedosa Formation (Figure 20). The boulder pavement is

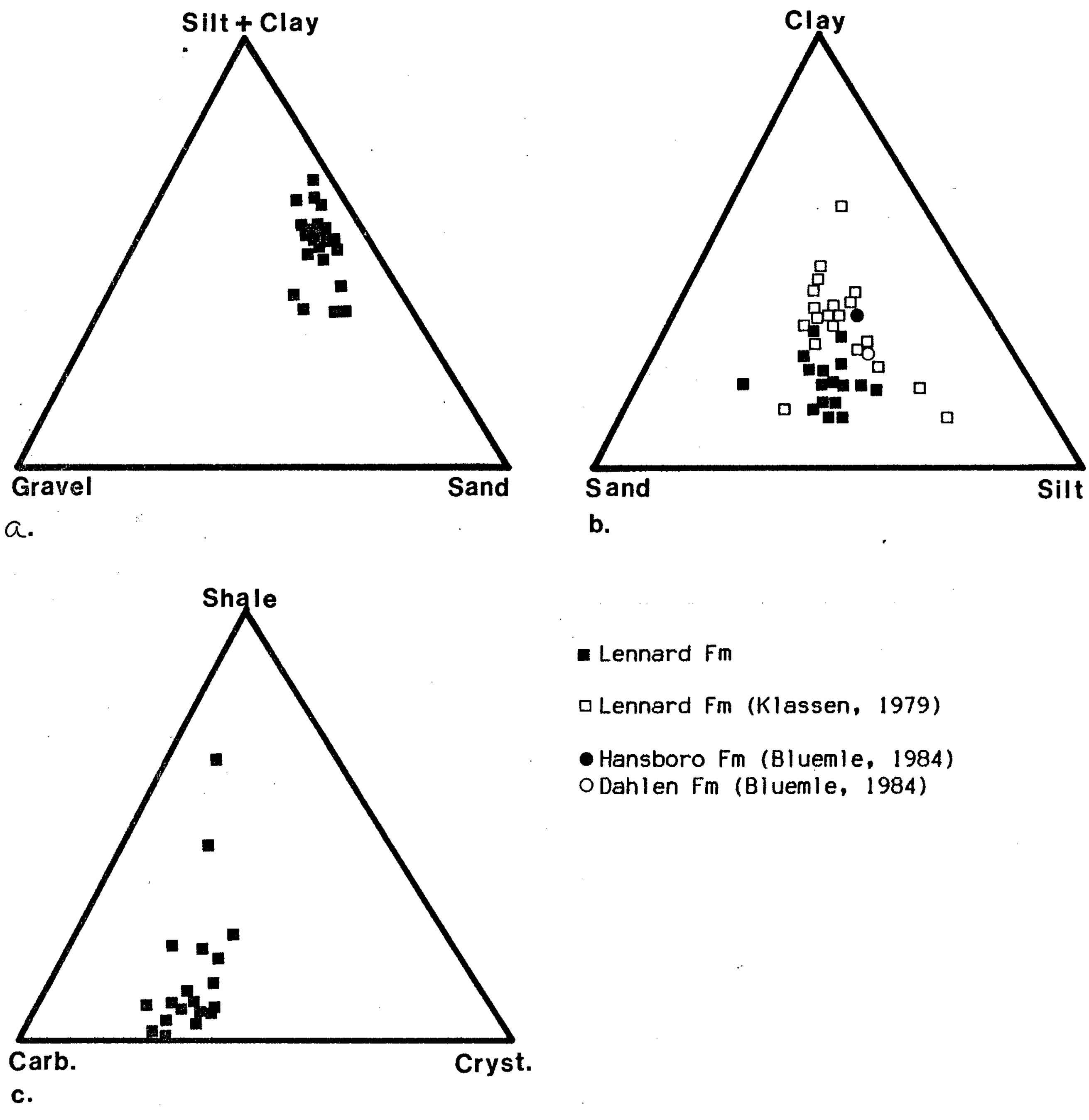


Figure 19. Ternary diagrams for the Lennard Formation of southwestern Manitoba and the Dahlen and Hansboro Formations of northeastern North Dakota: a) Gravel, sand, silt plus clay; b) sand, silt, clay; c) Clast analysis, carbonate, crystalline, shale, expressed as a percent of the total weight.

Figure 20. Boulder pavement outcropping in a road exposure along Highway 18 near Lena, Manitoba. The boulder pavement marks the contact between the Minnedosa Formation and the overlying Lennard Formation. The shovel is at the level of the pavement.

commonly present at the base of this formation where it overlies shale bedrock, sandstone of the Boissevain Formation, or sand and gravel outwash (Section GC324, Appendix I). Striations on the boulder pavement indicate glacier flow to the southeast.

In the absence of the striated boulder pavement it is difficult to differentiate between this till and the Minnedosa Till, both in the field and in the laboratory. Where both tills are present in a section, it is apparent that the Lennard Till is less oxidized than the Minnedosa Till. However, when one till is absent, the contrast in oxidation is not apparent.

This uppermost till on the Boissevain plain is considered to be the Lennard Formation of Klassen (1979) based on its stratigraphic position in relation to the boulder pavement and because it is the uppermost till in western Manitoba and southeastern Saskatchewan.

The Lennard Formation was deposited during the Late Wisconsinan glaciation by southeasterly flowing ice (Klassen, 1979).

Glenora Formation

Two highly calcareous tills outcrop north of the Pembina Spillway, and extend only as far south as the Darlingford moraine.

The lower of these two tills is typically olive brown (2.5Y 4/4) or light olive brown (2.5Y 5/4) or dark greyish brown (2.5Y 4/2). This till is generally less than a metre thick. A thin band of olive silt, 2 cm or less in thickness, is usually present at the contact with the overlying Belmont Formation (Figure 21). The type section within the study area is located 15.5 km west and 1.6 km north of the town of Glenora, after which this till is named (Section GC535, Appendix I). This section is located near the north edge of the

Figure 21. Contact between the Glenora and the overlying Belmont Formation. In this exposure the contact between the two formations is marked by the pink horizon.

Darlingford moraine. Outside the study area, a more complete section is located 11.3 km west and 6.4 km south of Wawanesa (Section GC400, Appendix I).

The carbonate content of the silt plus clay fraction ranges from 18 to 25%, with an mean of 21% (Table 1, Figure 9). The carbonate clast content ranges from 63 to 81% with a mean of 70%.

This till is similar in colour, but is slightly sandier than the Zelena Formation of Klassen (1979) (Figure 22b). The carbonate content of the silt plus clay fraction is slightly lower than that of the Zelena Formation, but significantly higher than that of the underlying Lennard Formation (Table 2). Analysis of the till of the Zelena Formation on Porcupine Mountain by Nielsen (pers. comm. 1986) indicates that the lithology of the pebble fraction and carbonate content of the silt plus clay fraction are nearly identical, in spite of the distance separating the two areas (Table 3). This till is considered to be the southern equivalent of the Zelena Formation of Klassen (1979) on the basis of the carbonate content of the silt plus clay fraction and the lithology of the pebble fraction, as analyzed by Nielsen (pers. comm. 1986).

Klassen (1979) believed the Zelena and Lennard Formations to be time equivalent in the Riding and Duck Mountains. The Zelena Formation outcrops at the surface on Riding and Duck Mountains and overlies the Minnedosa Formation. It underlies the Arran Formation on the Valley River plain (Klassen, 1979) (Figure 5). In the Killarney-Holmfield area, the Glenora Formation has been observed overlying the Lennard Formation in section GC578 in the Tiger Hills upland, north of the Darlingford moraine. The Darlingford moraine marks the maximum extent of a readvance from the north or northeast that deposited the

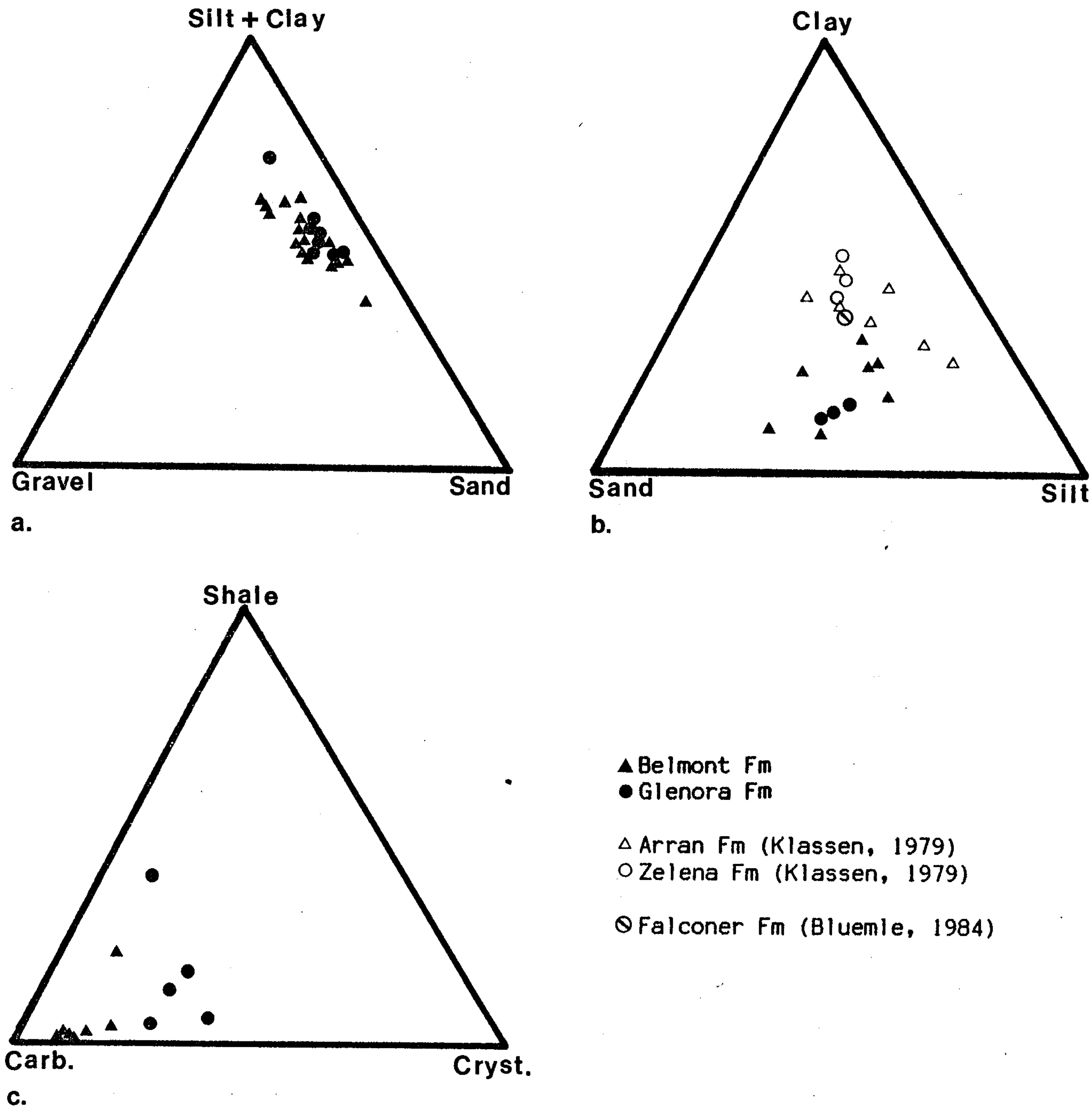


Figure 22. Ternary diagrams for the Glenora and Belmont Formations of the Killarney-Holmfield area, the Arran and Zelena Formations of the Riding and Duck Mountain areas and the Falconer Formation of northeastern North Dakota: a) Gravel, sand, silt plus clay; b) sand, silt, clay; c) Clast analysis, carbonate, crystalline, shale, expressed as a percent of the total weight.

	Pebble Lithology of 4-16 mm Fraction			Carb. <0.0625 mm CO3 (%)
	Cryst. (%)	Carb. (%)	Gwke. (%)	
Arran Formation (n=10)	12 10-17	88 83-90	0.4 0.2-0.8	41 38-45
Upper Till at Komarno (n=34)	15 11-20	85 80-89	0.5 0.0-1.0	N/A
Zelena Formation (n=10)	30 26-41	70 59-74	2.6 1.0-4.2	20 17-27

Table 3. Pebble lithology and carbonate content of the tills of the Arran Formation at Swan Wake, the Upper Till at Komarno and the Zelena Formation on Porcupine Mountain (Nielsen, pers. comm. 1986). The upper number is the mean, the lower number is the range. n is the number of observations. Swan Lake is located east of Porcupine Mountain and Komarno is located in the southern Interlake, 65 km north of Winnipeg. Carbonate content was performed using the Leco Induction Furnace.

Glenora Formation. Overlapping of the Lennard Formation by the Glenora Formation only occurs at this southern extent.

Belmont Formation

The youngest till in the area outcrops at the surface in the Tiger Hills, north of the Darlingford moraine. Its distribution is patchy, and it attains thicknesses greater than 4.5 metres. It overlies the Glenora, Lennard, Minnedosa, or Shell Formations. The type section for the Belmont Formation is 12.9 km west and 6.4 km north of the town of Belmont, after which it is named (Section GC413, Appendix I).

This till is typically light olive brown (2.5Y 5/4) or brown (10YR 5/3) or yellowish brown (10YR 5/4). It is characterized by a carbonate content of the silt plus clay fraction ranging from 27 to 44% with a mean of 35% (Table 1, Figure 9). The carbonate clast content ranges from 80 to 91% with a mean of 86%.

The Belmont Formation is similar in colour and carbonate content of the silt plus clay fraction to that of the Arran Formation of Klassen (1979) (Table 2). Analysis of the Arran Formation from Swan Lake, located east of Porcupine Mountain, and the upper till from the Komarno area in the Manitoba Interlake by Nielsen (pers. comm. 1986) (Table 3) indicate a close similarity with these tills with respect to the lithology of the pebble fraction and the carbonate content of the silt plus clay fraction. On the basis of the analyses, and as each of these tills represent the last drift deposited in their respective study areas, it would be possible to consider the Belmont Formation in the Killarney-Holmfield area and the the upper till at Komarno to be equivalent to the Arran Formation of Klassen (1979). However, on the basis of their interpretative work, Nielsen and Thorleifson (1985) believed that the ice which deposited the Arran Formation terminated in a large calving bay centered on the southern end of Lake Winnipeg at a moraine just south of Lake Manitoba. The maximum extent of the Belmont Formation in the Killarney-Holmfield area is marked by the Darlingford moraine, 110 km to the southwest of Lake Manitoba. The area between the two moraines is occupied by the Assiniboine Delta. It is not possible to correlate the Belmont Formation with the Arran Formation at this time.

REGIONAL CORRELATION

Introduction

Quaternary correlations for southwestern Manitoba, northwestern Minnesota, and northeastern North Dakota were summarized by Moran et al. (1976) and revised by Fenton et al. (1983) and Fenton (1984). However, the stratigraphy of southwestern Manitoba, south of Riding Mountain, was poorly known, and detailed correlation with this area was not possible by Fenton et al. (1983) and Fenton (1984).

Bluemle (1984) discussed a stratigraphic and correlation study by Howard Hobbs (unpublished) for northeastern North Dakota, and particularly for Towner County (Table 4). Seven formations were recognized throughout northeastern North Dakota, similar to those documented in the Killarney-Holmfield and the Riding and Duck Mountain areas. A tentative correlation of stratigraphic units in Killarney-Holmfield with units in the surrounding region is presented in Table 5. A location map of the areas discussed is presented in Figure 23.

Largs-Cando Formations

The oldest and stratigraphically lowest till units recognized are the Cando Formation in northeast North Dakota and the Largs Formation in Killarney-Holmfield. Both units overlie Cretaceous shale bedrock, however the Cando Formation overlies older unnamed glacial sediment in some places (Bluemle, 1984). The two tills are similar in texture, although the Cando Formation is slightly more silty than the Largs Formation (Figure 11b). The shale clast content is noticeably higher

Formations	Grain Size Analysis Sand (%)	Silt (%)	Clay (%)	Lithology of Coarse Sand Fraction Cryst. (%)	Carb. (%)	Shale (%)	Recalculated Coarse Sand Lithology Cryst. (%)	Carb. (%)
*Falconer	29	33	38	42	34	24	55	45
Hansboro	28	38	34	50	27	23	65	35
Dahlen	29	44	27	26	19	55	58	42
Gardar	32	42	26	10	8	82	56	44
Vang	34	35	31	40	25	35	62	38
*Tiber	27	38	35	21	28	51	43	57
Cando	35	41	24	25	16	59	61	39

Table 4. Texture and coarse sand (1-2 mm) lithology of the tills of Towner County (modified from Bluemle, 1984, p. 10). The last two columns are the coarse sand lithology recalculated to exclude shale. (* Not recognized in Towner County.)

<table>
<tr><th>STAGE</th><th>RIDING AND DUCK MOUNTAINS
1</th><th>SOUTHWEST MANITOBA
2</th><th>NORTHEAST NORTH DAKOTA
3</th><th>NORTHWEST MINNESOTA
4</th><th>SOUTHEAST MANITOBA
5</th></tr>
<tr><td rowspan="8">Late Wisconsinan</td><td rowspan="3">Arran Fm</td><td>Assin. Delta</td><td rowspan="3">Brenna Fm</td><td rowspan="3">Brenna Fm</td><td>Unit 1</td></tr>
<tr><td>Belmont Fm</td><td>Marchand Fm</td></tr>
<tr><td>Wawanesa Clay</td><td>Unit 1</td></tr>
<tr><td rowspan="5">Lennard/
Zelena Fm</td><td>Glenora Fm</td><td>Falconer Fm</td><td>Falconer Fm</td><td>Whitemouth L. Fm</td></tr>
<tr><td></td><td>Wylie Fm</td><td>Wylie Fm</td><td>Wylie Fm</td></tr>
<tr><td rowspan="3">Lennard Fm</td><td>Hansboro Fm</td><td>U. R.L. Falls Fm</td><td rowspan="2">Roseau Fm</td></tr>
<tr><td rowspan="2">Dahlen Fm</td><td>L. R.L. Falls Fm</td></tr>
<tr><td>St. Hilaire Fm</td><td>Senkiw Fm</td></tr>
<tr><td>Middle Wisconsinan</td><td colspan="4">U N C O N F O R M I T Y</td><td>Vita Fm</td></tr>
<tr><td rowspan="2">Early Wisconsinan</td><td rowspan="2">Minnedosa Fm</td><td rowspan="2">Minnedosa Fm</td><td rowspan="2">Gardar Fm</td><td rowspan="2">Marcoux Fm</td><td>Tolstoi Fm</td></tr>
<tr><td>Stuartburn Fm</td></tr>
<tr><td>Sangamonian</td><td>Roaring R. Clay</td><td colspan="3">U N C O N F O R M I T Y</td><td>St. Malo Fm</td></tr>
<tr><td rowspan="3">Pre-Wisconsinan</td><td>Shell Fm</td><td>Shell Fm</td><td>Vang Fm</td><td>Gervais Fm</td><td></td></tr>
<tr><td>Tee Lakes Fm</td><td>Tee Lakes Fm</td><td>Tiber Fm</td><td></td><td></td></tr>
<tr><td>Largs Fm</td><td>Largs Fm</td><td>Cando Fm</td><td></td><td></td></tr>
</table>

Table 5. Correlation of the tills of southwestern Manitoba with those in the surrounding region. Location of areas shown in Figure 23. 1) Klassen, 1979; 2) this paper; 3) Bluemle, 1984; 4) Fenton et al., 1983; Harris et al., 1974; 5) Fenton, 1984; Fenton et al., 1983. In the Riding and Duck Mountain areas, the Lennard Formation occurs on the Assiniboine River plain and the Zelena Formation occurs on the Riding and Duck Mountain uplands, and are believed to be time equivalent (Klassen, 1979).

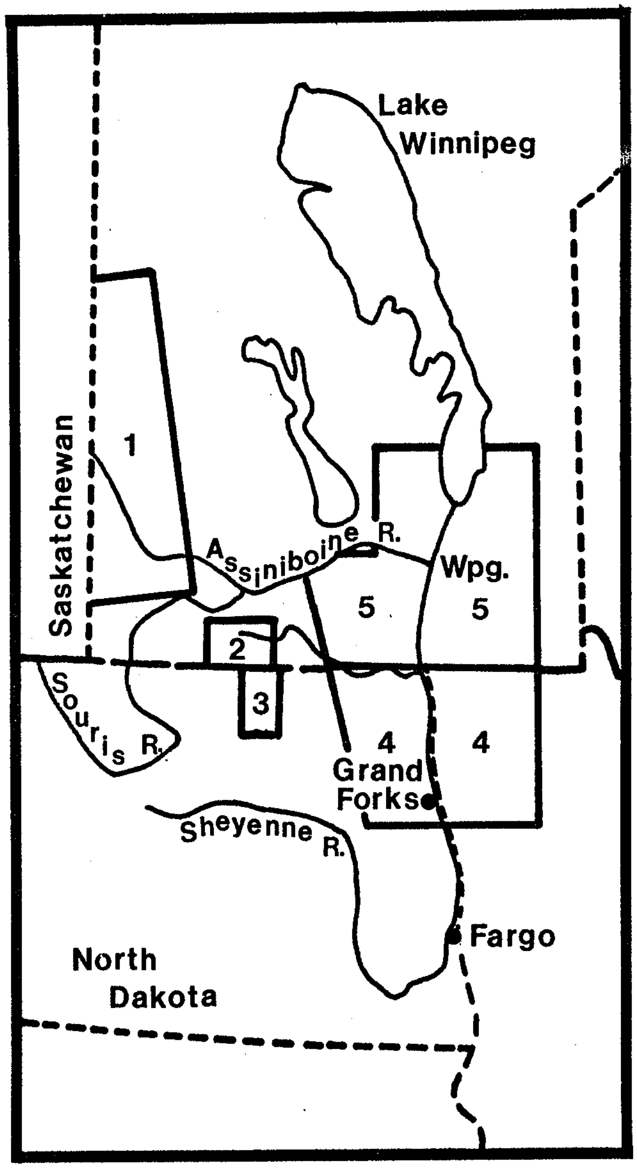


Figure 23. Location of study areas discussed in Table 5.

than that of the overlying till. Carbonate content is 62% for the 4-16 mm (pebble) fraction of the Largs Formation (Table 1) and 39% for the 1-2 mm (coarse sand) fraction of the Cando Formation (recalculated to exclude shale grains) (Table 4). Although different size fractions are compared, the relative carbonate content of these tills is significantly lower than that of the younger overlying tills. The Cando Formation is considered to be equivalent to the Largs formation on the basis of stratigraphic position, texture, and shale clast content. These formations are believed to be of pre-Wisconsinan age (Klassen, 1979, p. 7; Bluemle, 1984, p. 11).

Tee Lakes-Tiber Formation

The Tiber Formation overlies the Cando Formation in northeast North Dakota. It was not recognized in Towner County. The Tee Lakes Formation overlies the Largs Formation in Killarney-Holmfield. Outcrops of the Tiber and Tee Lakes Formations are very sparse. The distinguishing characteristic of the Tiber and Tee Lakes Formations is that the carbonate content is noticeably higher than that of the overlying or underlying formations (Table 1, Table 4). The Tiber Formation is considered to be equivalent to the Tee Lakes Formation on the basis of stratigraphic position and the higher carbonate content. The Tee Lakes Formation is believed to be of pre-Wisconsinan age (Klassen, 1979, p. 8).

Shell-Vang-Gervais Formations

The Vang Formation overlies the Cando Formation in Towner County and the Tiber Formation elsewhere in northeast North Dakota. The Shell Formation overlies the Tee Lakes Formation, or where absent, the Largs Formation or Cretaceous shale bedrock. The two tills are similar in texture (Figure 11b). The top of the Shell Formation is marked by an unconformity in the form of a cobble lag and the top of the Vang Formation is similarly marked by a cobble or boulder lag or a boulder pavement. This unconformity is believed to be of Sangamonian age and is marked by the Roaring River Clay in Riding and Duck Mountains and the St. Malo Formation in southeastern Manitoba (Fenton, 1984) (Table 5). The Shell Formation is correlated with the Vang Formation on the basis of stratigraphic position, the unconformity at the surface, and the texture. The Shell and Vang Formations are of pre-Wisconsinan age (Klassen, 1979, p. 8; Fenton, 1984)).

A problem in this correlation does exist. The till fabric analysis for the Shell Formation indicates deposition from the west-northwest (Figure 15). Bluemle (1984) believed that the Vang Formation was deposited from the east or northeast, bringing abundant crystalline sand from the Canadian Shield. However, the crystalline sand content is not significantly higher than that of the overlying Gardar or Dahlen Formations which were derived from the northwest (Table 4). It is suggested that in the absence of additional evidence, it is not necessary to postulate an advance from the east to account for an increase in crystalline sand.

The Vang Formation is believed to be correlative with the Gervais Formation of northwestern Minnesota (Table 6) and with the pre-Wisconsinan Shell Formation (Table 5), on the basis of the unconformity in the form of a cobble lag at the upper contact of these units.

Formations	Grain Size Analysis Sand (%)	Silt (%)	Clay (%)	Carb. <0.074 mm CO3 (%)	Lithology of Coarse Sand Fraction Cryst. (%)	Carb. (%)	Shale (%)	Recalculated Coarse Sand Lithology Cryst. (%)	Carb. (%)
Falconer/ Huot	6	22	72	25	41	53	6	44	56
Upper Red Lake Falls	37	42	21	28	54	33	13	62	38
Lower Red Lake Falls	46	38	16	36	55	42	3	57	43
St. Hilaire	33	39	28	25	41	31	28	57	43
Marcoux	54	35	11	28	78	21	1	79	21
Gervais	19	50	31	15	44	55	1	44	56

Table 6. Texture, carbonate content, and coarse sand (1-2 mm) lithology of the tills of northwestern Minnesota (modified from Moran et al., 1976, p. 141; Harris et al. 1974). The data presented are mean values expressed as a percent. The last two columns are the coarse sand lithology recalculated to exclude shale.

Minnedosa-Gardar-Marcoux-Stuartburn/Tolstoi Formations

The Gardar Formation is bounded by unconformities at the base and at the surface in the form of boulder pavements. Striations on the boulder pavement at the base of the Gardar Formation indicate deposition from the northwest. The Minnedosa Formation is likewise bounded by a cobble lag at the base and a boulder pavement at the surface. Till fabric analysis in the Killarney-Holmfield area indicates deposition from the north-northwest. The texture of the two formations is similar (Figure 18b) and both tills exhibit strong jointing and staining by iron and manganese. These formations are considered to be equivalent on the basis of stratigraphic position, the presence of unconformities at the top and bottom of the formations, texture, and deposition by ice flowing from the northwest. The unconformity marked by the boulder pavement in southwestern Manitoba and northeastern North Dakota, and by the Vita Formation in southeastern Manitoba, represent the Watino Nonglacial Interval of Middle Wisconsinan age (Fenton, 1984). The Minnedosa and Gardar Formations represent the Burke Lake Glaciation of Early Wisconsinan age (Fenton, 1984).

The Marcoux Formation of northwestern Minnesota, similar to the Minnedosa and Gardar Formations, is bounded by a cobble lag at the lower contact with the Gervais Formation (Harris et al., 1974. p. 6) and a boulder pavement at the upper contact with the overlying St. Hilaire Formation (Harris et al., 1974. p. 9). Therefore, the Marcoux Formation is correlated with the Minnedosa and Gardar Formations on the basis of stratigraphic position with respect to the cobble lag at the base and the boulder pavement at the surface. In contrast, Bluemle (1984, p. 12) and Harris et al. (1974, p. 143) correlated the

Marcoux Formation of northwestern Minnesota with the Vang Formation, which underlies the Gardar Formation, on the basis of abundance of crystalline rock and low shale content. The Minnedosa Formation was correlated with the Floral Formation in Saskatchewan and the Stuartburn and Tolstoi Formations in southeast Manitoba (Fenton, 1984) (Table 5, Table 7).

Lennard-Dahlen-St. Hilaire/Red Lake Falls-Senkiw/Roseau Formations

The Dahlen Formation overlies the boulder pavement at the top of the Gardar Formation and where the Gardar Formation is absent, the boulder pavement occurs between the Dahlen Formation and the underlying older formations (Bluemle, 1984). In Towner County it is overlain by till of the Hansboro Formation, which forms the surface till in the region. In the Red River Valley, the Dahlen Formation is separated from the overlying Falconer Formation by the laminated lake sediment of the Wylie Formation. The Hansboro Formation is believed to have been deposited during a readvance of the same ice that deposited the Dahlen Formation (Bluemle, 1984). The Lennard Formation overlies the boulder pavement at the top of the Minnedosa Formation and is the uppermost till in the southern Killarney-Holmfield area. Deposition of the Lennard and Dahlen Formations was from the northwest as indicated by striations on the boulder pavement and the alignment of washboard moraines and drumlins. The Lennard and Dahlen Formations are correlated on the basis of their stratigraphic position, association with the uppermost boulder pavement, and deposition from the northwest. The Lennard and Hansboro Formations are also considered to be equivalent because they form the surface till in the region.

Formations	Grain Size Analysis Sand (%)	Silt (%)	Clay (%)	Carb. <0.074 mm CO3 (%)	Lithology of Coarse Sand Fraction Cryst. (%)	Carb. (%)	Shale (%)	Lithology of 4-16 mm Fraction Cryst. (%)	Carb. (%)
Marchand	44	40	16	51	45	55	0	35	65
Whitemouth Lake	22	48	30	53	38	62	0	25	75
Roseau	33	44	23	58	38	62	Tr	30	70
Senkiw	60	29	11	38	58	42	0	47	53
Tolstoi	25	53	22	—	28	72	0	21	79
Stuartburn	41	45	14	—	41	59	0	20	79
Woodmore	29	49	22	—	27	73	0	19	89
Unnamed	46	37	17	—	85	15	0	74	19
Rosa	29	50	21	—	42	58	0	—	—

Table 7. Texture, coarse sand (1-2 mm), and pebble (4-16 mm) lithology of the tills of southeastern Manitoba (modified from Teller and Fenton, 1980; Moran et al., 1976). The data presented are mean values expressed as a percent. (— not available, Tr Trace)

Bluemle (1984) correlated the Gardar Formation with the St. Hilaire Formation in northwestern Minnesota on the basis of shale abundance. However, the contact between the Marcoux Formation and the overlying St. Hilaire Formation is marked by a boulder pavement. Where the St. Hilaire Formation is absent, the boulder pavement occurs between the Marcoux and the lower part of the Red Lake Falls Formation. This boulder pavement is believed to be the same pavement that occurs at the base of the Battleford Formation in Saskatchewan, the Lennard Formation in southwestern Manitoba, and the Dahlen Formation in northeastern North Dakota. The St. Hilaire Formation is correlated with the Lennard and Dahlen Formations on the basis of the boulder pavement at the base of the tills. Bluemle (1984) correlated the Dahlen Formation with the Upper Red Lake Falls Formation in northwestern Minnesota. The Roseau Formation was correlated with the Dahlen Formation and the Upper Red Lake Falls Formation (Moran et al., 1976). This correlation was later extended to include the Lower Red Lake Falls Formation (Fenton et al., 1983). The tills of the Battleford, Lennard, and Senkiw Formations mark the beginning of the Lostwood Glaciation of Late Wisconsinan age (Fenton, 1984).

The Red Lake Falls Formation consists of a lower and upper unit. The contact between the lower and upper unit is marked by a cobble concentration 'similar to the soled, striated boulder pavement at the base of the formation' (Harris et al., 1974, p. 12). It is not obvious from the description provided by Harris et al. (1974) whether the cobble concentration is actually a boulder pavement, or whether it only exhibits some similarities of a pavement.

Glenora-Falconer-Whitemouth Lake Formations

The till of the Falconer Formation is the youngest till in North Dakota and forms the surface till east of the Edinburg moraine. The Glenora Formation is the lowermost of two tills associated with the Darlingford moraine, thought to be a northward continuation of the Edinburg moraine. The carbonate content is very similar: 25 to 30% for the less than 0.074 mm fraction of the Falconer Formation (Harris, 1974, p. 18) and 21% for the less than 0.0625 mm fraction of the Glenora Formation. The textures are also similar (Figure 22b). The Glenora and Falconer Formations are correlated based on their stratigraphic association in the Darlingford and Edinburg moraines, the carbonate content of the fine fractions and the texture. The age of these formations is Late Wisconsinan. The Falconer Formation has been correlated with the Whitemouth Lake Formation of southeastern Manitoba (Teller and Fenton, 1980; Fenton et al., 1983).

Belmont-Marchand Formations

The Belmont Formation, that forms the surface till north of the Darlingford moraine, has no equivalent in North Dakota or Minnesota. In southeastern Manitoba, the till of the Marchand Formation forms the surface till and is similar to the Belmont Formation with respect to texture and carbonate content of the 4-16 mm fraction (Teller and Fenton, 1980, p. 22) (Table 7). The carbonate content of the fine fractions are considerably different. On the basis of stratigraphic position, the Belmont Formation is tentatively correlated with the Marchand Formation.

PLEISTOCENE GEOLOGY AND GEOMORPHOLOGY

The Killarney-Holmfield area can be divided into two distinct morphological regions: the Boissevain plain, with glacial features related to ice advance from the west or northwest, and the Tiger Hills upland, with glacial features related to ice advance from the east or northeast. The Turtle Mountain upland occupies only a small part of the area and will be discussed under the Boissevain plain section. A location map is presented in Figure 24.

Boissevain plain

The Boissevain plain occupies the southern portion of the Killarney-Holmfield map-area and is separated from the Tiger Hills upland by the Pembina spillway (Figure 2, Figure 5). The Largs, Tee Lakes, Shell, Minnedosa and Lennard Formations have been recognized in this area. These formations have generally been deposited by ice moving from the north or northwest. The Lennard Formation forms the surface and, where missing, the Minnedosa Formation, capped by a boulder pavement outcrops at the surface. Drift thickness ranges from 0 m to more than 10 m, but is generally less than 3 m. In the Turtle Mountain upland, the drift thickness is considerably greater.

Till plain. The area south of a line from Killarney to Cartwright is formed of flat to gently rolling Lennard Till (Figure 25). The surface was eroded by numerous proglacial streams. Many of the streams downcut until the boulder pavement at the top of the Minnedosa till was intersected and the stream bottom became armored (Figure 26a, b). When downcutting was halted the streams migrated in search of more favorable locations. The abandoned valleys

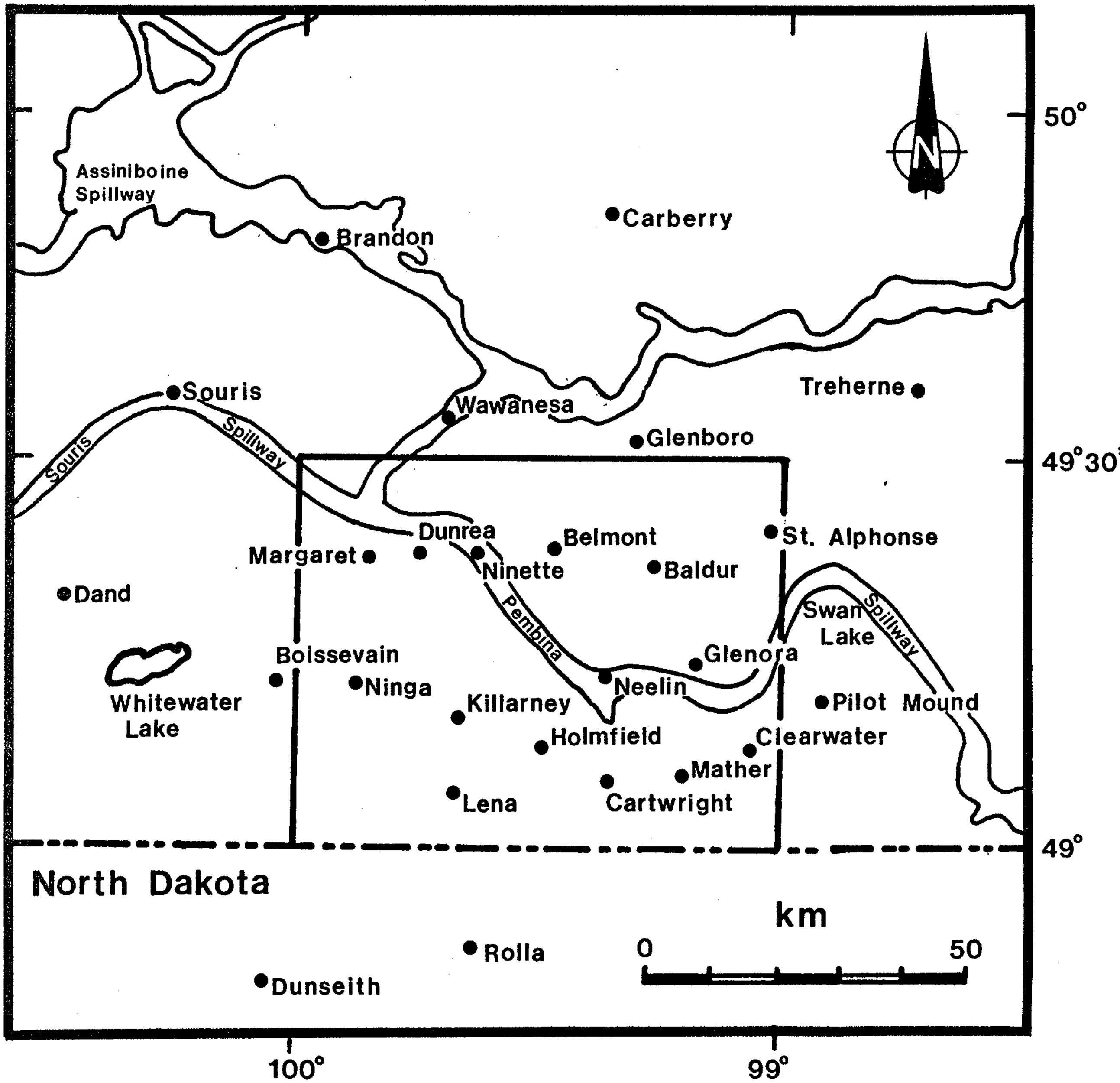


Figure 24. Location map of the Killarney-Holmfield study area and adjacent areas discussed in the text.

Figure 25. Gently rolling till plain of the Boissevain plain. The town of Killarney, 5 km to the northeast, is indicated by the arrow.

Figure 26. a) Shallow stream on the Boissevain plain that has intersected the boulder pavement. b) Close up of a stream bottom that has been armored by the eroded boulder pavement. A field book has been placed on one of the pavement stones for scale.

were left as hanging valleys where tributary to larger river valleys.

To the southwest, along the edge of the Turtle Mountain upland, the till has been slightly eroded by a proglacial lake, which deposited a discontinuous bed of silt, less than 2 cm thick. The silt unit was not mappable.

In the western part of the till plain is a small area of poorly developed washboard moraines, located 14 km west of Killarney on Highway 3 (Figure 2). The orientation of these moraines is from southwest to northeast.

Hummocky stagnation moraine. To the northwest of Killarney, a small area of about 20 km^2, is covered by hummocky stagnation moraine of low relief (Figure 2). This area is dominated by ring shaped hummocks and the centre of some of the hummocks contain small isolated sloughs. The hummocky area is bounded by washboard moraine to the north and south. To the southwest, near Boissevain, it is bounded by the lacustrine plain of the Whitewater basin.

End moraine. Two end moraines have been recognized on the Boissevain plain, namely the Turtle Mountain moraine and the Cartwright moraine (Figure 27).

The Turtle Mountain moraine forms the surface of the Turtle Mountain uplands. The moraine consists of hill and kettle topography, the hills frequently rising more than 10 m above the lake filled kettles. The lakes are generally isolated and only the larger lakes are connected by streams.

A belt of hills and kettles 1 to 2 km wide and 3 to 4 m high forms the Cartwright moraine (Figure 27). This moraine, composed of Lennard Till, was deposited during a readvance of the Lennard ice. It extends continuously from Cartwright, the town after which it is

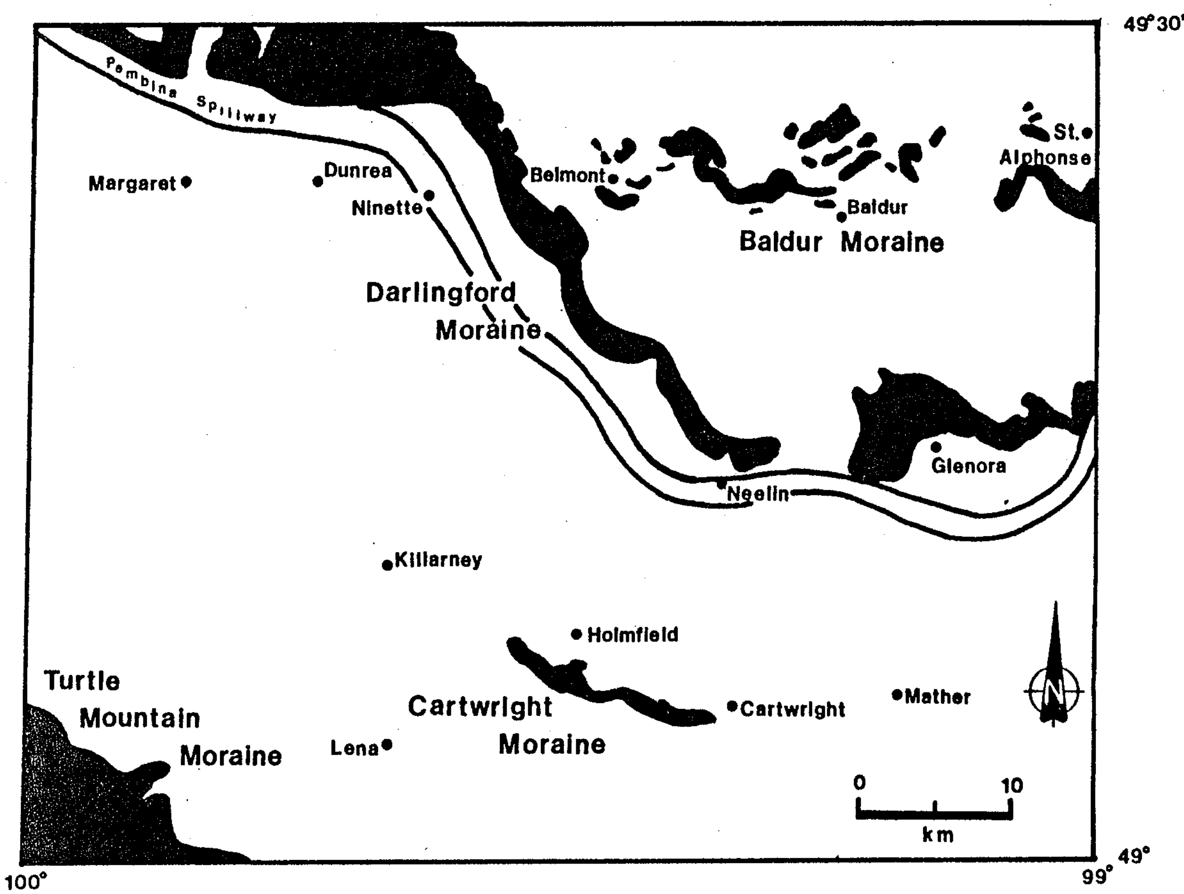


Figure 27. Map of major moraines in the Killarney-Holmfield area.

named, to about 6 km southeast of Killarney (Figure 2). The southern edge of the moraine exhibits the greatest relief where it is bounded by an outwash plain. The area north of the moraine is marked by prominent washboard moraines (Figure 28). The Cartwright moraine does not continue east of Cartwright or west of Killarney. However, the maximum extent of the ice sheet which deposited the moraine is marked by the outwash plain and the southern limit of the prominent washboard moraines which extend throughout this northern area.

Washboard moraines. Washboard moraines or corrugated moraines cover the area between the Cartwright ice margin and the Pembina spillway to the north (Figure 28). The washboard moraines consist of elongated till ridges 2 to 5 m high and generally less than 100 m wide (Figure 29). The ridges are aligned transverse to the ice flow and are generally slightly concave up-ice. The spacing between the moraines range from less than 100 m to more than 250 m. The length of the ridges range from 50 m to more than 1000 m. Near Cartwright, the washboard moraines curve up-ice in the vicinity of a large esker (Figure 28). This curved pattern persists over a distance of more than 8 km up-ice from the Cartwright moraine. Only remnants of the esker remain as most of it has been eroded by Badger Creek. Three kilometers east of Cartwright, the moraines curve up-ice slightly towards a smaller esker. However, deflection of the moraines is not prominent near smaller eskers.

The washboard moraines in Killarney-Holmfield are composed of a variety of sediments, although few sections through the moraines were available for examination in the Boissevain plain. Elson (1956, p. 73) described the moraines as being formed of sandy till, containing some stratified drift as contorted masses. In the Tiger

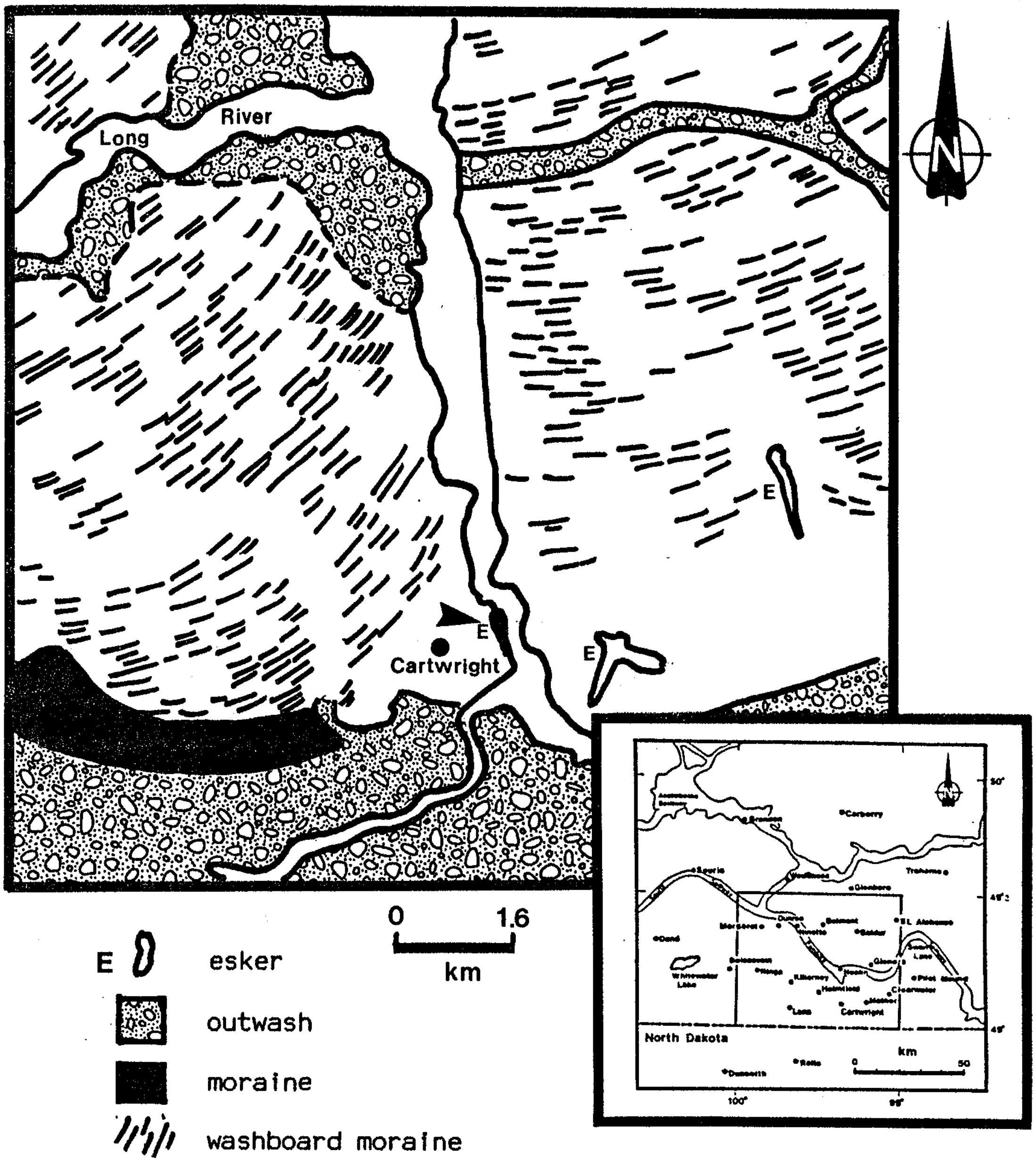


Figure 28. Area of washboard moraine curving up-ice in the vicinity of a large esker near Cartwright. Only remnants of the esker remain (marked by an arrow) and its former position is indicated by Badger Creek. The esker and washboard moraines are associated with the Cartwright readvance.

Figure 29. Two pronounced washboard moraines in the area north of the Cartwright moraine.

Hills upland, sections through several washboard moraines revealed that they were formed of a variety of sediments including till from the advance that formed the moraines, one or more older tills from previous events, and contorted silty sand or sand and gravel (Figure 30).

In an area 10 km west of Killarney and 3 km north of Highway 3, several washboard moraines terminate in hill-depressional forms or thrust features (Figure 31). Similarly, east of Cartwright several washboard moraines were observed to terminate in the ridges of thrust features. Both areas are coincident with the southern margin of the Cartwright advance.

The changing orientation of the washboard moraines (Figure 2) reflect the change in orientation of the ice margin as it retreated through the area. The readvance of the ice sheet produced a set of washboard moraines with a different orientation, such as that 13 km west of Killarney and south of of Highway 3, where the washboard moraines are aligned southwest-northeast (Figure 2). North of the North Pembina River, the moraines are aligned east-west, marking the southern extent of a readvance which terminated at the Cartwright moraine.

At Cartwright, the moraines are aligned almost east-west. As the ice retreated to the west through the area north of Killarney, the orientation of the ice margin gradually became north-south.

<u>Streamlined Terrain</u>. Several large drumlinoid hills or flutes occur in an outwash plain 4 to 5 km west of Killarney. The hills are about 5 m high and about 400 m long. They are oriented north-northwest to south-southeast, perpendicular to the orientation of the washboard moraines. These streamlined features and the associated

Figure 30. Cross-section through a washboard moraine on the Tiger Hills upland, near the Darlingford moraine. The core of the moraine is of contorted silty sand. A shovel near the middle of the moraine is included for scale.

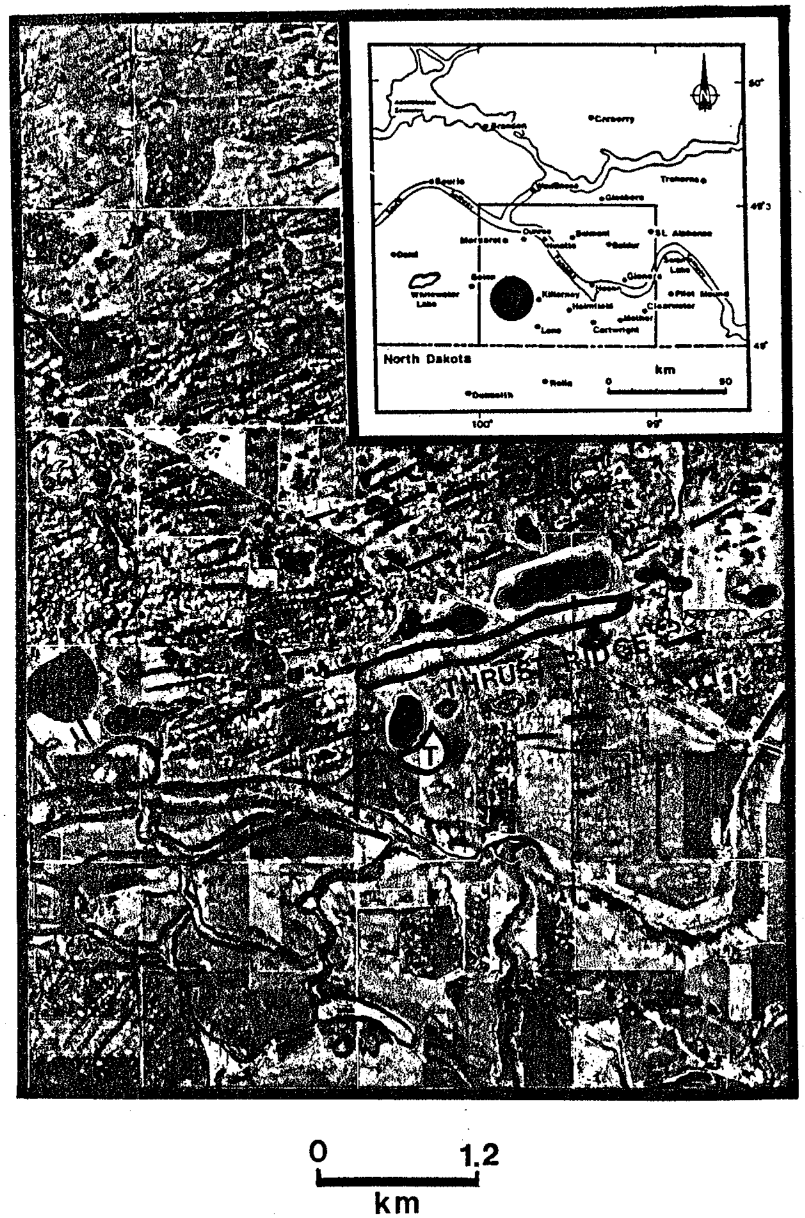


Figure 31. Aerial photograph of a washboard moraine terminating in a thrust feature. This area is located 10 km west of Killarney and 3 km north of Highway 3. It is about 2 km north of the margin of the Cartwright readvance.

washboard were formed during the Cartwright advance.

Eskers. Two sets of eskers occur within the Boissevain plain (Figure 2). The oldest set is located south of the margin of the Cartwright advance and is oriented perpendicular to the washboard moraines formed as the Leeds Lobe retreated north from North Dakota. The second set of eskers is located north of the Cartwright margin and is oriented perpendicular to the washboard moraines associated with this advance. Most of the eskers on the Boissevain plain are less than 2 m high and few of their cores are exposed. At Cartwright, a large esker, more than 10 m thick, formed in a location indicated by the up-ice curvature of the washboard moraines (Figure 28). The Cartwright esker is the largest esker in the Killarney-Holmfield area (Figure 32).

Spillways. The Pembina spillway is a 2 to 3 km wide and 40 to 50 m deep channel (Figure 33, Figure 2). A single occurrence of the Shell Formation was observed in a temporary exposure at the base of a gravel bar at elevation 450 m a.s.l., about 7 m below the top of the channel wall (Section GC405, Appendix I). The Lennard Formation outcrops at the bottom of the spillway at an elevation of 419 m (Figure 34, Section GC588, Appendix I). The formation of the spillway therefore predates the deposition of the pre-Wisconsinan Shell Formation.

West of the elbow of capture of the Souris River, the Pembina spillway is about 1 km wide. Sediment deposited in a river bar near the bottom of the spillway (Figure 35) contains more than 3 m of shale-rich gravel (Figure 36a). The gravel contained shale boulders up to a metre in length (Figure 36b). East of the Souris cutoff, the channel expands to 3 km in width and contains a 2-km-wide river bar

Figure 32. Cross-section through a remnant of the esker at Cartwright. The esker is more than 10 m thick at this location. A shovel is located at the top of the lower scree slope for scale. North is toward the right edge of the photograph.

Figure 33. View of the Pembina spillway, looking to the south from the edge of a large river bar near the elbow of capture of the Souris River (Section GC405, Appendix I). The spillway is about 2 km wide, as shown in the photograph. See Figure 37 for location.

Figure 34. The Lennard Formation outcropping at the bottom of the Pembina spillway, located immediately west of the elbow of capture of the Souris River. The Lennard Formation is overlain shale rich debris containing many large crystalline and carbonate boulders and cobbles. North is toward the right edge of the photograph.

Figure 35. A lower river bar located at the bottom of the Pembina spillway. The lower bar is observed along the south side of the roadway (west is to the right). The photograph was taken from the south edge of the upper river bar. See Figure 37 for location.

Figure 36. Cross-section through the low river bar shown in Figure 35. a) More than 3 m of cobbly and bouldery shale-rich gravel is exposed in a road cut at the bottom of the Pembina spillway. b) The gravel includes many blocks of shale a metre or more in length. Precambrian and carbonate cobbles and boulders are also present.

along the north wall of the channel (Figure 37). The bar contains more than 10 m of cross-bedded sand and gravel with a paleocurrent direction toward the east (Figure 38). The gravel contains a significantly higher percentage of carbonate clasts than anywhere else in the channel. The surface of the bar is at an elevation of 450 m a.s.l. and is immediately downstream of the Souris cutoff occupied by the present day Souris River.

At Rock Lake, about 3 km east of the town of Neelin, the Pembina spillway narrows to less than 1 km wide (Figure 2). A boulder lag overlying shale bedrock occurs along the north shore of Rock Lake at the constriction (Figure 39). Neelin is situated on an erosional bedrock bench formed along the north side of the spillway above 412 m a.s.l.

Outwash plains. The regional drainage on the Boissevain plain was to the north or northeast, as it is today. As the glaciers advanced and retreated through the Killarney-Holmfield area, the regional drainage was blocked and outwash plains formed along the ice margin. An extensive outwash plain, 1 to 2 km wide, was deposited along the southern margin of the Cartwright readvance from the Whitewater Basin west of Boissevain, to Cartwright in the east, and then northeast through Mather toward the Pembina spillway (Figure 40). This outwash plain also extends southward into North Dakota. The elevation of the outwash plain drops from 518 m near Boissevain to below 465 m east of Mather. It is named the Mather outwash plain, after the town of Mather located on the plain, to the east of Cartwright. The sediment consists primarily of shale-rich gravel and sand. East of Cartwright, shale bedrock occurs at or near the surface.

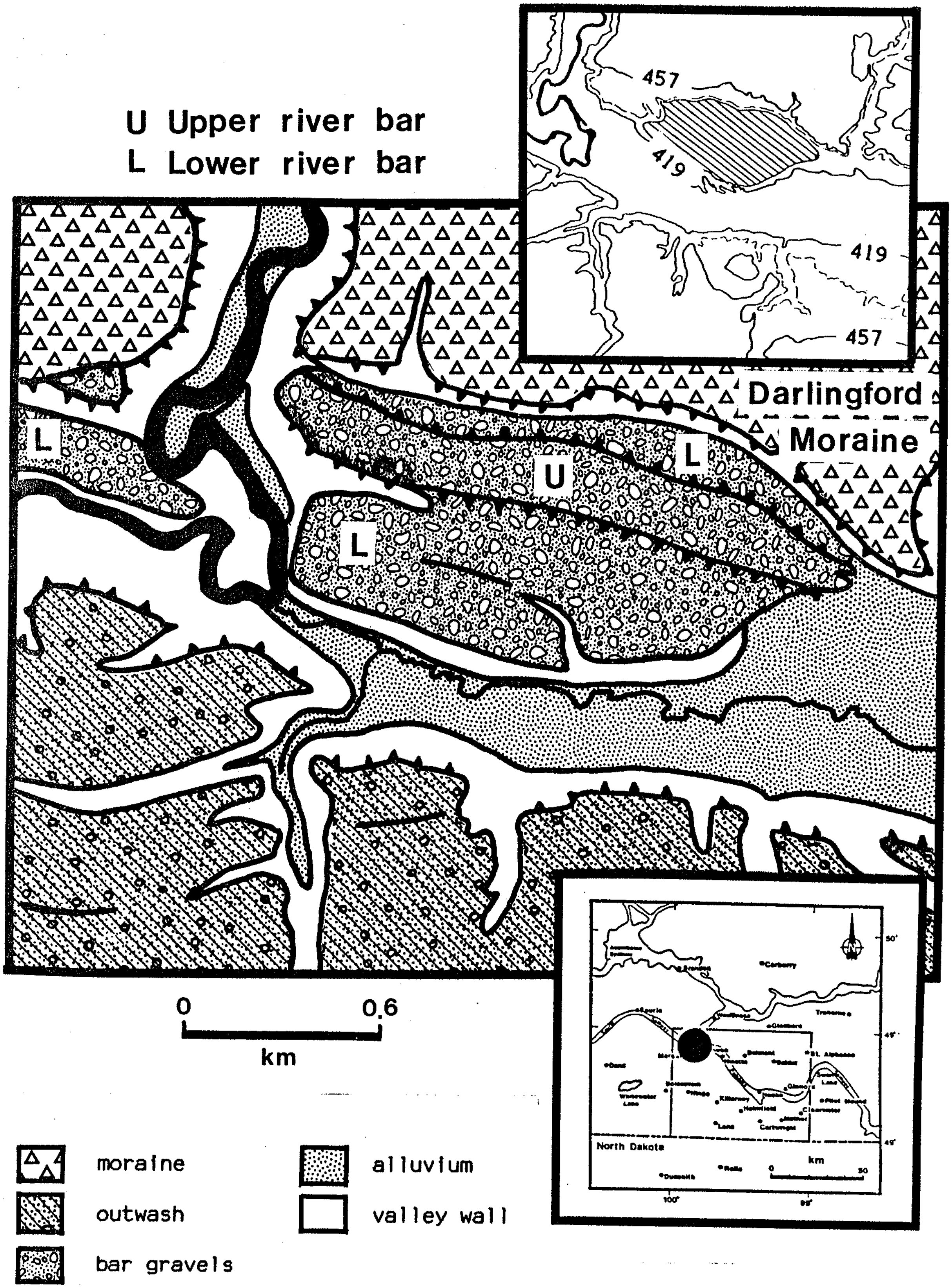


Figure 37. Simplified surficial geology and location map of the Pembina spillway at the elbow of capture of the Souris River. The river bars are indicated by the hachures in the upper inset figure.

Figure 38. Cross-section through the upper river bar. This exposure contains more than 10 m of bedded cobbly coarse gravel, with a high percentage of carbonate clasts. The gravel beds dip to the east.

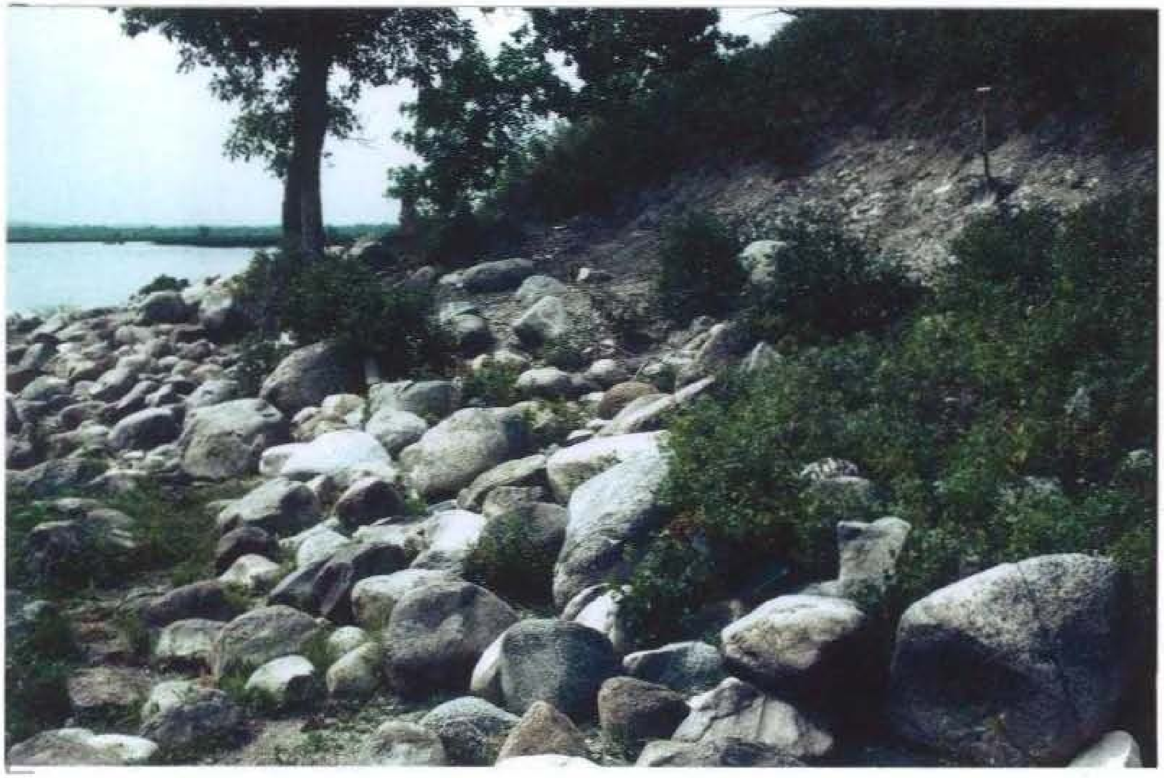


Figure 39. Boulder accumulation along the north shore of Rock Lake at the constriction in the Pembina Spillway. At this point, 3 km east of Neelin, the spillway is less than 1 km in width. As the fine grain size particles were eroded from the tills, the boulders accumulated as a lag deposit.

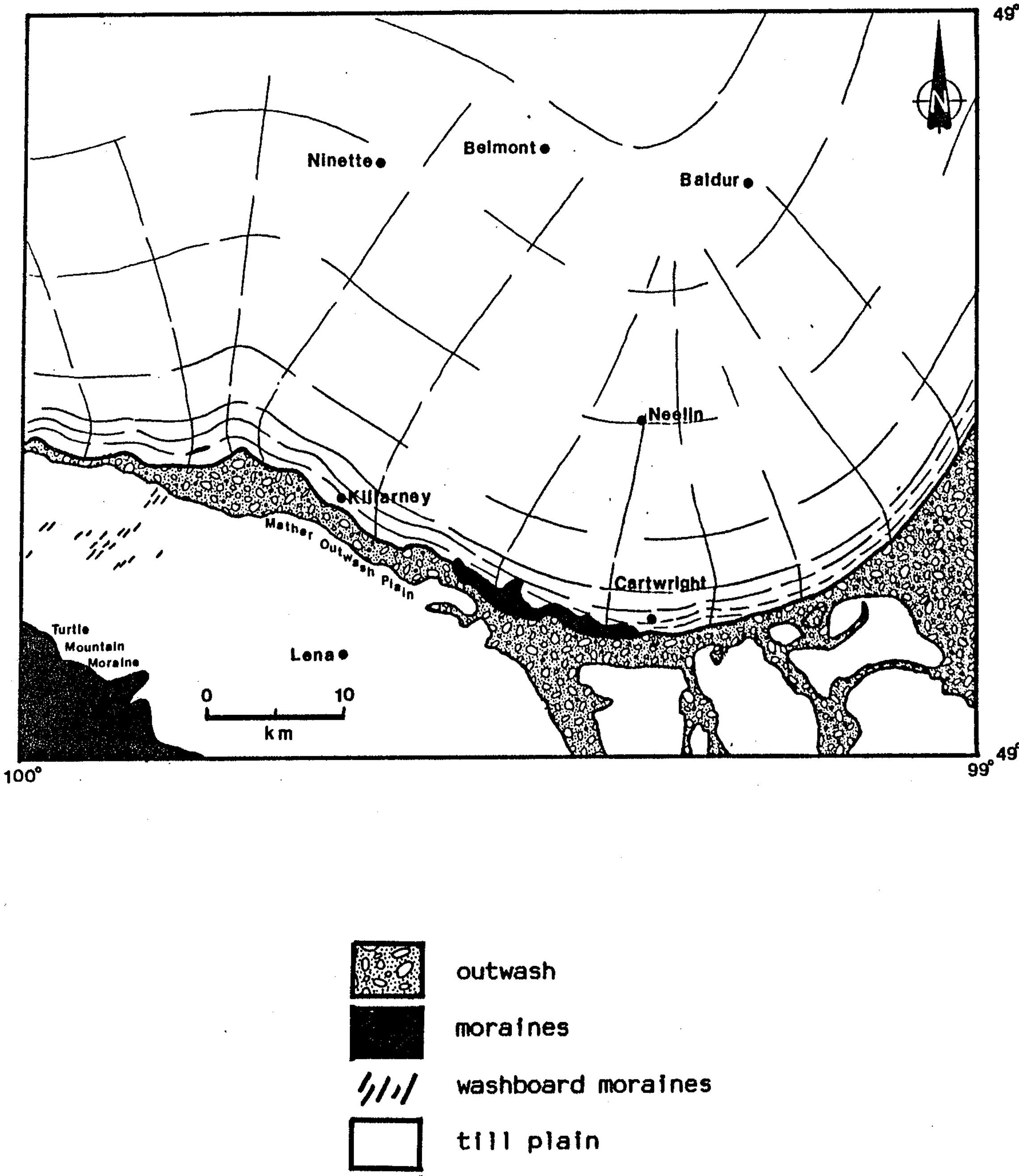


Figure 40. Location of the Mather outwash plain along the margin of the Cartwright readvance.

Meltwater discharge across the Mather outwash plain, along the southern edge of the Cartwright moraine, was abandoned in favor of a more northerly location at a lower elevation along the present day Long River channel (Figure 2).

A major outwash plain more than 10 km wide parallels the north and south banks of the Pembina spillway along the southern margin of the Darlingford moraine (Figure 2). The southern edge of the outwash plain is marked by truncation or infilling of the interfluves of the washboard moraines 8 km south of the spillway at an elevation of 465 m a.s.l. (Figure 41). Near Dunrea, the outwash sediments consist of silts and fine sands with minor amounts of gravel. Numerous small shallow channels were eroded in the surface of the plain east of Dunrea at an elevation of 457 m a.s.l.

On the north bank of the spillway, along the southern edge of the Darlingford moraine, varying thicknesses of coarse sediment were deposited. North of Ninette along Highway 18, up to 6 m of pebbly sand was deposited near the Darlingford moraine (Figure 42, Figure 2). Between Ninette and Neelin, sand, and sand and gravel are thickest adjacent to the spillway and decrease in thickness toward the moraine, where only a thin cobble and pebble lag remain. East of Neelin, the outwash plain extends across a flat plain north of the spillway at 457 m a.s.l. with many small shallow channels eroded in the surface. More than 7 m of poorly sorted cobbly shaly gravel are exposed in a gravel pit on the south bank of the spillway, 2 km east of where Cypress Creek drains into the Pembina spillway (Figure 43a, b).

Boulder Pavement. A boulder pavement, consisting of a single horizontal bed of boulders embedded in till, with faceted upper surfaces aligned in a common plain and bearing glacial striations,

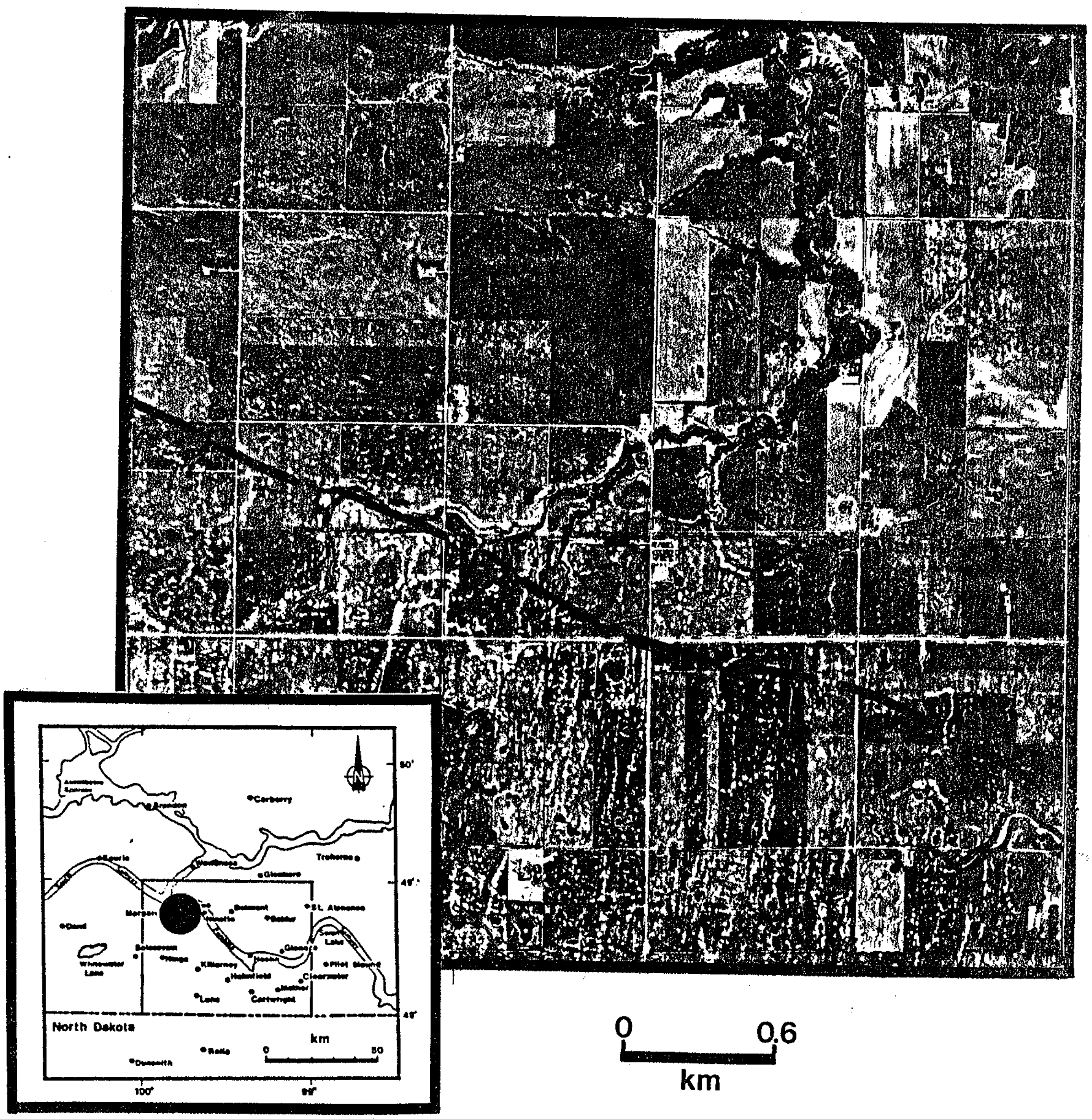


Figure 41. Aerial photograph illustrating the location of the outwash plain along the south edge of the Pembina spillway. The dashed line marks the limit of the washboard moraines.

Figure 42. Bedded outwash sands and gravels, deposited along the southern edge of the Darlingford Moraine, about 6 km north of Ninette on Highway 18. Deposition in an ice-contact environment is indicated by numerous faults in the sediment. Several faults can be observed below and to the right of the shovel. South is to the right.

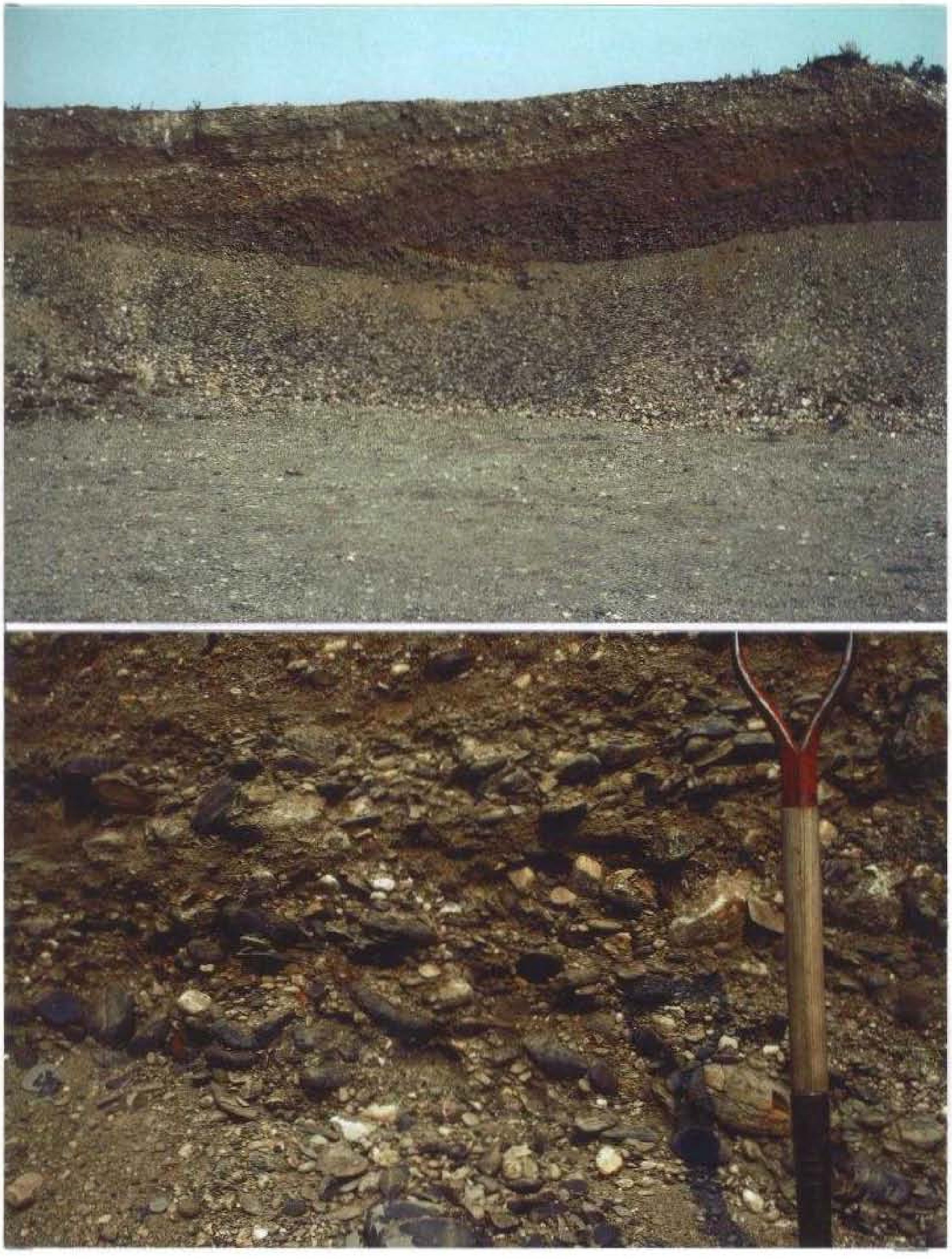


Figure 43. Outwash deposit along the south edge of the Pembina Spillway, about 2 km east of Cypress Creek. a) This outwash deposit is composed of more than 6 m of bedded shale gravel. A shovel is included on the left side of the photograph for scale. b) The gravel consists primarily of subrounded shale cobbles and pebbles with minor amounts of crystalline or carbonate pebbles.

outcrops in road and river cuts (Figure 20). The boulder pavement is very extensive. It extends throughout southwestern Manitoba where it marks the contact between the Lennard and Minnedosa Formations, west into Saskatchewan where it marks the contact between the Battleford and Floral Formations (Christiansen, 1968, p. 1171), south into North Dakota where it marks the contact between the Dahlen and Gardar Formations (Bluemle, 1984), and east into northwestern Minnesota where it marks the contact between the St. Hilaire and Marcoux Formations (Harris et al., 1974).

The pavement is most commonly embedded in till, but is also found embedded in sand, gravel, shale bedrock, and sandstone bedrock of the Boissevain Formation. Only one boulder pavement has been observed in the Killarney-Holmfield area.

The upper surface of the boulders were faceted and striated by the overriding glacier (Figure 44). The mean orientation of striae measured on 108 boulders at 20 locations was 136 degrees. At some locations striae deviated as little as 1 degree from the mean (Section GC345, Appendix I) while at other locations deviations were as high as 35 degrees from the mean. The boulders in the pavement range in size up to 2 m in diameter.

Tiger Hills upland

The Tiger Hills upland occupies the northern portion of the Killarney Holmfield area (Figure 2, Figure 5). It is bounded at the south by the Darlingford moraine and the Pembina spillway. Seven tills have been recognized in this area, namely the Largs, Tee Lakes, Shell, Minnedosa, Lennard, Glenora and Belmont Formations. The youngest are the Glenora and Belmont Formations which are highly

Figure 44. Photograph of the faceted and striated surface of the boulders in the boulder pavement. This boulder is embedded in till of the Minnedosa Formation, and Lennard Formation is absent at this location. The striae on the boulder surface are parallel to the orientation of the compass and are from the northwest.

calcareous tills deposited by ice moving from the north or northeast. The Belmont Formation generally forms the surface. Drift thickness ranges from 0 m to 5 m on the plains south of Baldur to more than 30 m in the Darlingford moraine.

End moraines. Two end moraines have been recognized on the Tiger Hills upland, namely the Darlingford and the Baldur moraines (Figure 27). The Baldur moraine is named after the town of Baldur, located along the southern margin of the moraine. The Darlingford moraine marks the maximum extent of deposition of the calcareous tills of the Glenora and Belmont Formations and both tills outcrop in the moraine. The width of the moraine ranges from more than 10 km wide north of Ninette to 1 km wide north of Neelin. It is more than 35 m thick where it reaches the maximum elevation of about 495 m, northwest of Neelin (Figure 2). Northeast of Ninette, a railroad cut through the moraine exposes contorted sands and silty sands along the southwestern margin (Figure 45). At Glenora, the moraine forms a northward arch away from the spillway (Figure 27). A large thrust feature occurs 1 km north of Glenora and several smaller thrust features occur 3 km north of it (Figure 2). The moraine has been breached by outwash discharging into the Pembina spillway at the Souris cutoff and at the southern end of the outwash plain east of Neelin.

The Baldur moraine is delineated by morphology, rather than by sediment deposition. The Baldur moraine, located north of Baldur Figure 27, Figure 47) is defined as a band of glacial thrust features, 6.5 km wide and 32 km long, stretching from Belmont in the west to St. Alphonse in the east (Figure 2). The thrust features occur as hill-depressional forms as defined by Bluemle and Clayton (1984). A hill-

Figure 45. Cross-section through the southwestern margin of the Darlingford moraine along a railroad cut, northeast of Ninette. The sediments at this location are composed of highly contorted sands and silty sands. The exposed section is about 2 m high.

depressional form is a roughly equidimensional hill located downglacier from a source depression of similar size and shape (Figure 46). A small outwash plain occurs at the margin of the Baldur moraine south of Belmont and a much larger outwash plain occurs at Baldur. Outwash south of the Baldur moraine at St. Alphonse, reached the Pembina spillway through the Dry River spillway.

In the Baldur moraine most of the thrust features occur as composite structures in which two or more hill-depression features are linked by ridges (Figure 47). These hills may be as low as 2 m or as high as 35 m. Individual hill-depressional forms consist of a discrete hill of ice-thrust material situated near or possibly up to several kilometres downglacier from the source depression (Figure 46). The hill may have been crumpled or streamlined by the overriding glacier. The core may be formed of Cretaceous shale bedrock (Figure 48) or glacial sediment (Figure 49). The source depression is usually now filled with water and may have been slightly infilled by drift from the overriding glacier (Figure 50). Some of the hills are associated with eskers which begin in the source depression and meander downglacier beside the thrust mass (Bluemle and Clayton, 1984; Clayton et al. 1980), although only one occurrence of this was observed in the Tiger Hills upland.

The composite structures that form the hills of the Baldur moraine can become very large. North of Baldur, one composite ridge is more than 10 km long and in places, more than 1 km wide. The hills are generally 30 m high and the connecting ridges are somewhat lower. Most of the composite ridges are concave to the north. Washboard moraines with tightly curved patterns frequently occur behind the ridges (Figure 47). The complex up-ice curvature of the composite

Figure 46. A single hill-depressional form or thrust feature of the Baldur moraine, located west of St. Alphonse. The hill in the distance is located to the south of the source depression, along the axis of flow of the glacier. The hill and the source depression are of similar size and shape. The core of this ridge appears to be formed of sandy glacial sediment, and bedrock was not observed.

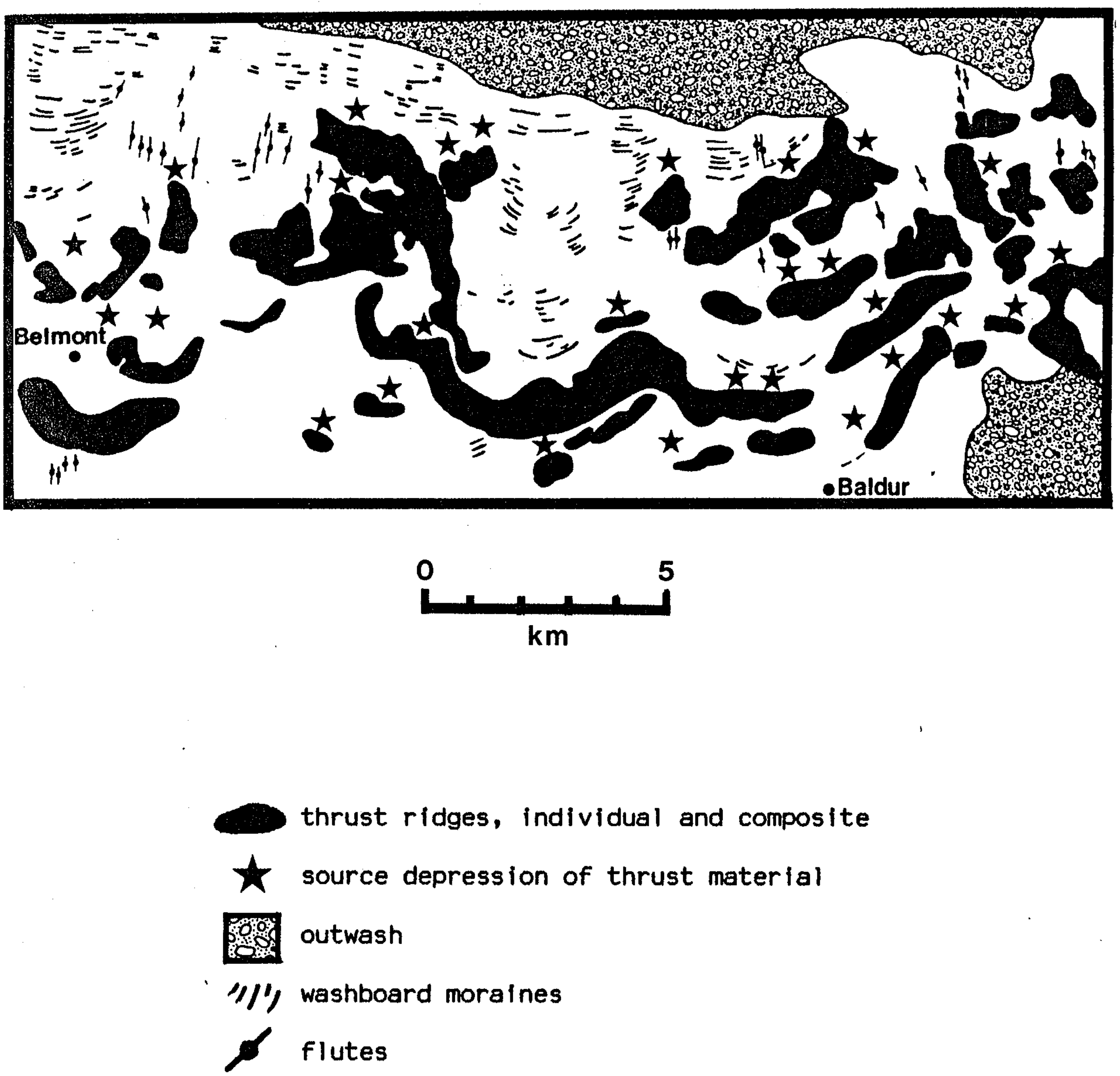


Figure 47. The Baldur moraine, between Belmont and Baldur, is composed of a series of individual and composite thrust ridges. The composite thrust ridges consist of two or more hill-depressional forms. Tightly curved washboard moraines occupy the area behind the moraine.

Figure 48. Cross-section through a bedrock-cored hill-depressional form, oriented from north to south (left to right). The bedrock is highly contorted and folded and in places contains pockets of glacial sediments. This feature is located 8 km north and 3 km east of Pilot Mound (east of the Killarney-Holmfield study area).

Figure 49. Cross-section through a hill-depressional form with a core of glacial sediment. a) The thrust feature is more than 30 m high. A shovel is located near the centre of the hill for scale. b) Close-up showing contorted bedded sand, silty sand and gravel.

Figure 50. Source area of a hill-depressional form that has been filled by water. This is typical of most of the thrust features in the Tiger Hills upland.

ridges and washboard moraines indicate that the ice was highly lobated during formation of the Baldur moraine. Flutes or drumlinoid ridges are present in the valleys between some thrust ridges (Figure 47).

Several hill-depressional forms are also associated with the Darlingford moraine and several have been previously described in association with the washboard moraines along the margin of the Cartwright advance in the Boissevain plain.

Washboard moraine. The oldest washboard moraines are found adjacent to the Darlingford moraine. The pattern of the moraines between Glenora in the south and Belmont and Baldur in the north indicates that the ice retreated northward rather than shrinking equidimensionally away from the Darlingford moraine (Figure 51). In the area south of Belmont, washboard moraines and flutings occur within a kilometre of each other but are otherwise mutually exclusive (Figure 2).

The youngest series of washboard moraines are located behind the margin of the Baldur moraine. These moraines are formed in tight arcs which mimic the shape of the composite thrust feature behind which they occur (Figure 51).

Streamlined Terrain. Flutes occur extensively along the north side of the Darlingford moraine in the northern part of the Tiger Hills upland (Figure 2, Figure 51). Along the northern edge of the Tiger Hills upland, the shale bedrock forms a small 'escarpment' that rises 45 to 60 m above the Assiniboine plain to the north (Figure 52). Most of the flutes were formed within 6 km south of this escarpment (Figure 51). Glacial drift is thin in this area and shale bedrock in places outcrops at the surface. The pattern of flutings along the northern part of the escarpment indicates that the ice, which flowed

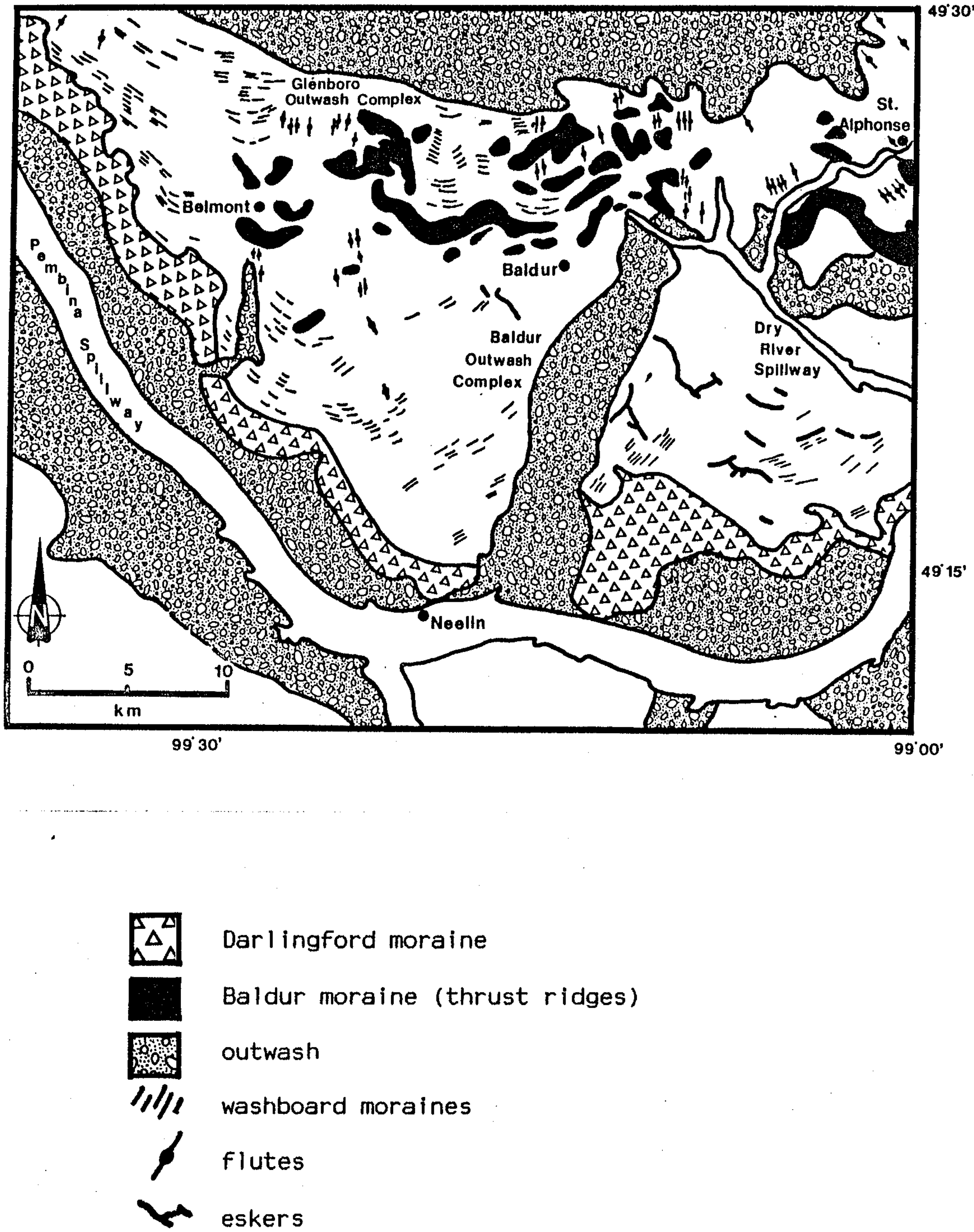


Figure 51. Glacial features of the Tiger Hills upland.

Figure 52. A view from the northern edge of the Tiger Hills upland, looking north from the escarpment towards the Assiniboine Delta. This escarpment also marks the northern boundary of the Darlingford moraine along Highway 18, north of Ninette. Cretaceous shale outcrops in the ditch along the edge of the roadcut.

from the north or north east, spread out into a broad lobate pattern as it entered the Tiger Hills upland.

Flutes were also formed on the plain between the Darlingford moraine and the Baldur moraine (Figure 51). Two large flutes occur 2 km south of Baldur. These flutes are more than a kilometre long and 23 m high. They appear to be bedrock cored with a thin veneer of glacial drift.

Eskers. Eskers are confined to the area south of the Baldur moraine (Figure 51). They are oriented northwest to southeast. The eskers north of Glenora are complex and in places have one or more tributaries (Figure 2). They are poorly exposed and the cores were not exposed. Some of the segments of these eskers are aligned parallel to the ice margin and may represent crevasse fillings.

Outwash plains and complexes. A prominent outwash complex with a north-south orientation formed at the southern margin of the Baldur moraine and extends from Baldur to the Pembina spillway (Figure 2, Figure 51). This outwash complex is 5 km wide and is formed of several anastamosing channels that have been eroded in the shale bedrock. Varying thicknesses of outwash have been deposited in the channels. At the southern end, the shallow channels extend to the edge of the Pembina spillway where the Darlingford moraine has been breached. The main channel has been graded to the spillway bottom and enters the spillway at an acute angle to the southwest at the constriction in the spillway. A boulder lag overlying shale bedrock occurs along the north shore of Rock Lake (Figure 39).

The Dry River spillway extends from the eastern end of the Baldur moraine near St. Alphonse and drained southeast toward the Pembina spillway (Figure 51). The head of the spillway also extends west toward Baldur (Figure 51).

A small outwash plain formed south of Belmont and drained the western portion of the Baldur moraine (Figure 51). The outwash plain drained south, and then west through the Darlingford moraine to the Pembina spillway. This outwash plain is not well defined.

North of the Baldur moraine and along the southern edge of the Assiniboine Delta, a large west to east oriented outwash complex formed (Figure 51). The Glenboro outwash complex, named after the town of Glenboro located along the north extent of the plain, is more than 10 km wide. West of Glenboro, the outwash complex is not well defined (Figure 53). At this location, 3 km south and 14.5 km west of Glenboro, 2 m of poorly sorted shale gravel, containing boulders and cobbles, was observed in a ditch exposure (Figure 54a, b). South and east of Glenboro, erosion was the dominant process and many channels more than a kilometre in width were eroded more than 6 m into the bedrock surface. Outwash deposits along the channel bottoms consist primarily of shale gravel and sand and in places may be more than 5 m thick (Figure 55a, b).

Figure 53. The Glenboro outwash plain, located 3 km south and 14.5 km west of Glenboro. The outwash plain is not well defined at this location.

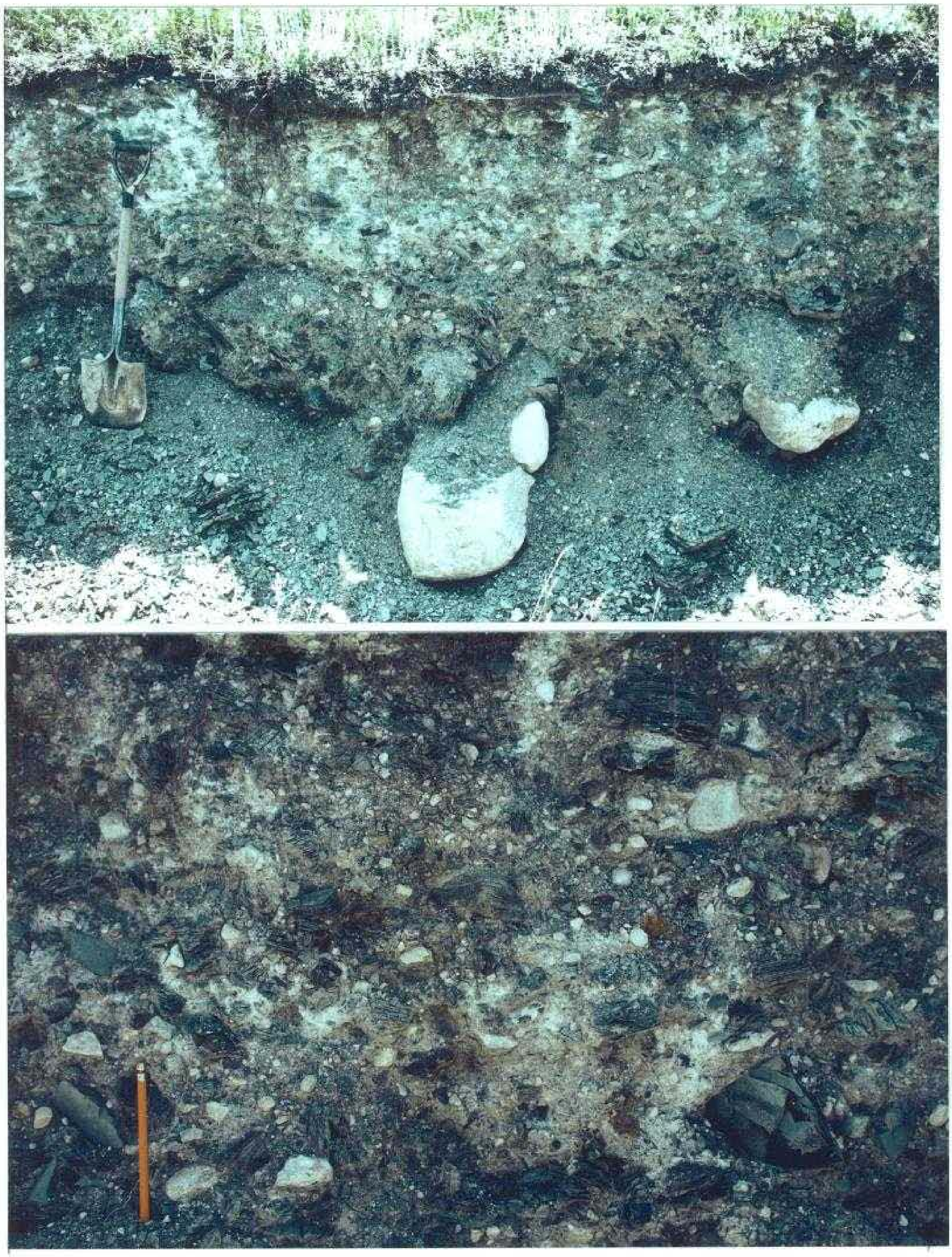


Figure 54. Cross-section through the Glenboro outwash plain at the location shown in Figure 53. a) More than 2 m of outwash sediment is exposed in a ditch section. Several large crystalline and carbonate boulders were observed near the bottom of the exposure. b) The outwash sediment is a very poorly sorted mixture of coarse and fine particle sizes. The clasts are dominantly Cretaceous shale with minor amounts of carbonate and crystallines.

Figure 55. The Glenboro outwash plain, 9 km south and 6 km east of Glenboro. a) At this location, more than 6 m of bedded outwash sediments are exposed. The sediments are capped by a well developed soil horizon. b) The outwash sediments are bedded and exhibit some degree of sorting. The dominant lithology is Cretaceous shale and only minor amounts of carbonate and crystalline clasts were present.

ERRATICS

An erratic is defined as a rock fragment carried by glacier ice and deposited when the ice melted at some distance from the outcrop from which the fragment was derived. In southwestern Manitoba, the Boissevain plain and the Tiger Hills upland are underlain by Cretaceous shale bedrock. The pebble fraction of the tills of the Killarney-Holmfield area contain large numbers of erratics in the form of carbonate and crystalline clasts (Table 1).

The moderately calcareous tills of the Largs, Shell, Minnedosa, and Lennard Formations have a carbonate clast content ranging from 49 to 71%. These tills are believed to have been deposited by Keewatin ice, and till fabric analyses indicate deposition from the north and northwest. Ice advancing from the north or northwest would have crossed a 125-km-wide band of Paleozoic bedrock, located about 475 km north of the Killarney-Holmfield area (Figure 6).

The highly calcareous tills of the Glenora and Belmont Formations have a carbonate clast content ranging from 63 to 91%. These tills were deposited by the Red River lobe, advancing to the south and southwest, across the Paleozoic carbonates of the Interlake-Westlake plain. Ice advancing from the northeast would have crossed a 225-km-wide band of Paleozoic bedrock, located about 275 km northeast of the Killarney-Holmfield area (Figure 6). The higher carbonate content of the Glenora and Belmont Tills reflect the larger source area of carbonate bedrock in the Interlake-Westlake plain and the shorter distance to the source rocks. The abundance of carbonate in both the pebble fraction and the silt plus clay fraction is an important factor in differentiating the tills of the Killarney-Holmfield area.

Greywacke, characteristic of the Omarolluk Formation, is another erratic observed in the tills of Killarney-Holmfield area (Table 1). Omarolluk greywackes originate in the greywacke beds of the Omarolluk Formation of the Belcher Group, which outcrops in the Belcher Islands along the east side of Hudson Bay (Ricketts and Donaldson 1981). Omarolluk greywacke content is highest in the tills of western provenence, namely the Shell, Minnedosa, and Lennard Formations (1.2 to 2.5%), and lowest in the the Belmont Formation (0.6%), a till of eastern provenence. In southern Manitoba, Nielsen (pers. comm. 1986) found that Omarolluk greywacke concentrations were highest in the Duck Mountain and Riding Mountain uplands, and that the largest concentration was in the tills of the Boissevain plain.

The largest Omarolluk cobble found in the Killarney-Holmfield area is 27 cm long, 25 cm wide, and 10 cm thick. The cobble, marked by four distinctive light concretions, was part of a disturbed boulder pavement outcropping along the south wall of the Pembina spillway (NW 32-03-15). Many other smaller cobbles have been found throughout the Killarney-Holmfield area.

Omarolluk greywackes are present in northern Manitoba in the tills along the Nelson River and in minor amounts in the tills of Saskatchewan and Alberta. Prest (1983) noted that cobbles and fist-sized stones of a distinctive greywacke (Omarolluk Formation), as well as oolitic jasper pebbles, from the Belcher Islands - Long Island belt in southeastern Hudson Bay are present in and on the glacial deposits of northwestern Ontario as much as 1100 km to the southwest. Oolitic jasper clasts are also observed in the tills of the Killarney-Holmfield area but its concentration is very low.

It is not known how these greywackes accumulated in the tills of southern Manitoba. Dyke et al. (1982) in their discussion of the Hudson Ice Dome state that while it can account for the dispersal of most dark erratics (Omarolluk greywacke), the model proposed does not totally explain the distribution of dark erratics on the Hudson Bay Lowland and adjacent Shield. They suggest that these erratics were transported by pre-Late Wisconsinan ice, and that this likely occurred cumulatively during successive glacial buildup periods when northern Ontario is thought to have been invaded by ice from Labrador. The occurrence of Omarolluk greywacke erratics in pre-Late Wisconsinan tills and in non-glacial sediments throughout the Hudson Bay Lowlands (Nielsen and Dredge, 1982) supports the suggestion that they are polycyclic.

RECONSTRUCTION OF LATE WISCONSINAN GLACIATION

Introduction

Pre-Wisconsinan glaciations in the Killarney-Holmfield area are represented by tills of the Largs, Tee Lakes, and Shell Formations. Early Wisconsinan glaciation is represented by the till of the Minnedosa Formation. Knowledge of these events is sketchy because of patchy preservation of the sediment and scarcity of glacial morphology (Clayton and Moran, 1982). The distribution of these formations is not well known.

A widespread unconformity between the Shell and Minnedosa Formations is represented by a cobble and boulder lag in North Dakota and the Killarney-Holmfield area, and by the Roaring River Clay in the Riding and Duck Mountains (Klassen, 1979). This unconformity is believed to be of Sangamonian age (Klassen et al., 1967).

A second widespread unconformity between the Early Wisconsinan Minnedosa Formation and the Late Wisconsinan Lennard Formation is represented by a boulder pavement in Saskatchewan, southwestern Manitoba, and North Dakota. Southeast of Killarney, the Minnedosa Formation is overlain by Early Wisconsinan outwash deposit. A boulder pavement occurs at the surface of the outwash where it is overlain by the Late Wisconsinan Lennard Formation and by gravel of the Mather outwash plain (Figure 56). This unconformity is believed to be of Middle Wisconsinan age (Fenton, 1984). Carbonaceous material from sediments overlying the Minnedosa Formation in the Zelena section were radiocarbon dated at 23 700$\pm$290 (GSC-1279) and 37 700$\pm$1500 (GSC-653)

Figure 56. Cross-section through the Mather outwash plain (Section GC324, Appendix I). The sand and gravel of the Mather outwash plain overlie till of the late Wisconsinan Lennard Formation. Faceted and striated boulders of the boulder pavement were observed at the contact of the Lennard Formation and the younger underlying sands and gravels. Till of the early Wisconsinan Minnedosa Formation was observed in the bottom of the pit.

on charcoal, and 28 220±380 (GSC-711) on marl (Klassen, 1979).

Láte Wisconsinan Events

The Early Phases. The nonglacial Middle Wisconsinan in southern Manitoba came to a close with the advance of the Laurentide Ice Sheet from the north or northeast. Till of the Senkiw Formation was deposited in southeastern Manitoba. This ice advanced from the Labradorean centre and may only have pushed as far as the western edge of the Lake Agassiz basin (Fenton et al., 1983).

At this time, ice of the Keewatin centre, which was centered to the west of Hudson Bay, had become strong enough to flow southward in the region (Fenton et al., 1983). This ice was deflected westward around the Labradorean ice that covered the carbonate rocks of the Manitoba lowland. As the Labradorean glacier began to waste back, the Keewatin ice flowing over the shaly terrain of the Manitoba Escarpment extended southwestward, depositing the till of the Lennard Formation in southwestern Manitoba (Manitoba Mineral Resources Division, 1981) and the Dahlen Formation in northeastern North Dakota. The St. Hilaire Formation is believed to have been deposited in northwestern Minnesota at this time (Fenton et al., 1983). The Keewatin ice reached western Iowa around 20 000 B.P. (Figure 57a) (Fenton et al, 1983; Clayton and Moran, 1982). A major withdrawal of ice into southern Manitoba is believed to have followed this advance (Fenton et al., 1983).

The boulder pavement at the contact between the Lennard Formation and the underlying Minnedosa Formation was formed during the deposition of the till of the Lennard Formation (Klassen, 1979, p. 22). Little is known about the source of the boulders, whether

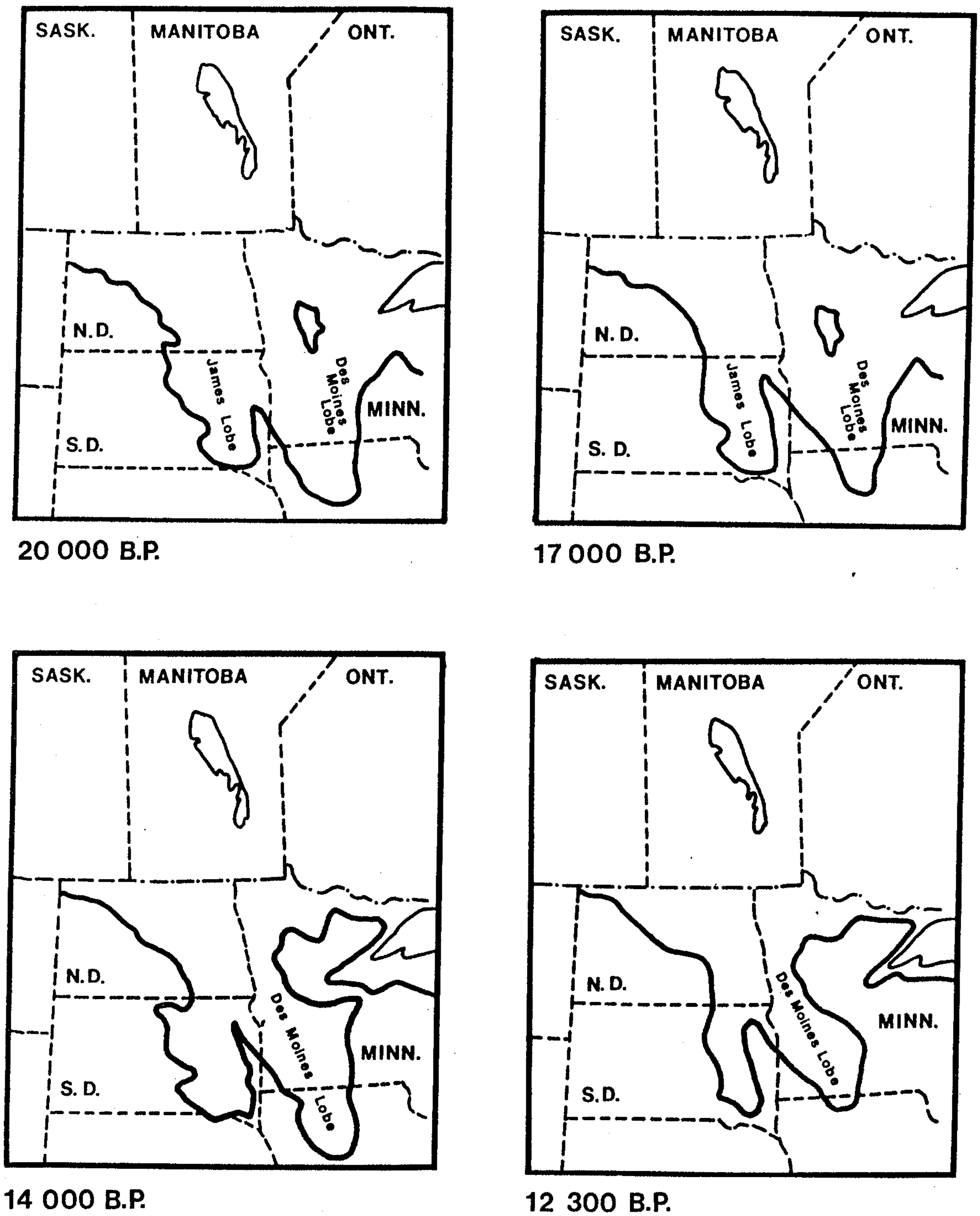


Figure 57. Ice-margin positions between 20 000 B.P. to 12 300 B.P. (Modified from Fenton et al., 1983). The Killarney-Holmfield area is indicated by a box along the Manitoba-North Dakota border.

they were brought in with the Lennard advance or whether they are erosional remnants, exposed previous to the last glaciation. The lithologies of the Lennard and Minnedosa Formations are so similar that it is impossible to determine which units provided the boulders.

Ice advancing southward from the Keewatin centre deposited tills of the Roseau Formation in southeastern Manitoba and the lower part of the Red Lake Falls Formation in Minnesota (Fenton et al., 1983). The Dahlen and Lennard Formations continued to be deposited in northeastern North Dakota and southwestern Manitoba, respectively, including in the Killarney-Holmfield area. This Keewatin ice reached its maximum across the Dakotas and Minnesota about 17 000 B.P. (Figure 57b) (Clayton and Moran, 1982). This advance is believed to have been followed by a major withdrawal of ice (Fenton et al., 1983).

Nielsen (Manitoba Mineral Resources Division, 1981) believed that the Lennard Formation was deposited by Keewatin ice, but that the tills in the Red River Valley and the till of the Zelena Formation on the uplands of Duck and Riding Mountains, were deposited by Labradorean ice. Theoretical work by Fisher et al., (1986, Fig. 6) suggests that Labradorean ice, crossing the boundary between the hard Canadian Shield rock and the deformable Prairie sediments, may have been deflected to the south along the axis of the Red River Valley.

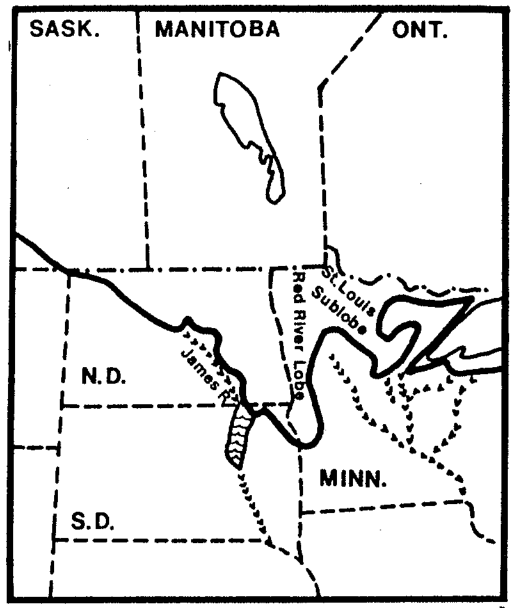
Renewed activity of the glacier sent ice once again through the Lake Agassiz basin to the maximum extent in central Iowa, about 14 000 B.P. (Fenton et al., 1983) (Figure 57c). The ice extended south into Minnesota and Iowa as the Des Moines Lobe and into South Dakota as the James Lobe. The Roseau Formation continued to be deposited in southeastern Manitoba and the upper part of the Red Lake Falls Formation was deposited in Minnesota (Fenton et al., 1983). The

Dahlen and Lennard Formations continued to be deposited in northeastern North Dakota and southwestern Manitoba, respectively. This event corresponds to Phase F of Clayton and Moran (1982) and was followed by one or two minor retreats and readvances before 12,300 B.P. (Clayton and Moran, 1982).

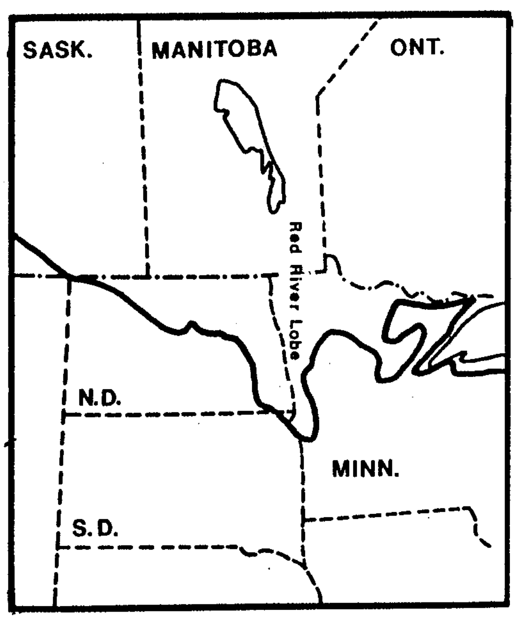
About 12,300 B.P., the ice readvanced and overrode trees along the margin of the James Lobe in South Dakota (Clayton and Moran, 1982) (Figure 57d). The Des Moines Lobe is believed to have advanced to the Algona moraine near the Iowa-Minnesota border Minnesota (Phase I of Clayton and Moran, 1982).

The glacier then retreated as far north as northeastern North Dakota and a lake formed around the margin of the ice in the southern Red River Valley (Fenton et al., 1983). The glacier was once again reactivated during Phase J (Figure 58a) and the ice-marginal lake was overridden (Clayton and Moran, 1982). In central North Dakota, margin J represents a significant glacial readvance and marks a major shift in ice flow direction, from southeasterly ice flow beyond margin J to southwesterly ice flow behind margin J (Clayton and Moran, 1982). Margin J, represented by the Kensal moraine in northeastern North Dakota and the Martin moraine in central and northwestern North Dakota, marks the western extent of deposition of the Dahlen Formation (Figure 59) (Moran et al., 1976). Much of north central North Dakota, south and west of margin J, was free of ice and the James River channel was initiated (Figure 58a). The Lennard Formation continued to be deposited in southwestern Manitoba, including the Killarney-Holmfield area.

After a minor wastage, the ice readvanced to the Cooperstown moraine in southeastern North Dakota, and to the Heimdal margin in the



Margin J



Margin K

Figure 58. Ice-margin positions. a) Location of the ice margin following reactivation during Phase J of Clayton and Moran (1982). b) Location of Margin K of Clayton and Moran (1982). (Modified from Clayton and Moran, 1982).

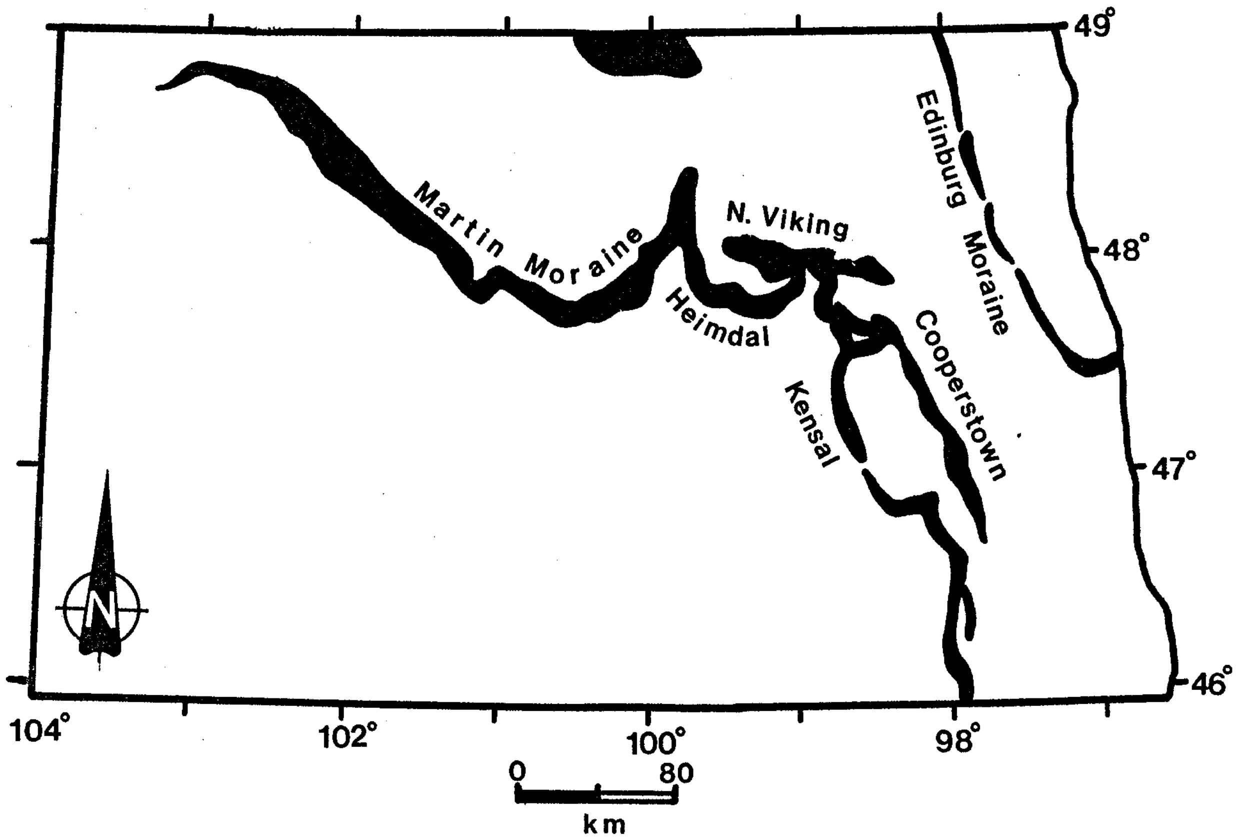


Figure 59. Location map of North Dakota moraines discussed in the text. (Modified from Lemke and Colton, 1958).

west (Figure 59). In northwestern North Dakota the ice remained at the Martin moraine. This corresponds to margin K of Clayton and Moran (1982) (Figure 58b). The Cooperstown moraine is marked by glacial thrust masses (Clayton and Moran, 1982). After a brief retreat, a significant readvance occurred to the North Viking margin (Figure 59). The Hansboro Formation may have been deposited in northeastern North Dakota during this advance. In the Red River Valley, the glacier margin was in southern North Dakota. In southern Manitoba, the dominant ice flow was now occurring through the Interlake, and the western ice was waning.

In northwestern North Dakota, the ice had separated into two lobes, the Souris Lobe to the west of Turtle Mountain and the Red River Lobe to the east (Clayton and Moran, 1982, p. 73). As wasting occurred, the eastern lobe became greatly reduced in size and this smaller lobe is known as the Leeds Lobe (Figure 60) (Lemke and Colton, 1958). East of the Killarney-Holmfield area, the eastern margin of the Leeds Lobe continued to retreat to the northwest and the Boissevain plain between the ice margin and the Red River Valley was relatively ice free. Meltwater from the receding ice margin drained east through the Pembina spillway to Lake Agassiz. The Pembina spillway is believed to have been formed prior to the deposition of the pre-Wisconsinan Shell Formation, which outcrops at the base of a gravel bar within the spillway. The Souris Lobe remained more vigorous than the Leeds Lobe for a slightly longer period of time, and readvanced into Towner County (Figure 61). This advance is marked by the truncation of washboard moraines of the Leeds Lobe by washboard moraines of the Souris Lobe, in the area west of Leeds (Bluemle, 1984). Water ponded along the margin of the Souris Lobe as it

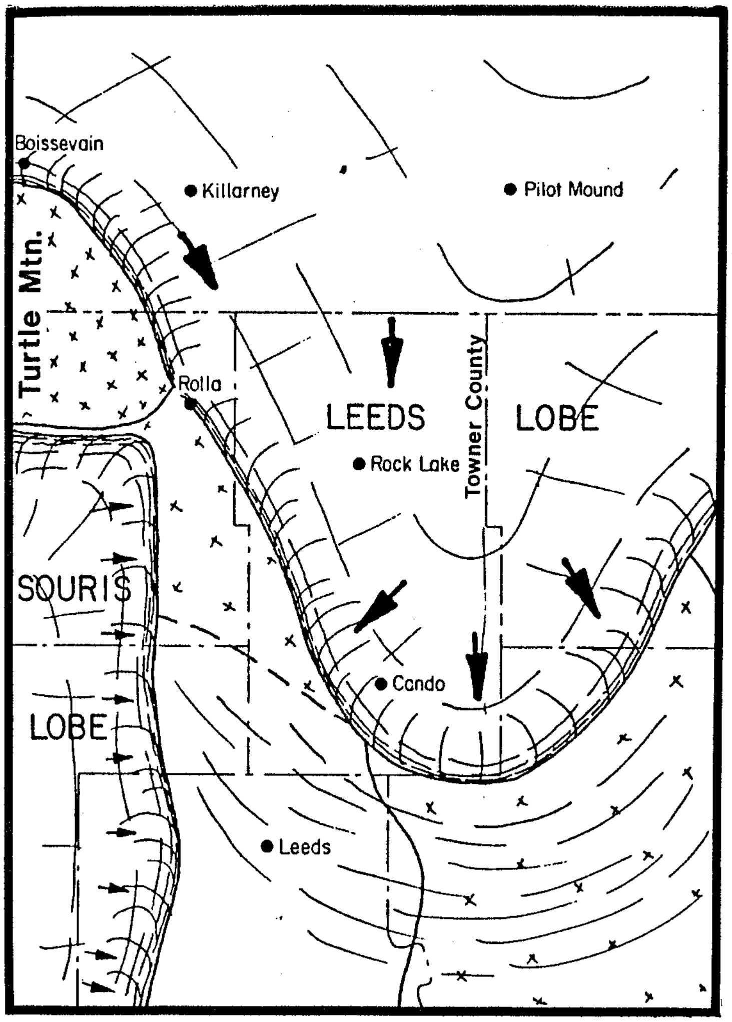


Figure 60. Ice margin in Towner County, and surrounding area of northeastern North Dakota. The ice separated into two lobes, the Leeds lobe to the east of Turtle Mountain and the Souris lobe to the west. (Modified from Bluemle, 1984) The Killarney-Holmfield area is located north of Towner County, between Boissevain and Pilot Mound. Stagnant ice is indicated by the pattern of x's.

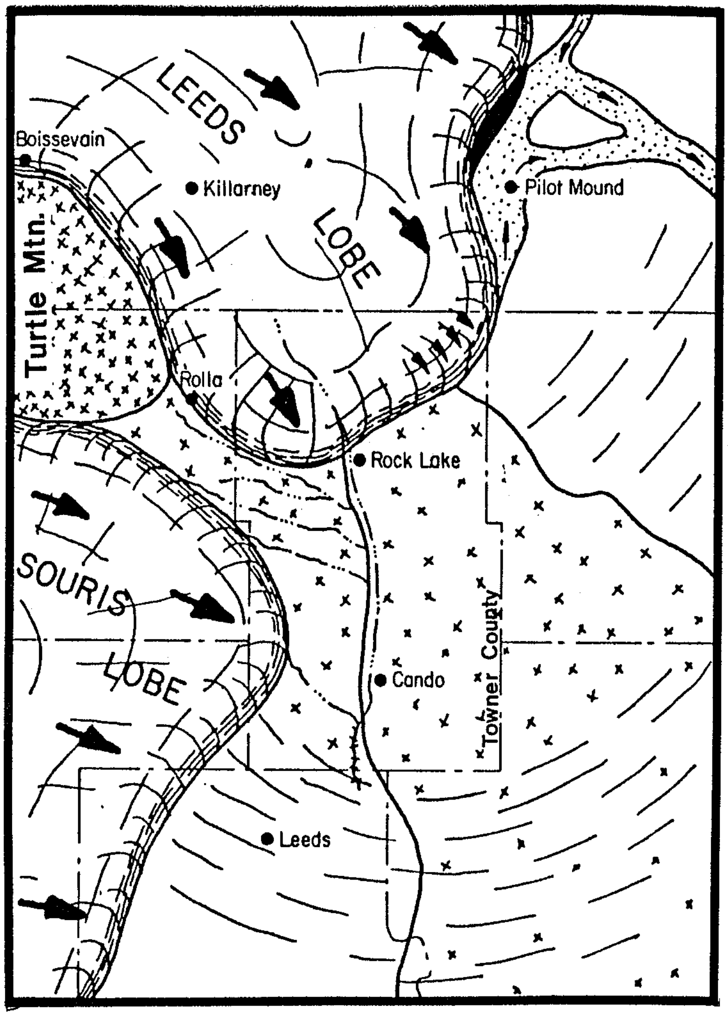


Figure 61. The Leeds lobe in southwestern Manitoba. Meltwater along the east margin formed an outwash plain near Pilot Mound. The plain drained north to the Pembina spillway. A brief readvance of the Souris lobe overrode the washboard moraines of the Leeds lobe, west of Leeds, North Dakota. (Modified from Bluemle, 1984) Stagnant ice is indicated by by the pattern of x's.

retreated northward through North Dakota, and Lake Souris began to fill the Souris basin. The ice stagnated over Turtle Mountain.

Bluemle (1984) believed that the glacier stagnated over much of Towner County in a relatively short period of time because evidence for active ice margins and deposition by actively moving glacier ice is largely absent from the area. Runoff from Turtle Mountain flowed eastward until it reached the edge of the stagnant glacier and then turned south along the margin.

As the ice retreated north into southwestern Manitoba, an outwash plain was deposited along the eastern margin of the Leeds Lobe, near Pilot Mound (Figure 61) (Bluemle, 1984, p. 38). The glacier retreated northwestward across the Boissevain plain and the eastern part of the Pembina spillway was free of ice. Discharge flowed north from Pilot Mound a short distance along the glacier margin to the Pembina spillway. The ice continued to retreat north of Cartwright and Killarney.

The Cartwright Readvance. The glacier readvanced to Cartwright where the Cartwright moraine was deposited (Figure 62). To the west, the glacier margin lay just south of Killarney and the Mather outwash plain formed along the entire extent of the margin. A proglacial lake, which had developed in the Whitewater basin between the Cartwright ice margin and Turtle Mountain to the south, drained eastward through the Mather outwash plain into the Pembina spillway.

As the glacier retreated north of Cartwright, a series of prominent washboard moraines were formed at or near the ice margin. The moraines curve up-ice in the vicinity of a large esker formed in an embayment in the ice margin near Cartwright (Figure 28). The association of the washboard moraines with thrust features west of

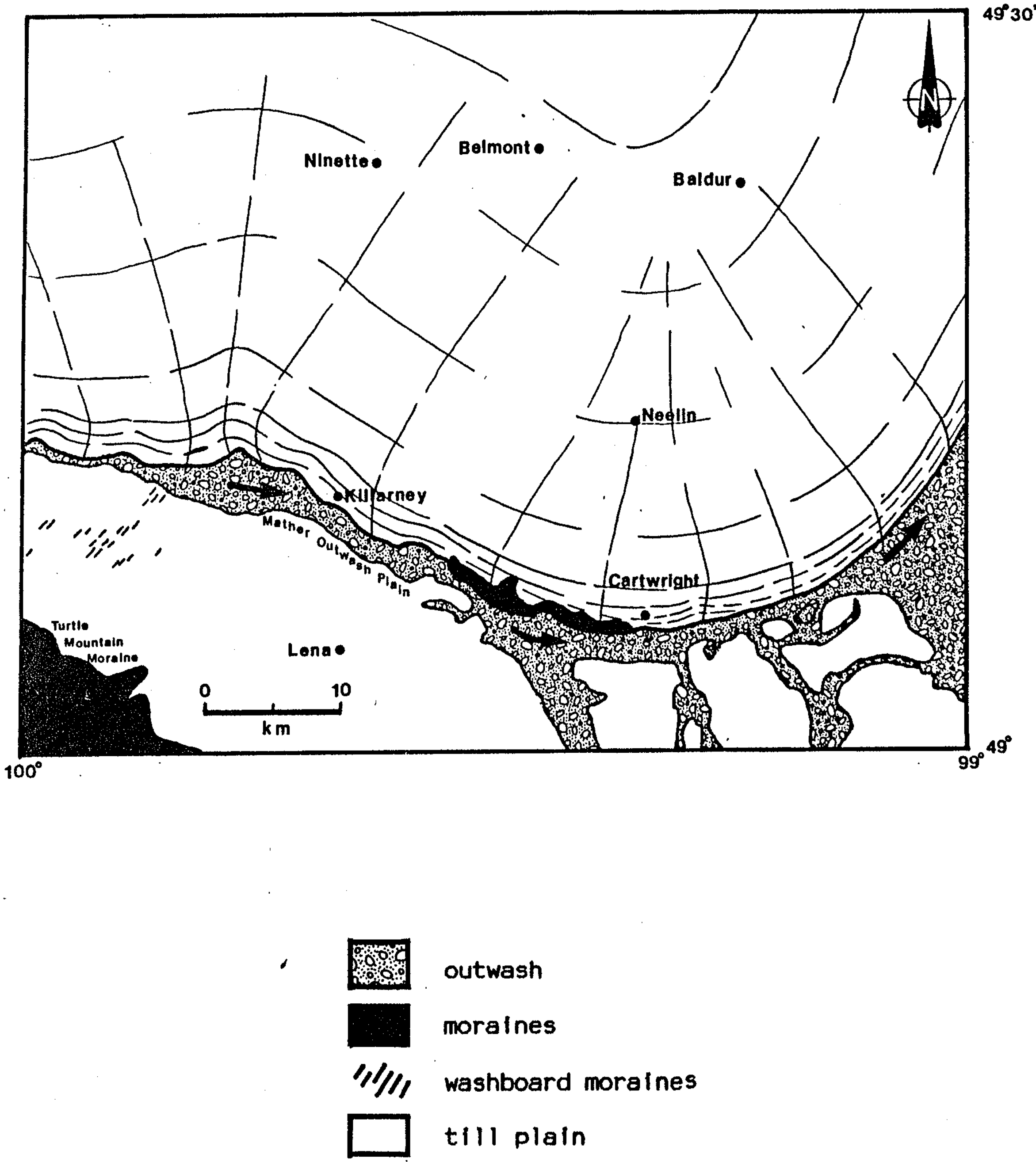


Figure 62. The Cartwright readvánce. The ice readvanced to the Cartwright Moraine. The Mather outwash plain was formed along the margin, draining meltwater from the glacier and the proglacial Whitewater Lake near Boissevain eastward into the Pembina Valley.

Killarney (Figure 31) and east of Cartwright, and the observation that some moraines are composed of contorted glacial drift of earlier events, suggest that thrusting was an important process involved in the formation of these washboard moraines. The orientation parallel to end moraines, such as the Cartwright moraine, and the up-ice curving of the moraines near eskers indicate deposition at or near the front of a retreating glacier.

Eventually, the eastern part of the Mather outwash plain was abandoned in favor of a new course at a lower elevation along the present day course of the Long River. The ice margin retreated first to the northwest and then later, almost due west in the area north of Killarney, as indicated by the changing orientation of the washboard moraines (Figure 2). The Mather-Long River outwash, east of the present day of Badger Creek, was also abandoned in favor of a more direct northward course to the Pembina spillway. As this northward extension of the Mather-Long River outwash plain became graded to the Pembina spillway, the eastern part of the outwash was left as a hanging valley.

As the ice retreated to the west along the axis of the Pembina spillway, more of the spillway was exposed and meltwater drained through it toward Lake Agassiz in the east. Once the ice retreated west of Turtle Mountain, the ice dam between Lake Souris and the western inlet of the Pembina spillway melted and Lake Souris drained through the Pembina spillway into Lake Agassiz.

In the Red River Valley, the offshore sediment of the Wylie Formation was deposited in the Lake Agassiz basin (Clayton and Moran, 1982; Fenton et al., 1983). Lake Agassiz remained at the Herman level during the Cass and Lockhart Phases of Lake Agassiz (Thorleifson, 1983). The margin of the Red River Lobe had retreated into southern Manitoba and the Leeds and Souris Lobes had retreated west of Lake Souris. The Boissevain plain and the Tiger Hills upland were free of ice at this time. Depending on the proximity of the western extent of the Red River lobe to the Manitoba Escarpment, Lake Agassiz may have extended westward into the Assiniboine Delta region.

<u>The First Darlingford Advance</u>. Reactivation of the Red River Lobe about 11 400 B.P. resulted in a readvance of more than 200 km to ice margin M (Figure 63), depositing till of the Falconer Formation in northeastern North Dakota and the Whitemouth Lake Formation in southeastern Manitoba (Clayton et al., 1982, p. 75). This margin is marked by the Edinburg moraine in northeastern North Dakota (Figure 59). In southwestern Manitoba, the glacier advanced to the Darlingford moraine, the northern extension of the Edinburg moraine, and deposited the till of the Glenora Formation. The First Darlingford advance crossed the Pembina spillway at Swan Lake, preventing drainage to the east, and the main glacier in the Red River Valley blocked the eastern end of the spillway where it drained into Lake Agassiz (Figure 64). With the spillway blocked by an ice dam at Swan Lake, water began to pond along the southern margin of the Darlingford moraine and glacial Lake Souris was re-established.

At Swan Lake, the ice stagnated and became thinner. Meltwater began to drain across the southern margin of the ice, toward the Pembina spillway and several channels were eroded into the plain (Figure 65). The ice dam weakened and broke, resulting in a flood of very large or catastrophic magnitude, and glacial Lake Souris emptied. To the east of Swan Lake, the gradient of the Pembina spillway changes considerably. This may have been a result of the catastrophic

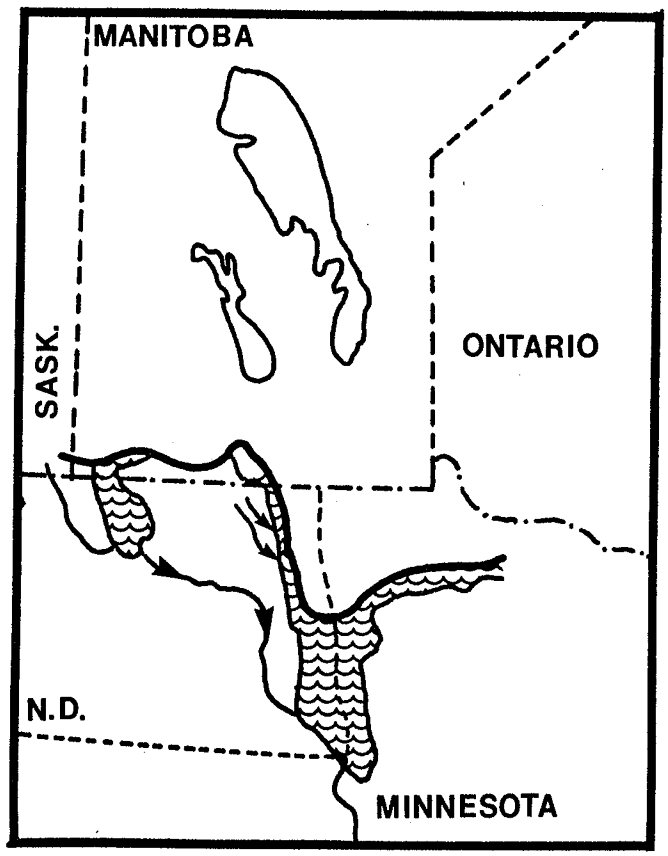


Figure 63. The first Darlingford advance. Reactivation of the ice resulted in an advance to the Darlingford moraine in the Tiger Hills upland and the Edinburg moraine in northwestern North Dakota. (Modified from Fenton et al., 1983)

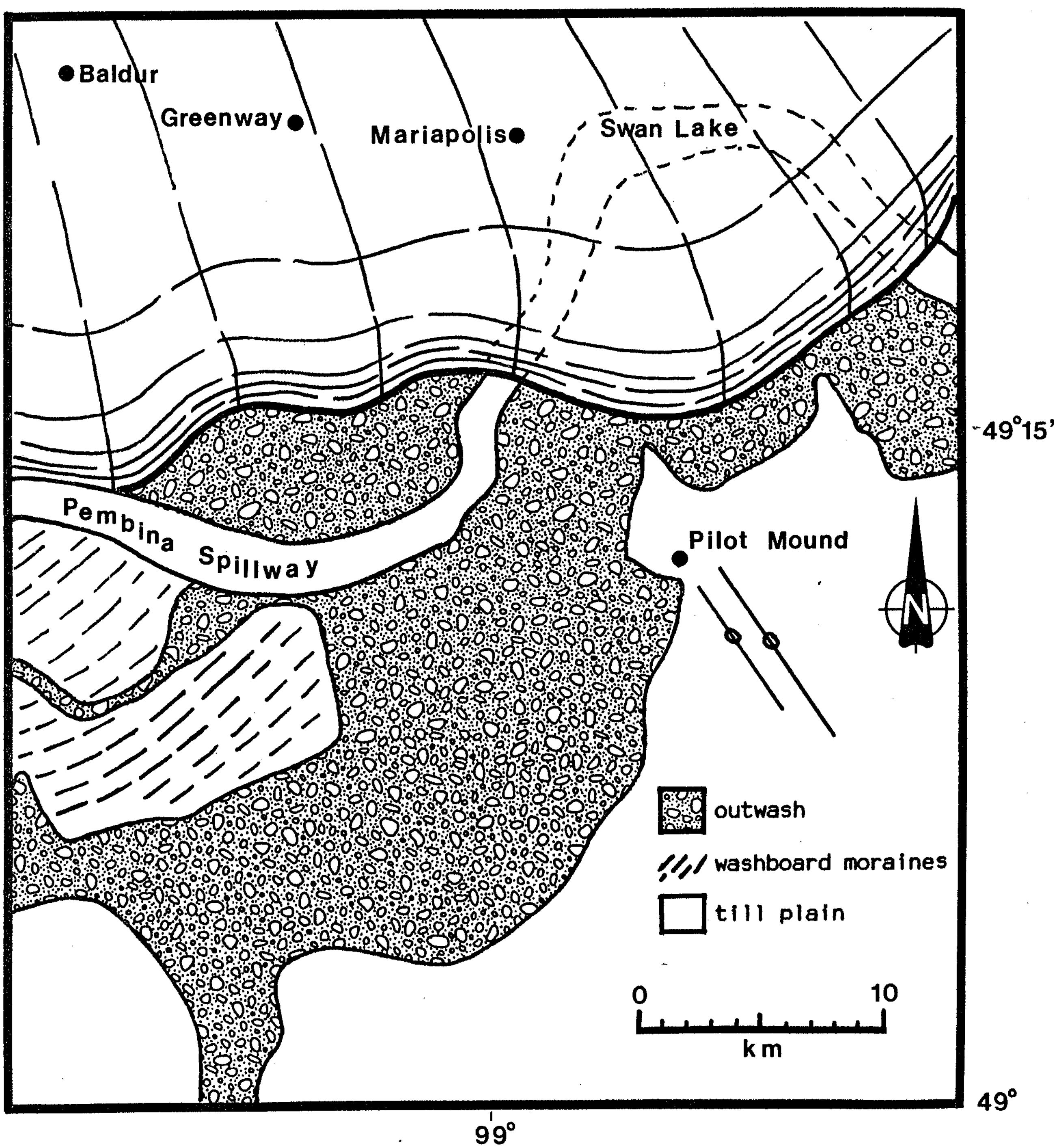


Figure 64. East of the Killarney-Holmfield area, the Red River lobe crossed the Pembina spillway at Swan Lake. The ice margin is marked by a series of thrust features north of Pilot Mound. An outwash plain developed along the ice margin. Water ponded in the Pembina valley, flowed west into glacial Lake Hind and Souris, which in turn, overflowed and flowed south through the Sheyenne spillway into Lake Agassiz (Kehew and Lord, 1986). Figure 66 places this diagram in the regional perspective.

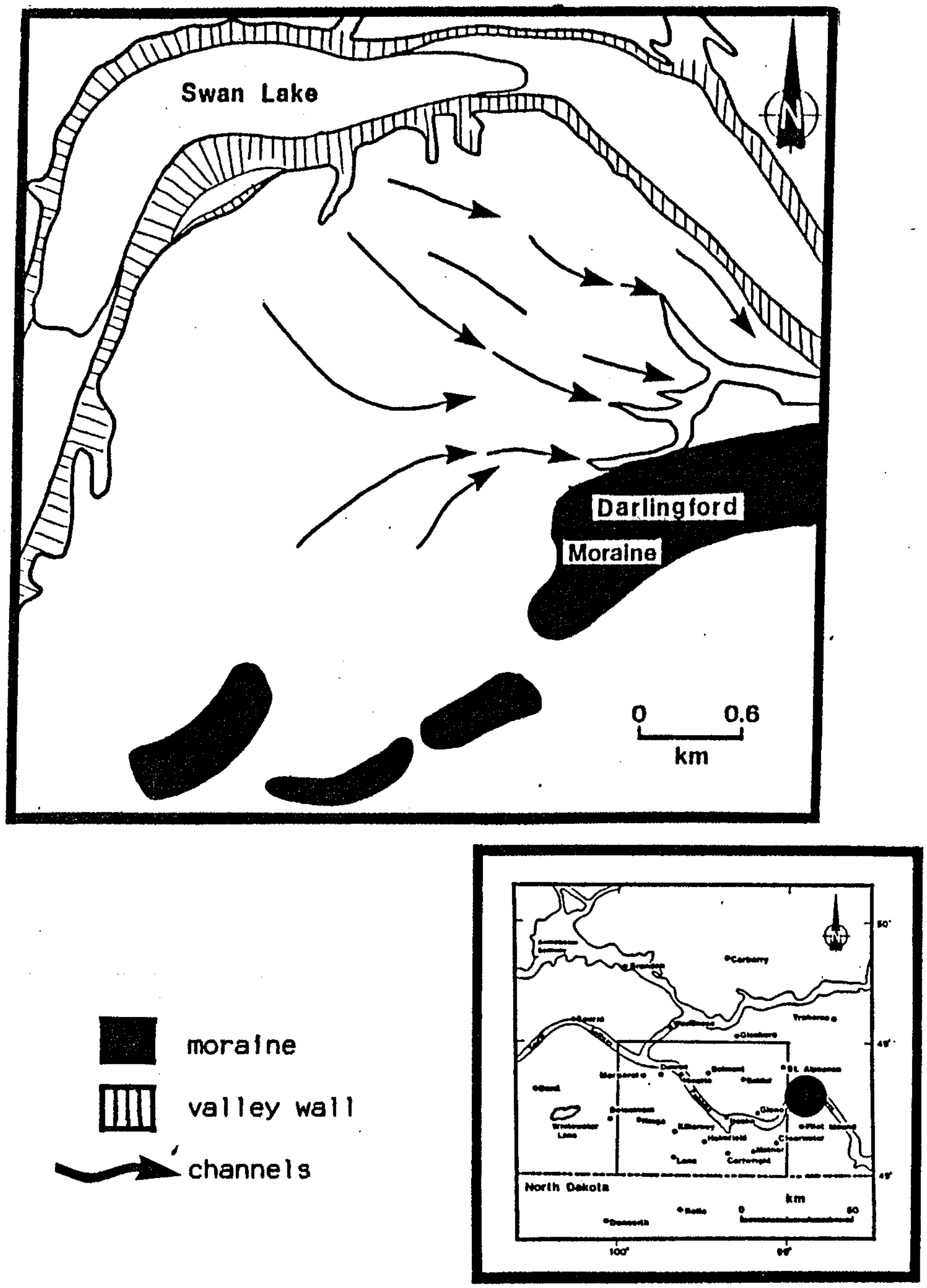


Figure 65. As the Red River lobe at Swan Lake thinned, water that was ponded west of the ice dam began to flow around the margin. Several channels were eroded in the plain south of Swan Lake.

discharge.

During this time, ice in the Red River Valley, lay to the south of the Pembina spillway. Initial drainage occurred between the Pembina Escarpment on the west and the Edinburg moraine on the east, and the Elk Valley Delta was deposited (Fenton et al., 1983) (Figure 66). As the ice retreated, the Elk Valley Delta was abandoned and the Pembina spillway emptied directly into Lake Agassiz near Walhalla, North Dakota, forming the Pembina underflow fan (Fenton et al., 1983).

In Saskatchewan, the Weyburn Lobe had retreated and glacial Lake Regina began to form in the depression. Water from Lake Regina flowed down the Des Lacs and Souris spillways to Lake Souris (Figure 66) (Clayton and Moran, 1982). Lake Souris had two outlets, the Girard Lake spillway in the south, and the Pembina spillway to the north. The Girard Lake spillway experienced several phases of activity separated by an ice advance across the Lake Souris basin (Kehew and Clayton, 1983). Initially, drainage flowed along the ice-marginal Heimdal spillway to the James spillway, and later, down the Sheyenne spillway to Lake Agassiz (Figure 66) (Kehew and Lord, 1986). Lake Souris is believed to have rapidly formed a spillway to the north, leading to Lake Hind, when water breached a melting ice dam during final ice retreat from the region (Kehew and Lord, 1986). This flood, which is believed to have been triggered by the catastrophic inflow of water to Lake Souris from Lake Regina, induced Lake Hind to drain rapidly through the Pembina spillway (Kehew and Clayton, 1983). Kehew and Clayton (1983) believe that this catastrophic event occurred prior to Phase M (prior to the First Darlingford advance). Shortly after the erosion of the connecting spillway between Lake Hind and Lake

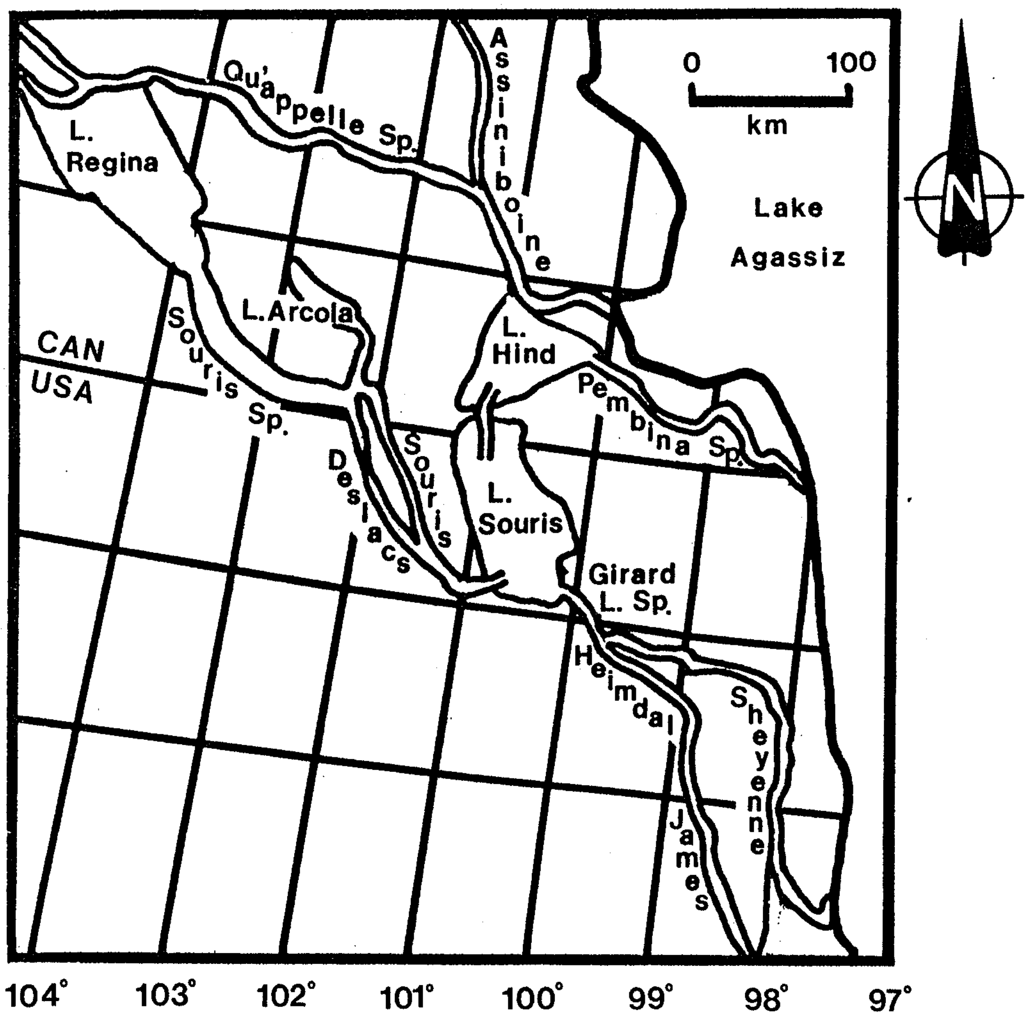


Figure 66. The Souris-Pembina spillway system, connecting Lake Regina, in Saskatchewan, to Lake Agassiz. The Elk River and Pembina underflow fans are located east of 98 degrees longitude. (Modified from Kehew and Lord, 1986)

Souris, the two lakes are believed to have drained for the last time (Kehew and Clayton, 1983). However, the timing of these events is somewhat uncertain as the outlet from Lake Souris was dammed during the First Darlingford advance and possibly during the Second Darlingford advance. The level of Lake Souris rose to at least 465 m a.s.l. during both advances.

The Red River Lobe in the southern Tiger Hills retreated an unknown distance to the north of Wawanesa, and a lake formed in the vicinity of Wawanesa in which clay was deposited. It is not known whether this was an isolated lake or whether the ice had retreated far enough to the north to allow a connection to the main Lake Agassiz basin.

<u>The Second Darlingford Advance</u>. The glacier advanced once again to the Darlingford moraine about 11 200 B.P. (Fenton et al., 1983), this time from the carbonate-rich terrain to the northeast (Figure 67). This advance deposited till of the Belmont Formation in the Tiger Hills upland and that of the Marchand Formation in southeastern Manitoba (Figure 68). The Wawanesa clays were overridden and incorporated into the till of the Belmont Formation (Section GC602, Appendix I). As the ice advanced, the lake in which the Wawanesa clays were deposited was trapped between the ice margin and the escarpment to the south. The water was forced over the divide and drained south to the Pembina spillway, eroding the Dry River spillway and the anastamosing channels of the Baldur outwash complex, located between Baldur and the Pembina spillway near Neelin (Figure 51). Water may also have drained south through the gap, occupied by the present day Souris River.

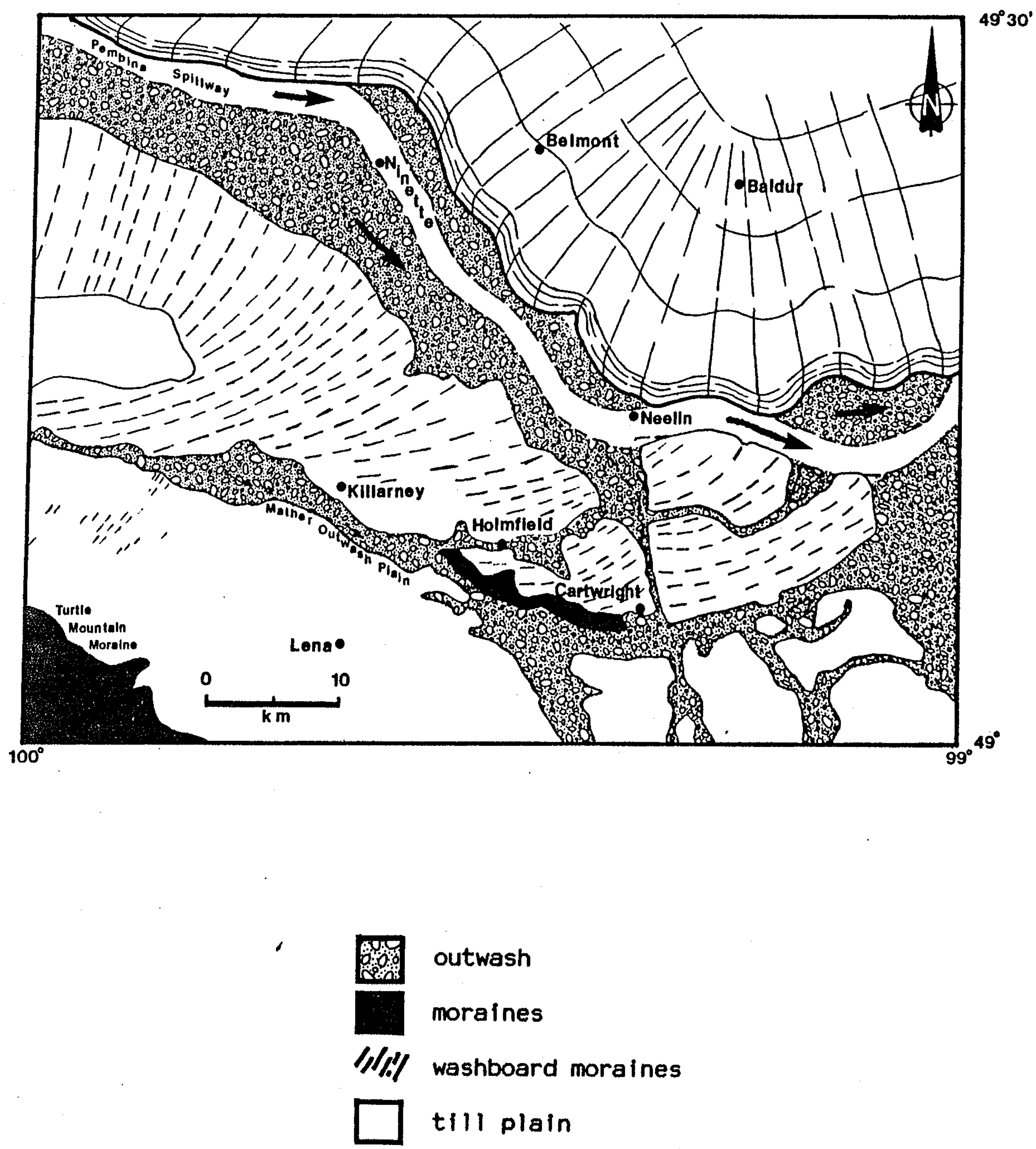


Figure 67. The Second Darlingford advance. The ice readvanced a second time to the Darlingford moraine in the Tiger Hills upland. A 10 km wide outwash was formed along the southern margin of the moraine.

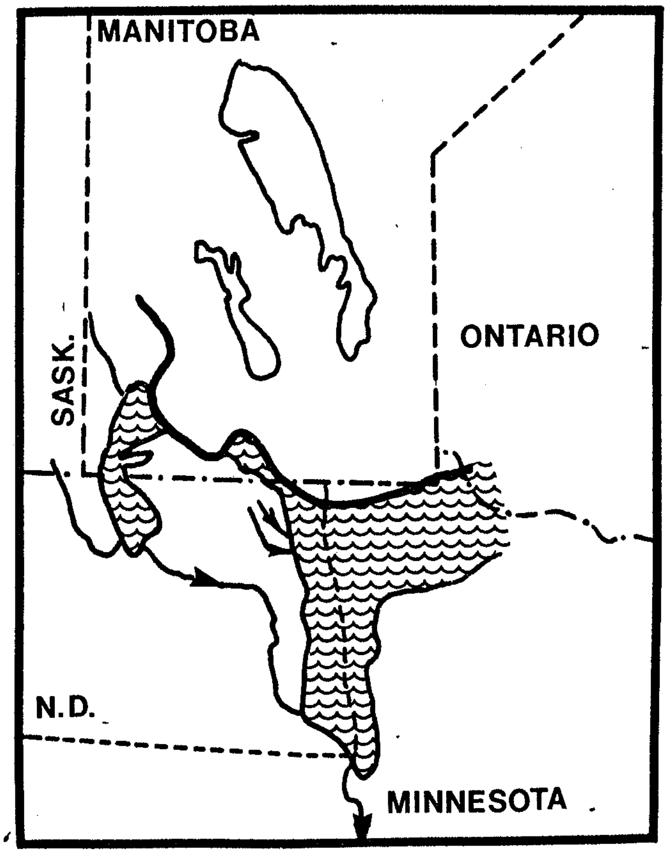


Figure 68. The Second Darlingford advance. In the Lake Agassiz basin, the ice readvanced across the International Border a short distance into North Dakota (Fenton et al., 1983). The till of the Marchand Formation was deposited in southeastern Manitoba and the till of the Belmont Formation was deposited in the Killarney-Holmfield area.

In the Tiger Hills upland, large flutes were formed along the north edge of the escarpment (Figure 51). The orientation of the flutes suggests that the glacier advanced into the area and spread out in a broad lobe. The lobate pattern and digitation along the edge of the moraine indicate that the ice was relatively thin. This advance may have only extended as far west as the Brandon Hills, and a study of the surface till in the Brandon Hills by Welsted and Young (1980) indicates that till of the Lennard Formation forms the surface there.

The Second Darlingford advance is also believed to have crossed the Pembina spillway east of the study area at Swan Lake about as far as shown in Figure 64 for the First Darlingford advance. The southern extent of this advance is marked by a series of thrust features formed within the ice margin north of Pilot Mound (Figure 48). Once again, drainage to the east was blocked by an ice dam, and glacial Lake Souris was re-established. Lake Souris overflowed south through the Sheyenne spillway to Lake Agassiz, depositing coarser sediment on the Sheyenne underflow fan (Fenton et al., 1983). The blockage of the Pembina spillway is marked by the deposition of a finer grained unit in the Pembina underflow fan (Fenton et al., 1983, p. 66).

The elevation of Lake Souris at this time was 465 m a.s.l., as indicated by the truncated or infilled washboard moraines along the northern Boissevain plain and the outwash deposits along the edge of the spillway (Figure 41). The water may also have spread into the abandoned Mather outwash plain, south of Cartwright. Eventually, the water level dropped below 455 m a.s.l. and shallow channels were eroded into the plain at several locations near Dunrea, southeast of Ninette, and southeast of Glenora (Figure 2).

Water discharging south through the Souris gap from the carbonate-rich terrain to the north, deposited a large gravel river bar along the north wall of the spillway at 450 m a.s.l. (Figures 37 and 38). The source is believed to be meltwater discharging from the glacier margin as it occupied a position at the Darlingford moraine. The outwash channel would have initially been graded to the surface elevation of the river bar at 450 m a.s.l. and may have continued downcutting as the water level dropped in the spillway. The duration of downcutting was dependent upon continued discharge from the north.

As the ice wasted, the Pembina spillway was reopened and Lake Souris drained again, depositing coarse sediment on the Pembina underflow fan of Lake Agassiz (Fenton et al., 1983). Water at this time drained eastward through the Pembina Valley to its mouth at Pembina, North Dakota.

<u>The Baldur Moraine</u>. The glacier waned again and retreated an unknown distance north of Baldur. The pattern of washboard moraine indicates that the direction of retreat was almost due north from the Darlingford moraine. A brief readvance brought the glacier to the Baldur moraine (Figure 69), where a series of thrust features were formed within the ice margin. The ice margin west of Belmont remained at or readvanced back to the Darlingford moraine. A small, poorly defined outwash plain south of Belmont, crosses the Darlingford moraine and is the result of meltwater discharging into the Pembina spillway to the west (Figure 51). South of Baldur, meltwater flowed south to the Pembina spillway, depositing outwash sediments in the anastamosing channels eroded in shale bedrock between Baldur and

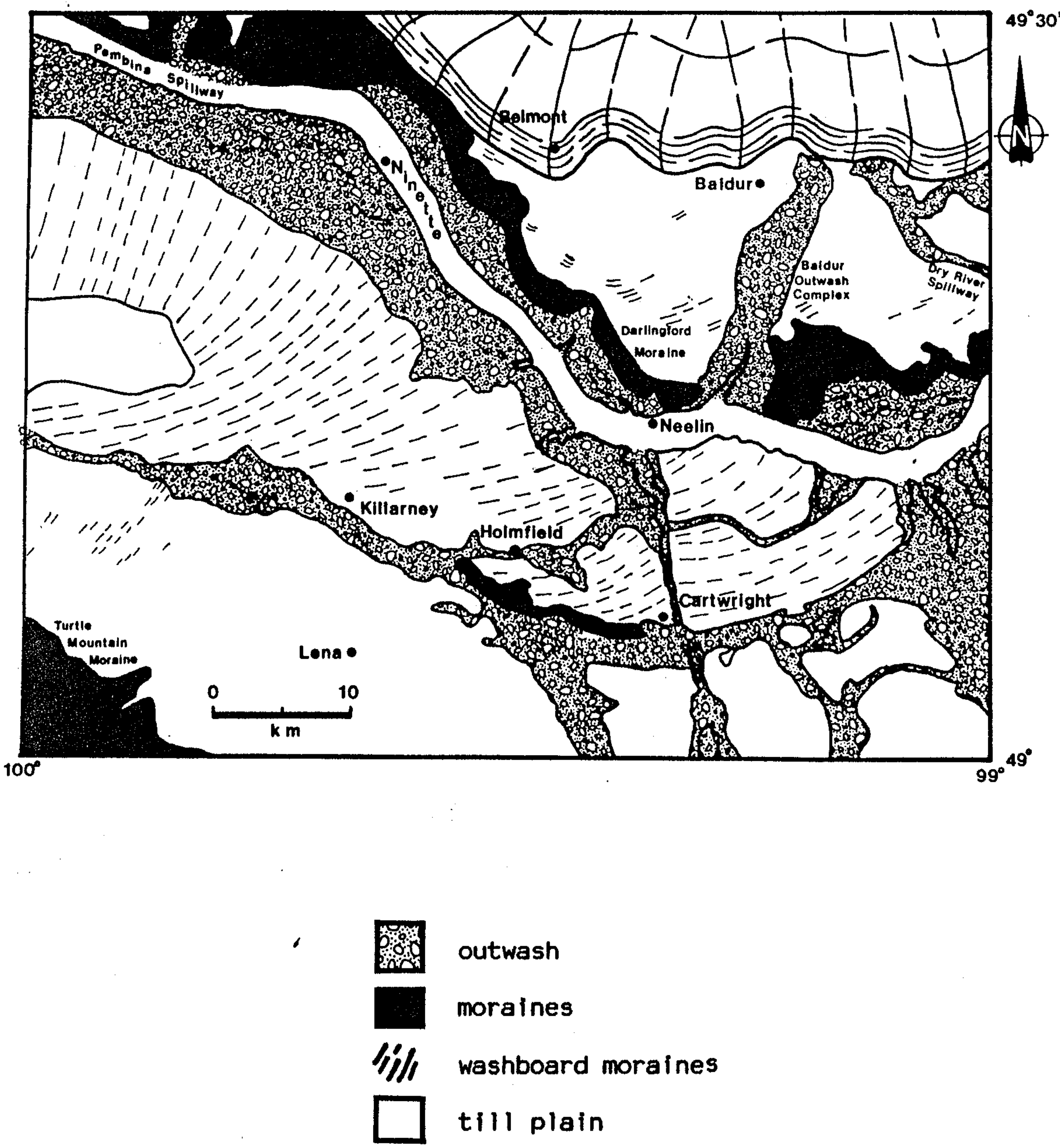


Figure 69. The Baldur ice-margin. The ice retreated to the north and then readvanced a short distance to form the thrust features of the Baldur moraine.

Neelin. The Dry River spillway drained the ice margin east of Baldur.

The lobated nature of the Baldur moraine indicates the glacier was very thin. A series of tightly curved washboard moraines formed between and behind the thrust blocks as the ice retreated (Figure 47).

The thrust hill-depressional features formed where the glacier overrode permeable material that was confined by less permeable material. As the pore-water pressure rose in the permeable material the effective stress was decreased, allowing shearing of large blocks of material upward into the glacier (Bluemle and Clayton, 1984). According to Clayton and Moran (1974), in order to incorporate large blocks of material in the base of the glacier, conditions of compressing flow must exist within the glacier itself. When compressing flow occurs, the flow lines within the glacier have an upward component of motion. In the Tiger Hills upland, the ice was advancing upgrade. This resulted in ponding of the water at the front of the ice, creating a waterlogged area over which the glacier advanced. According to Bluemle and Clayton (1984), elevated pore water pressures may develop in the overridden, waterlogged materials, allowing shearing to take place. These conditions of compressive flow might have occurred as the southward-moving ice pushed up out of the valley presently occupied by the Assiniboine Delta. Dependent upon the thickness of sediment that had been previously deposited in the Assiniboine Valley, the ice sheet would have had to climb more than 100 m onto the Tiger Hills upland.

During the two major readvances of the Red River Lobe west to the Darlingford moraine, the ice margin continued to retreat in Saskatchewan. The Qu'Appelle-Assiniboine spillway system began to discharge meltwater into the northern part of Lake Souris and through the Pembina spillway to Lake Agassiz. As the Red River Lobe retreated to the north, a lake once again formed in the vicinity of Wawanesa, in which more than 3 m of sandy silt interbedded with clay was deposited over the Belmont Formation. This is believed to be Lake Brandon of Elson (1956). South of Wawanesa, stony silts and gravelly lag deposits were observed at an elevation of 396 m a.s.l. Elson (1956, p. 238) believed the altitude of Brandon Lake to have been between 419 and 412 m. Initially drainage may have been from Lake Brandon, south into the Pembina spillway and additional downcutting of the Souris gap may have taken place at this time. As the ice continued to retreat to the north or northeast, a channel opened up between the glacier margin to the north and the height of land to the south (Figure 70). Drainage was re-established at a lower elevation along the Glenora outwash complex. As the water drained east to Lake Agassiz through the Glenora outwash complex, a system of channels was eroded in the shale bedrock between Hilton and Treherne and the Treherne spillway (Elson, 1956) was formed. In the Souris gap, between the elbow of capture in the Pembina spillway and Wawanesa, meltwater began to spill north and downcutting by the Souris River was rapid. The valley walls became very unstable and slumping occurred extensively along this reach of the river. The upper terrace of the Souris River in the Souris gap formed at an elevation of 396 m a.s.l. As the ice continued to retreat to the north or northeast, the level of the lake dropped and the Souris River continued downcutting in the area of the Souris gap. The Souris River was thus established in its present course and eventually flow east of the elbow of capture in the Pembina spillway was abandoned. The ice continued to retreat to the north and the Assiniboine underflow fan was deposited east of Brandon.

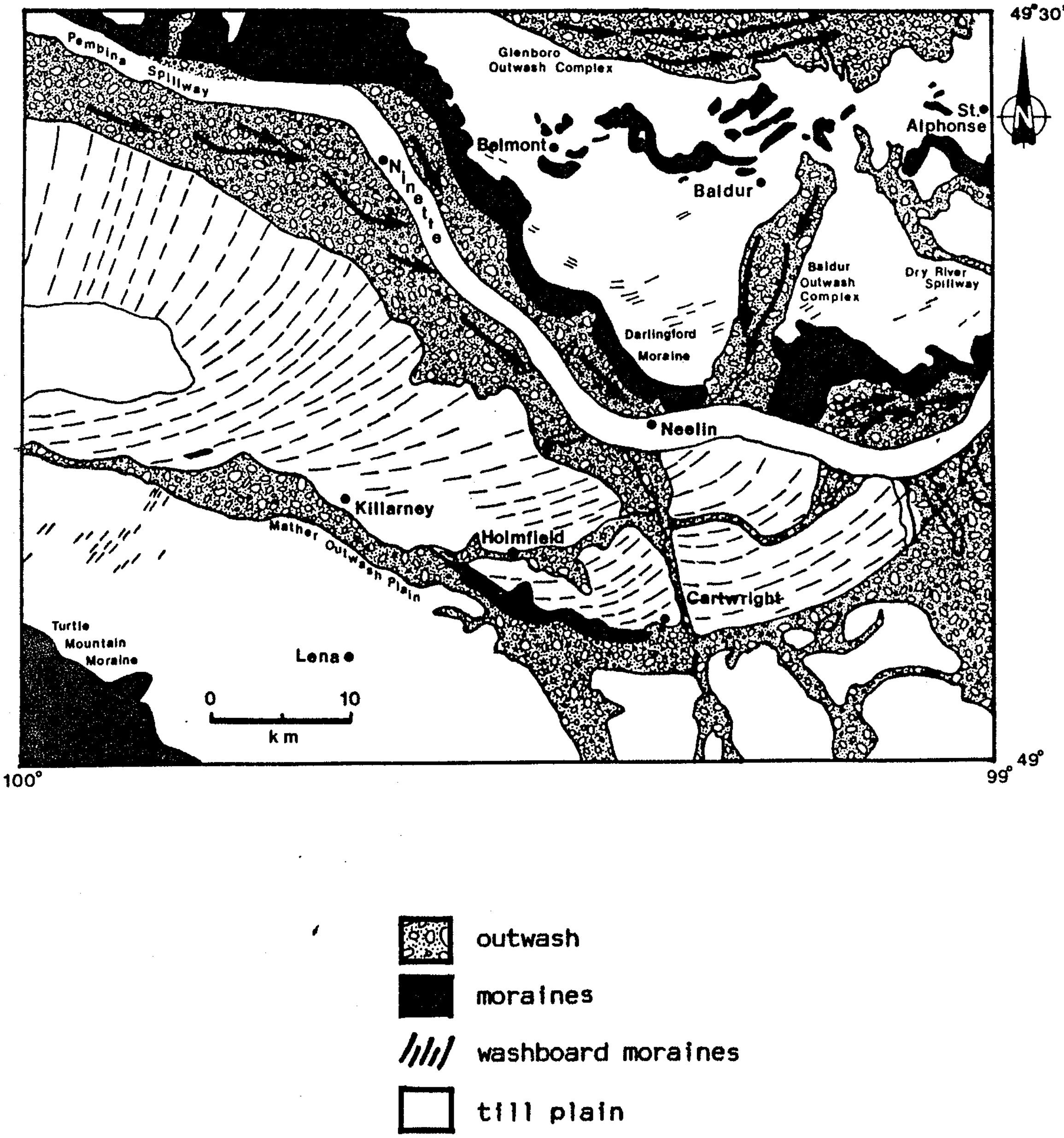


Figure 70. The ice retreated north of the escarpment, opening up a channel between the ice margin and the height of land to the south. The ice margin lay just north of the Killarney-Holmfield area. Meltwater from the west flowed through this channel to Lake Agassiz.

SUMMARY OF THE LATE WISCONSINAN GLACIATION

The Late Wisconsinan began with the deposition of the Senkiw Formation in southeastern Manitoba, by an advance of the Laurentide Ice Sheet from the north or northeast prior to 20 000 B.P. The Keewatin centre, west of Hudson Bay, was gaining strength and the ice advanced to the southeast, across the shaly terrain of the Manitoba Escarpment. This advance, the first Late Wisconsinan ice to reach the Killarney-Holmfield region, deposited the Lennard Formation in southwestern Manitoba, the Dahlen Formation in northeast North Dakota, and the St. Hilaire Formation in northwest Minnesota. The Keewatin ice reached western Iowa around 20 000 B.P. A major withdrawal may have followed this advance.

The Keewatin ice flowed continuously over southwestern Manitoba and northeastern North Dakota and deposition of the Lennard and Dahlen Formation continued uninterrupted until about 12 000 B.P. The eastern and southern margins registered several major fluctuations. About 17 000 B.P., the eastern edge of the Keewatin ice advanced into southeastern Manitoba and deposited the Roseau Formation and the lower part of the Red Lake Falls Formation in northwestern Minnesota. This advance was followed by a major withdrawal of ice into North Dakota.

Renewed activity of the Keewatin centre sent ice into Minnesota and Iowa as the Des Moines Lobe and into South Dakota as the James Lobe about 14 000 B.P. The Roseau Formation continued to be deposited in southeastern Manitoba and the upper part of the Red Lake Falls Formation was deposited in Minnesota.

The ice margin in South Dakota and Minnesota advanced and retreated several times and eventually the glacier retreated into North Dakota. The dominant ice flow was now occurring through the Interlake, and the Keewatin ice was waning.

In northwestern North Dakota, the ice had separated into two lobes, the Souris Lobe to the west of Turtle Mountain and the Leeds Lobe to the east. The Leeds Lobe retreated into the Killarney-Holmfield area and then readvanced a short distance to the Cartwright moraine. Proglacial Lake Whitewater drained east through the Mather outwash plain to the Pembina spillway at this time. The Keewatin ice retreated to the west for the last time by about 12 000 B.P. Once the ice had retreated west of Turtle Mountain, Lake Souris and Lake Hind drained east through the Pembina spillway to Lake Agassiz. In the Lake Agassiz basin, the Red River lobe had retreated into southern Manitoba and the offshore sediment of the Wylie Formation was being deposited. Inflow to the lake through the Pembina spillway flowed between the margin of this lobe and the Manitoba Escarpment in North Dakota.

The Red River lobe was reactivated about 11 400 B.P. and readvanced more than 200 km south to the Darlingford-Edinburg moraine. This advance deposited the Glenora Formation in southwestern Manitoba, the Falconer Formation in northeastern North Dakota and the Whitemouth Lake Formation in southeastern Manitoba. The ice crossed the Pembina spillway at Swan Lake, blocking drainage to the east. Meltwater was ponded behind the ice dam, and glacial Lake Souris was re-established. When the glacier waned and the ice dam failed, water discharged rapidly through the Pembina spillway and deposited the Pembina underflow fan near Walhalla, North Dakota.

The ice retreated an unknown distance and a lake formed in the vicinity of Wawanesa. About 11 200 B.P., the Red River Lobe advanced again to the Darlingford-Edinburg moraine, depositing the highly calcareous Belmont Formation in southwestern Manitoba and the Marchand Formation in southeastern Manitoba. This advance is not believed to have extended west of the Brandon Hills, south of Brandon. The Pembina spillway was again blocked by ice at this time and meltwater west of the dam reached an elevation of 465 m. The blockage of the Pembina spillway is marked by the deposition of a finer grained unit in the Pembina underflow fan. Once more, the ice dam broke and water discharged rapidly toward Lake Agassiz depositing coarse sediment on the Pembina underflow fan. An outwash plain 10 km wide was formed along the south margin of the Darlingford moraine.

The ice retreated and then readvanced to Baldur, where the Baldur thrust moraine was formed within the margin of the glacier. The lobated nature of the Baldur moraine and the tightly curved washboard moraines behind the thrust blocks indicate that the glacier was very thin.

Once the ice had retreated north of the Tiger Hills upland, Lake Brandon formed and discharged water south into the Pembina spillway. As the ice continued to retreat to the north, the Glenboro outwash complex formed between the ice margin and the height of land to the south. The Pembina spillway was soon abandoned in favor of the Glenboro outwash complex at a lower elevation. The Souris River was diverted north through the elbow of capture to Lake Agassiz. As the ice retreated further north the Assiniboine underflow fan was deposited in Lake Agassiz.

REFERENCES

Bamburak, J.D., 1978, Stratigraphy of the Riding Mountain, Boissevain and Turtle Mountain Formations in the Turtle Mountain Area, Manitoba: Mineral Resources Division, Geological Survey, Geological Report 78-2, 47 p.

Bannatyne, B.B., 1970, The Clays and Shales of Manitoba: Manitoba Department Mines and Natural Resources, Manitoba Mines Branch, Publication 67-1, 107 p.

Bluemle, J.P., 1984, Geology of Towner County, North Dakota: North Dakota Geological Survey Bulletin 79, North Dakota State Water Commission, County Groundwater Studies 36, Pt 1, 44 p.

Bluemle, J.P., and Clayton, L., 1984, Large-scale glacial thrusting and related processes in North Dakota: Boreas, v. 13 p. 279-299.

Christiansen, E.A., 1968, Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada: Canadian Journal of Earth Sciences, v. 5, p. 1167-1173.

Clayton, L., and Moran, S.R., 1982, Chronology of Late Wisconsinan Glaciation in Middle North America: Quaternary Science Reviews, v. 1, p. 55-82.

Clayton, L., Moran, S.R., and Bluemle, J.P., 1980, Explanatory text to accompany the geologic map of North Dakota: Report of Investigation No. 69, 93 p.

Clayton, L, Teller, J.T., and Attig, J.W., 1985, Surging of the southwestern part of the Laurentide Ice Sheet: Boreas, v. 14, p. 235-241.

Dreimanis, A., 1982, The influence of researchers upon glacial stratigraphy: Geoscience Canada v. 9, 1, p. 37-42.

Dyke, A.S., Dredge, L.A., and Vincent, J.S., 1982, Configuration and dynamics of the Laurentide Ice Sheet during the Late Wisconsinan maximum: Geographie physique et Quaternaire, v. 36, p. 5-14.

Elson, J., 1956, Surficial geology of the Tiger Hills Region, Manitoba, Canada: Unpublished PhD thesis, Yale University, New Haven, Connecticut, 316 p.

Fenton, M.M., 1984, Quaternary stratigraphy of the Canadian prairies: in Fulton, R.J., ed., Quaternary Stratigraphy of Canada A Canadian Contribution to IGCP Project 24, Geological Survey of Canada, Paper 84-10, p. 58-68.

Fenton, M.M., Moran, S.R., Teller, J.T., Clayton, L., 1983, Quaternary stratigraphy and history in the southern part of the Lake Agassiz Basin: in Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz, Geological Association of Canada Special Paper 26, p. 49-74.

Fisher, D.A., Reeh, N., and Langley, K., 1985, Objective reconstructions of the Late Wisconsinan Laurentide Ice Sheet and the significance of deformable beds. Geographie physique et Quaternaire, 1985, v. 39, 3, p. 229-238.

Folk, R.L., 1968, Petrology of Sedimentary Rocks: Hemphills, 170 p.

Halsted, E.C., 1959, Ground-water resources of the Brandon map-area, Manitoba: Geological Survey of Canada, Memoir 300, 67 p.

Harris, K.L., Moran, S.R., and Clayton, L., 1974, Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota: North Dakota Geological Survey, Miscellaneous Series 52, 47 p.

Kehew, A.E., and Clayton, L., 1983, Late Wisconsinan Floods and development of the Souris-Pembina Spillway system in Saskatchewan, North Dakota, and Manitoba: in Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz, Geological Association of Canada Special Paper 26, p. 187-209.

Kehew, A.E., and Lord, M.L., 1986, Origin and large-scale erosional features of glacial-lake spillways in the northern Great Plains: Geological Society of America Bulletin, v. 97, p. 162-177.

Klassen, R.W., 1969, Quaternary stratigraphy and radiocarbon chronology in southwestern Manitoba: Geological Survey of Canada Paper 69-27.

Klassen, R.W., 1971, Nature, thickness and subsurface stratigraphy of the drift in southwestern Manitoba: Geological Association of Canada, Special Paper Number 9, p. 253-261.

Klassen, R.W., 1975, Quaternary geology and geomorphology of Assiniboine and Qu'Appelle Valleys of Manitoba and Saskatchewan: Geological Survey of Canada, Bulletin 228, 61 p.

Klassen, R.W., 1979, Pleistocene geology and geomorphology of the Riding Mountain and Duck Mountain areas, Manitoba-Saskatchewan: Geological Survey of Canada, Memoir 396, 52 p.

Klassen, R.W., Delorme, L.D. and Mott, R.J., 1967, Geology and paleontology of Pleistocene deposits in southwestern Manitoba: Canadian Journal of Earth Science, v. 4, p. 433-447.

Lemke, R.W., and Colton, R.B., 1958, Summary of the Pleistocene geology of North Dakota. Guidebook Ninth Annual Field Conference, Mid-western Friends of the Pleistocene. North Dakota Geological Survey, Miscellaneous Series No. 10, p. 41-57.

Manitoba Mineral Resources Division, 1979, Geological Map of Manitoba, Map 79-2, Scale 1:1 000 000.

Manitoba Mineral Resources Division, 1981, Surficial Geological Map of Manitoba, Map 81-1, Scale 1:1 000 000.

Moran, S.R., Arndt, M., Bluemle, J.P., Camara, M., Clayton, L., Fenton, M.M., Harris, K.L., Hobbs, H.C., Keatinge, R., Sackreiter, D.K., Salomon, N.L., and Teller, J.T., 1976, Quaternary stratigraphy and history of North Dakota, Southern Manitoba, and Northwestern Minnesota: in Mahaney, W.C., ed., Quaternary Stratigraphy of North America, p. 133-158.

Nielsen, E., and Dredge, L., 1982, Quaternary Stratigraphy and Geomorphology of a Part of the Lower Nelson River: Geological Association of Canada, Field Trip Guidebook 5, 56 p.

Nielsen, E., and Thorleifson, L.H., 1985, Glaciological reconstruction of a Late Wisconsinan sublobe of the Laurentide ice sheet, southern Manitoba, Canada: Geological Association of Canada, Program with Abstracts, V. 10, p. A43.

Prest, V.K., 1983, Canada's Heritage of Glacial Features: Geological Survey of Canada, Miscellaneous Report 28, 119 p.

Ricketts, B.D., and Donaldson, J.A., 1981, Sedimentary History of the Belcher Group of Hudson Bay: in F.H.A. Campbell, ed., Proterozoic Basins of Canada, Geological Survey Paper 81-10.

Teller, J.T., and Bluemle, J.P., 1983, Geological setting of the Lake Agassiz Region: in Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz, Geological Association of Canada Special Paper 26, p. 355-374.

Teller, J.T., and Fenton, M.M., 1980, Late Wisconsinan glacial stratigraphy and history of southeastern Manitoba: Canadian Journal of Earth Sciences, 17, p. 19-35.

Thorleifson, L.H., 1983, The Eastern Outlets of Lake Agassiz: unpublished MSc. Thesis, University of Manitoba, Winnipeg, Manitoba, 87 p.

Welsted, J., and Young, H.R., 1980, Geology and origin of the Brandon Hills, southwest Manitoba: Canadian Journal of Earth Sciences, 17, p. 942-951.

APPENDICES

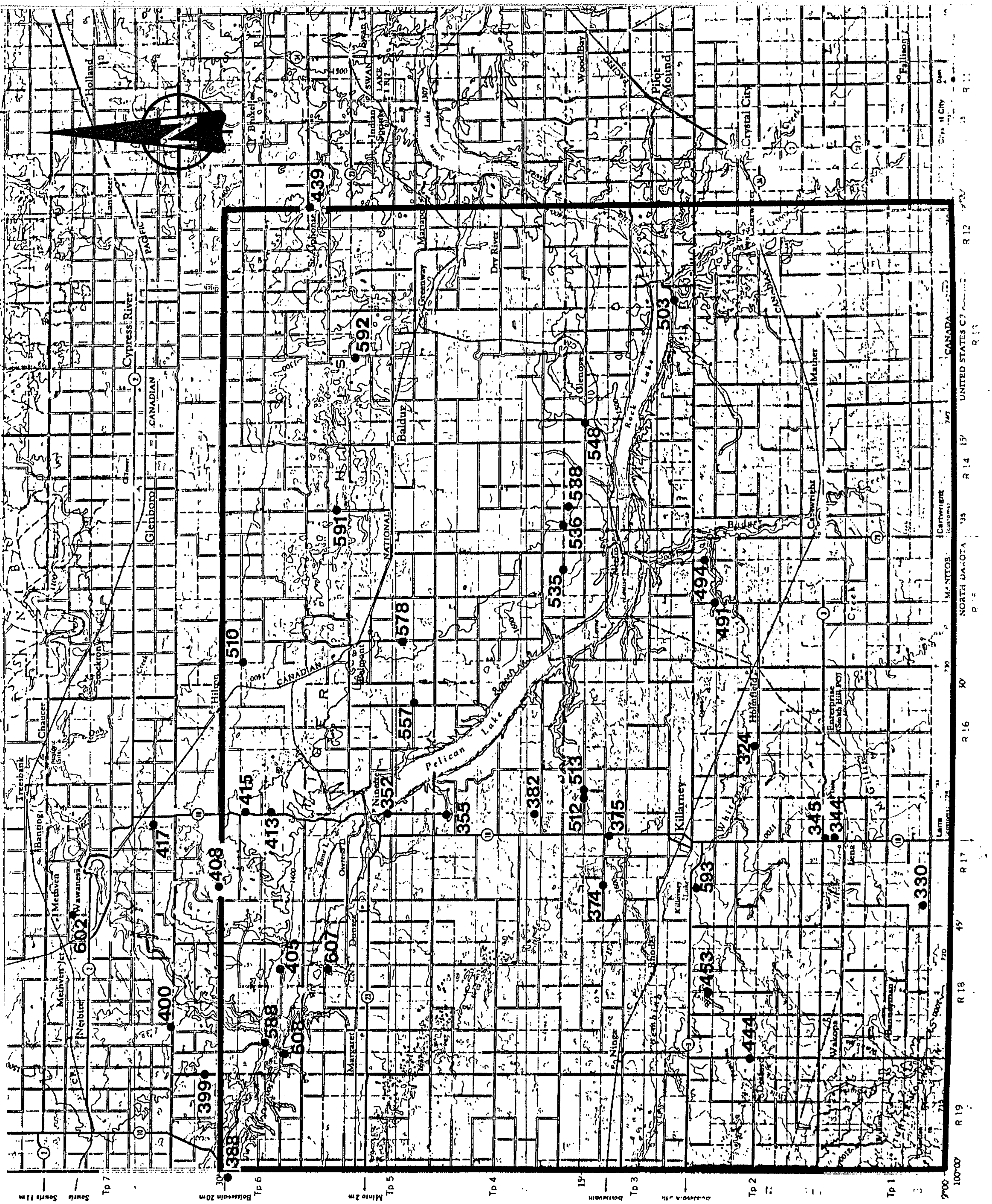


Figure 71. Index map of sample locations. The Killarney-Holmfield area is indicated by the black border.

APPENDIX I

Description of Stratigraphic Sections
(see Figure 71 for location of sections)

Formation	Unit Number	Description	Unit Thickness (m)	Total depth (m)
Section GC324 This section is from a cut in a gravel pit, 5.6 km west of Holmfield (SW-21-02-16W).				
Lennard	5	Sand and gravel: cross bedded; strongly oxidized; pebble/cobble lag at lower contact with till, then fine sand and granules grading upward into coarse sands and gravels; Current direction dip 28 degrees to 26 degrees N.E.	1.0	1.0
Lennard	4	Till: olive brown (2.5Y 6/2); compact and hard; gravel 16%, sand 48%, silt plus clay 36%; carbonate clasts 59%, Shield clasts 41%, Omarolluk greywacke clasts 1.0%	0.3	1.3
	3	Boulder Pavement: boulders dislodged due to excavation of overlying gravel		
	2	Sand and gravel: coarse pebble gravel; poorly bedded; appears massive; Current direction dip 38 degrees to 134 degrees S.E.	1.5	2.8
Minnedosa	1	Till: olive brown (2.5Y 4/4); hard; compact; gravel 10%, sand 33%, silt plus clay 57%; carbonate clasts 57% Shield clasts 43%, Omarolluk greywacke clasts 1.1%	>2.0	4.8
Section GC330 This section is from a roadcut on the north side of a side road 4.8 km west of Highway 18 and 2 km north of the Canada-United States Border SW-08-01-17W.				
Lennard	3	Till: olive brown (2.5Y 4/4); gravel 7%, sand 38%, silt 38%, clay 17%; carbonate 13%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 0.6%	2.0	2.0
Lennard	2	Sand: poorly sorted, silty, sharp contact between units 2 and 3; indistinct contact between units 2 and 1	1.0	3.0
Lennard	1	Till: light olive brown (2.5Y 5/4); gravel 6% sand 33%, silt 39%, clay 22%; carbonate 13% carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 1.4%	>1.0	4.0

Formation	Unit Number	Description	Unit Thickness (m)	Total depth (m)
Section GC344 This section is from a roadcut on the east side of Highway 18, 0.8 km north of Lena (NW-35-01-17W).				
Lennard	3	Till: olive brown (2.5Y 4/4); loose; gravel 8%, sand 39%, silt 42%, clay 11%; carbonate clasts 55%, Shield clasts 45%, Omarolluk greywacke clasts 4%	2.0	2.0
	2	Boulder pavement: sparse boulders; striae and grooves oriented to 142 degrees S.E. (1 obs.);Oolitic Jasper cobble in pavement		
Minnedosa	1	Till: light yellowish brown (2.5Y 6/4); compact; gravel 8%, sand 37%, silt 34%, clay 21%; carbonate clasts 63%, Shield clasts 37%, Omarolluk greywacke clasts 3.7%	>2.0	4.0
Section GC345 This section is from a roadcut on the east side of Highway 18, 1.6 km north of Lena (NW-35-01-17W).				
Lennard	3	Till: olive brown (2.5Y 4/4); hard; fissile; compact; gravel 9%, sand 38%, silt 32%, clay 21%; carbonate clasts 56%, Shield clasts 44%, Omarolluk greywacke clasts 3.9%; thin boulder lag at surface	2.0	2.0
	2	Boulder Pavement: striations and grooves oriented to 137 degrees S.W. (8 obs.)		
Minnedosa	1	Till: light yellowish brown (2.5Y 6/4); strongly oxidized; hard; compact; contains sandy lenses; gravel 11%, sand 39%, silt 33%, clay 17%; carbonate clasts 62%, Shield clasts 38%, Omarolluk greywacke clasts 3.9%	>1.5	3.5
Section GC352 This section is from the west side of the Pembina Spillway, 1.1 km south of Ninette and 1.6 km east of Highway 18 (NE-13-05-17W).				
	4	Cobble lag: thin; cobbles not faceted	0.1	0.1
Lennard	3	Till: olive brown (2.5Y 4/4); hard; compact; gravel 11%, sand 37%, silt 40%, clay 13%; carbonate clasts 66%, Shield clasts 34%, Omarolluk greywacke clasts 0.3%; contained 0.5 m rounded block of Boissevain sandstone near lower contact	2.0	2.1

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
	2	Boulder pavement: poorly faceted surfaces		
Minnedosa	1	Till: olive brown (2.5Y 4/4); soft; loose; gravel 12%, sand 36%, silt 35%, clay 17%; carbonate clasts 64%, Shield clasts 36%, abundant shale clasts	>2.0	4.1

Section GC355
This section is from the north side of a small stream cut, 6 km south of Ninette and 1.6 km east of Highway 18 (SW-31-04-16W).

Lennard	3	Till: olive brown (2.5Y 4/4); hard, fissile: gravel 11%, sand 39%, silt 38%, clay 12%; carbonate clasts 58%, Shield clasts 42%, Omarolluk greywacke clasts 0.9%; contains several sandy lenses of limited horizontal and vertical extent	2.0	2.0
	2	Boulder Pavement: poorly developed, faceted surfaces and striations randomly oriented; contained Oolitic Jasper cobble		
Minnedosa	1	Till: light olive brown (2.5Y 5/5); gravel 13%, sand 36%, silt 41%, clay 10%; carbonate clasts 62%, Shield clasts 38%, Omarolluk greywacke clasts 1.0%; upper zone contained 3 cm lens of sand with fine gravel	>1.0	3.0

Section GC374
This section is from the south side of a side road 6.4 km north of Killarney and 3.9 km west of Highway 18 (NE-21-03-17W).

Lennard	3	Till: light olive brown (2.5Y 5/4); hard; compact; gravel 4%, sand 30%, silt 48%, clay 18%; carbonate 15%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 3.5%; sharp contact with gravel of unit 2	3.0	3.0
	2	Sand and Gravel: interbedded with silt; variable	1.0	4.0
Lennard	1	Till: olive brown (2.5Y 4/4); mottled gravel 6%, sand 32%, silt 44%, clay 18%; carbonate 15%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 1.3%	>1.0	5.0

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Section GC375 This sample is from a roadcut on the west side of Highway 18, 4.2 km north of Killarney (NE-23-03-17W).				
Lennard	5	Till: olive (5Y 4/3); loose; gravel 9%, sand 38%, silt 36%, clay 17%; carbonate 15.4%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 3.2%; contains small sand lenses	3.0	3.0
	4	Silt: contains sandy lenses; sharp contact with unit 5; contact with unit 3 gradual, but distinct	0.8	3.8
Lennard	3	Till: slightly oxidized olive brown (2.5Y 4/4); compact; blocky; gravel 9%, sand 36%, silt 39%, clay 16%; carbonate 16; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 0.1%; contained Oolitic Jasper cobble	2.2	6.0
	2	Sand: grading down to gravel at contact with unit 1; clasts greater than 2 cm subrounded; clasts smaller than 2 cm generally angular	1.0	7.0
Minnedosa	1	Till: highly oxidized olive (5Y 4/3); very hard; gravel 12%, sand 44%, silt 30%, clay 14%; carbonate 16%; carbonate clasts 61%, Shield Shield clasts 39%, Omarolluk greywacke clasts 3.6%	3.0	10.0
Section GC382 This section is from a roadcut on the west side of a side road, 1.6 km west of Highway 18 and 12.6 km south of Ninette (SW-12-04-17W).				
Lennard	3	Till: light olive brown (2.5Y 5/4); gravel 4% sand 32%, silt 46%, clay 18%; carbonate 24%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 1.6%; possibly water modified; contact gradational with unit 2	1.0	1.0
Lennard	2	Till: olive brown (2.5Y 4/4); loose; fissile; gravel 8%, sand 39%, silt 30%, clay 23%; carbonate 15%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 0.5%; greyish mottle; many small sandy stringers	4.0	5.0
Minnedosa	1	Till: olive brown (2.5Y 4/4); gravel 11%, sand 37%, silt 35%, clay 17%; carbonate 16%; carbonate clasts 54%, Shield clasts 46%, Omarolluk greywacke clasts 0.6%	>1.0	6.0

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Section GC388 This section is from a roadcut on the east side of Highway 10, about 0.5 km south of the Pembina Spillway (NW-20-06-19W).				
	8	Silt: yellow	1.0	1.0
	7	Pebble Lag		
Lennard	6	Till: olive brown (2.5Y 4/4); hard and compact; gravel 11%, sand 33%, silt 28%, clay 28%; carbonate 16%; carbonate clasts 67%, Shield 33%, Omarolluk greywacke clasts 1.2%	1.0	2.0
	5	Cobble Lag		
Shell	4	Till: oxidized olive brown (2.5Y 4/4); hard and compact; gravel 9%, sand 29%, silt 34%, clay 28%; carbonate 14%; carbonate clasts 68%, Shield clasts 32%, Omarolluk greywacke clasts 1.4%	1.0	3.0
	3	Cobble and Pebble Lag: poorly developed		
Shell	2	Till: strongly oxidized olive brown (2.5Y 4/4); gravel 16%, sand 31%, silt 28%, clay 25%; carbonate 12%; carbonate clasts 59%, Shield clasts 41%, Omarolluk greywacke clasts 1.4%	0.5	3.5
	1	Bedrock:		3.5
Section GC399 This section is from a road cut on the east side of a side road 4.8 km east of Highway 10 and 4 km north of the Pembina Spillway (NW-30-06-18W).				
Belmont	3	Till: pale brown (10YR 6/3 dry); gravel 15%, sand 23%, silt 40%, clay 22%; carbonate 44%; carbonate clasts 90%, Shield clasts 10%, Omarolluk greywacke clasts 0.1%; no shale	1.0	1.0
	2	Silt: grey, sharp contact between units 2 and 3	0.1	1.1
Glenora	1	Till: olive brown (2.5Y 4/4); compact; fissile; gravel 6%, sand 44%, silt 40%, clay 10%; carbonate 18%; carbonate clasts 68%, Shield clasts 32%, Omarolluk greywacke clasts, 0.5%; minor shale; sharp contact with unit 2	>1.0	2.1

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Section GC400				
This section is from a road cut on the south side of a side road, 14.5 km north of Ninette and 14.5 km west of Highway 18 (SW-03-07-18W).				
Belmont	3	Till: brown (10YR 5/4); gravel 12%, sand 26%, silt 46%, clay 16%; carbonate clasts 83%, Shield clasts 17%, Omarolluk greywacke clasts 1.4%	2.0	2.0
	2	Silt: grey; sharp contact between units 2 and 3	0.1	2.1
Glenora	1	Till: olive brown (2.5Y 4/4); fissile; gravel 12%, sand 37%, silt 39%, clay 12%; carbonate clasts 63%, Shield clasts 37%, Omarolluk greywacke clasts 2.4%; sharp contact between units 1 and 2	>0.5	2.6

Section GC405

This section is from a temporary exposure in a gravel pit 4 km west of Dunrea and 6.4 km north of Highway 23 (NE-02-06-18W). This is from a large gravel bar on the north side of the Pembina Spillway. Section 405A is located at the west end of the bar and 405B is located near the centre of the bar.

Formation	Unit Number	Description	Unit Thickness	Total depth
Section GC405A				
Lennard	1	Till: olive brown (2.5Y 4/4); very hard and compact; gravel 8%, sand 39%, silt plus clay 53%; carbonate clasts 67%, Shield clasts 33%, Omarolluk greywacke clasts 1.1%; many fine silty lenses	>2.3	2.3
Section GC405B				
	2	Sand and Gravel: Cobbly coarse sand and gravel, coarsest to the west, finer to the east; crossbedded; Current direction dip 30 degrees to 80 degrees E.	>10.0	>10.0
Shell	1	Till: strongly oxidized very dark greyish brown (10YR 4/2); very hard and compact; gravel 9%, sand 41%, silt 36%, clay 14%; carbonate 17%; carbonate clasts 56%, Shield clasts 44%, Omarolluk greywacke clasts 0.6%	>1.0	>11.0

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Section GC408 This section is from a roadcut on the south side of a side road 11 km north of Ninette and 5.5 km west of Highway 18 (SE-28-06-17W).				
Belmont	2	Till: pale brown (10YR 6/3); hard; gravel 15%, sand 25%, silt 39%, clay 21%; carbonate 40%; carbonate clasts 87%, Shield clasts 13%, Omarolluk greywacke clasts 0.9%	0.3	1.3
Glenora	1	Till: light olive brown (2.5Y 5/4); gravel 9%, sand 35%, silt 41%, clay 15%; carbonate 22%; carbonate clasts 79%, Shield clasts 21%, Omarolluk greywacke clasts 1.3%; sharp contact between units 1 and 2	>1.0	2.3
Section GC413 This section is from a roadcut on the east side of Highway 18, 7.7 km north of Ninette (NW-07-06-16W). This cut is across the centre of the Darlingford moraine.				
Belmont	1	Till: yellowish brown (10YR 5/4); gravel 9%, sand 42%, silt 39%, clay 10%; carbonate clasts 87%, Shield clasts 13%, Omarolluk greywacke clasts 0.7%; sample from 1.5 m	4.5	4.5
Belmont	1	Till: yellowish brown (10YR 5/4); gravel 8%, sand 53%, silt 29%, clay 10%; carbonate clasts 80%, Shield clasts 20%, Omarolluk greywacke clasts 0.8%; sample from 4.0 m		
Section GC415 This section is a roadcut on the east side of Highway 18, 9.2 km north of Ninette (NW-15-06-17W). This cut is across the Darlingford moraine.				
Belmont	3	Till: light olive brown (2.5Y 5/4); gravel 13%, sand 37%, silt 29%, clay 21%; carbonate 31%; carbonate clasts 82%, Shield clasts 18%, Omarolluk greywacke 1.2%	3.0	3.0
Belmont	2	Till: light brown (7.5YR 6/4); gravel 15%, sand 24%, silt 35%, clay 26%; carbonate 42; carbonate clasts 90%, Shield clasts 10%, Omarolluk greywacke clasts 0.5%; sharp contact between unit 2 and 3	0.5	3.5

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Shell	1	Till: olive brown (2.5Y 4/4); gravel 7%, sand 32%, silt 27%, clay 34%; carbonate 12%; carbonate clasts 61%, Shield clasts 39%, Omarolluk greywacke clasts 2.8%; sharp contact between unit 1 and 2	>1.0	4.5

Section GC417
This section is from a road cut on the north side of a side road 1.6 km south of Highway 2 and 0.8 km west of Highway 18 (SW-07-07-16W).

	4	Silty Gravel: poorly sorted gravelly-silty mixture; no bedding visible	1.0	1.0
Lennard	3	Till: olive brown (2.5Y 4/4); compact; compact; gravel 11%, sand 47% silt and clay 42%; carbonate clasts 57%, Shield clasts 43%, Omarolluk greywacke clasts 2.2%; very shaly	1.0	2.0
Minnedosa	2	Till: oxidized olive brown (2.5Y 4/4 wet); hard; fissile; gravel 13%, sand 38%, silt and clay 49%; carbonate clasts 51%, Shield clasts 49%, Omarolluk greywacke clasts 2.9; very shaly	1.0	3.0
	1	Shale: light grey		3.0

Section GC439
This section is from a rivercut on the Cypress River, 0.8 km north of St. Alphonse (NE-34-05-12W). This section was strongly deformed.

Lennard	1	Till: olive brown (2.5Y 4/4); gravel 8%, sand 42%, silt 37%, clay 13%; carbonate clasts 65%, Shield clasts 35%, Omarolluk greywacke clasts 1.5%		
Lennard	1	Till: olive brown (2.5Y 4/4); gravel 7%, sand 36%, silt 36%, clay 21%; carbonate clasts 67%, Shield clasts 33%, Omarolluk greywacke clasts 0.4%		

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)

Section GC444
This section is from a roadcut on the west side of a side road 3.2 km west of Wakopa and 4.8 km south of Highway 3 (SE-19-02-18W).

Lennard	1	Till: unoxidized olive brown (2.5Y 4/4); very compact and hard; gravel 7%, sand 38%, silt and clay 55.%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke 3.3%; sample from 2.0 m	>4.5	4.5
Lennard	1	Till: unoxidized olive brown (2.5Y 4/4); gravel 7%, sand 37%, silt and clay 56%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke 1.4%; sample from 3.0 m		
Lennard	1	Till: olive brown (2.5Y 4/4); gravel 7%, sand 37%, silt and clay 56%; carbonate clasts 59%, Shield clasts 41%, Omarolluk greywacke 2.33%; contains large fragments of Boissevain Sandstone at 4.2 m; sample from 4.0 m		

Section GC453
This section is from a rivercut of the Pembina River 11.3 km west of Killarney and 1.2 km south of Highway 3 (SE-33-02-18W.

Lennard	3	Till: olive brown (2.5Y 4/4); gravel 14%, sand 50, silt 20%, clay 16%; carbonate clasts 59%, Shield clasts 41%, Omarolluk greywacke clasts 2.3%	1.0	1.0
	2	Boulder Pavement: poorly developed; several boulders faceted but striations not consistent		
Minnedosa	1	Till: oxidized olive brown (2.5Y 4/4); gravel 6%, sand 36%, silt and clay 58%; carbonate clasts 57%, Shield clasts 43%, Omarolluk greywacke clasts 3.6%; contains sandy zones and silty grey stringers to a depth of 2.0 m; sample from 2.0 m	4.0	5.0
Minnedosa	1	Till: olive brown (2.5Y 4/4 wet); gravel 3%, sand 29%, silt and clay 68%; carbonate clasts 50%, Shield clasts 50%, Omarolluk greywacke clasts 2.2; sample from 4.2 m		

Formation	Unit Number	Description	Unit Thickness (m)	Total depth (m)
Section GC491 This section is from a rivercut of a tributary of the Long River, 1.9 km west and 8.9 km north of Cartwright (SE-33-02-15W). The upper 4 m are covered by vegetation.				
	6	Covered interval:	4.0	4.0
Lennard	5	Till: strongly oxidized olive brown (2.5Y 4/4); compact; gravel 10%, sand 35%, silt and clay 55%; carbonate 15%; carbonate clasts 62%, Shield clasts 38%, Omarolluk greywacke clasts 0.3%	1.0	5.0
	4	Boulder Pavement: poorly developed; some boulders faceted; orientation of striations not consistent		
Minnedosa	3	Till: weakly oxidized light olive brown (2.5Y 5/4); very hard; very compact; gravel 12%, sand 43%, silt and clay 45%; carbonate 15%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 0.8%; shaly	2.0	7.0
	2	Boulder Lag: most boulders of Shield origin; no faceted surfaces		
Minnedosa	1	Till: oxidized olive brown (2.5Y 4.4); very hard; very stony; gravel 49%, sand 32%, silt and clay 19%; carbonate 13%; carbonate clasts 54%, Shield clasts 46%, Omarolluk greywacke clasts 0.6%; shaly; contains many selenite crystals; contains many inclusions of black till	2.0	9.0
Section GC494 This section is from the north side of a rivercut of the Long River, 1.6 km west and 8.9 km north of Cartwright (SW-36-02-15W).				
	12	Silt: grey; fine grained; no bedding or structures visible	1.0	1.0
	11	Sand: yellow; thickness variable; sharp contact between units 10 and 11	0.2	1.2
Lennard	10	Till: slightly oxidized olive brown (2.5Y 4.4); gravel 10%, sand 39%, silt 40%, clay 11%; carbonate 15%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 2.8%; contact sharp between units 9 and 10	0.4	1.6
	9	Sand: yellow; no bedding observed; contact sharp between units 8 and 9.	0.2	1.8

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Minnedosa	8	Till: oxidized olive brown (2.5Y 4/4); jointed; hard and compact; gravel 10%, sand 37%, silt 39%, clay 14%; carbonate 17%; carbonate clasts 62%, Shield clasts 38%, Omarolluk greywacke clasts 1.5%; contains large inclusions of sand; sharp contact between units 7 and 8	1.2	3.0
	7	Sand: oxidized yellow; thin; variable thickness	0.1	3.1
Minnedosa	6	Till: strongly oxidized olive brown (2.5Y 4/4); gravel 11%, sand 35%, silt 39%, clay 15%; carbonate 15%; carbonate clasts 61%, Shield clasts 39%, Omarolluk greywacke clasts 3.1%; sharp contact between units 5 and 6	1.4	4.5
	5	Boulder and cobble lag: some boulders are faceted and striated, no consistent orientation of striations		
Shell	4	Till: oxidized dark grey (10YR 4/1); gravel 10%, sand 42%, silt 34%, clay 14%; carbonate 12%; carbonate clasts 49%, Shield clasts 51%, Omarolluk greywacke clasts 5.1%; sample from 5.2 m	1.5	6.0
Shell	4	Till: oxidized dark grey (10YR 4/1);gravel 7%, sand 38%, silt and clay 55%; carbonate 12%; carbonate clasts 61%, Shield clasts 39%, Omarolluk greywacke clasts 1.7%; sample from 5.8 m		
Largs	3	Till: oxidized light olive brown (2.5Y 5/4); gravel 11%, sand 38%, silt and clay 51; carbonate 8%; carbonate clasts 56%, Shield clasts 44%, Omarolluk greywacke clasts 2.1%	1.9	6.0
	2	Silt: interbedded with sand and clay; compact	0.1	6.1
	1	Shale: bedrock weathered in situ; appears as shale 'gravel'	>0.5	6.6

Section GC503
This section is from a rivercut on the south bank of the Pembina Spillway, 4.8 km west and 6.4 km north of Clearwater (NW-01-03-13W).

Minnedosa	2	Till: oxidized dark greyish brown (2.5Y 4/2); hard; gravel 11%, sand 39%, silt and clay 50%; carbonate clasts 55%, Shield clasts 45%, Omarolluk greywacke clasts 2.5%	1.0	1.0
Minnedosa	1	Till: very strongly oxidized very dark greyish brown 2.5Y 3/2); very hard and compact; gravel 10%, sand 38%, silt and clay 52%; carbonate clasts 55%, Shield clasts 45%, Omarolluk greywacke clasts 2.5%	>2.0	3.0

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Section GC510 This section is from a roadcut on the east side of a side road 8 km north and 1.6 km west of Belmont (NW-17-06-15W).				
	3	Lag Deposit: coarse; carbonate boulders up to 46 cm diameter; poorly sorted; grades down into till of unit 2	0.6	0.6
Belmont	2	Till: yellowish brown (10YR 5/4); gravel 13%, gravel 13%, sand 36%, silt and clay 51; carbonate 35%; carbonate clasts 89%, Shield clasts 11%, Omarolluk greywacke clasts 1.2	0.3	0.9
Lennard	1	Till: olive brown (2.5Y 4/4); gravel 9%, sand 40%, silt and clay 51%; carbonate 14%; carbonate clasts 69%, Shield clasts 31%, Omarolluk greywacke clasts 1.8%; contains greyish silty stringers; contact sharp between units 1 and 2	>1.0	1.9
Section GC512/GC513 This section is from a rivercut of the Pembina River, 6.4 km north of Killarney and 3.2 km east of Highway 18 (SE-30-03-16W). Section 512 is from the west bank and section 513 is from the east bank. The lower part of 512 was not exposed and the upper part of 513 was disturbed.				
	3	Stony Silt: yellowish grey; some pebbles; no bedding	1.0	1.0
Lennard	2	Till: oxidized olive brown (2.5Y 4/4); compact; gravel 9%, sand 40%, silt and clay 51; carbonate 15%; carbonate clasts 63%, Shield clasts 37%, Omarolluk greywacke clasts 0.5; 1 cm thick grey silt bed at 2 m	3.0	4.0
Shell	1	Till: heavily oxidized brown-dark brown (10YR 4/3); gravel 8%, sand 43%, silt and clay 49%; carbonate clasts 51%, Shield clasts 49%, Omarolluk greywacke clasts 2.4; strongly jointed; sample from 4.5 m	2.0	6.0
Shell	1	Till: heavily oxidized dark yellowish brown (10YR 4/4); gravel 8%, sand 39%, silt and clay 52%; carbonate clasts 56%, Shield clasts 44%, Omarolluk greywacke clasts 3.0%; strongly jointed; sample from 6 m		

Formation	Unit Number	Description	Unit Thickness (m)	Total depth (m)
Section GC535 This section is from a roadcut on the north side of PTH 253, 4.5 km west of PTH 258 (SW-01-04-15W). This cut is across the Darlingford moraine at an elevation of 491 m a.s.l.				
Belmont	2	Till: brown (10YR 5/3); gravel 11%, sand 35%, silt and clay 54%; carbonate clasts 81%, Shield clasts 19%, Omarolluk greywacke clasts 0.4%; contains many thin lenses of various tills, ranging in color from grey to 'pink'	0.3	0.3
Glenora	1	Till: olive brown (2.5Y 4/4); gravel 9%, sand 38%, silt and clay 53%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke 0.4%; contact between unit 1 and 2 marked by sharp contact with thin 'pinkish' silt bed	>1.0	1.3
Section GC536 This section is from a roadcut on the north side of PTH 253, 1.7 km west of PTH 258 (SE-06-04-14W). This cut is across the Darlingford moraine at an elevation of 466 m a.s.l.				
Belmont	2	Till: yellowish brown (10YR 5/4); gravel 10%, sand 31%, silt and clay 59%; carbonate clasts 86%, Shield clasts 14%, Omarolluk greywacke clasts 0.2%	0.5	0.5
Glenora	1	Till: olive brown (2.5Y 4/4); gravel 8%, sand 36%, silt and clay 56%; carbonate clasts 65%, Shield clasts 35%, Omarolluk greywacke clasts 1.0%	>1.0	1.5
Section GC538 This section is from a roadcut on the south side of a side road at the intersection of PTH 258 and 253 (NW-33-03-14W). This cut is 1 km east of the Darlingford moraine at an elevation of about 453 m a.s.l.				
Belmont	2	Till: yellowish brown (10YR 5/4); gravel 13%, sand 34%, silt and clay 53%; carbonate 41%; carbonate clasts 89%, Shield clasts 11%, Omarolluk greywacke clasts 0.7	0.5	0.5

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Belmont	1	Till: olive brown (2.5Y 4/4); gravel 7%, sand 30%, silt and clay 63%; carbonate 32%; carbonate clasts 85%, Shield clasts 15%, Omarolluk greywacke clasts 0.7%	>1.0	1.5

Section GC548
This section is on the north side of PTH 253, 5 km west of Glenora (SE-36-03-14W). This cut is across the Darlingford moraine.

Formation	Unit Number	Description	Unit Thickness	Total depth
Belmont	2	Till: yellowish brown (10YR 5/4); gravel 8%, sand 43%, silt and clay 49%; carbonate 28%; carbonate clasts 91%, Shield clasts 9%, Omarolluk greywacke clasts 0.1%; sample from 1.3 m	3.0	3.0
	1	Silt: almost stone free; minor sand; fissile; same color as unit 2b; contact with 2b appeared gradational	>0.5	3.5

Section GC557
This section is from a roadcut on the south side of a side road 4.5 km west of Belmont and 4.5 km south of Highway 23 (NW-01-05-16W). This cut is across the Darlingford moraine.

Formation	Unit Number	Description	Unit Thickness	Total depth
Belmont	2	Till: slightly oxidized light olive brown (2.5Y 5/4); loose; fissile; gravel 12%, sand 32%, silt and clay 56%; carbonate clasts 80%, Shield clasts 20%, Omarolluk greywacke clasts 0.3%	1.0	1.0
Belmont	1	Till: brown (10YR 5/3); loose; gravel 7%, sand 40%, silt and clay 53%; carbonate clasts 87%, Shield clasts 13%, Omarolluk greywacke clasts 0.3%; sharp contact between units 1 and 2; contains inclusions of olive till	>1.0	2.0

Formation	Unit Number	Description	Unit Thickness (m)	Total depth (m)
Section GC578 This section is from a roadcut on the east side of PTH 340, 3.2 km south of Belmont (NW-08-05-15W).				
Glenora	5	Till: olive brown (2.5Y 4/4); gravel 8%, sand 42%, silt and clay 50%; carbonate 21%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 2.5%	0.3	0.3
Lennard	4	Till: olive brown (2.5Y 4/4); gravel 10%, sand 38%, silt and clay 52%; carbonate 15%; carbonate clasts 64%, Shield clasts 36%, Omarolluk greywacke clasts 2.3%	1.7	2.0
	3	Sand: oxidized; fine	0.1	2.1
	2	Sand and Gravel: oxidized; much shale gravel	1.0	3.1
Minnedosa	1	Till: strongly oxidized brown - dark brown (10YR 4/3); very hard and compact; strongly jointed; gravel 11%, sand 38%, silt and clay 51%; carbonate 16%; carbonate clasts 59%, Shield clasts 41%, Omarolluk greywacke clasts 1.9%	>1.0	4.1
Section GC588 This is a section from a roadcut on the north side of the Pembina spillway, 7 km north of Margaret (NW-08-06-18W).				
	4	Cobble lag:	0.3	0.3
Lennard	3	Till: olive brown (2.5Y 4/4); gravel 11%, sand 35%, silt and clay 54; carbonate 14%; carbonate clasts 65%, Shield clasts 35%, Omarolluk greywacke clasts 0.5%	1.0	1.3
	2	Cobble gravel and sand: strongly oxidized; poorly sorted; weakly bedded	2.0	3.3
	1	Shale bedrock		3.3
Section GC589 This section is from a river cut on a tributary of the Souris River, 4.8 km west of the intersection of PTH 347 and 348, near Bunclody (NE-35-06-20W).				
		Covered interval	1.0	1.0
Shell	3	Till: heavily oxidized light greyish brown (2.5Y 4/2 dry); gravel 12%, sand 27%, silt and clay 61%; carbonate 14%; carbonate clasts 71%, Shield clasts 29%, Omarolluk greywacke clasts 1%; upper 2 m contain lenses of stratified gravel	3.0	4.0

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
	2	Flow Unit?: interbedded sand, silt, shale gravel till and gravel; till exhibits flow bedding	0.3	4.3
Largs	1	Till: oxidized olive brown (2.5Y 4/4); very hard and compact; gravel 19%, sand 32%, silt and clay 49; carbonate 11%; carbonate clasts 67%, Shield clasts 33%, Omarolluk greywacke clasts 0.8%; contains many small soft reddish iron concretions	>1.5	5.8

Section GC591
This section is from a roadcut on the east side of PTH 258, 4 km north of Highway 23 (SW-28-05-14W).

Lennard	1	Till: olive brown (2.5Y 4/4); hard and compact; gravel 9%, sand 39%, silt and clay 52%; carbonate 16%; carbonate clasts 61%, Shield clasts 39%, Omarolluk greywacke clasts 0.5%; contains some large shale cobbles; contains some small sand lenses	2.5	2.5

Section GC592
This section is from a road cut on the east side of a side road 6.4 km east of Baldur and 2.1 km north of Highway 23 (SE-21-05-13W).

Glenora	2	Till: slightly oxidized dark greyish grown (2.5Y 4/2); gravel 9%, sand 19%, silt and clay 72%; carbonate 18%; carbonate clasts 81%, Shield clasts 19%, Omarolluk greywacke clasts 0.3%; minor oxidation; becomes more silty and stone poor toward surface; includes some sand lenses	2.0	2.0
	1	Silt: yellow; interbedded with occasional sand bed	>1.0	3.0

Section GC593
This section is from a road cut on the west side of a side road, 3.2 km west of Killarney and 0.6 km south of Highway 3 (NE-32-02-17W). Many pavement stones lie loose in the ditch but none were observed in situ.

	3	Gravel: crossbedded, dip 28 degrees toward 18 degrees north-northeast; highly oxidized; sandy; variable thickness	0.3	0.3

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Minnedosa	2	Till: oxidized brown-dark brown (10YR 4/3); very hard and compact; gravel 10%, sand 34%, silt and clay 56%; carbonate 16%; carbonate clasts 69%, Shield clasts 31%, Omarolluk greywacke clasts 0.6%; thickness variable	0.4	0.7
Tee Lakes	1	Till: oxidized very dark grey (10YR 3/1); gravel 12%, sand 36%, silt and clay 52%; carbonate 23%; carbonate clasts 73%, Shield clasts 27%, Omarolluk greywacke clasts 0.9%	>1.0	1.7

Section GC602
This section is from the north bank of a rivercut of a tributary of the Souris River, 3.2 km west and 1.6 km north of Wawanesa (NW-23-07-17W).

	5	Silt:	0.6	0.6
	4	Sand: very fine: interbedded with clay; very fine sand: crossbedded; apparent dip 17 degrees toward 168 degrees South; thickness of sand beds range from 13cm to 36cm; uppermost sand bed 42cm to 65cm thick clay lenses: thickness of clay beds range from 3cm to 18cm; large amounts of selenite crystals are selectively growing in these beds; some clay beds are slightly silty	2.4	3.0
	3	Cobble lag: thin		
Belmont	2	Till: light yellowish brown; mottled; contains many inclusions of clay	0.5	3.5
Minnedosa	1	Till: strongly oxidized brown-dark brown (10YR 4/3); very hard and compact; gravel 11%, sand 33%, silt and clay 56%; carbonate 17%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 1%; contains some selenite crystals; contact between units 1 and 2 is contorted	1.5	5.0

Section GC607
This section is from the north bank of a rivercut of a tributary of the Pembina Spillway, 4 km west of Dunrea and 3.2 km north of Highway 23 (NE-26-05-18W).

Minnedosa	2	Till: oxidized olive brown (2.5Y 4/2 wet); hard and compact; gravel 10%, sand 35%, silt and clay 55%; carbonate 16%; carbonate clasts 60%, Shield clasts 40%, Omarolluk greywacke clasts 1.9%	2.5	2.5

Formation	Unit Number	Description	Unit Thickness	Total depth
			(m)	(m)
Shell	1	Till: oxidized very dark greyish brown (2.5Y 3/2); extremely hard and compact; fissured; gravel 8%, sand 29%, silt and clay 63%; carbonate 16%; carbonate clasts 62%, Shield clasts 38%, Omarolluk greywacke clasts 1.3; contains many selenite crystals	>2.5	5.0

Section GC608
This section is from a roadcut on the west side of PTH 346, 6.4 km north of Highway 23 (NE-05-06-18W).

	2	Cobble lag capped by thin cover of sandy silt	0.8	0.8
Lennard	1	Till: strongly oxidized olive brown (2.5Y 4/4); hard and compact; gravel 13%, sand 36%, silt and clay 51%; carbonate 17%; carbonate clasts 74%, Shield clasts 26%, Omarolluk greywacke clasts 0.8%; white carbonaceous stringers; sample from 1.5 m	3.7	4.5
Lennard	1	Till: oxidized olive brown (2.5Y 4/4) hard and compact; gravel 21%, sand 42%, silt and clay 37%; carbonate 15%; carbonate clasts 68%, Shield clasts 32%, Omarolluk greywacke clasts 1.1; sample from 2.8 m		
Lennard	1	Till: oxidized olive brown (2.5Y 4/4); hard and compact; gravel 21%, sand 39%, silt and clay 41%; carbonate 15%; carbonate clasts 65%, Shield clasts 35%, Omarolluk greywacke clasts 0.8%; contains white carbonaceous stringers; contains thin sand lenses; sample from 4.1 m		

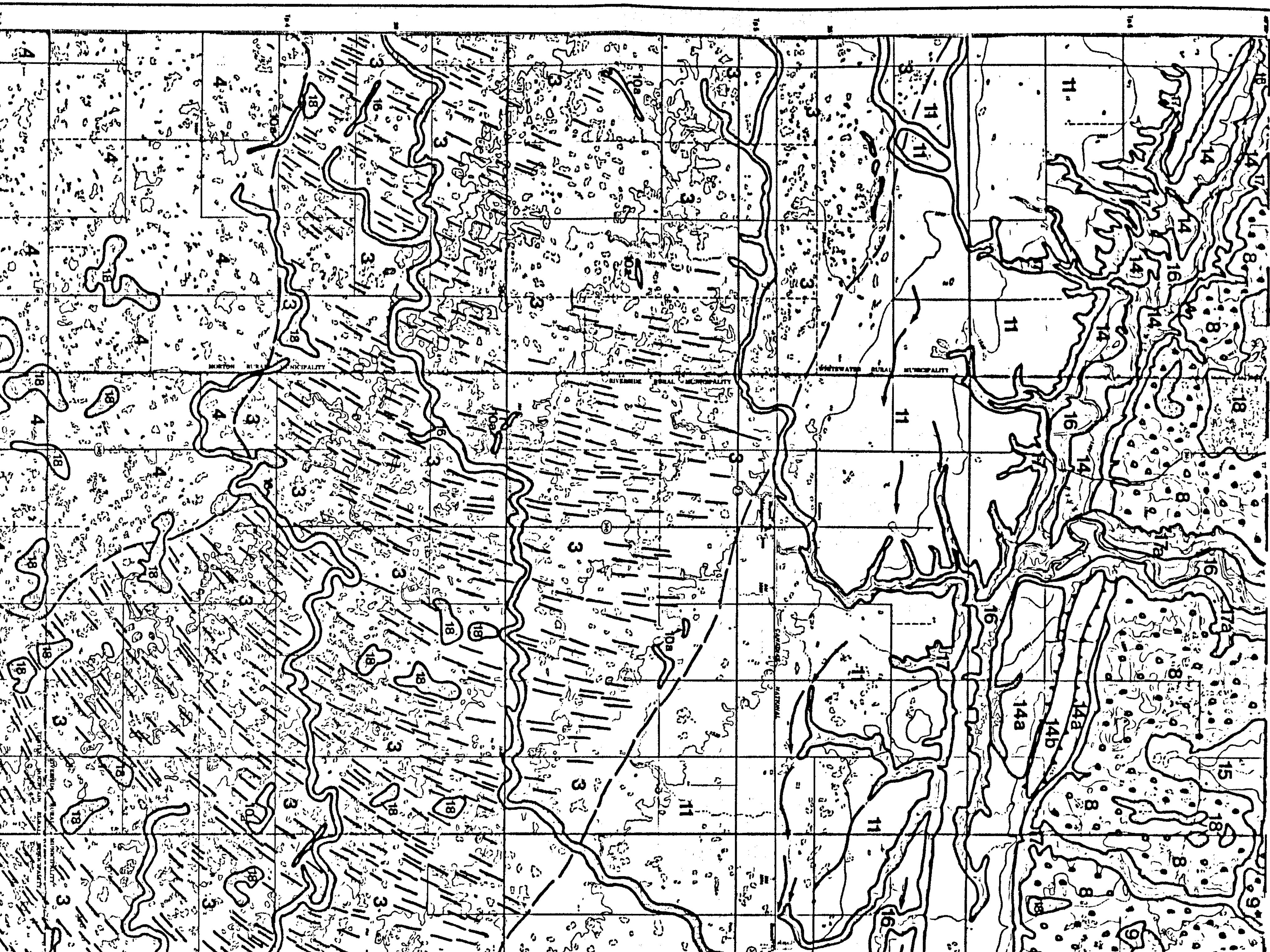
APPENDIX II

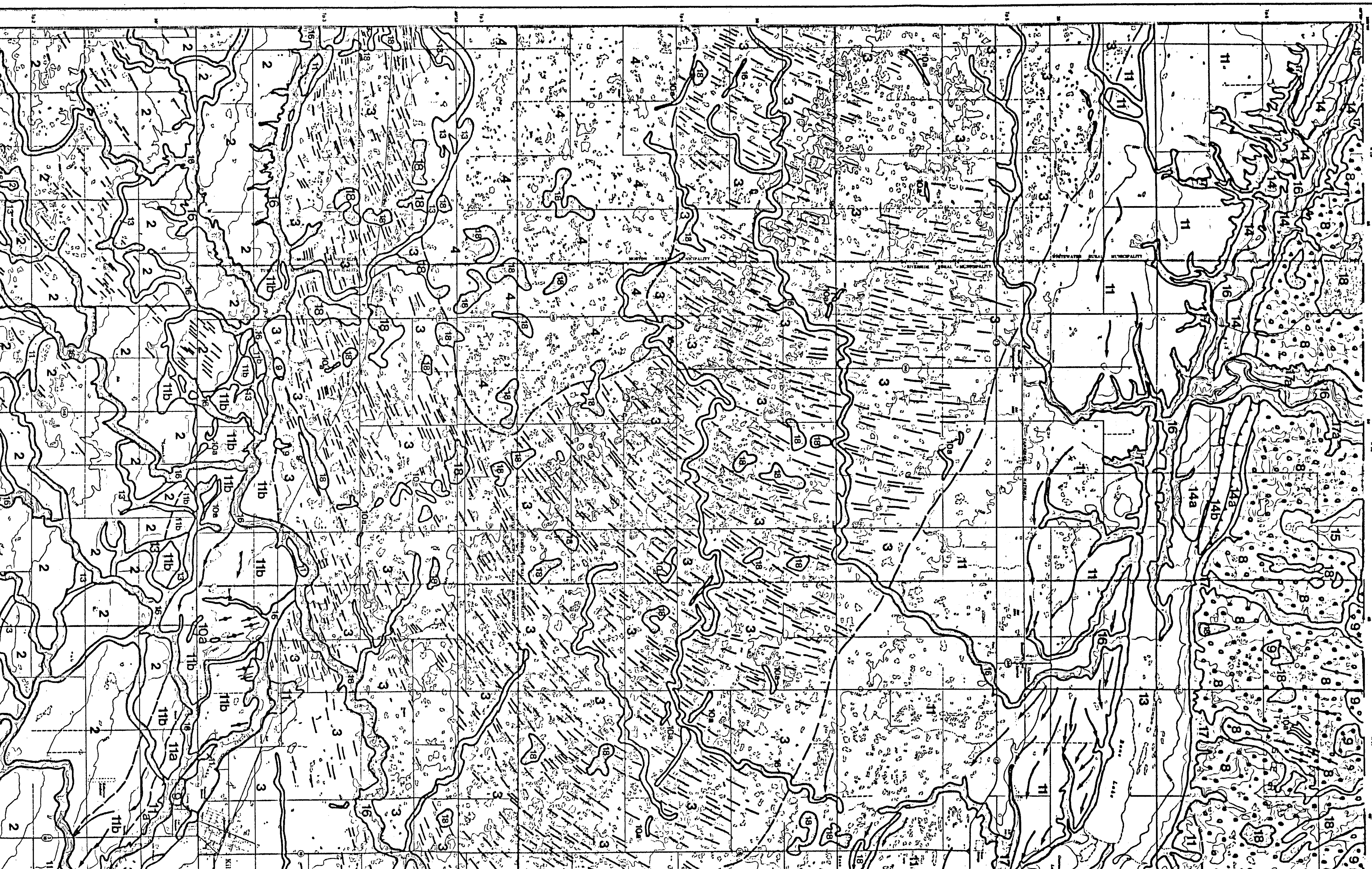
Till data grouped by section
(— not available)

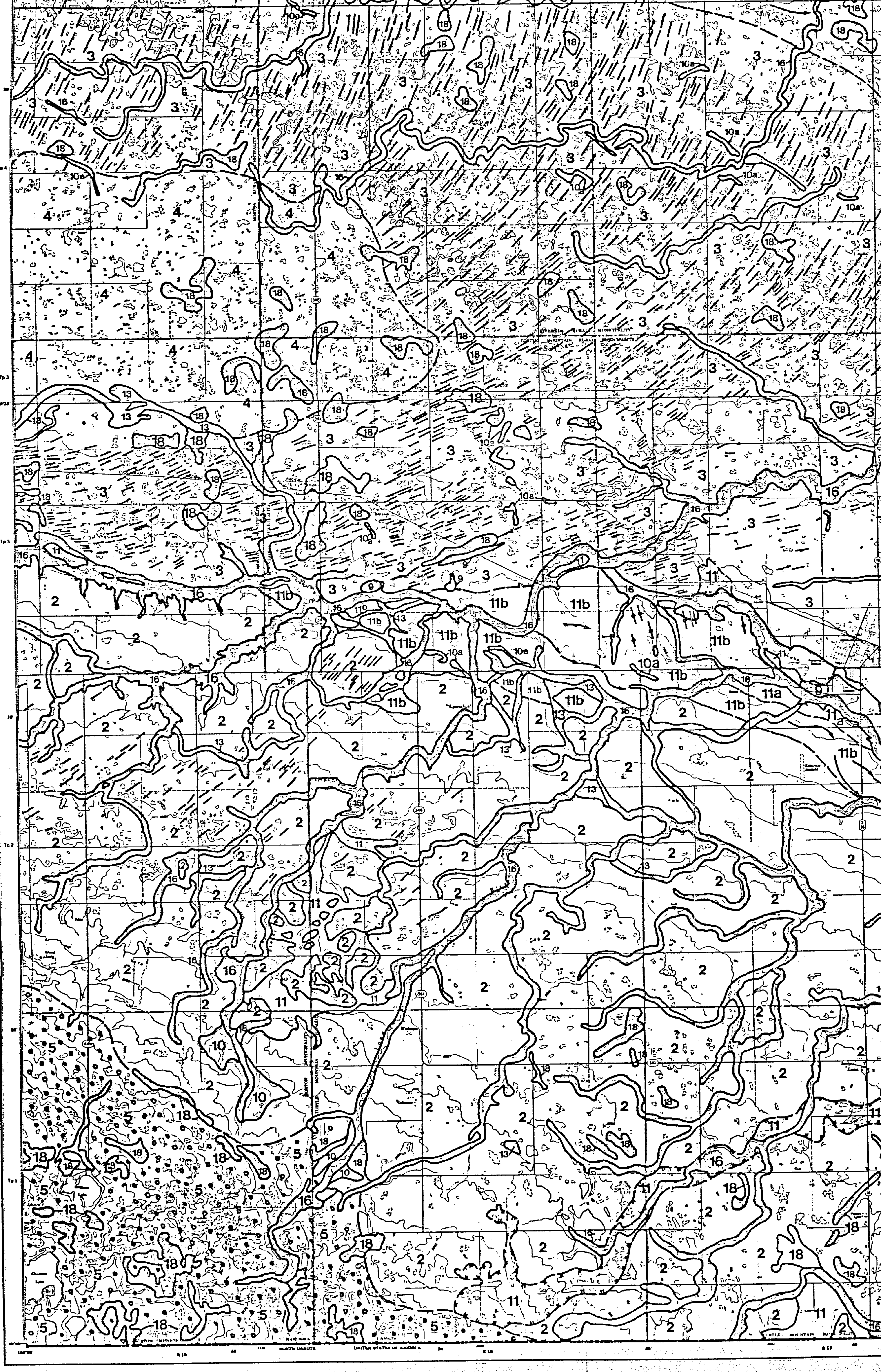
	Size Analysis of Whole Sample					Size Analysis Analysis of Matrix Only			Carb. Anal. <0.063 mm	Pebble Lithology of 4-16 mm Fraction Count Percent				Pebble Lithology of 4-16 mm Fraction Weight Percent			
	GRAV	SAND	SILT	CLAY	SI+CL	SAND	SILT	CLAY	%CO3	CARB	CRYST	CRYST:CARB	GWKE	CARB	CRYST	SHALE	GWKE
GC324B(a)	16	48	—	—	36	57	—	—	—	59	41	0.69	1.0	56	38	6	0.2
GC324B(b)	10	33	—	—	57	37	—	—	—	57	43	0.74	1.1	59	29	12	1.3
GC330(a)	7	38	38	17	55	41	40	19	13	60	40	0.68	0.6	54	37	9	0.9
GC330(c)	6	33	39	22	61	35	41	24	13	64	36	0.56	1.4	48	32	20	0.5
GC344(a)	8	39	42	11	53	42	46	12	—	55	45	0.82	4.2	52	34	14	2.6
GC344(b)	8	37	34	21	55	40	37	23	—	63	37	0.58	3.7	70	30	0	2.5
GC345(a)	9	38	32	21	53	42	35	23	—	63	37	0.58	1.6	58	35	7	0.6
GC345(b)	11	39	33	17	50	44	37	19	—	62	38	0.61	2.8	58	33	9	1.7
GC352(a)	11	37	39	13	52	41	44	15	—	66	34	0.52	0.3	70	27	3	0.2
GC352(c)	12	36	35	17	52	40	40	20	—	64	36	0.56	0.0	50	28	22	0.0
GC355(a)	11	39	38	12	50	43	42	15	—	58	42	0.72	0.9	60	35	5	0.3
GC355(b)	13	36	41	10	51	41	47	12	—	62	38	0.62	1.0	55	39	6	1.4
GC374(a)	4	30	48	18	66	32	50	18	15	60	40	0.66	3.5	57	31	12	2.9
GC374(b)	6	32	44	18	62	34	47	19	15	60	40	0.67	1.3	56	37	7	2.2
GC375(a)	9	38	36	17	53	42	39	19	15	64	36	0.58	3.2	—	—	—	—
GC375(b)	9	36	39	16	55	38	43	19	16	64	36	0.56	0.1	—	—	—	—
GC375(c)	12	44	30	14	44	50	34	16	16	61	39	0.64	3.6	—	—	—	—
GC382(a)	4	32	46	18	64	33	48	19	24	64	36	0.56	1.6	57	40	3	4.8
GC382(b)	8	39	30	23	53	42	32	26	16	64	36	0.56	0.5	68	23	9	0.2
GC382(c)	11	38	34	17	51	41	38	21	16	54	46	0.85	0.6	52	37	11	0.4
GC388(b)	11	33	28	28	56	37	31	32	16	67	33	0.50	0.0	—	—	—	—
GC388(c)	9	29	34	28	62	32	37	31	14	68	32	0.47	1.4	56	21	23	0.9
GC388(d)	16	31	28	25	53	37	33	30	12	59	41	0.69	1.4	36	15	49	0.7
GC399(a)	15	23	40	22	62	27	47	26	44	90	10	0.12	0.1	90	10	0	0.1
GC399(b)	6	44	39	11	50	46	41	13	18	68	32	0.48	0.5	68	26	5	0.4
GC400(a)	12	26	46	16	62	30	52	18	—	83	17	0.20	1.4	90	9	1	0.9
GC400(b)	12	36	39	13	52	41	44	15	—	63	37	0.60	2.4	56	37	7	2.4
GC405 A	8	39	—	—	53	42	—	—	—	67	33	0.50	1.1	66	29	5	1.4
GC405 B	9	41	36	14	50	45	40	15	17	56	44	0.77	0.6	53	39	8	0.6

	Size Analysis of Whole Sample					Size Analysis Analysis of Matrix Only			Carb. Anal. <0.063 mm	Pebble Lithology of 4-16 mm Fraction Count Percent				Pebble Lithology of 4-16 mm Fraction Weight Percent			
	GRAV	SAND	SILT	CLAY	SI+CL	SAND	SILT	CLAY	%CO3	CARB	CRYST	CRYST:CARB	GWKE	CARB	CRYST	SHALE	GWKE
GC408(a)	7	35	40	18	58	37	43	20	25	78	22	0.28	1.3	—	—	—	—
GC408(b)	15	25	39	21	60	29	46	25	40	87	13	0.14	0.9	—	—	—	—
GC408(c)	9	35	41	15	56	38	45	17	22	79	21	0.26	1.3	—	—	—	—
GC413(a)	9	42	39	10	49	47	43	10	—	87	13	0.15	0.7	89	11	0	0.2
GC413(b)	8	53	29	10	39	57	32	11	—	80	20	0.25	0.8	80	20	0	1.2
GC415(a)	13	37	29	21	50	43	33	24	31	82	18	0.23	1.2	—	—	—	—
GC415(b)	15	24	35	26	61	28	41	31	42	90	10	0.11	0.5	—	—	—	—
GC415(c)	7	32	27	34	61	34	30	36	12	61	39	0.43	2.8	67	30	3	2.8
GC417(a)	11	47	—	—	42	53	—	—	—	57	43	0.77	2.2	42	33	25	2.1
GC417(b)	13	38	—	—	49	43	—	—	—	51	49	0.98	2.9	30	19	51	3.6
GC439(a)	8	42	37	13	50	46	40	14	—	—	—	—	—	—	—	—	—
GC439(b)	7	36	36	21	57	39	39	22	—	67	33	0.44	0.4	68	30	2	0.5
GC444(b)	7	38	—	—	55	41	—	—	—	64	36	0.56	0.0	—	—	—	—
GC444(c)	7	37	—	—	56	39	—	—	—	60	40	0.68	1.4	—	—	—	—
GC444(d)	7	37	—	—	56	40	—	—	—	59	41	0.71	2.3	—	—	—	—
GC453(a)	14	50	20	16	36	58	23	19	—	59	41	0.65	2.3	—	—	—	—
GC453(b)	6	36	—	—	58	38	—	—	—	57	43	0.76	3.6	—	—	—	—
GC453(c)	3	29	—	—	68	30	—	—	—	50	50	0.99	2.2	—	—	—	—
GC491(a)	10	35	—	—	55	39	—	—	15	62	38	0.62	0.3	61	32	7	0.1
GC491(b)	12	43	—	—	45	49	—	—	15	64	36	0.57	0.8	41	22	36	0.5
GC491(c)	49	32	—	—	19	64	—	—	13	54	46	0.86	0.6	39	37	24	0.3
GC494(a)	10	39	40	11	51	44	44	12	15	60	40	0.65	0.0	—	—	—	—
GC494(b)	10	37	39	14	53	41	43	16	27	62	38	0.61	1.5	—	—	—	—
GC494(c)	11	35	39	15	54	40	43	17	15	61	39	0.65	3.1	—	—	—	—
GC494(d)	10	42	34	14	48	46	38	16	12	49	51	1.04	5.1	—	—	—	—
GC494B(a)	7	38	—	—	55	41	—	—	12	61	39	0.64	1.7	21	16	63	1.8
GC494B(b)	11	38	—	—	51	43	—	—	8	56	44	0.80	2.1	13	16	71	3.1
GC503(a)	11	39	—	—	50	44	—	—	—	55	45	0.83	2.5	49	33	18	2.8
GC503(b)	10	38	—	—	52	42	—	—	—	55	45	0.81	2.5	50	40	10	1.7
GC510(a)	13	36	—	—	51	41	—	—	35	89	11	0.12	1.2	—	—	—	—
GC510(b)	9	40	—	—	51	44	—	—	14	69	31	0.46	1.8	—	—	—	—
GC512(a)	7	42	—	—	51	45	—	—	15	63	37	0.59	0.4	62	30	8	0.2
GC512(b)	11	39	—	—	50	44	—	—	15	63	37	0.59	0.5	57	33	10	1.8
GC513(a)	8	43	—	—	49	47	—	—	—	51	49	0.95	2.4	54	38	8	3.0
GC513(b)	8	40	—	—	52	43	—	—	—	56	44	0.78	3.0	51	41	8	2.5

	Size Analysis of Whole Sample					Size Analysis Analysis of Matrix Only			Carb. Anal. <0.063 mm	Pebble Lithology of 4-16 mm Fraction Count Percent				Pebble Lithology of 4-16 mm Fraction Weight Percent			
	GRAV	SAND	SILT	CLAY	SI+CL	SAND	SILT	CLAY	%CO3	CARB	CRYST	CRYST:CARB	GWKE	CARB	CRYST	SHALE	GWKE
GC535(a)	11	35	—	—	54	40	—	—	—	81	19	0.24	0.4	75	20	5	0.6
GC535(b)	9	38	—	—	55	41	—	—	—	64	36	0.56	0.4	54	28	18	0.3
GC536(a)	10	31	—	—	59	34	—	—	—	86	14	0.16	0.2	87	12	1	0.5
GC536(b)	8	36	—	—	56	40	—	—	—	65	35	0.54	1.0	59	27	14	2.0
GC538(a)	13	34	—	—	53	39	—	—	41	89	11	0.13	0.7	90	9	1	0.7
GC538(b)	7	30	—	—	63	32	—	—	32	85	15	0.17	0.7	85	12	3	1.2
GC548(a)	8	43	—	—	49	47	—	—	28	91	9	0.10	0.1	66	12	22	0.1
GC548(b)	6	45	—	—	49	48	—	—	27	84	16	0.19	0.0	—	—	—	—
GC557(a)	12	32	—	—	56	36	—	—	—	80	20	0.25	0.3	82	14	4	0.6
GC557(b)	7	40	—	—	53	44	—	—	—	87	13	0.14	0.3	87	10	3	0.1
GC578(a)	8	42	—	—	50	46	—	—	21	64	36	0.56	0.0	—	—	—	—
GC578(b)	10	38	—	—	52	42	—	—	15	64	36	0.56	2.3	—	—	—	—
GC578(c)	11	38	—	—	51	43	—	—	16	59	41	0.70	1.9	57	37	6	4.3
GC588	11	35	—	—	54	39	—	—	14	65	35	0.54	0.5	62	28	10	0.9
GC589(b)	12	27	—	—	61	31	—	—	14	71	29	0.42	1.0	22	10	68	0.6
GC589(c)	19	32	—	—	49	40	—	—	11	67	33	0.50	0.0	—	—	—	—
GC591	9	39	—	—	52	43	—	—	16	61	39	0.63	0.5	49	29	22	0.5
GC592	9	19	—	—	72	21	—	—	18	81	19	0.24	0.3	50	11	39	0.3
GC593(a)	10	34	—	—	56	38	—	—	16	69	31	0.46	0.6	46	22	32	0.5
GC593(b)	12	36	—	—	52	41	—	—	23	73	27	0.38	0.9	49	18	33	0.6
GC602	11	33	—	—	56	37	—	—	17	60	40	0.68	1.0	51	38	11	1.4
GC607(b)	8	29	—	—	63	32	—	—	16	62	38	0.61	0.0	—	—	—	—
GC608(a)	13	36	—	—	51	41	—	—	17	73	27	0.36	0.8	45	19	36	0.3
GC608(b)	21	42	—	—	37	53	—	—	—	68	32	0.48	1.1	36	18	46	1.1
GC608(c)	21	39	—	—	41	49	—	—	15	65	35	0.55	0.8	23	12	65	0.4

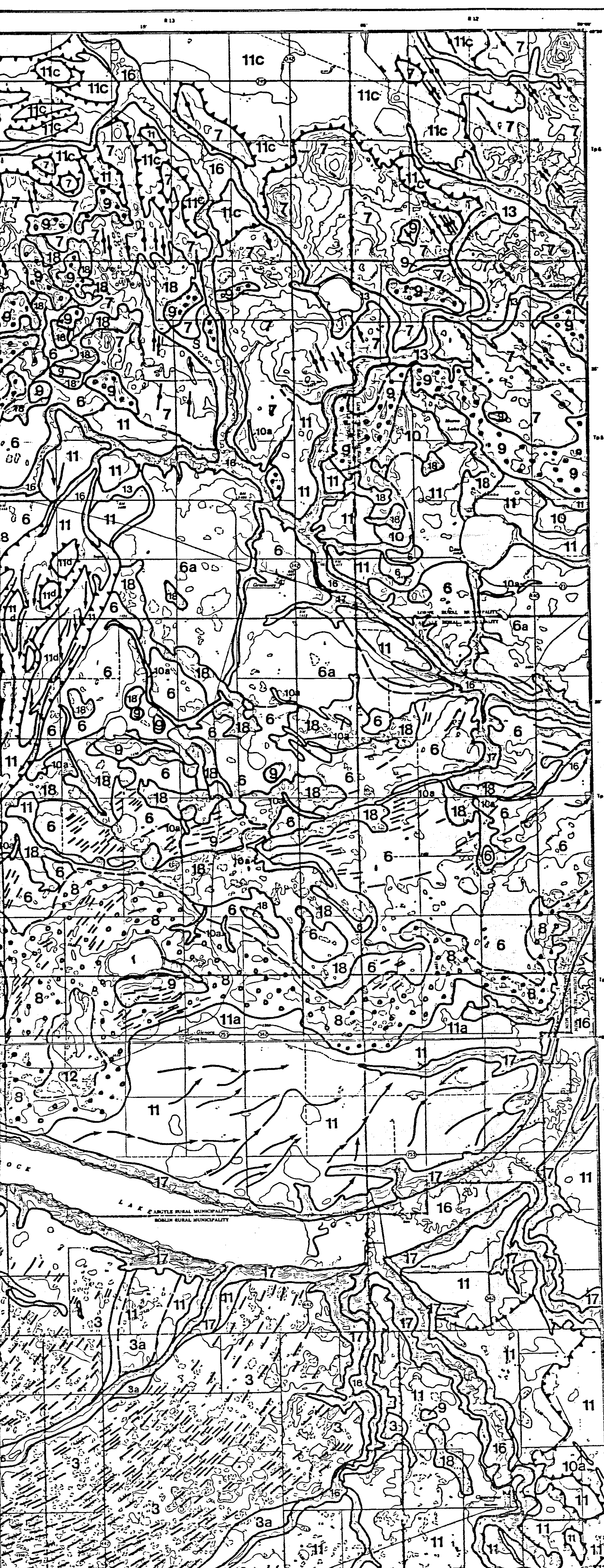

MORTON RURAL MUNICIPALITY
RIVERSIDE RURAL MUNICIPALITY
WHITEWATER RURAL MUNICIPALITY


MORTON RURAL MUNICIPALITY
RIVERSIDE RURAL MUNICIPALITY
WHITEWATER RURAL MUNICIPALITY


NORTH DAKOTA
UNITED STATES OF AMERICA
R 19
R 18
R 17
Tp 1
Tp 2
Tp 3
Tp 4


PELICAN
LAKE
Pelican Lake
Lorne Lake
Louise Lake


PELICAN LAKE
Pelican Lake
Lorne Lake
Louise Lake
UNITED STATES OF AMERICA
NORTH DAKOTA
CANADA



FIGUR

SURFICIAL GEOLOGY OF THE K

LEGE

QUATERNARY

POSTGLACIAL DEPOSITS AND LAND

18 Organic deposits: peat and

17 Undifferentiated deposi
glacial sediments on steep
bottoms); includes drift
colluvium, alluvium, and
dominated by major slump s

16 River alluvium (modern
gravel; stream sedimen
bottoms of modern streams

LATE GLACIAL AND EARLY POSTGL

15 Glaciolacustrine deposits:

14 Valley terrace deposits:
shale gravel; 14b, dominan

13 Alluvium and outwash:
abandoned channels; gravel

ICE-CONTACT GLACIAL DEPOSITS

12 Supraglacial lake depos
glaciolacustrine silt,
organic deposits

11 Outwash complexes: sand
or hummocky, mainly gra
undulating; 11c, flat t
gravel; 11d, bar, mainly

10 Glaciofluvial deposits:
10a, eskers

9 Composite thrust ridges
either local bedrock an
ridge located immedia
depression; size of block
of source depression

GLACIAL DEPOSITS AND LANDFOR

8 Hummocky stagnation mora
and kettle topography of
sand and gravel; relief g

7 Hummocky moraine: pro
till; relief greater than

6 Corrugated moraine: wea
trending ridges *of highl*
water erosion, local silt

GLACIAL DEPOSITS AND LANDFO

5 Hummocky stagnation mora
and kettle topography of
silt, sand and gravel; r

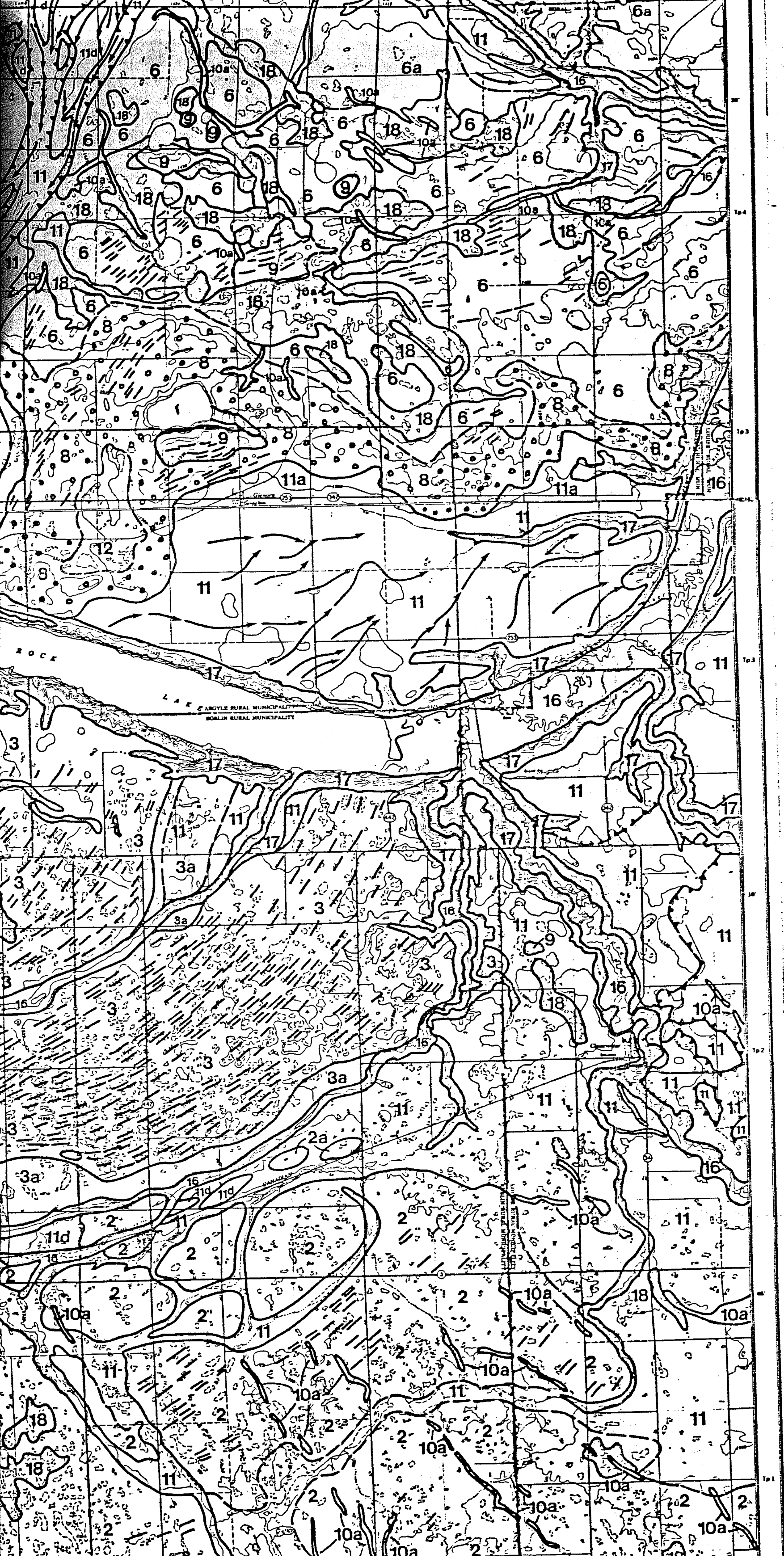
4 Hummocky stagnation m
topography, weak to str
closed rings of modera
includes minor outwash a

3 Corrugated moraine: we
trending ridges of moder
by water erosion, local

2 Till plain: flat to ge
till; 2a, modified by w
and gravel

CRETACEOUS

1 Bedrock plains: flat
modified by water ero
silt, and sand and grave



12 glaciolacustrine silt
organic deposits

11 Outwash complexes: san
or hummocky, mainly g
undulating; 11c, flat
gravel; 11d, bar, main

10 Glaciofluvial deposits:
10a, eskers

9 Composite thrust ridg
either local bedrock
ridge located immed
depression; size of bl
of source depression

GLACIAL DEPOSITS AND LANDF

8 Hummocky stagnation mo
and kettle topography c
sand and gravel; relief

7 Hummocky moraine: p
till; relief greater th

6 *Corrugated moraine:*
trending ridges of hig
water erosion, local s

GLACIAL DEPOSITS AND LAND

5 Hummocky stagnation mo
and kettle topography
silt, sand and gravel;

4 Hummocky stagnation
topography, weak to s
closed rings of mode
includes minor outwash

3 Corrugated moraine:
trending ridges of mo
by water erosion, loca

2 Till plain: flat to
till; 2a, modified by
and gravel

CRETACEOUS

1 Bedrock plains: fl
modified by water e
silt, and sand and gr

Geological contact (defined, ap

Buried or partly filled channe

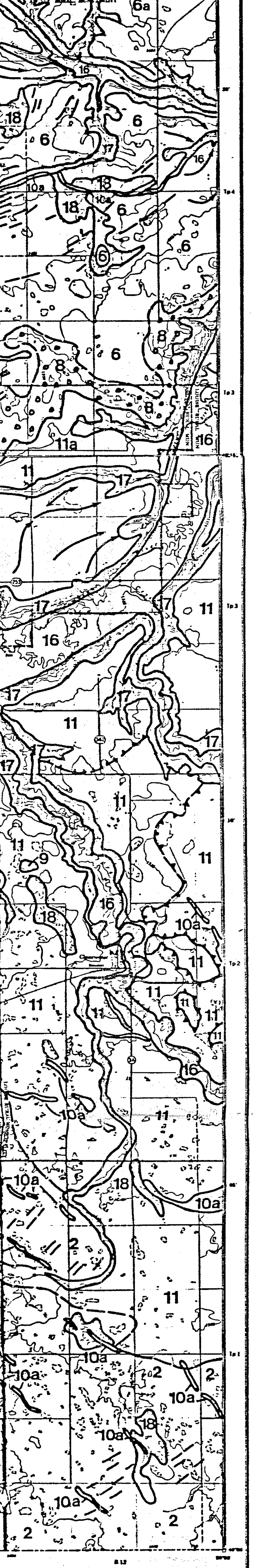
Meltwater channel (large, smal

Minor moraine ....

Moraines (including end, later

Striae and grooves on boulder
direction of ice flow)....

Ice flow feature: drumlins, f



12 Supraglacial lake deposits: ice-supported and ice-walled glaciolacustrine silt, sand and minor gravel, and minor organic deposits

11 Outwash complexes: sand and silt, minor gravel; 11a, pitted or hummocky, mainly gravel and sand; 11b, flat to gently undulating; 11c, flat to gently irregular, mainly shale gravel; 11d, bar, mainly sand, minor gravel

10 Glaciofluvial deposits: gravel, sand and silt, minor till; 10a, eskers

9 Composite thrust ridges (pop-up structures) comprised of either local bedrock and/or drift: ice-thrust block or ridge located immediately down-ice from the source depression; size of block or ridge directly related to size of source depression

GLACIAL DEPOSITS AND LANDFORMS RELATED TO ICE ADVANCE FROM EAST

8 Hummocky stagnation moraine identifed as end moraine: knob and kettle topography of highly calcareous till, local silt, sand and gravel; relief greater than 10 m

7 Hummocky moraine: promenent knobs of highly calcareous till; relief greater than 25 m; local silt, sand and gravel

6 Corrugated moraine: weak to strongly developed subarcuate trending ridges of highly calcareous till; 6a, modified by water erosion, local silt, sand and gravel

GLACIAL DEPOSITS AND LANDFORMS RELATED TO ICE ADVANCE FROM WEST

5 Hummocky stagnation moraine identified as end moraine: knob and kettle topography of moderately calcareous till, local silt, sand and gravel; relief greater than 10 m

4 Hummocky stagnation moraine: broad area of dead ice topography, weak to strongly marked pattern dominated by closed rings of moderately calcareous till; low relief; includes minor outwash and organic deposits

3 Corrugated moraine: weak to strongly developed subarcuate trending ridges of moderately calcareous till; 3a, modified by water erosion, local silt, sand and gravel

2 Till plain: flat to gently rolling, moderately calcareous till; 2a, modified by water erosion, local minor silt, sand and gravel

CRETACEOUS

1 Bedrock plains: flat to gently ridged bedrock, locally modified by water erosion; may include local organic, silt, and sand and gravel patches

SYMBOLS

Geological contact (defined, approximate)..................

Buried or partly filled channel..............................

Meltwater channel (large, small, sidehill)...................

Minor moraine ....

Moraines (including end, lateral, and terminal moraines)...

Striae and grooves on boulder pavement (dominant direction of ice flow)..................................

Ice flow feature: drumlins, flutes.........................

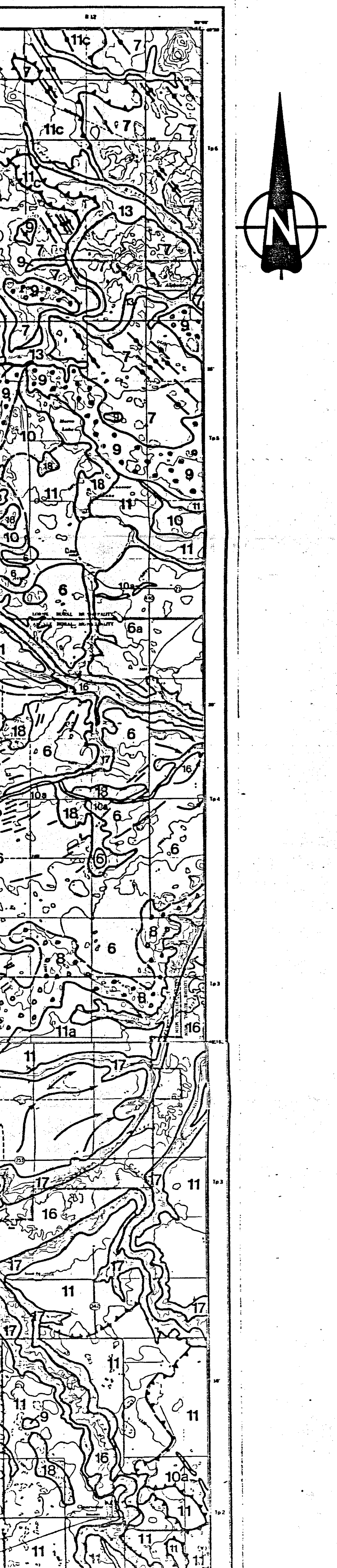


FIGURE 2

SURFICIAL GEOLOGY OF THE KILLARNEY-HOLMFIELD AREA

LEGEND

QUATERNARY

POSTGLACIAL DEPOSITS AND LANDFORMS

18 Organic deposits: peat and muck over silt and clay

17 Undifferentiated deposits: (includes glacial and non-glacial sediments on steep slopes and along valley walls and bottoms); includes drift and shale, commonly mantled with colluvium, alluvium, and slump debris; 17a, valley walls dominated by major slump scars

16 River alluvium (modern stream deposits): sand, silt, gravel; stream sediment occuring along the flanks and bottoms of modern streams; 16a, alluvial fan

LATE GLACIAL AND EARLY POSTGLACIAL DEPOSITS AND LANDFORMS

15 Glaciolacustrine deposits: clay, silt, sand

14 Valley terrace deposits: gravel and sand; 14a, dominantly shale gravel; 14b, dominantly carbonate-rich gravel

13 Alluvium and outwash: stream deposits in and along abandoned channels; gravel, sand

ICE-CONTACT GLACIAL DEPOSITS AND LANDFORMS

12 Supraglacial lake deposits: ice-supported and ice-walled glaciolacustrine silt, sand and minor gravel, and minor organic deposits

11 Outwash complexes: sand and silt, minor gravel; 11a, pitted or hummocky, mainly gravel and sand; 11b, flat to gently undulating; 11c, flat to gently irregular, mainly shale gravel; 11d, bar, mainly sand, minor gravel

10 Glaciofluvial deposits: gravel, sand and silt, minor till; 10a, eskers

9 Composite thrust ridges (pop-up structures) comprised of either local bedrock and/or drift: ice-thrust block or ridge located immediately down-ice from the source depression; size of block or ridge directly related to size of source depression

GLACIAL DEPOSITS AND LANDFORMS RELATED TO ICE ADVANCE FROM EAST

8 Hummocky stagnation moraine identifed as end moraine: knob and kettle topography of highly calcareous till, local silt, sand and gravel; relief greater than 10 m

7 Hummocky moraine: promenent knobs of highly calcareous till; relief greater than 25 m; local silt, sand and gravel

6 Corrugated moraine: weak to strongly developed subarcuate trending ridges of highly calcareous till; 6a, modified by water erosion, local silt, sand and gravel

GLACIAL DEPOSITS AND LANDFORMS RELATED TO ICE ADVANCE FROM WEST

5 Hummocky stagnation moraine identified as end moraine: knob and kettle topography of moderately calcareous till, local silt, sand and gravel; relief greater than 10 m

4 Hummocky stagnation moraine: broad area of dead ice topography, weak to strongly marked pattern dominated by closed rings of moderately calcareous till; low relief; includes minor outwash and organic deposits

3 Corrugated moraine: weak to strongly developed subarcuate trending ridges of moderately calcareous till; 3a, modified by water erosion, local silt, sand and gravel

2 Till plain: flat to gently rolling, moderately calcareous till; 2a, modified by water erosion, local minor silt, sand and gravel

CRETACEOUS

1 Bedrock plains: flat to gently ridged bedrock, locally modified by water erosion; may include local organic, silt, and sand and gravel patches